# SYSTEMS ANALYSIS OF A COMPLEX WATER RESOURCES SYSTEM

A THESIS

*submitted in fulfilment of the*
*requirements for the award of the degree*
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*in*
HYDROLOGY

By

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# CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"SYSTEMS ANALYSIS OF A COMPLEX WATER RESOURCES SYSTEM"** 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**, is an authentic record of my own work carried out during a period from March 1992 to January 1995, under the supervision of Professor **D.K. Srivastava.**

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

Date : 10-1-1995

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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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**(MOHAMMAD SADEGH SADEGHIAN)**

# ABSTRACT

Basin resources planning has become an increasingly important concept in comprehensive planning of a complex water resources system. Comprehensive basin water resources planning is a complex and a difficult task, posing numerous social, economic, environmental and engineering problems.

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. For a large scale water resources system the difficulty in the system analysis is primarily due to large number of possible alternative development strategies, and hence the vast computational effort required to establish an optimal development plan. Therefore, in a large and complex system, one of the major challenge is to reduce the large set of alternative configurations that need to be examined in detail to a reasonable number without mistakenly eliminating an attractive option. The most commonly suggested approach has been first to screen all alternative configurations with mathematical programming technique to determine the most attractive alternatives, then further screen them with a detailed simulation model.

In this study an attempt was made to combine the major advances of systems analysis by optimization-simulation screening models, which are to be used for analyzing a complex water resources system. Linear programming has been used as an optimization technique for very obvious reasons of large number of variables involved in such problems.

The specific decision problem under consideration was screening of a multiple reservoir system (multi purpose, multi reservoir, and multi irrigation areas system) on the Karun river in Iran, to meet the current and forecast growth in demand of water, for irrigation, hydropower, flood control, and municipal and industrial water supply. The system consisted of 5 major dams, one run-of-river hydropower scheme and a number of multi-irrigation areas. The various alternative configurations of the above system were studied, based on various project proposals and engineering considerations for deciding the optimal configuration and the optimal project targets.

The approach was to develop a suitable methodology to identify the combination of multi-reservoir alternative to maximize the economic benefits as well as to obtain desired project dependabilities, subjected to continuity constrains, technological constrains, and policy constraints. In this context, it was profitable to investigate the value of linear programming in preliminary screening and how it should be coupled with a finer screening simulation study.

The computer software (INDMAG PACKAGE) developed for generation of Input Data Matrix coupled with simplex algorithm for linear programming, and a flexible simulation package were used for screenings in two phases. The Phase-I was project by project analysis, and the Phase-II was analysis of integrated developmental strategies. The average monthly flows and the monthly flows of a representative dependable flow year were used independently in preliminary screening optimization model, where as 38 years historical monthly flows were used in simulation model. For screening, the economic, and water use dependability criterias were used.

The development of INDMAG software package to create the Input Data Matrix for LP model made the construction of the optimization model for all potential feasible alternatives a less data-intensive and non-Herculean task. The approach used in INDMAG software algorithm is one such step towards preparing a generalized algorithm (computer programme) very well fitting to the basic multireservoir design and planning problems.

The results of linear programming model were helpful in simulation as they could select the upper and lower ranges of the design variables by regulating the average and the annual flow of a given dependability based on the desired project success respectively.

The use of optimization-simulation models for screening and analysis by (a) project by project analysis and (b) integrated development strategy analysis, suggest a suitable scheme in the reduction in the number of alternatives of development to be examined and analyzed.

The project by project analysis and the integrated developmental strategy analysis is likely to guarantee a configuration of reservoirs and project sizes very near to a global optimum.

Based on the results, it can be concluded that the approach used in this study is simple and can be easily used to analyze large and complex river basins planning problems.

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# CHAPTER-I

# INTRODUCTION

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## Chapter-I

# INTRODUCTION

Water is an important constitute of the geosystem. It is a natural resource vital for the existence of the life on this planet. The growth of ancient civilizations can be traced to regions associated with mighty rivers, e.g., the Nile in Egypt, the Yangtze and Yellow river in China, the Ganga in India, the Rhine in Europe, and the Euphrates and Tigris in Asia.

Water has been closely related to development of different civilizations, and in future it will continue to play same role. With world population growing rapidly, pressure on all type of natural resources is constantly being intensifying. By the year 2000, the population of the world will exceed 6 billions. Also this figure is anticipated to reach 10 to 16 billions by the year 2050(U.N., 1973). Due to population explosion in most parts of the tropics, pressure on Water Resources which are distributed unequally in space and time will be extremely acute. Therefore, in spite of the availability of water as the abundant substance on earth, now water is a scarce resource and needs careful planning for its conservation and use. Over the past 50 years, water resources planning has evolved from a relatively straight forward methodology to a complex procedure. The task of water resources system planners may be broadly described as identification or development of possible water resources systems, designs or management plans and evaluation of their economic, ecological, environmental, and social impacts.

Planning is now more broadly based. Instead of emphasizing a single project to meet a specific defined requirement, all needs and opportunities for water resources development are considered in a region such as a river basin, as a large scale water resources systems.

Although water resources projects have been constructed for thousands of years, modern water resources planning has evolved over only about 50 years. Such projects may range from a single project meeting a single purpose need to a regional systems in a multiunit and multipurpose framework.

Optimum planning of a complex and large scale water resources systems are having a high priority consideration in the economic development of the countries. The complexity of such systems make the analysis of water resources investment alternative very difficult and complex. A simultaneous development in river basin planning increased the application of systems analysis techniques.

The tools of systems analysis are many and varied in their usefulness. The approach and appropriate techniques naturally vary from problem to problem. It depends on the characteristics, i.e., the objectives, scope of planning, state of development of system, the space and time of planning process. For example on one extreme, there may be the case where no development may have taken place and the first stage decision in the morphology of developmental planning has to be on screening the candidate system configurations. On the other hand, there may be the case where the system has already been developed and the issue is preliminary of management of the system. There may be mixed stages of development. Therefore, the approach is likely to vary over a vast range. Usually optimization techniques (mathematical models), simulation, and a combination of these are generally used.

The first step is the screening stage, in which mathematical optimization models (screening models) are ~~to~~ be used to limit the range of development for further analysis by discovering unfavorable alternatives. The remaining alternatives were then investigated in the second stage by a detailed simulation model of whole system.

## 1.1 PROBLEM IDENTIFICATION

Although, considerable interest has developed of late in systems planning of water resources and it has been generally accepted that real - life applications are required to validate the efficacy and worthwhileness of certain techniques. Studies of real - life complex systems are still relatively rare. For instance, it is well known that in view of the non-linearities and discontinuities in the objective function, the final analysis of a complex large real - life system could be best carried out by simulation. On the other hand, simulation over even a promising feasible set would be computationally impossible. Preliminary screening by a mathematical programming model on the basis of which simulation could be planned has often been recommended (Dorfman, 1962; Hufschmidt & Fiering, 1966; Roefs, 1968; Roefs & Bodin, 1970; Loucks, 1969; Jacoby & Loucks, 1972; Srivastava, 1976; Chaturvedi & Srivastava, 1981; Karamouz et al., 1992). On the other hand, firstly a simulation model and then, subsequently an optimization model were used to analyze a multipurpose, multi reservoir river basin (Lall and Miller, 1988 ; and Razavian et al., 1990). In this context, it is profitable to investigate the value of mathematical programming in preliminary screening and how it should be coupled with a simulation study. For instance it may be instructive to ascertain how deterministic linear programming models would help in identifying the optimal set in view of the stochastic inputs. An attempt was, therefore, made to study a real-life large scale complex system, the Karun basin in Iran, by a combination of a mathematical programming preliminary screening model and a finer screening-simulation model. In view of the large number of reservoirs being involved and the preliminary planning nature of the study a deterministic linear programming (LP) technique was adopted.

The earlier studies on mathematical screening models considered the following:

(i) A few selected integrated alternative configurations only for analysis, but project by project analysis was not considered.

(ii) The scope of irrigation was as a single irrigation area (self irrigation) per project, but did not consider a large number of individual potential irrigation areas (multi-irrigation areas) under the command of a project/projects.

(iii) Earlier preparation of input data for computation of linear programming by computer for all potentially feasible alternatives, were data-intensive and Herculean task (Razavian et al., 1990), but generalized algorithm (computer programme) for input data matrix generation very well fitting to basic multi-reservoir multi-purpose design and planning in water resources were not developed to over come the above difficult task of input data feeding.

Keeping in mind the above considerations and recognizing the need of a suitable approach, this study is directed to evaluate the different developmental alternatives, and the following objectives were set as the scope of this work.

## 1.2 OBJECTIVES OF PRESENT STUDY

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

(i) To develop a Linear Programming optimization model for river basin planning and development.

(ii) To test the above developed model by applying it to a large scale river basin system, consisting of multi purpose, multi-reservoirs, and multi -irrigation areas.

(iii) To limit the range of developmental alternatives and the ranges of the values of decision variables for further analysis, by discovering unfavorable developmental alternatives, and identifying infeasible decision space with the help of optimization model.

(iv) To explore the best configuration of the development potential of the river system, with respect to the design criteria for each project.

(v) To apply simulation technique for detailed investigations and for analyzing and verifying the results of the whole system in respect of the out come of the optimization model.

(vi) To develop a suitable computer software for generating the input data matrix for linear programming optimization problem applicable to water resources systems.

(vii) To draw suitable conclusions from the above results and the experience of applying the above optimization-simulation models onto a large scale water resources system~~s~~ in order to utilize its full developmental potential in the best possible manner.

## 1.3 THE APPROACH

The mathematical optimization model and simulation model were used to analyze the Karun river system. The Linear Programming (LP)model is considered to be the most suitable methodology for modeling in the initial phases of the investigations, in such a large scale river basin system development. Therefore initially, in the first step the LP model has been applied to the proposed individual potential reservoir sites to find the ranges of the design variables and to investigate and formulate the whole range of individual developmental alternatives. In the second step a finer search by a detailed simulation model is carried out for the whole system. Finally, again the above models were used to study and analyze the combined developmental strategies of the system in two steps as mentioned above, to develop the design criteria~~s~~ for the whole system by which the best configuration of the systems can be drawn. Ultimately, the above approach and the characteristics of the types of the models used suggested a methodological frame work for optimal river basin planning. The results of the present study, carried out under different conditions, confirm and extend earlier findings.

This thesis is an attempt to combine the major advances of systems analysis by optimization-simulation screening models, which is to be used for multi-reservoir, multi purpose and multi irrigation areas water resources systems. The planning, formulation and solution procedure of this analysis in this dissertation is described as below.

## 1.4 THE CHAPTER WISE PLANNING OF THE THESIS REPORT

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

### CHAPTER-2

In this chapter a literature review is presented related to the topics of the screening using linear programming, and simulation within the frame work of design of the multi purpose, multiple reservoir, and multi irrigation areas system. Literature survey has been done in ~~the~~ Journals of such as 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/models developed by different researchers is presented in chronological order as far as possible.

### CHAPTER-3

This chapter is devoted towards "The Linear Programming model (LP model) formulation in the context of the multipurpose, multiple reservoir and multi irrigation areas system development.

**CHAPTER-4**

This Chapter deals with Simulation model formulation.

**CHAPTER-5**

A brief introduction of the problem is presented for the Karun river basin in Iran on which the proposed model(s) were applied.

**CHAPTER-6**

Development of a computer software package called **(INDMAG PACKAGE),** to generate required input data matrix for LP model is presented.

**CHAPTER-7**

Deals with "The model application ". The proposed LP model and Simulation approach have been applied onto the Karun river system keeping in mind the objectives mentioned in Chapter-1. The results and discussions are also presented in this chapter.

**CHAPTER-8**

Based on results and experience of the computations carried out analysis is done and suitable conclusions have been drawn, and suggestions for future work are presented.

# CHAPTER-II

# LITERATURE REVIEW

## Chapter-II

# LITERATURE REVIEW

A brief look at the history of water-development planning reveals a long series of evolutionary changes in both issue definition and analytic methodology. Resevoirs are the most important elements of complex water resouce system (Simonovic, 1992; Helweg et al., 1982). The development of methods to define reservoir design as well as operating rules has been the focus of research for many years. These methods can be classified by such characteristics as the type of optimization solution procedure used(e.g., Linear programming and Dynamic programming), Karamouz et al. (1992). As water planning has become more complex, corresponding analytic 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 behavior of existing or proposed water resource system. Over the past 30 years, we have witnessed advances in our abilities to model the engineering, economic, ecologic, hydrologic, and sometimes even the institutional or practical aspects of large complex multipurpose water resource systems. Applications of models to real systems have improved our understanding of such systems, and hence have often contributed to improved system design, management, and operation. Evaluating the applications of numerous types of models has also taught us how limited our modeling skills remain (Loucks, 1992).

Despite the many applications appearing in the literature mathematical programming techniques are not commonly applied in practice to complex environmental systems (Uber et al., 1992)

One of the earliest methods which was used to calculate the active storage capacity required to meet a specified reservoir release in sequence of periods was developed by Rippl in 1883. His Mass diagram analysis as a conventional method still is used 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. Potter (1977) used the sequent peak procedure for sizing of the reservoirs.

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 (Maass et al., 1962; Hufschmidt and Fiering, 1966; Hall and Dracup, 1970; Haimes, 1977; Loucks et al., 1981; Stedinger et al., 1983; Marino and Mohammadi, 1983a and 1983b; Mohammadi and Marino, 1984a and 1984b; Marino and Mohammadi, 1984; Goodman, 1984; Loaiciga and Marino, 1986; Srivastava, 1987; Chavez-Morales et al., 1987; Chaturvedi, 1987; Flynn and Marino, 1988 and 1989; Sadeghian, 1991; Afshar et al., 1991; Chavez-Morales et al., 1992; Simonovic, 1992; Srivastava and Patel, 1993; Wurbs, 1993; Boney, 1993).

For a large scale water resources system the difficulty in the system analysis is primarily due to large number of possible alternative development strategies, and hence the vast computational effort required to establish an optimal development plan. However, the huge costs involved in the construction and operation of such a system and the great potential for cost reduction through improved system design necessitate a planning programme that will determine such an optimal development strategy. Therefore, in a large and complex system, one of the major challenge is to reduce the large set of alternative configurations that need to be examined in detail to a reasonable number without mistakenly eliminating an attractive option. The most commonly suggested approach has been first to screen all alternative configurations with mathematical programming technique to determine the most attractive alternatives, then further screen them with a detailed simulation model. A critical review related to the problems of screening and simulation within the frame work of multiple reservoirs planning and management, available in literature of water resources planning and management have been presented in three parts as follows :

## 2.1. REVIEW OF APPLICATION ON MULTI RESERVOIR ANALYTIC SCREENING MODELS

The concept of a screening model as an integral part of the analysis of water resources is found frequently in the literature.

The screening model is used for analyzing large river basins with multiple resources and water uses to identify potentially better alternatives, so that money, time and effort could be diverted to examine in detail these alternatives. This process is believed to identify cost effective and potentially efficient system configurations and the size of components. Many screening models have been developed, majority of them being linear programming based for very obvious reasons of large number of variables involved in such problems.

These screening models are static in concept and incorporate implicitly the probability distribution of natural unregulated flows in a model by having the representation of system performance of the model and depend on either a historical or an average stream flow sequence. The simplest examples of this approach are use of average seasonal flows in Linear Programming (LP) model of system operation (Dorfman, 1962; and Thomas and Revelle 1966).

This approach was used in M.I.T's development study for the Rio Colorado in Argentina (Major and Lenton, 1979). This model incorporated irrigation and hydropower purposes. The objective function was to maximize net benefits with capital cost and benefits were assumed linear. The constraints were the continuity constraints for all the reservoirs, land constraints and water requirement constraints for irrigation incorporating return flows and power generation relationship. Flood control was not incorporated in the study. Average stream flows were used and the time period used was one month. No carry over storage or provisions for sediment deposition were made. They have reported that the use of mean flow rates in design could result in reservoir capacity estimates that are insufficient to supply target releases with reasonable reliability. In the first example reported by them, the total reservoir capacity was increased to 5. 5 times that of recommended by their screening model to obtain satisfactory performance. In their second example, almost tripling, of the reservoir capacity suggested by the screening model was necessary.

In practice reservoir system designs are often based on critical flows of record. The linear programming model used to select prospective reservoir capacities that would be similar to the one mentioned above, except that mean monthly flow sequences must be replaced by the critical sequence of monthly flows. The distribution of critical flow and its distribution to various sites in a river basin is to be resolved taking into consideration the cross correlation exhibited by the river flows at various sites.

The yield model is an implicitly stochastic screening model that can be used to deliver various releases with specified reliabilities. The model estimates separately over year and within year reservoir capacity requirements to meet specified release and reliability targets. Constraints on storage volumes, releases, and inflows are written for both within-year periods and yearly operations when both over year and within year system operation are of importance. The model requires both historical annual flows and estimates of within year monthly flows. The model can be viewed as an extension of the critical period model obtained by allowing a specified number of annual failures and employing a simplifying within-year system operation approximation (Loucks et al., 1981).

Several types of multi-reservoir screening models have been developed since 1950. These include the explicitly stochastic reservoir models, explicitly stochastic models based on linear decision rules and chance constraints on release and storage volume.

One of the first application of screening models to water resources development was by Dorfman (1962). He applied linear programming technique to a hypothetical problem of a river basin. The way in which this method uses operating considerations to reduce optimal designs is illustrated by his first example, which deals with a relatively simple configuration of uses and installations under conditions in which the pattern of inflows repeats itself each year with certainty so that over year storage is not required. The second example introduce methods applicable to situations in which over year storage is needed. This feature adds considerable complications to the analysis. Then is a third case in which uncertainty is taken into account.

Some of the subsequent applications of screening models that appeared in the literature are similar to those presented in (Maass et al., 1962), i.e., linear programming models of the form, maximize net benefit, and subjected to continuity constraints, technological constraints, and policy constraints. See for example, Blanchard (1964), Wallance (1966), Rogers (1967), Loucks (1969), Stephenson (1970), Smith (1970), Poblete and McLaughlin (1970), Bargur (1972), Windsor and Chow (1972), Nayak and Arora (1971, 1973), Srivastava and Tiwari (1978), and Srivastava and Uddihal (1985).

Stephenson (1970) illustrates the optimum design of multi-interlinked river basins using linear programming and the principle of decomposition of linear programmes.

Bargur (1972) presented a multisector planning and management approach to water resources that is based on a general equilibrium analysis employing input-output model and linear programming techniques. A dynamic multisector programming model that takes into account the sectoral, spatial, and temporal aspects of regional planning and an extension to an activity analysis model are formulated and applied empirically to California and the western United States for a 15-year planning horizon. The results of the empirical application include water requirement forecasts, interregional water transfer requirements, efficient production and cropping patterns, 'shadow prices' for water and labor, and an optimal investment programme for water resources projects.

Nayak and Arora (1973) considered a chance constrained formulation of a multireservoir system. Minimum and maximum release requirements, minimum pool level, and minimum free board capacity are specified by the management for each reservoir. The management also specifies the maximum probabilities beyond which these requirements are not violated. By proposing linear decision rules for the releases, the authors reduce the chance constrained formulation to an ordinary linear programming formulation. The linear, decision rule states that the release from a reservoir during a given time period is defined by the difference between the 'net initial storage' and a decision parameter for the reservoir during that period. The objective function considers only the total cost of reservoirs, because the primary objective is to meet the various given demands at a minimum cost. This model has been applied to the Minnesota River Basin.

The differences found in the constraints sets of the models are the degree of detail and complexity with which the author choose to represent the physical system. For example Poblete and McLaughlin (1970) who investigated the sensitivity of solutions to the number of time periods, formulated relatively simple constraint sets which included only continuity constraints. On the other hand, Loucks (1968) presented some fairly large formulations with relatively detailed constraints set. The only exception was Rogers (1967) who investigated the effect of a flood control project on the national incomes of India and Pakistan.

Some of the other applications in multi-reservoir analytic screening models are Simonovic and Marino (1982), Marino and Loaiciga (1985a and 1985b); Pereira and Pinto (1985), Gunaa et al.(1990) and Benedito et al.(1991).

Construction of an optimization model for all potentially feasible alternatives can be a data intensive and Herculean Task. Further more, the more complex the optimization model, the more difficult it is to insure that a global optimum has been found. On the other hand simplifying can lead to planning errors.

## 2.2. REVIEW OF APPLICATION ON MULTI RESERVOIR SIMULATION IN WATER RESOURCES

As early as the 19th century, Rippl (1883) devised the mass curve analysis to investigate the reservoir storage capacity required to provide a desired pattern of releases despite inflow fluctuations.

Simulation models are better suited to the modelling of a physical system for decision making as some of the approximation essential in an optimization model may not be necessary in a simulation model. However, simulation models are not able to directly generate optimal solutions except by exhuative search of all possible alternatives scenario.

Before the advent of digital computers, the simulation or operation study, which was conventionally known as "working table" covered a few years of critical flow. These studies were limited to investigate at most one reservoir and one irrigated area or one hydropower station (Proceedings of a seminar on Reservoir System Analysis, 1969; Srivastava and Sundar, 1985). No attempts were made to simulate the performance of a large number of alternative designs, nor were simulation extended to handle time periods as long as the selected periods of analysis. As the computer developed in speed and capacity, it became possible to simulate the performance of large and complex river basin systems over extended periods of time (Sigvaldson, 1967). The application of systems analysis to water resources have increased rapidly since then.

Simulation modelling of large river basins began in U. S. A. with a study of hydropower potential on the main stream of the Missouri river by the (U. S. Army Corps of Engineers, 1957). Application of systems analysis techniques in the field of water resources planning and management can be considered to have begun in U. S. A. with the Harvard Water Program in 1962. The first full river basin simulation was performed in the Nile basin in 1955 by (Morrice, 1958 ). The Corps of Engineers also performed a simulation study of the Columbia river system for development of hydropower (Lewis and Shoemaker, 1962). In the early 1960's the famed Harvard programme took place, as described by Maass et al. (1962). This programme was the first to systematically present the modern, interdisciplinary system analysis approach to water resources planning. In this work, a simulation model was applied to the economic analysis of water resource systems. The model analyzed hydropower, irrigation and flood control purposes in a multi project system.

The simulation modeling work of the Harvard Water Programme was later discussed by Hufschmidt and Fiering (1966), who presented a detailed analysis of their simulation model and discussed its use in the study of multipurpose planning of the Lehigh River basin.

The Corps of Engineers have also developed simulation packages, the HEC-3, HEC-5 and the SSARR models, which have found wide international use for river flow simulation. The HEC-3 (US Army Crops of Engineers, 1974) program simulates the operation of a reservoir system for conservation purposes like water supply, navigation, recreation, low flow augmentation and hydroelectric power. The various demands are supplied from reservoirs so as to maintain a balance of storage in the reservoir system. While flood control operation can be handled in some respects, a more complete simulation is possible using HEC-5. The program can accept any configuration of reservoirs, diversions, power plants and stream control points. However, the programme while accepting system power demands that override individual power plant requirements, does not provide for percolation losses or channel routings. The economic values can be computed for meeting selected targets and the programme can assign economic values to all outputs and summarise and allocate them in various ways. The Arkanas-White-Red river system in USA were studied earlier in 1972 by using the HEC-3 (Hydrologic Engineering Centre, 1972).

The U. S. Army Corps of Engineers (1976) have used HEC-5 programme, for a study of the Susquehanna River Basin in USA to evaluate the flood control effects of a proposed system of reservoirs.

The HEC-5, (US Army Crops of Engineers, 1982) programme is for simulation of flood events to assist in sizing the flood control and conservation storage requirements for each project recommended for the system. The programme can be used in studies to evaluate pre-project condition and to show the effects of existing and/or proposed reservoirs on flows and damages in the system. The programme can also be used for indicating proper reservoir releases throughout the system during flood emergencies in order to minimise flooding as much as possible while maintaining optimum balance of control storage among the reservoirs. The above purposes are accomplished by simulating the sequential operation of a system of reservoirs of any configuration for short interval historical or synthetic floods or for long duration non-flood periods or for combinations of the two.

The SSARR (US Army Crops of Engineers, 1986) (Streamflow Synthesis and Reservoir Regulation) model consists of the following three basic components:

(a) A generalised watershed model for synthesising runoff from rainfall and/or snowmelt

(b) A river system model for routing runoff downstream through channel and/or lake storage

(c) A reservoir regulation model for evaluating various modes of reservoir operation

The SSARR model is particularly useful in flood forecasting with real-time precipitation.

The Department of Civil Engineering, MIT, have developed a series of river basin simulation models MITSM-1 (McBean et al., 1973; and Lenton and Strzepek, 1979; and Strzepek and Lenton, 1978) was developed as a part of the UNDP sponsored study of the Vardar/Axios river basin in Yugoslavia and Greece. The model provides for detailed simulation of both the physical and economic performance of the river basin, including multipurpose and multiobjective surface water projects as well as ground water projects. It is claimed that this model is sufficient for planning purposes where standard rules for reservoir operation are used.

Another version of MITSIM-1 was used by MIT to plan the Rio Colorado (Major and Lenton, 1979) river basin in Argentina. The model described in detail by McBean et al. (1973). The study consisted of screening (LP), simulation and sequencing models. A number of issues like equity, shadow prices of inputs and outputs have been considered in this study. This is perhaps the most comprehensive planning model reported so far. There is, however, no information about the implementation of the results of these studies by the Government of Argentina.

The MITSIM-1 has been updated by the International Institute for Applied Systems Analysis (IIASA), Austria, to overcome certain difficulties and this revised programme is called MITSIM-II. This has been used by IIASA for water management studies of the South Western Skane Water Supply System in Sweden (Strzepek, 1981).

The MITSIM-II model has also undergone various revisions. A very versatile version of this model was allowing simulation at variable time steps ranging from one week upward and with an option to incorporate priorities for various releases.

Simulation models called MITTAMS and EXTG1 were used to evaluate the basin configuration in the integrated development of the 2400 square Kilometer Vardar/Axios River Basin in Yoguslavia and Greece (TAMS, 1978). These models accommodated a large number of projects and an enormous quantity of data, and provided measures of performance in hydrologic and economic terms. They were also effective in accounting for the complementary between projects and purposes (for example, water used in a reservoir for hydropower and for recreation can be released for use in other projects downstream). The simulation models reproduced the interactions among the elements of the system and described the outcome of operating the system under a given set of inputs and operating assumptions. By successive and systematic runs of the models, the response to the variations in inputs or operating conditions or both were evaluated. When used in conjunction with engineering and economic criteria, the results of these runs allowed:

(1) the systematic comparison of alternative configurations of water resources projects in the basin; and

(2) the evaluation of the effect of the upstream development on the flows at the border and the consequent downstream development.

In the early 1970's a set of models named Dynamic Economic Simulation (DES) was developed as a part of research for Texas Water Development Board (now named as Texas Department of Water Resources). They have developed computerised models for planning large scale, multi-basin surface water resources systems and have used them to formulate the Texas Water Plan. The three principal models are SIMYLD-II (Texas Water Board, 1972), SIM-V (Martin, 1982) and AL-V (Martin, 1984).

SIMYLD II analyses water storage and water transfer within a multi-reservoir or multi-basin system. It can simulate the movement of water through a system of river reaches, pump canals, reservoirs and non-storage river junctions. Water demand to be made on the system can be applied to either the storage or non-storage junctions and the option is available to reckon these demands as monthly values or as total annual demand which will be reduced to monthly demand according to a set of user supplied demand distributing factors. SIMLYD II also offers the ability to set priorities for meeting water demands and maintaining reservoir storage at each reservoir. The second purpose of SIMLYD II is determination of the firm yield of a single reservoir within a multi-reservoir system. This mdoel has been used by TWDB for adjudication of water rights in the Cypress Creek basin, for inter-basin transfer connected with the coastal canal and for studies of Nueces river basin.

SIM V is a computerised procedure designed to simulate the operation of a large complex surface water storage and transfer system. SIM V computer routine allows individual network system elements to be introduced at any point of time in the simulation time span. This capability provides the option of investigating various pattern of construction schedules so that the least cost analysis can be selected for implementation. In SIM V, capital costs are entered individually for each system (canal and reservoir) and system operating costs are computed by the model. In general, the movement of water via transfer links are done at a cost which is a known function of the quantity of water flowing and the pumping lift. It is the function of SIM V to meet system storage requirements, water demands and hydropower generation while minimising cost of transportation within the system and no water is supplied from the system if storage capacity remains in the reservoir.

AL V, an improved version of AL III, is a general hydrological optimisation model used for analysing the surface water resource systems. It is designed to analyse the simulated multi-period operation of any interconnected configuration of reservoirs, pump canals and pipelines. The capabilities of AL V model include :

(a) To find minimum cost operating plan for a system of reservoirs, river junctions, canals and river reaches

(b) To find minimum cost of sizing individual reservoirs, canals or closed conduits

(c) To determine the reservoir operating rules for use in related simulation models

(d) To find the minimum cost of construction, sizing and sequencing of a number of water storage and conveyance projects in a multiple purpose river basin system.

Besides the above, TWDB has also prepared several programmes such as

(a) FILLIN-1, MOSS-III, a and SSEQUEN-If for d data m management a and d data generation,

(b) DES and ECOSYM for dynamic economic simulation,

(c) DOSAG-1 and QUAL-1 for simulation of water quality in streams and canals,

(d) GWSIM, for ground water simulation,

(e) CAPEX-I, PIPEX-I, and CANAL-I for water resources conveyance systems optimal capacity expansion and

(f) design models.

TWDB is the first and perhaps the only agency to prepare a set of programmes which are directed to all planning aspects of a river basin. However, it is understood that the models have been put to only limited use and Texas Water Plan could not make much headway. Recently SIM V and AL V programmes have been applied (Martin, 1983) to a large scale system comprising 27 reservoirs on the Arkansas-White-Red River system in USA. The derived system operating policy computed a potential increase of approximately 8 per cent in firm power production of the system over the previous study.

The Department of Water Resources, State of California has developed a generalised computer planning model for California's Central Valley and its two major systems, the Central Valley Project (CVP) and the State Water Project (SWP). The model named Department of Water Resources Planning Simulation Model (DWRSIM)(Department of Water Resources, State of California, 1985 and 1986)is designed to simulate the operation of the CVP-SWP system on a monthly time basis. It considers the whole system consisting of surface reservoirs, ground water reservoirs, conveyance facilities, pumping plants and hydropower plants. This effectively being used for managing existing water resources projects and to plan new facilities. Planning studies carried out involve determination of incremental yield resulting from the addition of each new reservoir into the existing system (assuming different capacities for each) keeping in view the various constraints like the formula for sharing water between SWP and CVP.

The Bureau of Reclamation studied the Colorado River System, a very complex river system in USA with numerous treaties and acts constraining its water use. A computer package was developed for the this purpose incorporating the provision of all the treaties, acts and agreements and capable of simulating the whole system of reservoirs. The package named Colorado River Simulation System, (US Department of

Interior, Bureau of Reclamation 1981 and 1986) has the Colorado River Simulation Model (CRSM) as its main component. It has been used to study changes in operation policies and alternate developmental strategies for the river basin. After the unprecedented flood of 1983 the model was used to review the operation policies and formulate alternative operation strategies that will increase the beneficial use of the Colorado water in excess of the project uses that at present include water supply, power generation, recreation and also flood control.

Maji and Heady (1980) constructed a simulation model to estimate the physical and economic performance of alternative river basin development. The paper shows 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.

A generalized reservoir-system simulation model routinely used in the USACE Southwestern Division (SWD) is described by Hula (1981). The SWD model simulated the daily sequential regulation of a multipurpose reservoir system, performing generally the same types of hydrologic and economic simulation computations as HEC-5. The SWD model uses a one day computation interval, whereas HEC-5 allows a variable time interval. MITSIM (Strzepek et al., 1989) provides the capability to evaluate the economic as well as hydrologic performance of a river basin system involving hydroelectric power, irrigation, municipal and industrial water supply, and other purposes. The Water Rights Analysis Programme (TAMUWRAP) simulates surface-water management and reservoir -system operation under a prior-appropriation water-rights permit system (Wurbs et al., 1993). Unlike many simulation models in which computations proceed from upstream to downstream, TAMUWRAP is based on meeting water demands in according to a user -specified priority. The distinctive feature of the Interactive River System Simulation Programme (IRIS) is its extensive use of interactive computer graphics for information transfer between machine and user. IRIS simulates a water-supply and conveyance system of any normal configuration and also has limited hydroelectric-power simulation features (Loucks et al., 1989, 1990). The interactive-graphics oriented River Simulation System (RSS) is being developed at the Center for Advanced Decision Support for Water and Environmental Systems (CADWES), sponsored by Bureau of Reclamation. The RSS package allows the user to develop a model for a particular reservoir/river system using preprogrammed objects and functions. The object-oriented-programme structure also facilitates a programmer's altering the RSS software to include additional objects for functions as needed for particular applications.

## 2.3 STUDIES IN SYSTEMS ANALYSIS OF COMPLEX WATER RESOURCES SYSTEM

Basin resources planning has become an increasingly important concept in comprehensive planning of a complex water resources system. Comprehensive basin water resources planning is a complex and a difficult task, posing numerous social, economic, environmental and engineering problems. One of the most difficult engineering aspects of such a planning effort is the development of optimum expansion policies for the timing, sizing and sequencing of surface water storage and conveyance facilities. For large scale water resources systems the difficulty of this task is primarily due to large number of possible alternative development strategies.

Knowledge of the magnitude of physical phenomena relating to water resources and water uses, economic evaluation of different possible programmes of development and the selection procedure of development programme providing the best choice among different alternatives is the key issue in water resources planning. Within this frame work, multiple reservoir planning is a subset of the activities of river basin planning. The tools of calculations that can contribute to analyze such a system are the use of multi-reservoir screening models.

A simultaneous development in river basin planning was the increased application of systems analysis techniques. Experience and expertise were gained by water resources systems analysis in using two type of models which allowed consideration of the many interactions and interdependancies of system components. Mathematical optimization models which are relatively less detailed and realistic but could systematically investigate the whole range of the development alternatives were formulated. Physical simulation model were built to consider complex river basin systems in detail The characteristics of the two type of models suggested a methodological framework for river basin planning. The first step was a screening stage in which mathematical optimization models (screening models) were used to limit the range of development for future analysis by simulation model.

Dorfman (1965) defines two types of models:Analytic models that optimize and simulation models. Dorfman's planning sequence begins with the identification of a preliminary optimal design using an analytic model. The simulation model is then used to explore variations around the optimal solution.

The first step in the planning sequence is the screening process, and the analytic model is the screening model. The comparison of analytic and simulation models by Rogers (1968) supports Dorfman's planning process. Analytic models are relatively less realistic than simulation models due to many simplifying assumptions that are necessary for model formulation and solution. However, while simulation models capture more of the characteristics of the problem, it is computationally infeasible to design solely with this model. Rogers concludes, therefore, that the best approach is a combination of the two: Analytic (screening models) for reduction of the range of desirable alternatives and simulation models for detailed more realistic analysis of the remaining alternatives.

Hufschmidt (1965) describes the screening process in more detail. Preliminary screening begins with the easiest decisions by eliminating alternatives that are obviously inferior. Progressively more difficult decisions are made with increasingly more complex analysis. The process continues until a satisfactory range of optimal designs have been defined, i.e., when the analysis becomes prohibitively complex or when continued analysis will not further reduce the size of optimal range. Thus, the screening philosophy as outlined by Hufschmidt is to attempt to limit the range of alternatives for detailed analysis by simulation through the elimination of inferior alternatives by progressively more complex analysis.

A large river basin offers a variety of development opportunities, the number of alternative system plans from which one can choose be extremely large. An investigation (Jacoby and Loucks, 1972) of the use of analytical optimization models to 'screen' the set of possible plans and to select a small number worthy of simulation analysis is presented. Deterministic and stochastic optimization models were developed and applied to both static and dynamic (multi period) planning problems. The resulting designs were further analyzed by simulation to determine the ability of the screening models to identify high-valued alternatives. The results indicated considerable promise for the combined use of optimization and simulation models. The Delaware River basin was used as an example.

A study (Srivastava, 1976; and Chaturvedi and Srivastava, 1981) dealt with the first stage preliminary screening design model in the context of a sequential system analysis iterative modelling of a complex water resources system. The models were developed in the context of River Narmada, a large river basin in India. Two types of analytical optimization models were used to find a reasonably small set of possible optimal design alternatives. These were linear programming deterministic continuous (LPDC) model and linear programming deterministic discontinuous (LPDD) model. The simulation continued screening on the basis of the information obtained from linear programming model. The LPDC model results may be assumed to be nearly optimum in terms of the objective function and could serve as an input for further screening by simulation. The LPDD model was helpful in selecting the ranges of variables for simulation by random sampling.

A compact, non-linear optimization formulation for selecting among and sizing potential reservoirs is derived by decomposing the problem into simulation and optimization components. Reservoir storage capacities needed are determined using a modified sequent peak algorithm to simulate monthly reservoir operation (Lall and Miller, 1988). Simulation is also employed to determine optimal sizes for hydropower generators at each site. Similarly, average annual flood control and recreation benefits are determined through simulation. An optimization scheme that considers annual yields for each purpose with specified reliabilities and conservation and flood storage as decision variables is used to integrate these simulations into an optimal screening algorithm. Significant savings in computational and memory requirements over other formulations are offered at the expense of nonlinear functional forms. Applications of the model developed with data from sites on Lower Bear River are presented.

A simulation model in conjunction with an optimization model was developed for water-development planning and policy-issue analysis on Platte River in Nebraska (Razavian et al., 1990). The general model consisted of three components: simulation, screening, and optimization. The focus of this paper was on the economic simulation component, which consisted of water-use and economic sub models. The economic simulation model simulated water uses and losses and calculated associated system costs and economic benefits for a large number of alternative water-development options. The output was used to analyze the physical and economic efficiencies of each alternative, to select preferred alternatives for further analysis, and to generate data for direct input to a subsequent multi-objective optimization model. The technique was found to be a very efficient and cost effective method of evaluating development opportunities for a complex, multipurpose, multi-reservoir river basin.

In a study by Karamouz et al. (1992), a multivariate hydrological time-series analysis and a deterministic implicitly stochastic optimization technique for determining reservoir operating rules for multiple reservoirs were investigated. The scheme comprised a three-step cyclic procedure that attempts to improve the initial operating rules for the system. The system required two sets of synthetically generated contemporaneous stream flow series to be used in simulation model. The three step cycle begins with an optimization of reservoir operations for a given set of stream flows. The optimal operations from the solution are then analyzed in a regression procedure to obtain a set of operating rules. These rules are evaluated in a simulation model using a different set of data. Based on the simulation results, bounds are placed on operations and cycle returns to the optimization model. This continues until one of the stopping rule is satisfied.

Some of the other applications were Simonovic (1987); Jan-Tai Kuo et al. (1990); and Boney (1993).

Various techniques and design aspects, considered by authors in this literature review is presented in Appendix-2.I.

# CHAPTER-III

# THE LINEAR PROGRAMMING SCREENING MODEL

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# THE LINEAR PROGRAMMING SCREENING MODEL

## 3.1 INTRODUCTION

~~The~~ Linear programming and its offshoots are probably the most widely used methods of operations research. The scope of linear programming ~~model~~ is very wide and can be also applied to the problems of other disciplines. It is often applied in certain areas of water resource planning, and are suitable for problems in which it is desired to allocate scarce resources among various activities in an optimal diversion nodes, junction nodes and confluence nodes, and municipal and industrial demand nodes.

The task of the linear programming screening model is to analyze the whole range of development alternatives in a river basin, i.e., to "screen" the alternatives for more detailed analysis by simulation models and to answer the questions of which alternatives and how big should they be ? (Jacoby and Loucks, 1972; Srivastava, 1976; Chaturvedi and Srivastava, 1981; and Karamouz et al., 1992). To perform this task, a Linear Programming model for multipurpose, multi-reservoir and multi- irrigation areas is formulated as realistic as possible while maintaining the ability to solve it analytically.

The constraint of solvability which is considered on the model is a critical one in that it results in the following major simplifying assumptions:

1) In a linear model the objective function and the constraints are in linear form.
2) It is deterministic in nature, i.e., hydrologic inputs are taken as known values and as being certain to occur.
3) The model is run for one representative year only i.e., every year is the same.

These major simplifications will be elaborated as they pertain to specific aspects of the model. Several other assumptions which were made for ease of formulation are discussed below. A sample site is shown in Figure 3.1. The variables/parameters of a reservoir are shown in Figure 3.2.

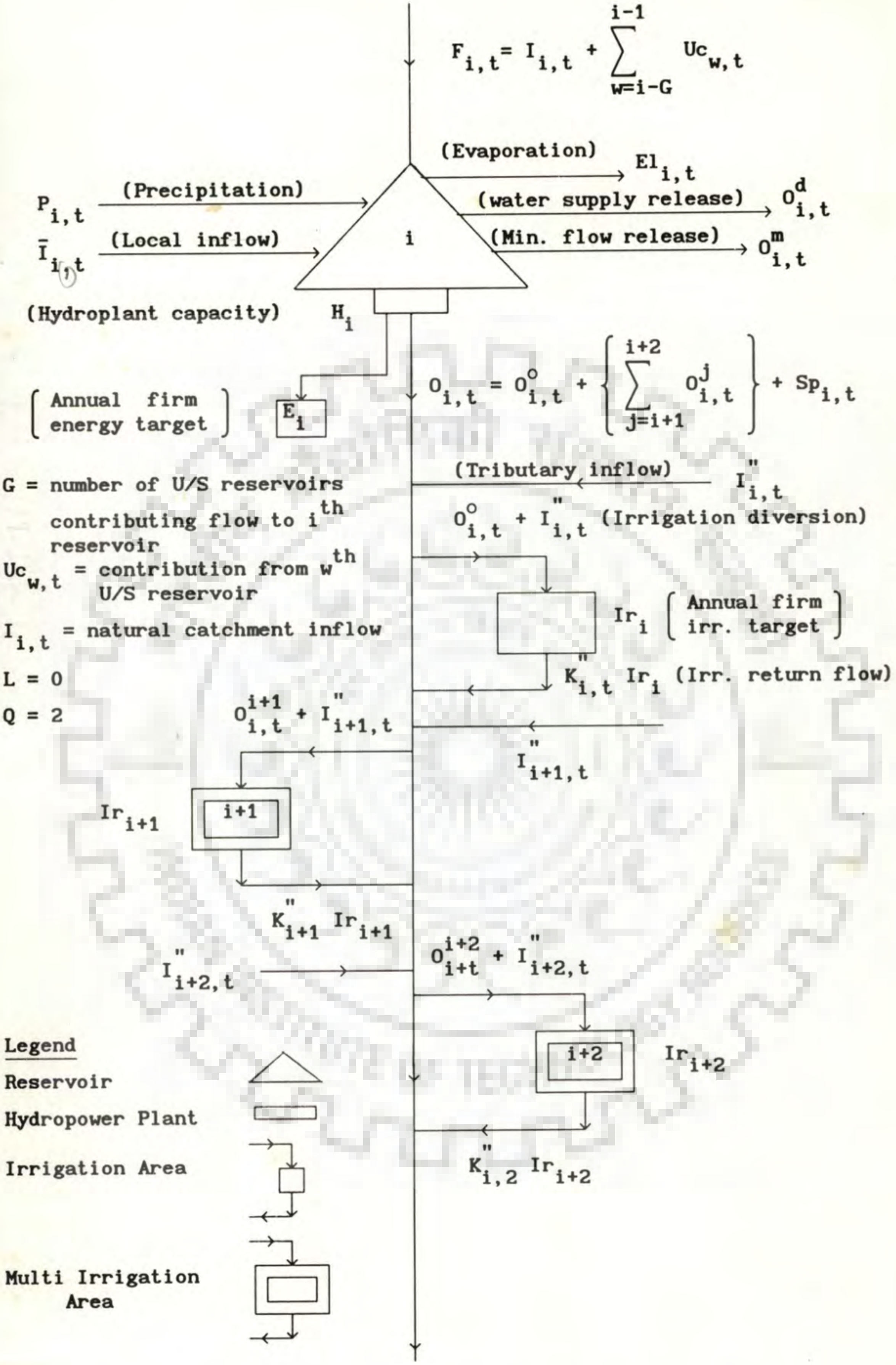


Fig. 3.1. A Sample Site with One Multipurpose Reservoir and 2 Multi-irrigation Areas

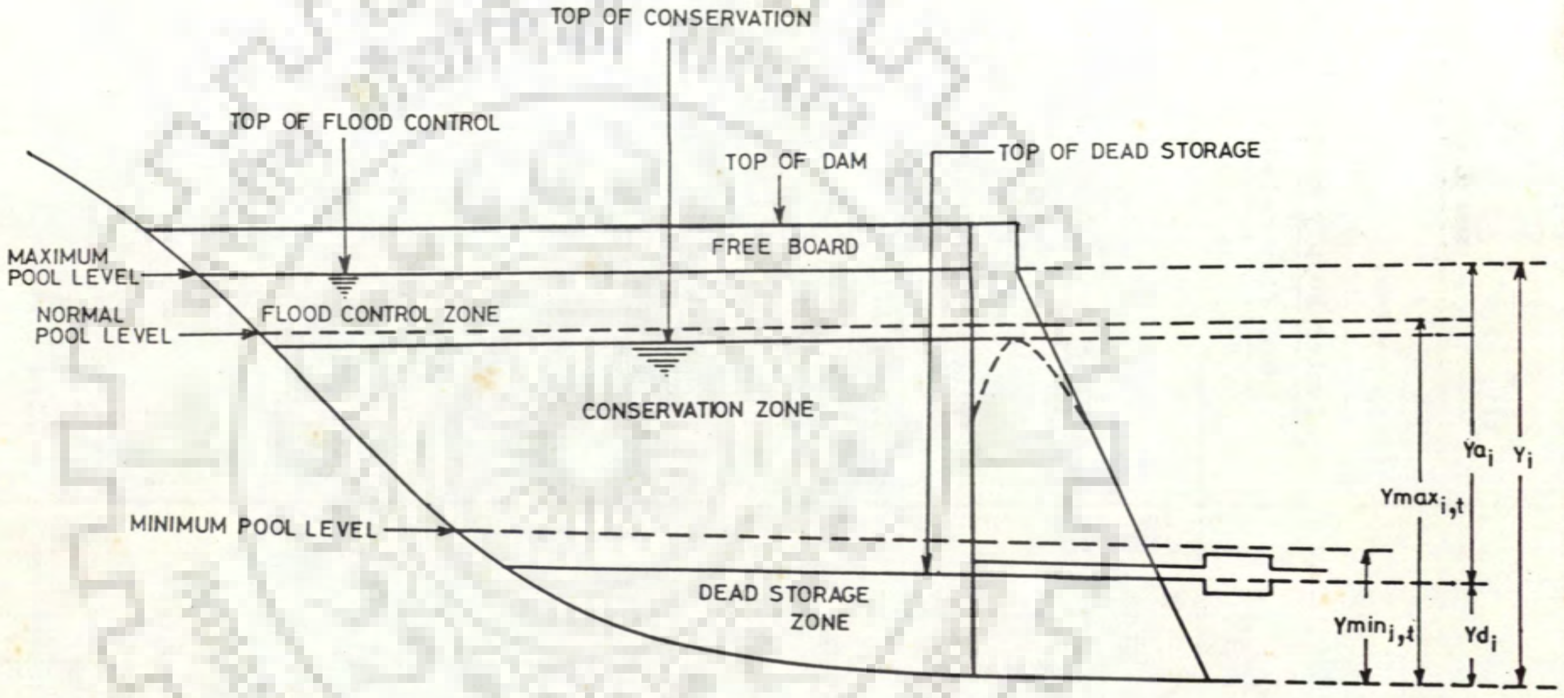


Fig. 3·2–Various Reservoir Storage & Variables Related to a Reservoir

## 3.2 THE CONSTRAINTS

The constraint set consists of the following basic types of constraints.

### 3.2.1 Reservoir Constraints

#### (i) Continuity constraints

Continuity constraints are those constraints that are included in the model to insure conservation of mass in a given time. In terms of a river system this means that the water that enters a point on the stream must leave that point on the stream, if it has not been stored in a reservoir or diverted out of the stream for a water use. This basic continuity princip~~al~~le applies throughout the entire reach of the stream for all the times. However, it is necessary to write the continuity constraints only at sites where water is stored, diverted or imported.

The continuity relationship for multi-reservoir system with reservoir/sites in series and/or parallel, (Figure 3.3)can be written as follows:

$$S_{i,t}=S_{i,t-1}+F_{i,t}+P_{i,t}+\bar{I}_{i,t}-El_{i,t}-O_{i,t}-O^{d}_{i,t}-O^{m}_{i,t} \quad \text{for all i and t} \qquad (3.1)$$

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

The reservoir evaporation (Loucks, 1981), $El_{i,t}$ in Equation (3.1) may be written as below, also see Figure 3.4.

$$El_{i,t} = Aa_i * e^0_{i,t}\left(\frac{S_{i,t-1}+S_{i,t}}{2}\right) + Ao_i * e^0_{i,t} \quad \text{for all i and t} \qquad (3.2)$$

put
$$\bar{a}_{i,t} = 0.5\ Aa_i * e^0_{i,t} \quad \text{for all i and t} \qquad (3.3)$$

Now combine Equations (3.1), (3.2) and (3.3) and rewrite the terms, which yields

$$(1+\bar{a}_{i,t})\ S_{i,t} - (1-\bar{a}_{i,t})\ S_{i,t-1} + O_{i,t} = F_{i,t} + P_{i,t} + I_{i,t}$$

$$-Ao_i\ e^0_{i,t} - O^d_{i,t} - O^m_{i,t} \quad \text{for all i and t} \qquad (3.4)$$

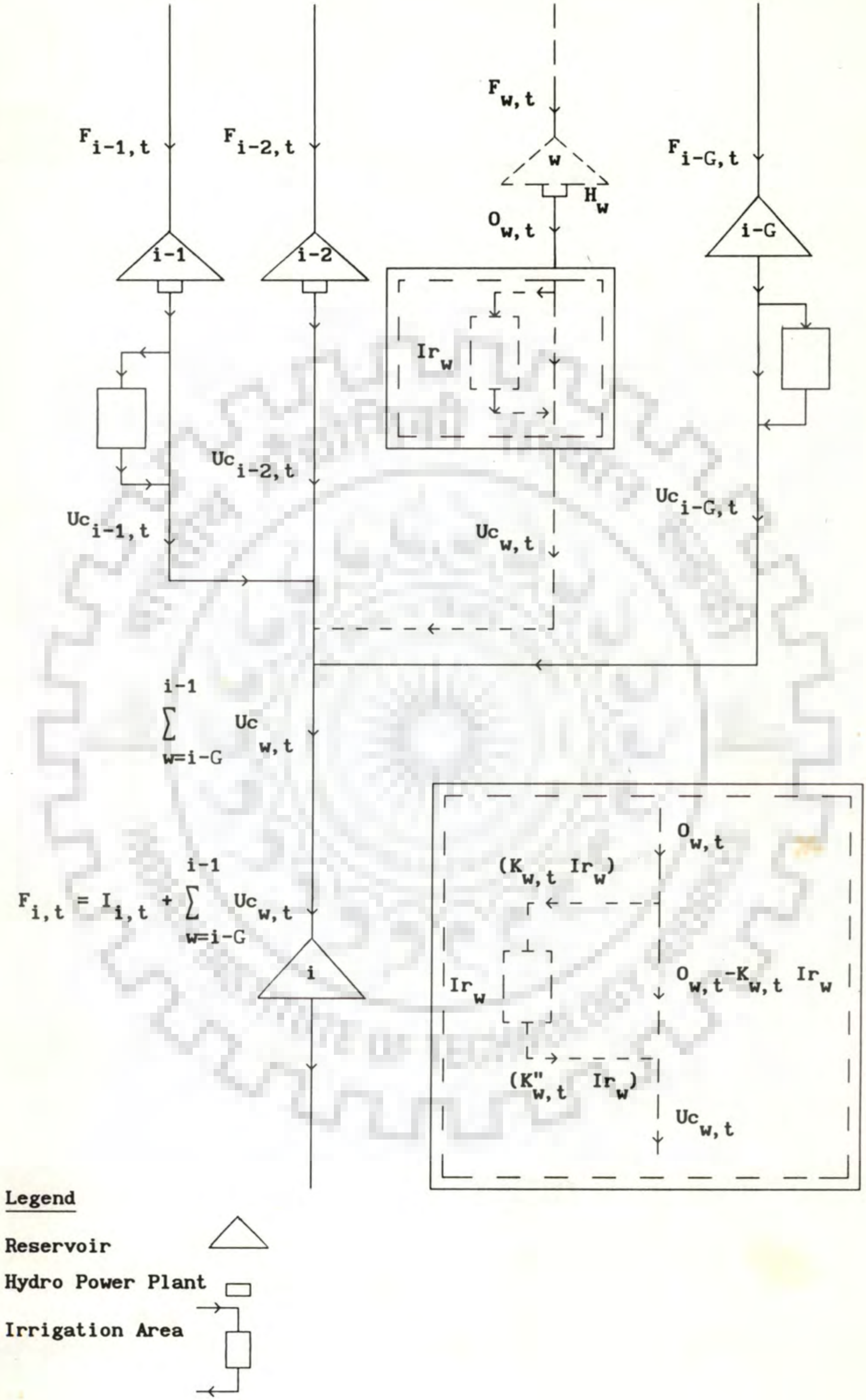


Fig 3.3 Diagramatic Representation of Continuity Equation

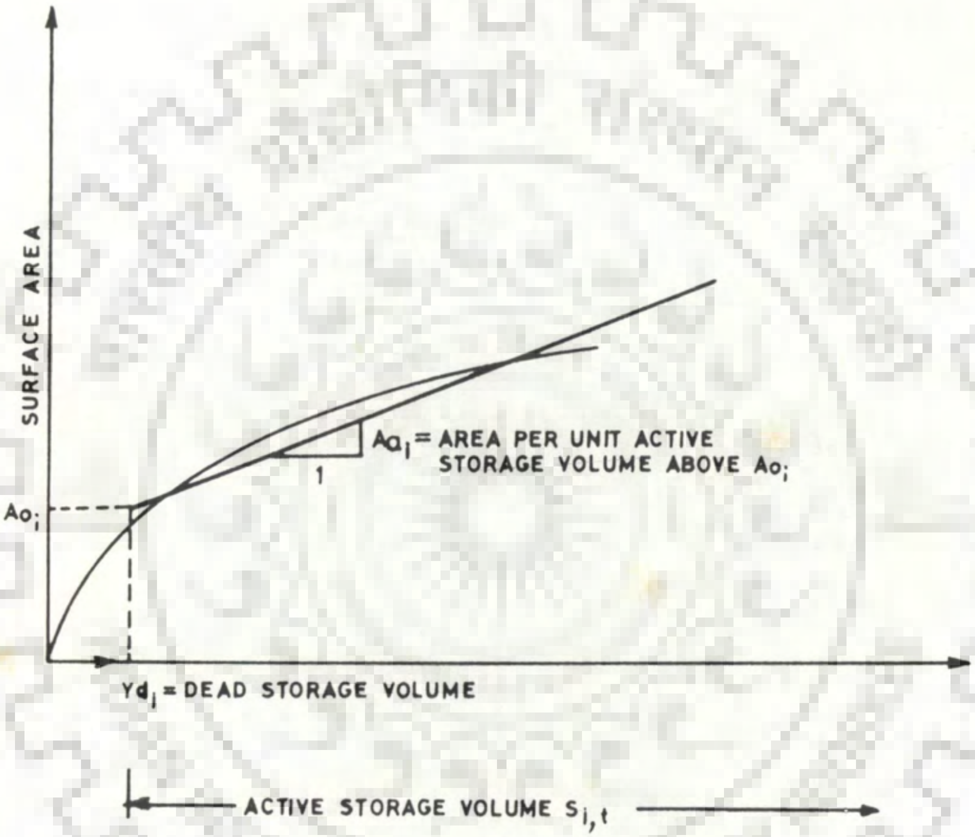


Fig.3·4–Storage Area Relationship and Approximation of Surface Area per Unit Active Storage Volume

For a barrage, the continuity equation is modified as follows:

$$O_{i,t} = F_{i,t} + I_{i,t} - O^{d}_{i,t} - O^{m}_{i,t} \qquad \text{for all i and t} \qquad (3.4a)$$

where,

i = $i^{th}$reservoir/site,

$S_{i,t}$ = final gross reservoir content or storage of $i^{th}$ reservoir in time t,

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

$O_{i,t}$ = total reservoir release from $i^{th}$ reservoir in time t,

$F_{i,t}$ = natural inflow from its own catchment plus contributions of all possible regulated flows from upstream reservoirs and return flows from U/S irrigations at $i^{th}$ reservoir in time t,

$P_{i,t}$ = precipitation effect directly upon the $i^{th}$ reservoir in time t,

$I_{i,t}$ = local inflow to the $i^{th}$ reservoir from surrounding area in time t,

$O^{d}_{i,t}$ = release for water supply from $i^{th}$ reservoir in time t,

$O^{m}_{i,t}$ = release from $i^{th}$ reservoir to keep minimum flow on downstream in time t,

$Aa_i$ = area per unit active storage volume above $Ao_i$ for $i^{th}$ reservoir,

$Ao_i$ = reservoir surface area corresponding to the dead storage of reservoir, $Yd_i$, for $i^{th}$ reservoir, and

$e^{0}_{i,t}$ = average reservoir evaporation rate for $i^{th}$ reservoir in time t.

The value of $F_{i,t}$ is given by:

$$F_{i,t} = I_{i,t} + \sum_{w=i-G}^{i-1} Uc_{w,t} \qquad \text{for all i and t} \qquad (3.5)$$

$I_{i,t}$ = natural catchment inflow to $i^{th}$ reservoir in time t,

$Uc_{w,t}$ = regulated contributions including irrigation return flow from $w^{th}$ U/S reservoir/site to the $i^{th}$ D/S reservoir site in time t,

$w$ = $w^{th}$ u/s reservoir/site contributing to the flow of $i^{th}$ D/S reservoir/site and is given by

$w$ = i-G, i-G+1...............,i-1, and

$G$ = total number of U/S reservoir/site contributing to the flow of $i^{th}$ D/S reservoir/site.

Again,

$$Uc_{w,t} = \left\{ O_{w,t} - \left[ \left( K_{w,t} - K''_{w,t} \right) Ir_w \right] \right\} \quad \text{for all i and t} \qquad (3.6)$$

where,

$O_{w,t}$ = total release from $w^{th}$ reservoir/site in time t,

$Ir_w$ = firm annual irrigation target at $w^{th}$ site,

$K_{w,t}$ = proportion of annual firm irrigation target, $Ir_w$ to be diverted for irrigation canal at $w^{th}$ site in time t, and

$K''_{w,t}$ = irrigation return flow as a proportion of irrigation diversions at $w^{th}$ site in time t.

**Note:** If $w^{th}$ reservoir/site has no irrigation, all the irrigation terms will be zero in Equation (3.6).

In the model the reservoirs storage at beginning of the next season $S_{i,t}$ are assumed equal to the reservoir contents at the starting of the present season $S_{i,t-1}$ plus any possible additions during present season, (catchment natural inflow and any imports of down stream releases from the upstream reservoirs, including spills and the return flows from irrigated areas and the municipal and industrial uses upstream of the reservoir linked to the $i^{th}$ reservoir minus any deductions during the present season, reservoir release and any diversions). This is sometimes called a continuous model. All the inflow and outflow terms in Equation (3.4) present flow volume throughout the time t.

Similar continuity constraints can be written without storage terms at all the junction points where, sum of all inflows is equal to release downstream and at diversion points sum of all inflows is equal to sum of all outflows including diversions to all the uses.

**(ii) Storage bounds**

**(a)** The contents of reservoir can not exceed the storage capacity of reservoir during any period t at any site i.

$$S_{i,t-1} \le Y_i \qquad \text{for all i and t} \qquad (3.7)$$

where $Y_i$ is the gross storage capacity of the reservoir at site i.

**(b)** Also the dead storage of the reservoir puts a lower limit on the reservoir storage capacity.

$$Yd_i \le S_{i,t-1} \qquad \text{for all i and t} \qquad (3.8)$$

**(c)** Same way for all reservoirs the storage has to satisfy specific upper and lower bounds, i.e.,

$$Yd_i \le Ymin_{i,t} \le S_{i,t-1} \le Ymax_{i,t} \le Y_i \qquad \text{for all i and t} \qquad (3.9)$$

which shows the non negativity of storage capacity at all the time periods and a minimum storage which is site specific and maximum storage corresponding to the conservation storage at the end of each time period, the maximum of which determines the full reservoir level. Specification on $Ymin_{i,t}$ is an iterative process as this is a function of the quantity of sediment inflow into the reservoir, the trap efficiency of the reservoir which is in turn a function of the valley shape and operation of the reservoir, and the sediment distribution in the reservoir over time during life of the reservoir. These relationships are only empirical and are difficult to incorporate into mathematical model, if not impossible. $Ymin_{i,t}$ is also sometimes governed by the minimum off-take levels of water extraction, minimum draw down levels for power generation, recreation, and wild life considerations, conservation for extreme drought situation and others. If we club all these considerations except sedimentation as a set by, m, and the corresponding storage as $Ym_{i,t}$ and the sediment storage by $Ys_{i,t}$ we can write

couple?

$$Ymin_{i,t} = \max\ (\ Ym_{i,t},\ Ys_{i,t}) \tag{3.10}$$

$Ymax_{i,t}$ is also governed by various factors. It is bound on the lower side by the compromised or uncompromised flood storage requirement and on the upper side by the topographic conditions of site and the limits on land submergence and social considerations.

Therefore,

$Ymin_{i,t}$ = gross capacity of reservoir up to the minimum pool level of the ith reservoir in time t,

$Ymax_{i,t}$ = gross capacity of reservoir up to normal pool level (top of the conservation) of the ith reservoir in time t, and

$Yd_i$ = dead storage of ith reservoir.

**(d)** The total storage capacity of reservoir $Y_i$ is determined as the sum of $Ymax_{i,t}$ , and the flood storage.

$$Y_i = (Ymax_{i,t} + Yf_{i,t}) \qquad \text{for all i and t} \tag{3.11}$$

where,

$Yf_{i,t}$ = the flood storage of ith reservoir in time t.

Equation (3.9) also can be written as

$$0 \le Ymin'_{i,t} \le S_{i,t-1} \le Ymax'_{i,t} \le Ya_i \qquad \text{for all i and t} \tag{3.12}$$

Where,

$S_{i,t-1}$ = initial live reservoir storage of $i^{th}$ reservoir in time t,

$Ymin'_{i,t}$ = live capacity of reservoir up to the minimum pool level of $i^{th}$ reservoir in time t,

$Ymax'_{i,t}$ = live capacity of reservoir up to the normal pool level of $i^{th}$ reservoir in time t, and

$Ya_i$ = total live capacity of $i^{th}$ reservoir at maximum pool level.

### 3.2.2 Flood Control Constraints

The total of dead storage, live storage, and flood storage is limited by the gross reservoir capacity, i.e.,

$$Yd_i + S_{i,t-1} + Yf_{i,t} \leq Y_i \qquad \text{during flood period} \qquad (3.13)$$

$$Yd_i + S_{i,t-1} \leq Y_i \qquad \text{during non flood period} \qquad (3.14)$$

Equation (3.13) can be written as

$$Yd_i + S_{i,t-1} + (Ya_i - Ymax'_{i,t}) \leq Y_i \qquad (3.15)$$

$$Yd_i + Ya_i + S_{i,t-1} - Ymax'_{i,t} \leq Y \text{ , i.e.,} \qquad (3.16)$$

because $Yd_i + Ya_i = Y_i$. Therefore Equation (3.16) is

$$S_{i,t-1} - Ymax'_{i,t} \leq 0 \qquad \text{for all i and t} \qquad (3.17)$$

here, $S_{i,t-1}$ is live reservoir storage.

For gross reservoir storage Equation (3.17) is written as

$$S_{i,t} - Ymax_{i,t} \leq 0 \qquad \text{for all i and t} \qquad (3.18)$$

### 3.2.3 Irrigation constraints

The volume of water released from the reservoir must be sufficient to meet irrigation demand in period t. For a multi purpose reservoir with multi-irrigation areas as shown in figure 3.5., the constraints are described below.

#### (i) Irrigation Constraint for $p^{th}$ reservoir for its own irrigation command area

The irrigation release $O^{0}_{p,t}$ from $p^{th}$ reservoir for its own irrigation area plus local inflow joining should satisfy its corresponding irrigation demand in time t, i.e.,

$$O^{0}_{p,t} + I''_{p,t} \geq K_{p,t}\, Ir_{p} \qquad \text{for all p and t} \tag{3.19}$$

$O^{0}_{p,t}$ = release from $p^{th}$ reservoir for its own irrigation command area in time t,

$I''_{p,t}$ = water that joins the main stem just above irrigation diversion canal at $p^{th}$ reservoir site in time t,

$K_{p,t}$ = proportion of firm annual irrigation target at $p^{th}$ reservoir site in time t, and

$Ir_{p}$ = firm annual irrigation target at $p^{th}$ reservoir site.

where,

p = i, i + 1,..............., i + L,

p = $p^{th}$ parallel reservoir, and

L = number of parallel reservoirs (excluding $i^{th}$ reservoir), i.e., total number of parallel reservoirs are, (L+1). For single reservoir, p=i only with L=0.

#### (ii) Irrigation constraint for $j^{th}$ multi-irrigation area

The irrigation release $O^{j}_{p,t}$ made from $p^{th}$ reservoir for $j^{th}$ multi - irrigation area plus local inflow joining, should satisfy the irrigation demand of $j^{th}$ multi-irrigation area in time t, i.e,

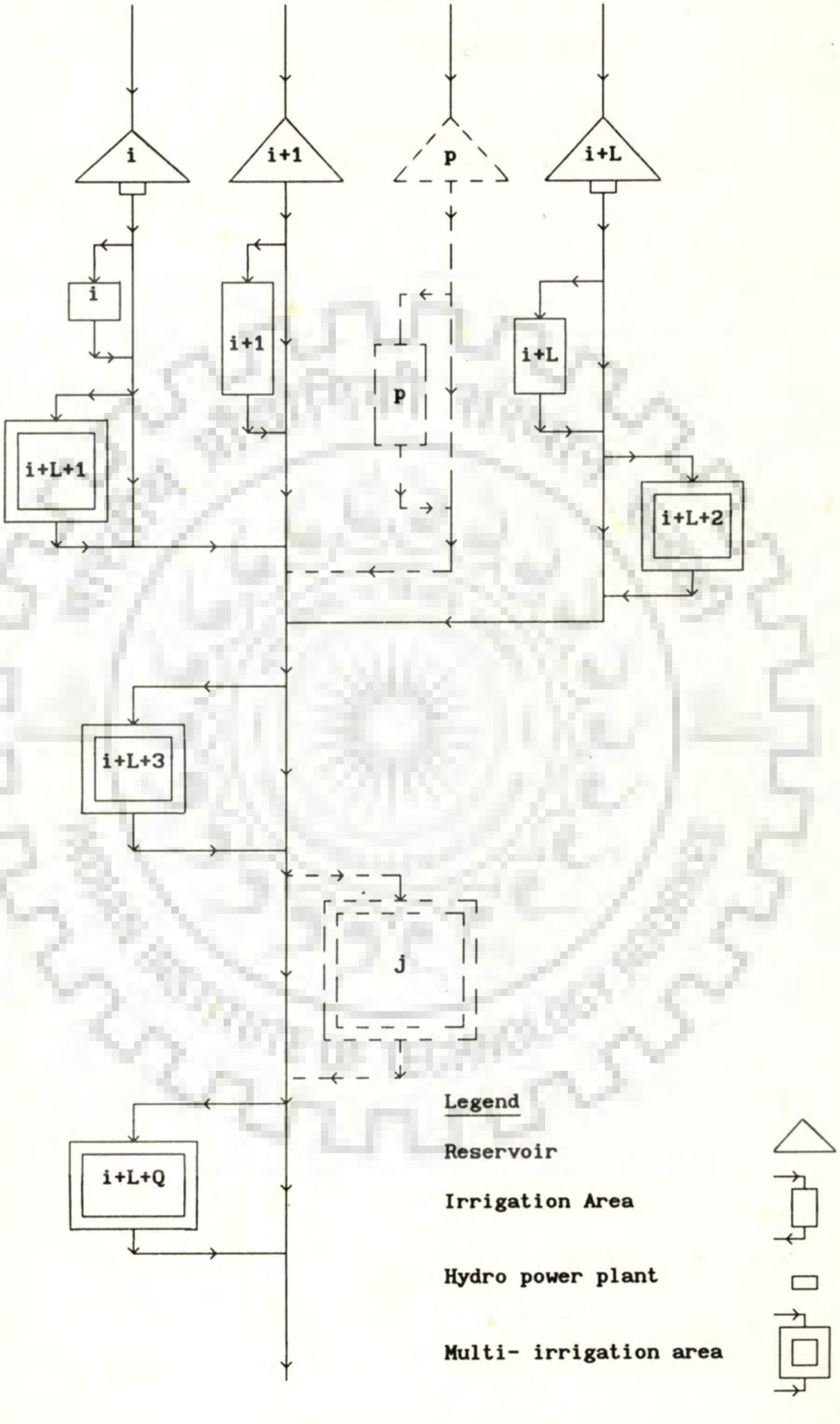


Fig. 3.5 Parallel Reservoir with Multi-Irrigation Areas

$$\left\{\sum_{p=i}^{i+L} O^{j}_{p,t}\right\} + I^{''}_{j,t} \geq \left\{\sum_{p=i}^{i+L} K_{j,t}\, Ir^{p}_{j}\right\} \qquad \text{for all j and t} \qquad (3.20)$$

$j$ = $j^{th}$ multi-irrigation area given by,

$j$ = $i + L + 1, i + L + 2, \ldots\ldots\ldots\ldots, i + L + Q$,

$O^{j}_{p,t}$ = release from $p^{th}$ reservoir for $j^{th}$ multi-irrigation area in time t,

$I^{''}_{j,t}$ = water that joins the main stem just above irrigation diversion canal at $j^{th}$ site in time t,

$K_{j,t}$ = proportion of firm annual irrigation target at $j^{th}$ site in time t,

$Ir^{p}_{j}$ = firm annual irrigation to be served for $j^{th}$ multi-irrigation area by $p^{th}$ reservoir in time t.

### (iii) Total release constraints for $p^{th}$ reservoir

Total release, $O_{p,t}$, made from $p^{th}$ reservoir i in time t is also given by

$$O_{p,t} = O^{0}_{p,t} + \left\{\sum_{j=i+L+1}^{i+L+Q} O^{j}_{p,t}\right\} + Sp_{p,t} \qquad \text{for all p and t} \qquad (3.21)$$

$O_{p,t}$ = total release from $p^{th}$ reservoir in time t,

$Sp_{p,t}$ = spill from $p^{th}$ reservoir in time t,

$Q$ = total number of multi irrigation areas.

### (iv) Annual Irrigation target at $j^{th}$ multi-irrigation area

The annual irrigation target $Ir_j$ at sit j is defined as

$$Ir_j = \sum_{p=i}^{i+L} Ir^{p}_{j} \qquad \text{for all j} \qquad (3.22)$$

where,

$Ir_j$ = firm annual irrigation target at $j^{th}$ multi-irrigation area.

### 3.2.4 Hydroelectric Energy Constraints

The production of Hydroelectric energy is a relatively well defined technical process. There are only three decision variables which effect

- The flow through the turbine of the power plant.
- The head associated with flow
- The capacity of power plant

The relationships of these variables to electric energy production are the origins of the energy constraints.

**(i)** The flow through turbines should meet energy generation demand.

$$E^{T}_{i,t} - (C_f\, e_i\, He_{i,t}) * O_{i,t} = 0 \qquad \text{for all i and t} \qquad (3.23)$$

where,

$E^{T}_{i,t}$ = total energy generated from reservoir $i^{th}$ in time t, in MW-hr,

$C_f$ = conversion factor from M.C.M/month to Mw-hr,

$e_i$ = turbine and generator efficiency for hydroplant i,

$He_{i,t}$ = average storage head at $i^{th}$ reservoir in time t, and

$O_{i,t}$ = water released from $i^{th}$ reservoir in time t.

**(ii)** Energy production is also limited by the percent of time that the plant will produce power specified by the load factor.

$$E^{T}_{i,t} - \alpha_{i,t}\, h_{i,t}\, H_i = 0 \qquad \text{for all i and t} \qquad (3.24)$$

**(iii)** Total energy is defined by

$$E^{T}_{i,t} = \eta_{i,t}\, E_i + \hat{E}_{i,t} \qquad \text{for all i and t} \qquad (3.25)$$

where,

$E_i$ = firm annual energy target at $i^{th}$ site,

$H_i$ = hydropower plant capacity at $i^{th}$ site,

$\alpha_{i,t}$ = load factor for hydropower at $i^{th}$ site in time t,

$\eta_{i,t}$ = percentage of annual energy target to be supplied in time t at $i^{th}$ site i,

$h_{i,t}$ = number of hours in a period t at $i^{th}$ site, and

$E_{i,t}$ = nonfirm (secondary) energy generated in time t at $i^{th}$ site.

$He_{i,t}$ = is not a known constant. Therefore, together with $O_{i,t}$ it makes Equation (3.23) a nonlinear one. Appropriate $He_{i,t}$ may be determined by trial & error.

### 3.2.5 Bounds on Variables

Further, if necessary, bounds on the individual design/operating variable may be also put, i.e.,

$$LL_{1,i} \le Y_i \le UL_{1,i}\ ; \qquad LL_{2,i} \le Ir_i \le UL_{2,i}\ ;$$

$$LL_{3,i} \le H_i \le UL_{3,i}\ ; \qquad LL_{4,i} \le E_i \le UL_{4,i}\ ;$$

and $$Omin_{i,t} \le O_{i,t} \le Omax_{i,t}$$

where,

$LL_{1,i}$, $LL_{2,i}$, $LL_{3,i}$, and $LL_{4,i}$ = lower limits (bounds) on $Y_i$, $Ir_i$, $H_i$, and $E_i$ respectively,

$UL_{1,i}$, $UL_{2,i}$, $UL_{3,i}$, and $UL_{4,i}$ = upper limits (bounds) on $Y_i$, $Ir_i$, $H_i$, and $E_i$ respectively,

$Omax_{i,t}$ = maximum limit (bound) on $O_{i,t}$, and

$Omin_{i,t}$ = minimum limit (bound) on $O_{i,t}$.

## 3.3 THE OBJECTIVE FUNCTION

The objective function is to maximize the total annual net benefit from irrigation, hydropower and flood control at all site i. The benefit can be calculated as

$$\text{Maximize: } \sum \left[ B_{2,i} + B_{3,i} + B_{4,i} - \left( C_{1,i} + C_{2,i} + C_{3,i} \right) - \left( Om_{1,i} + Om_{2,i} + Om_{3,i} \right) \right] \quad (3.26)$$

The first subscript 1, 2, 3 and 4 represent reservoir, irrigation, hydropower and flood control respectively, and the second subscript i represents a site in the system. The various terms in the objective function are given by:

$$B_{2,i} = a_{2,i}\, Ir_i,\; B_{3,i} = a_{3,i}\, E_i,\; B_{4,i} = a_{4,i} \sum_t Yf_{i,t}$$

where, $\sum_t Yf_{i,t} = \sum_t \left( Y_i - Ymax_{i,t} \right)$

$$C_{1,i} = C'_{1,i}\, Y_i\,,\; C_{2,i} = C'_{2,i}\, Ir_i,\; C_{3,i} = C'_{3,i}\, H_i\,,$$

$$Om_{1,i} = Om_{i,t}\, Y_i,\; Om_{2,i} = Om'_{2,i}\, Ir_i,\; Om_{3,i} = Om'_{3,i}\, H_i$$

where,

$a_{2,i}$ = the long run benefit function for firm irrigation at site i,

$a_{3,i}$ = the benefit per unit of firm energy at site i,

$a_{4,i}$ = the flood control benefit as a function of the flood control reserve for $i^{th}$ reservoir,

$B_{2,i}$, $B_{3,i}$, $B_{4,i}$ = gross annual firm irrigation, firm hydropower, and flood control benefits, respectively at site i,

$C_{1,i}$, $C_{2,i}$, $C_{3,i}$ = annual capital cost of reservoir capacity, irrigation, and hydropower plant respectively at site i,

$Om_{1,i}$, $Om_{2,i}$, $Om_{3,i}$ = annual operation and maintenance cost of reservoir capacity, irrigation and hydropower plant respectively at site i,

$C'_{1,i}$, $C'_{2,i}$, $C'_{3,i}$ = annual capital cost function for reservoir capacity, irrigation and hydropower plant respectively at site i, and

$Om'_{1,i}$, $Om'_{2,i}$, $Om'_{3,i}$ = annual operation and maintenance cost function for reservoir capacity, irrigation, and hydropower plant respectively at site i.

## 3.4 LIST OF VARIABLES

$Aa_i$ = area per unit active storage volume above $Ao_i$ for $i^{th}$ reservoir,

$Ao_i$ = reservoir surface area corresponding to the dead storage of reservoir, $Yd_i$, for $i^{th}$ reservoir,

$a_{2,i}$ = the long run benefit function for firm irrigation at site i,

$a_{3,i}$ = the benefit per unit of firm energy for site i,

$a_{4,i}$ = the flood control benefit as a function of the flood control reserve for $i^{th}$ reservoir,

$B_{2,i}$, $B_{3,i}$, $B_{4,i}$ = gross annual firm irrigation, firm hydropower, and flood control benefits, respectively at site i,

$C_{1,i}$, $C_{2,i}$, $C_{3,i}$ = annual capital cost of reservoir capacity, irrigation, and hydropower plant respectively at site i,

$C'_{1,i}$, $C'_{2,i}$, $C'_{3,i}$ = annual capital cost function for reservoir capacity, irrigation and hydropower plant respectively at site i, and

$C_f$ = conversion factor from M.C.M to Mw-hr,

$E_i$ = firm annual energy target at $i^{th}$ site,

$E^T_{i,t}$ = total energy generated from $i^{th}$ reservoir in time t, in MW-hr,

$E_{i,t}$ = nonfirm (secondary) energy generated in time t at $i^{th}$ site,

$El_{i,t}$ = evaporation from $i^{th}$ reservoir in time t,

$e_i$ = turbine and generator efficiency for hydroplant i,

$e^0_{i,t}$ = average reservoir evaporation rate for $i^{th}$ reservoir in time t,

$F_{i,t}$ = natural inflow from its own catchments plus contributions of all possible regulated flows from upstream reservoirs and return flows from U/S irrigations at $i^{th}$ reservoir in time t,

G = total number of U/S reservoir/site contributing to the flow of $i^{th}$ D/S reservoir/site,

$H_i$ = hydropower plant capacity at $i^{th}$ site,

$He_{i,t}$ = average storage head at $i^{th}$ reservoir in time t,

$h_{i,t}$ = number of hours in a period t at $i^{th}$ site,

$I_{i,t}$ = natural catchment inflow to $i^{th}$ reservoir in time t,

$I_{i,t}$ = local inflow to the $i^{th}$ reservoir from surrounding area in time t,

$I''_{j,t}$ = water that joins the main stem just above irrigation diversion canal at $j^{th}$ site in time t,

$I''_{p,t}$ = water that joins the main stem just above irrigation diversion canal at $p^{th}$ reservoir site in time t,

$Ir_i$ = firm annual irrigation target at site i,

$Ir_j$ = annual irrigation target at $j^{th}$ multi-irrigation area,

$Ir_p$ = firm annual irrigation target at $p^{th}$ reservoir site,

$Ir^p_j$ = firm annual irrigation to be served for $j^{th}$ multi-irrigation area by $p^{th}$reservoir in time t,

$Ir_w$ = firm annual irrigation target at $w^{th}$ site,

i = $i^{th}$ reservoir/site,

j = $j^{th}$ multi-irrigation area,

$K_{j,t}$ = proportion of annual irrigation target at $j^{th}$ site in time t,

$K_{p,t}$ = proportion of annual irrigation target at $p^{th}$ reservoir site in time t,

$K_{w,t}$ = proportion of firm annual irrigation target, $Ir_w$ to be diverted for irrigation canal at $w^{th}$ site in time t,

$K''_{w,t}$ = irrigation return flow as a proportion of irrigation diversions at $w^{th}$ site in time t,

L = number of parallel reservoirs (excluding $i^{th}$ reservoir), i.e., total number of parallel reservoirs are, (L+1),

$LL_{1,i}$, $LL_{2,i}$, $LL_{3,i}$, and $LL_{4,i}$ = lower limits (bounds) on $Y_i$, $Ir_i$, $H_i$, and $E_i$ respectively,

$O_{i,t}$ = total reservoir release from $i^{th}$ reservoir in time t,

$O^d_{i,t}$ = release for water supply from $i^{th}$ reservoir in time t,

$O^m_{i,t}$ = release from $i^{th}$ reservoir to keep minimum flow on downstream in time t,

$O_{p,t}$ = total release from $p^{th}$ reservoir in time t,

$O^0_{p,t}$ = release from $p^{th}$ reservoir for its own irrigation command area in time t,

$O^j_{p,t}$ = release from $p^{th}$ reservoir for $j^{th}$ multi-irrigation area in time t,

$O_{w,t}$ = total release from $w^{th}$ reservoir/site in time t,

$Om_{1,i}$, $Om_{2,i}$, $Om_{3,i}$ = annual operation and maintenance cost of reservoir capacity, irrigation and hydropower plant respectively at site i,

$Om'_{1,i}$, $Om'_{2,i}$, $Om'_{3,i}$ = annual operation and maintenance cost function for reservoir capacity, irrigation, & hydropowerplant respectively at site i.

$Omax_{i,t}$ = maximum limit (bound) on $O_{i,t}$,

$Omin_{i,t}$ = minimum limit (bound) on $O_{i,t}$,

$P_{i,t}$ = precipitation effect directly upon the $i^{th}$ reservoir in time t,

p = $p^{th}$ parallel reservoir,

Q = total number of multi irrigation areas.

$S_{i,t}$ = final live/gross reservoir content or storage of $i^{th}$ reservoir in time t,

$S_{i,t-1}$ = initial live/gross reservoir content or storage of $i^{th}$ reservoir in time t,

$Sp_{p,t}$ = spill from $p^{th}$ reservoir in time t,

$Uc_{w,t}$ = regulated contributions including irrigation return flow from $w^{th}$ U/S reservoir/site to the $i^{th}$ D/S reservoir site in time t,

$UL_{1,i}$, $UL_{2,i}$, $UL_{3,i}$ and $UL_{4,i}$ = upper limits (bounds) on $Y_i$, $Ir_i$, $H_i$, and $E_i$ respectively,

w = $w^{th}$ U/S reservoir/site contributing to the flow of $i^{th}$ D/S reservoir/site,

$Y_i$ = gross capacity of $i^{th}$ reservoir,

$Ya_i$ = total live capacity of the reservoir i at maximum pool level,

$Yd_i$ = dead storage of reservoir i,

$Yf_{i,t}$ = flood storage of $i^{th}$ reservoir in time t,

$Ymax_{i,t}$ = gross capacity of reservoir up to normal pool level (top of the conservation) of the $i^{th}$ reservoir in time t,

$Ymax'_{i,t}$ = live capacity of reservoir up to the normal pool level of the $i^{th}$ reservoir in time t,

$Ymin_{i,t}$ = gross capacity of reservoir up to the minimum pool level of the $i^{th}$ reservoir in time t,

$Ymin'_{i,t}$ = live capacity of reservoir up to the minimum pool level of the $i^{th}$ reservoir in time t,

$\alpha_{i,t}$ = load factor for hydropower at $i^{th}$ site in time t,

$\eta_{i,t}$ = percentage of annual energy target to be supplied in time t at $i^{th}$ site.

# CHAPTER-IV

# SIMULATION MODEL

## Chapter-IV

# SIMULATION MODEL

### 4.1 INTRODUCTION

Simulation can be defined as reproducing the essence of a system without reproducing the system itself. in reality The essential characteristics of the system are reproduced in a model which is then studied in an abbreviated time scale.

Simulation is perhaps the most widely used method for evaluating alternative water resource systems. The reasons for its popularity lies in its mathematical simplicity and versatility.

Simulation is not an optimizing procedure. Rather, for any set of design and operating policy parameter values, it merely provides a rapid means for evaluating the anticipated performance of the system. It is necessary for the analyst to specify the trial design (or, equivalently, to allow the computer to do so in accordance with some algorithm), whereupon the simulation model yields estimates of the economic, environmental and other responses associated with the trial. Simulation methods do not identify the optimal design and operating policy, but they are an excellent means of evaluating the expected performance resulting from any design and operating policy. Hence they are often used to assist water resources Planners in evaluating those designs and operating policies defined by simpler optimisation models.

### 4.2 THEORY

The simulation problem can be stated as follows (Mass et al, 1962 ; Hufshmidt and Fiering, 1966 ; System Analysis in Water Resources Planning, 1975 ; and Srivastava, 1976 ):

Determine:

(1) a combination of reservoirs, power plants, and irrigation-diversion and distribution facilities,

(2) firm, and secondary annual target levels of irrigation and energy outputs,

(3) and 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 reservoirs.

### 4.2.1 System Design Variables, Parameters and Constraints

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:

#### 4.2.1.1 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 reservoirs, and

(b) Power plant capacities of power plants.

(ii) Allocation of Reservoir Capacity:

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

(b) Flood storage in reservoirs, and

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

(iii) Target Outputs:

(a) Firm and secondary annual target outputs for irrigation for the command areas (yearly)

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

(c) 12-element vector of annual target outputs for water supply and energy (monthly percent of the annual values).

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

(1) Equation used for energy generation,

(ii) Pen stock capacities,

(iii) Maximum head for power plants, and

(iv) Turbine and generator efficiencies.

### 4.2.1.2 Cost and benefit functions

1. For each irrigation area :

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

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

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

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

2. For each power plant :

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

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

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

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

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

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

**3.** For each reservoir :

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

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

**4.** Others :

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

### 4.2.1.3 Stream flow data

✓ **1.** Monthly river flows for each reservoir site.

Specify what kind. For example, average monthly flow.

## 4.3 OPERATION OF THE SYSTEM

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 and among reservoirs in a given period) in a form suitable for the computer (Srivastava, 1992).

### 4.3.1 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.,

$$O_{i,t} \le S_{i,t-1} + F_{i,t} + P_{i,t} + I_{i,t} - O^{d}_{i,t} - O^{m}_{i,t} - El_{i,t} - Ymin_{i,t}$$

for all i and t (4.1)

**2.** The continuity equation

$$S_{i,t} = S_{i,t-1} + F_{i,t} + P_{i,t} + I_{i,t} - O_{i,t} - El_{i,t} - O^{d}_{i,t} - O^{m}_{i,t}$$

for all i and t (4.2)

3. The contents of the reservoir at any period can not exceed the capacity of the reservoir (or the live 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

$$Yd_i \le Ymin_{i,t} \le S_{i,t-1} \le Ymax_{i,t} \le Y_i \quad \text{for all i and t} \tag{4.3}$$

where,

$El_{i,t}$ = reservoir evaporation for $i^{th}$ reservoir in time t,

$F_{i,t}$ = natural inflow from its own catchment plus contributions of all possible regulated flows from upstream reservoirs and return flows from U/S irrigation at $i^{th}$ reservoir in time t,

$I_{i,t}$ = local inflow to $i^{th}$ reservoir from surrounding areas in time t,

$O_{i,t}$ = total reservoirrelease from $i^{th}$reservoir in time t,

$P_{i,t}$ = precipitation effect directly upon $i^{th}$ reservoir in time t,

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

$S_{i,t}$ = gross reservoir storage or content of $i^{th}$ reservoir at the end of time t,

t = any time,

$Y_i$ = gross storage capacity of $i^{th}$ reservoir,

$Yd_i$ = dead storage of $i^{th}$ reservoir,

$Ymin_{i,t}$ = gross capacity of reservoir up to minimum pool level of $i^{th}$ reservoir in time t,

$Ymax_{i,t}$ = gross capacity of reservoir up to normal pool level(top of the conservation) of the $i^{th}$reservoir in time t,

$O^d_{i,t}$ = release for water supply from $i^{th}$ reservoir in time t, and

$O^m_{i,t}$ = release from $i^{th}$reservoir to keep minimum flow on downstream in time t.

$O^m_{i,t}$ = release from $i^{th}$reservoir to keep minimum flow on downstream in time t.

### 4.3.2 Reservoir Operation among Reservoirs

In establishing an operating procedure among reservoirs for simulation the hydrologic properties of the basin, the physical configuration of the system, and the water use points are important. The operation policy is discussed later in Section para 4.7.

## 4.4 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, $K_{1,i}$ of irrigation, $K_{2,i}$, and of hydropower, $K_{3,i}$ at each site i are calculated. The gross benefits in time j (usually a year), from irrigation, $B_{2,i,j}$, and from energy, $B_{3,i,j}$, are calculated. The net benefits $B'_{i,j}$, from irrigation and hydropower in time j is given by:

$$B'_{i,j} = (B_{2,i,j} + B_{3,i,j}) - (Om_{1,i,j} + Om_{2,i,j} + Om_{3,i,j}) \tag{4.4}$$

Where,

$Om_{1,i,j}$ = operation and maintenance (OM) cost of reservoir at site i in time j,
$Om_{2,i,j}$ = OM cost of irrigation works at site i in time j, and
$Om_{3,i,j}$ = OM cost of hydropower at site i in time j.

Then,

$$PW_{nb} = \sum_{i} \left( K_{1,i} + K_{2,i} + K_{3,i} \right) + \sum_{j=1}^{N} \sum_{i} \left( \frac{P}{F}, i_f\ \%, j \right) B'_{i,j} \tag{4.5}$$

$$= -K + \sum_{j=1}^{N} \sum_{i} \left[1/(1 + i_f/100)^j\right] B'_{i,j} \tag{4.6}$$

Where,

$$K = \sum_{i} \left(K_{1,i} + K_{2,i} + K_{3,i}\right)$$

$i_f$ = the discount rate for finding present worth,

N = the economic life of the project, and

j = any time period (usually a year).

In equation (4.4) the bracketted term is the abbreviation of the present worth factor. In equation (4.5) the term in the bracket is the actual present worth factor.

## 4.5 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 Panning, 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.

### 4.5.1 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 side 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.

### 4.5.2 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 analyse 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.

## 4.6 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.

### 4.6.1 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).

### 4.6.2 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).

### 4.6.3 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).

## 4.7 OPERATION POLICY OF RESERVOIRS IN MULTI- RESERVOIR SYSTEM

The reservoir operation policy has been prepared for the operation of different reservoirs (Islam, 1991; Rath, 1991; and Srivastava, 1992) in the following manner :

**(i)** The reservoir operation starts from the upper most reservoir and continues to the next reservoir in the D/S and so on to the next, in a given unit period of time (here a month). The starting month in a year is April.

✓ **(ii)** The individual reservoir operation policy is described in Section para 4.3.1.

**(iii)** All water demands shall be met by various shares of water. Two types of water shares are defined. Share-1 means meeting various U/S and D/S water demands from the total monthly inflow reaching a reservoir. Share-2 means meeting deficits in various U/S and D/S water demands, if any, from the water available within the conservation storage (AWWCS).

Not clear → Who decides on the priority?

**(iv)** The water uses of same priority, if any, among all the water uses are initially clubbed for all the computation purposes. After the computations for a unit time period (here a month) are over then the deficits in clubbed water users are distributed into the unclubbed water users in the ratios of their amounts. These are done separately for U/S and D/S water uses.

**(v)** Water can be diverted (transfered) from a reservoir/site to other reservoir/site, in terms of priority of water uses.

**(vi)** Any number of water uses can be considered in any sequence. The water among various water uses will be shared on the basis of a pre-decided priority of water uses. This priority can be changed in any simulation run.

(vii) To meet the energy demand an option has been kept whether the non-hydropower releases, i.e., towards M & I water supply and irrigation requirements can be put to power generation or not. Another option has also been put forth whether the spilled water can be put to power generation or not, in case power is generated on a canal power house.

(viii) In case of all the reservoirs & run-of river schemes, the total monthly inflow to a reservoir/site includes the return flows from various water users U/S of the reservoir/site under consideration, plus the return flows from various water uses D/S of the reservoirs, and reservoir spills, if any, from the U/S reservoirs contributing to the flow of the reservoir/site under consideration. In the present context 25 % of the releases made towards M & I requirements and 20 % of the releases made towards irrigation requirements are taken as contribution towards return flows.

How were these selected?

## 4.8 WORKING PRINCIPLE OF COMPUTER PROGRAMME

The computer programme for the simulation of multi reservoir system is a huge model (Garudkar 1992; Dayaratne, 1992; and Jain, 1993). It comprises of 13 subroutine sub-programmes and 11 function sub-programmes alongwith the main programme (Appendix 4.I). The programme works in accordance with the operation policy framed earlier. A general flow chart for simulation steps are presented in Figure 4.1. The functions of the various sub-programmes are mentioned below:

1. **Subroutines STAT1 :**

   This subroutine instructs to make U/S subtractions and D/S releases from share-1 and share-2

2. **Subroutines WATER :**

   This subroutine does the following :

(i) **Use of Share-1 :**

Firstly, makes subtractions for U/S water uses from Share-1, then makes releases for D/S water uses from unutilised water of Share-1. Secondly, it calculates deficits in U/S and D/S water demands, if any.

(ii) **Use of Share-2 :**

It makes releases for D/S water uses from Share-2, if there were any deficits as calculated earlier.

3. **Subroutine RELES :**

This subroutine calculates and defines the current net water available and deficits after every U/S subtractions and D/S releases.

4. **Subroutine POWER :**

This subroutine does basic computations for energy generation.

5. **Subroutine CAL1 :**

This subroutine calculates statistics for various U/S and D/S water demands (clubbed) for behaviour analysis.

6. **Subroutine CAL11 :**

This subroutine calculates statistics for various U/S and D/S water demands (unclubbed) for behaviour analysis.

7. **Subroutine INTI1 :**

clubbed?

This subroutine initialises the statistical variables for various U/S and D/S water demands ( clubbed) for a study to zero.

8. **Subroutine INIL1 :**

This subroutine initialises the statistical variables for various U/S and D/S water demands (unclubbed) for a study to zero.

9. **Subroutine WRT11 :**

   This subroutine writes the statistics of variables for various U/S and D/S water demands (unclubbed).

10. **Subroutine WRT12 :**

    This subroutine writes the data used.

11. **Subroutines WRTM, and WRT :**

    These subroutines write the intermediate calculations giving distribution of water shares among various U/S and D/S water demands (clubbed) and their deficits for each time period.

12. **Subroutine DIST1 :**

    This subroutine distributes the water deficits of the clubbed demands to the unclubbed demands.

13. **Subroutine BENFT :**

    This subroutine calculates the present worth of net benefit.

14. **Function AREA :**

    This function calculates the reservoir water spread area.

15. **Function ELEVAT :**

    This function calculates the reservoir water elevation.

16. **Function ABFD1 :**

    This function calculates annual benefit for D/S water use ii at $i^{th}$ reservoir/site.

17. **Function ALFD1 :**

    This function calculates annual loss in benefit for D/S water use ii at $i^{th}$ reservoir/site.

**18.** **Function ADFD1 :**

This function calculates annual dump energy benefit for hydropower use ii at $i^{th}$ reservoir /site.

**19.** **Function AOFR1 :**

This function calculates annual OM cost of reservoir at $i^{th}$ reservoir/site.

**20.** **Function AOFP1 :**

This function calculates annual OM cost of hydroplant at $i^{th}$ reservoir/site.

**21.** **Function AOFD1 :**

This function calculates annual OM cost of D/S water use ii at $i^{th}$ reservoir/site.

**22.** **Function CFRE1 :**

This function calculates capital cost of reservoir at $i^{th}$ reservoir /site.

**23.** **Function CFPP1 :**

This function calculates capital cost of hydropower at $i^{th}$ reservoir/site.

**24.** **Function CFWD1 :**

This function calculates capital cost of D/S water ii at $i^{th}$ reservoir/site.

## 4.9 LIST OF VARIABLES

$B_{2,i,j}$ = gross benefit from irrigation in time j at $i^{th}$site,

$B_{3,i,j}$ = gross benefit from hydropower in time j at $i^{th}$site,

$B_{i,j}$ = gross benefit from irrigation and hydropower in time j at $i^{th}$site,

$El_{i,t}$ = reservoir evaporation for $i^{th}$ reservoir in time t,

$F_{i,t}$ = natural inflow from its own catchment plus contributions of all possible regulated flows from upstream reservoirs and return flows froms U/S irrigation at $i^{th}$ reservoir in time t,

$i_f$ = the discount rate for finding present worth,

$I_{i,t}$ = local inflow to $i^{th}$ reservoir from surrounding areas in time t,

j = any time period (usually a year),

K = total initial capital cost of the system,

$K_{1,i}$ = initial capital cost of reservoir at $i^{th}$ site,

$K_{2,i}$ = initial capital cost of irrigation at $i^{th}$ site,

$K_{3,i}$ = initial capital cost of hydropower at $i^{th}$ site,

N = the economic life of the project,

$O_{i,t}$ = total reservoir release from $i^{th}$reservoir in time t,

$O^d_{i,t}$ = release for water supply from $i^{th}$ reservoir in time t,

$O^m_{i,t}$ = release from $i^{th}$ reservoir to keep minimum flow on downstream in time t,

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

$Om_{2,i,j}$ = OM cost of irrigation works at $i^{th}$ site in time j,

$Om_{3,i,j}$ = OM cost of hydropower at $i^{th}$ site in time j,

$P_{i,t}$ = precipitation effect directly upon $i^{th}$ reservoir in time t,

$PW_{nb}$ = present worth of net benefits,

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

$S_{i,t}$ = gross reservoir storage or content of $i^{th}$ reservoir at the end of time t,

t = any time (a month),

$Y_i$ = gross storage capacity of $i^{th}$ reservoir,

$Yd_i$ = dead storage of $i^{th}$ reservoir,

$Ymax_{i,t}$ = gross capacity of reservoir up to normal pool level (top of the conservation) of the $i^{th}$ reservoir in time t, and

$Ymin_{i,t}$ = gross capacity of reservoir up to minimum pool level of $i^{th}$ reservoir in time t.

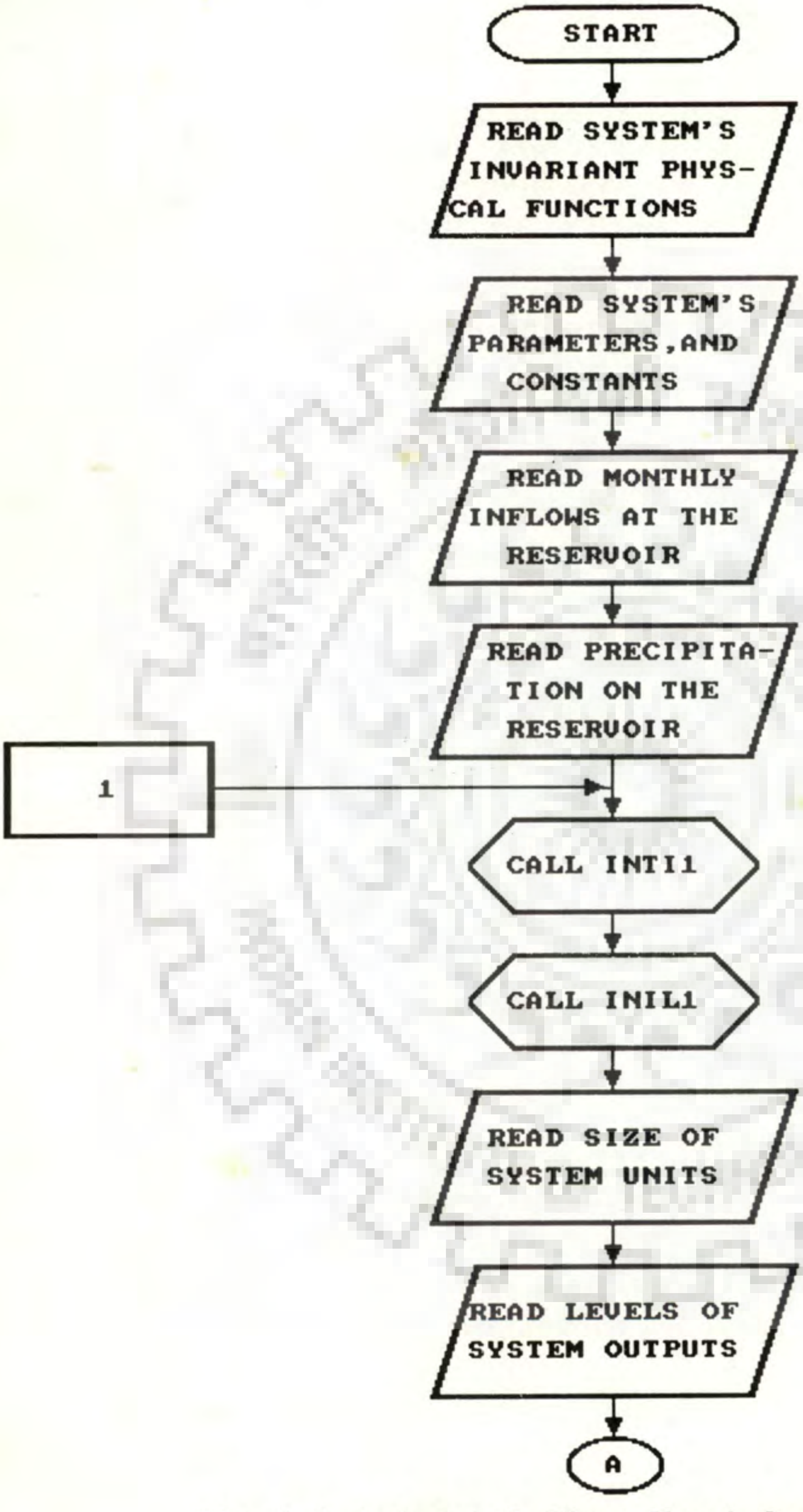


**Fig.4.1 A General Flow Chart for Simulation**

Fig.4.1 continued

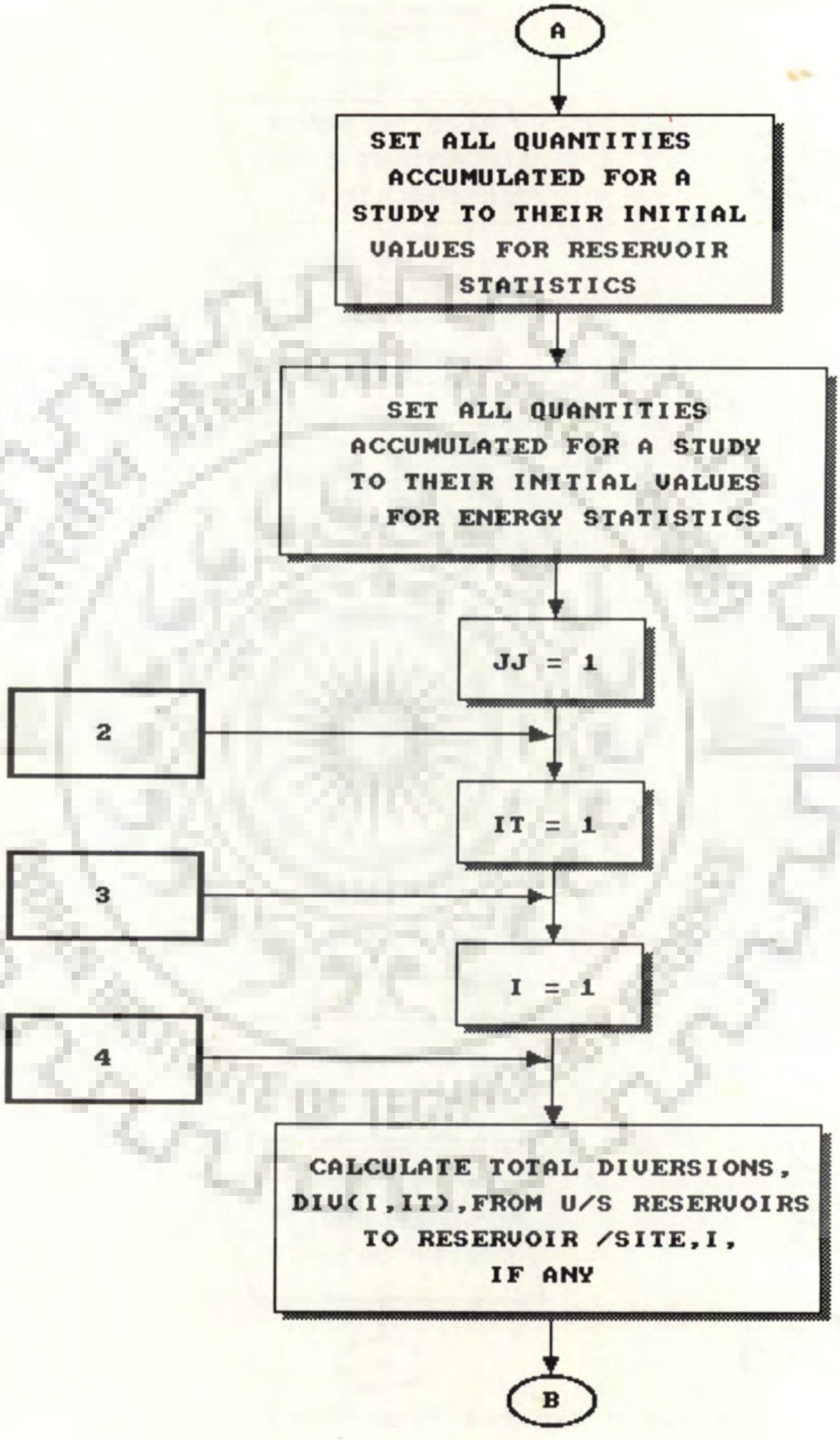


**Fig.4.1 continued**

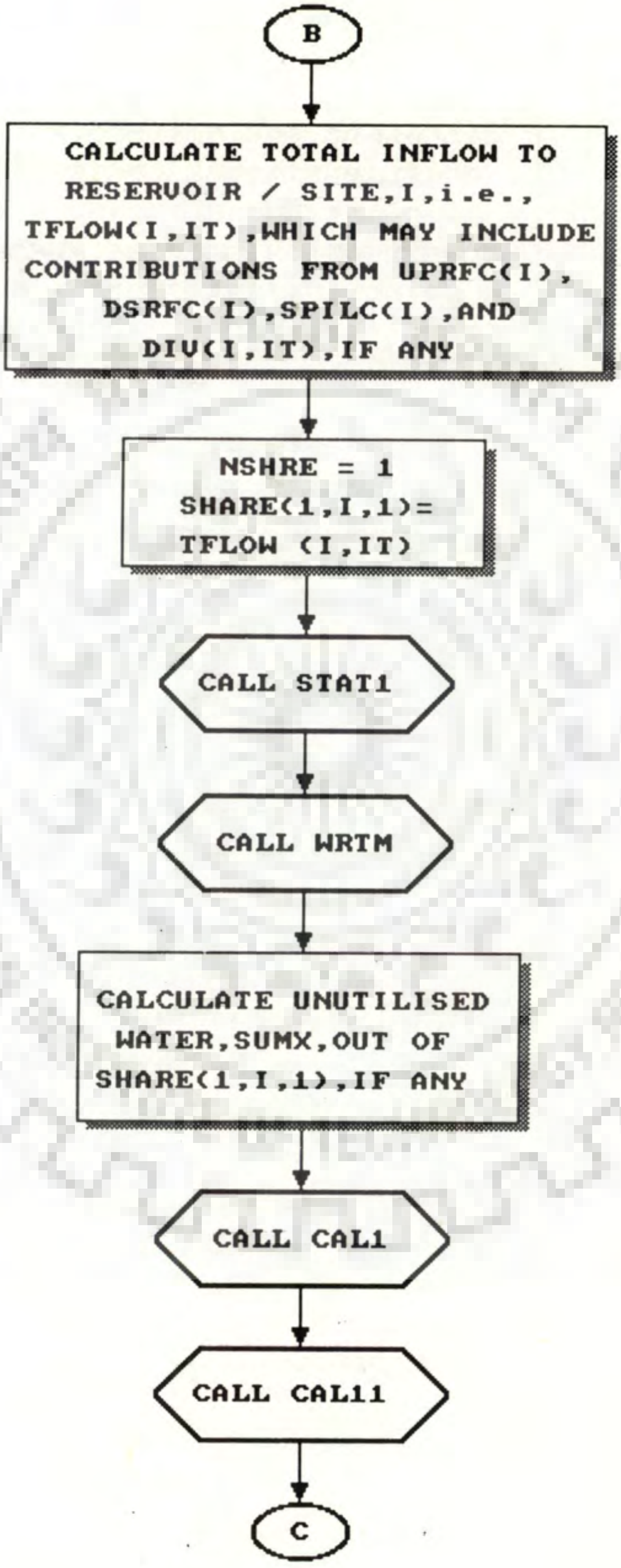


Fig. 4.1 continued

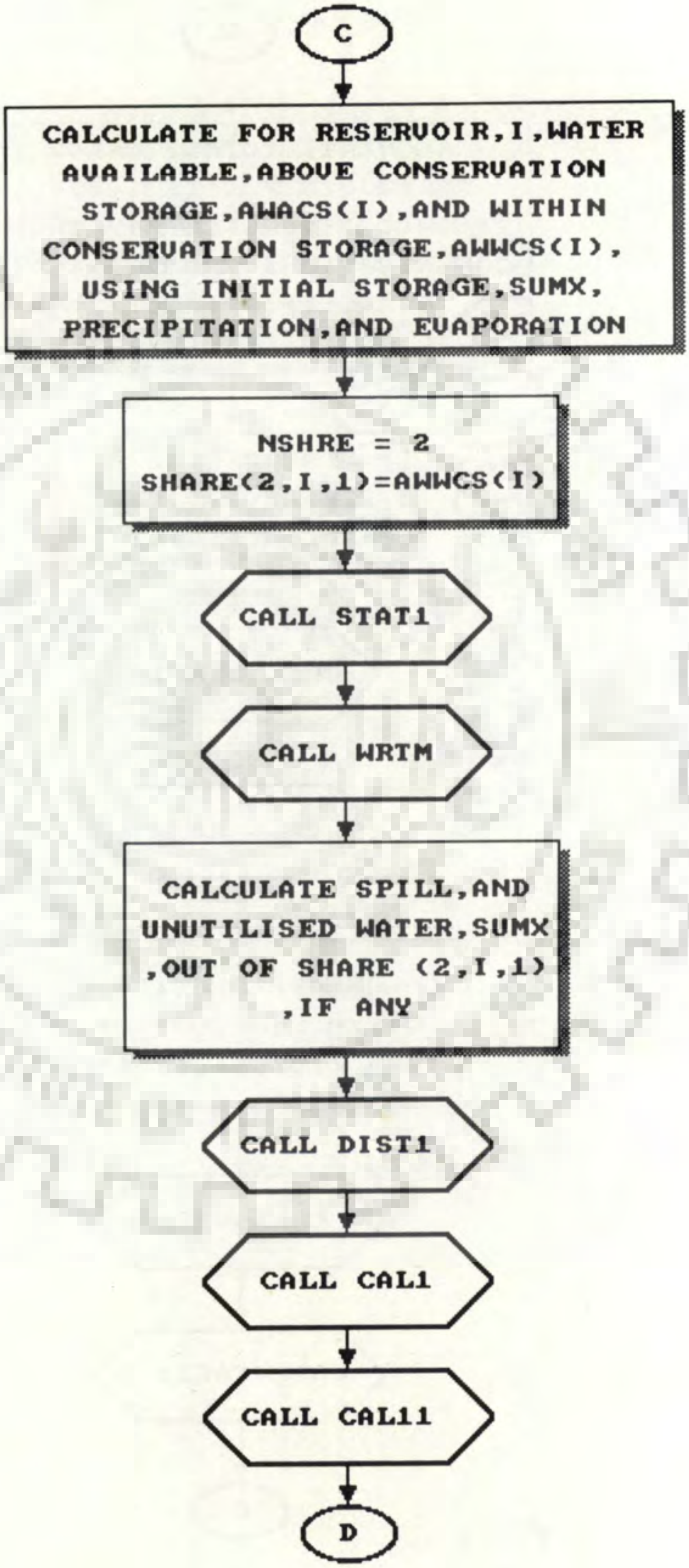


Fig.4.1 continued

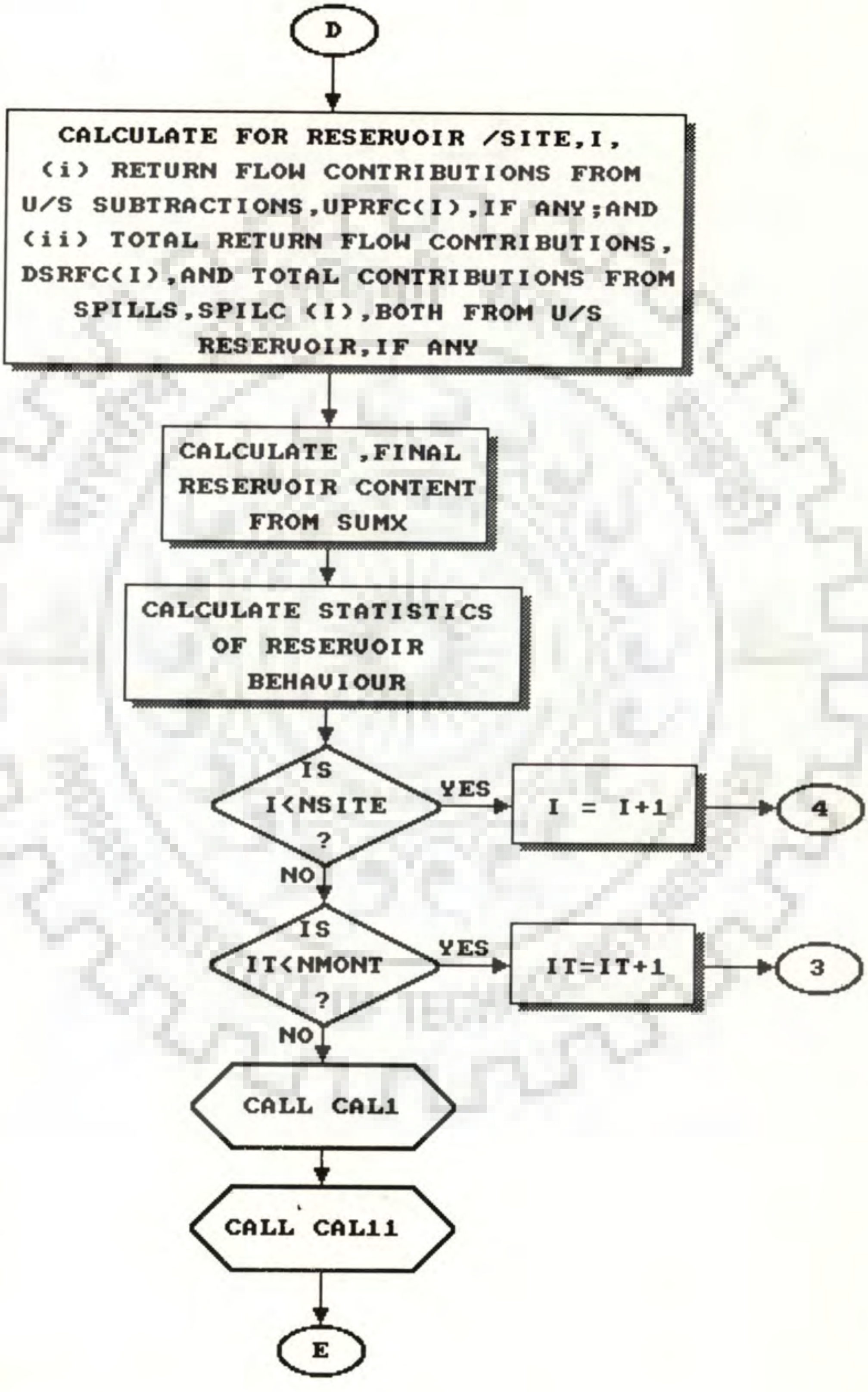
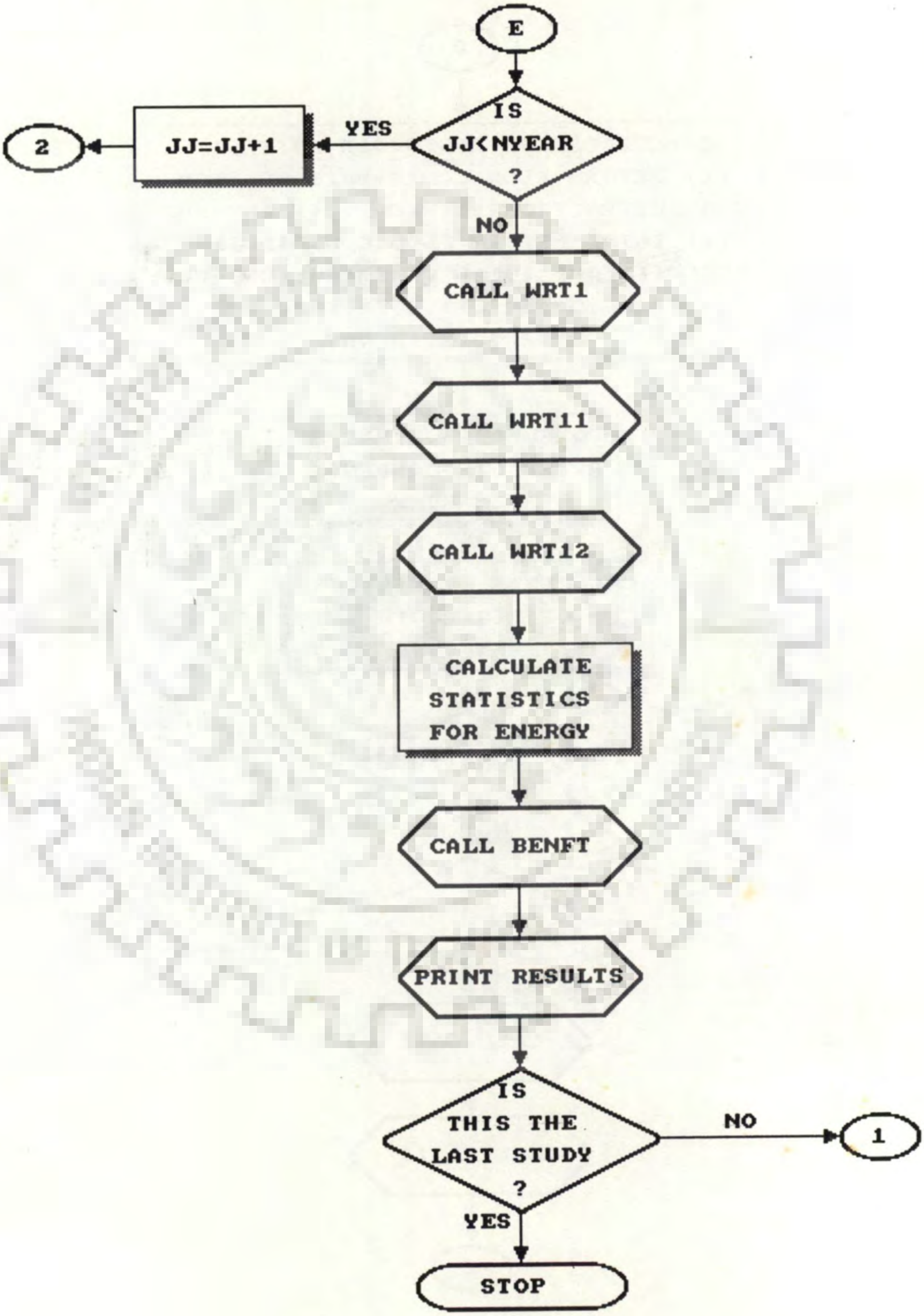


Fig. 4.1 continued



# CHAPTER-V

# RIVER SYSTEM AND STATEMENT OF THE PROBLEM

# Chapter V

# RIVER SYSTEM AND STATEMENT OF THE PROBLEM

It was earlier mentioned in the objectives ~~of present work~~ (Section para 1.2), that the scope of the present work is to develop optimization-simulation models for river basin planning and development and apply them it to a real-life large-scale river basin system, consisting of multi-purpose, multi-reservior, and multi-irrigation areas. For this reason, the Karun river system is Iran is chosen for application.

## 5.1 STUDY AREA

The Karun river is one of the most important and largest river systems in Iran. It emerges out of the Zagross mountain ranges (Southwestern Iran). The river originates at about 4409 m above mean sea level. It flows generally in a southernly direction into the Persian Gulf.

The Headwaters of the Karun river consist of four major sub basins, namely, of the rivers Khersan, Vanak, Bazuft, and upper Karun. All of the sub basins are mountainous, with limited access and no major population centers.

The Karun river follows a tortuous course through the mountains until it finally emerges on the Khuzestan plain near Gotvand. The length of the river up to the Gotvand is 450 km. From Gotvand the river flows across the plain where it is joined at Band-e-Ghir by the Dez river from north. The combined river which is known as Karun river passes through Khuzestan province and empties into the Arvand river at Khorramshahr (Figure 5.1). The catchment area of the Karun river is 37036 sq. km. at its confluence with the Dez river, while at this point the total catchment area of Karun and Dez rivers are 59017 sq. km. Figure 5.2 shows a Schematic diagram of Karun river Basin with all possible developmental potential ~~is shown in Figure 5.2~~.

Fig. 5·1 – Plan Showing Karun-Dez River Basin

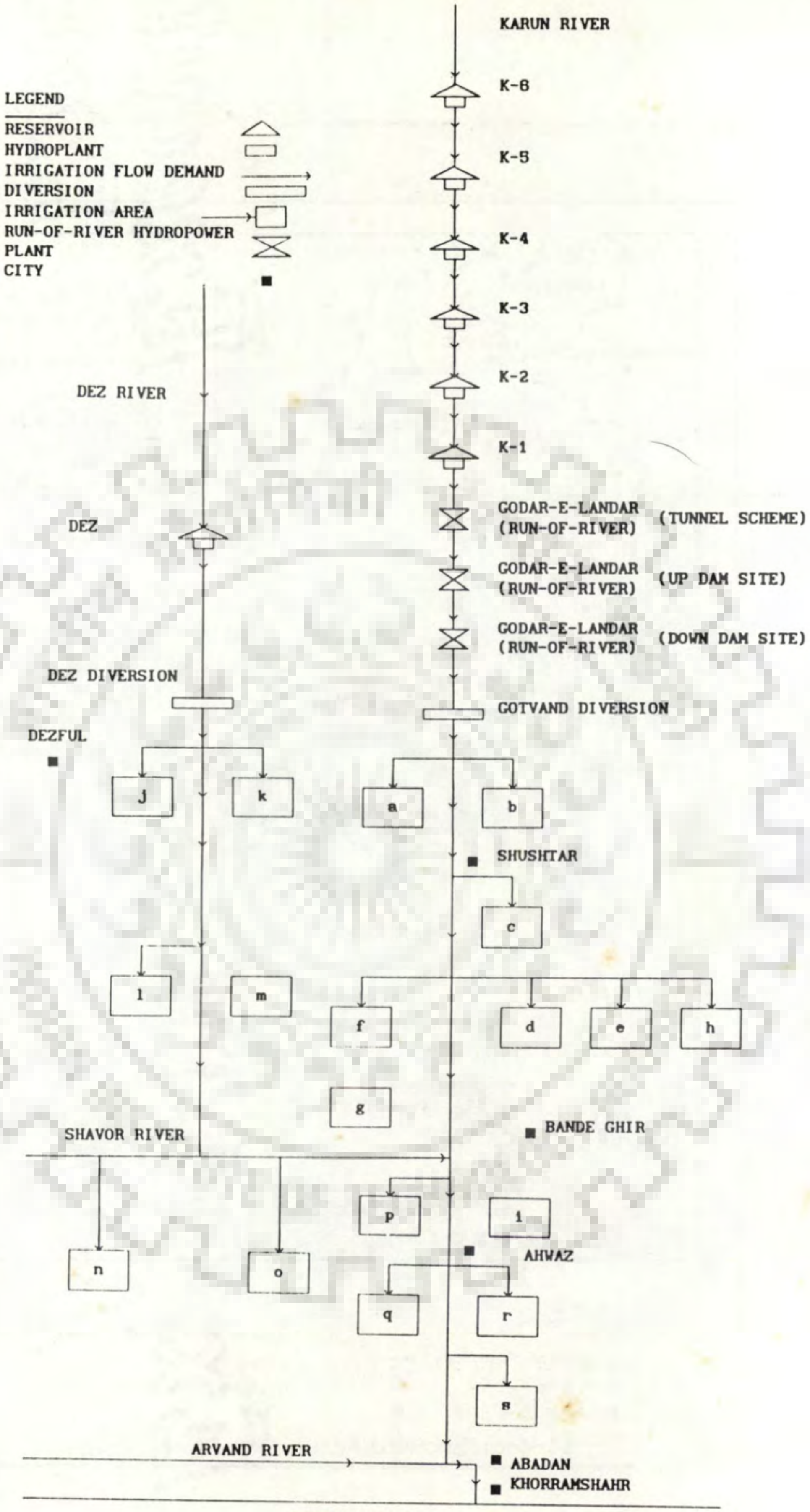


Fig. 5.2 : Schematic Diagram of Karun River System With All Possible Developmental Potential

## 5.2 CLIMATE AND RAINFALL

The catchment area of the Karun river system can be divided into the following parts:

### 5.2.1 Mountainous Area

This part of catchment is from the source of the river up to the Gotvand (drainage area up to Gotvand is 31899 sq. km.). The average slope of the river at Gotvand is 0.11. Mean monthly temperature in this area falls to -5$^{o}$C during winters and reaches 28$^{o}$C in summer. Average annual precipitation is around 750 mm, but rises considerably in higher altitudes. Most of the precipitation occurs in the period from December to February and this is why stream flow is strongly influenced by the snow melt. ~~The~~ Figure 5.3 shows ~~represents~~ the variation of annual precipitation during the period of 68 years (1918 to 1985) at Gotvand.

### 5.2.2 Plain Area

Between Gotvand up to the end point of the river which is entering into Persian Gulf, the elevations of the plain area vary between 10 and 100 meters. The mean monthly temperature in this area ranges between 11.8$^{o}$C and 35. 7$^{o}$C in the months of January and July respectively. Average annual precipitation is around 241.4 mm. Most of the precipitation occurs in the winter (55% out of total annual precipitation) and in autumn and spring it is 30% and 15% respectively. ~~The~~ Figures 5.4 to 5.6 show the variation of annual precipitation at Dezful, Ahwaz, and Abadan respectively (over the period of 1918 to 1985) which can be a representative value of plain area. Also an average annual isoheytal map of the Karun river basin during period of 1964 to 1984 is shown in Figure 5.7.

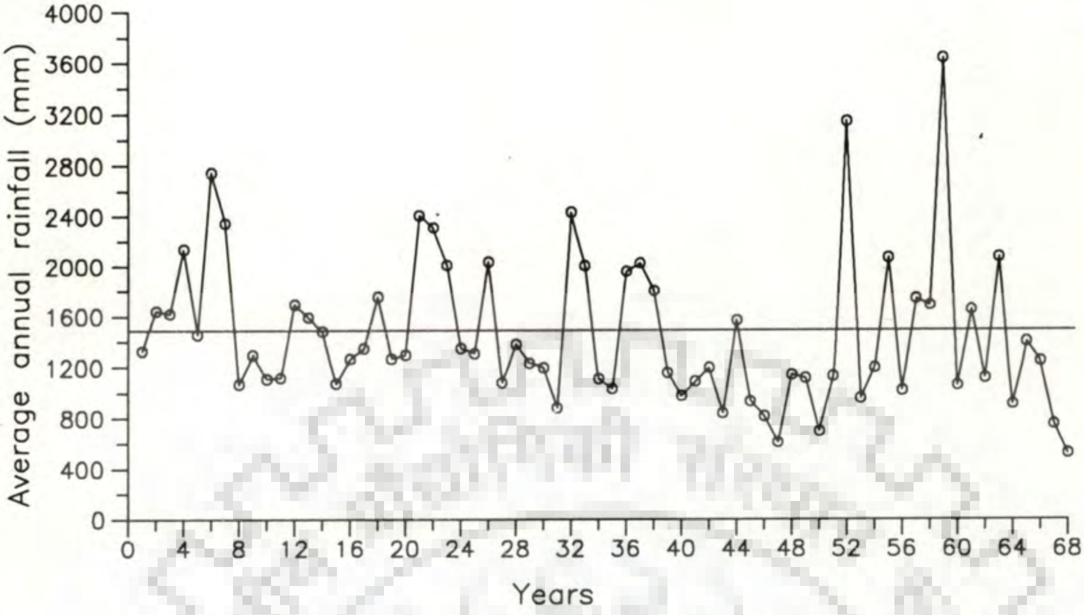


Fig. 5.3 : Average Annual Rainfall at Gotvand for Period (1918–1985)

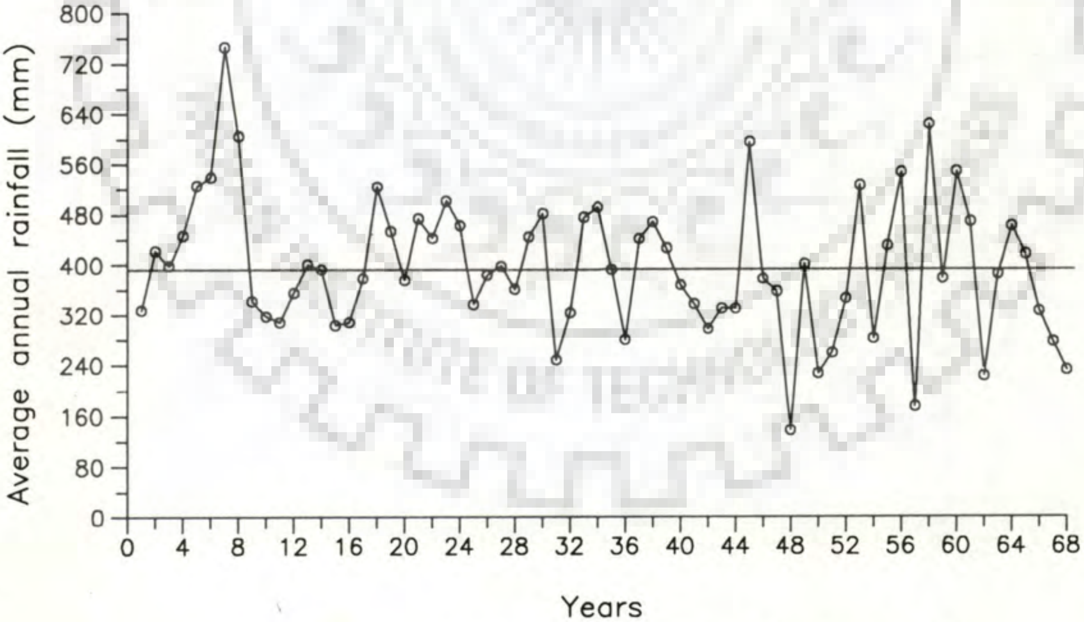


Fig. 5.4 : Average Annual Rainfall at Dezful for Period (1918–1985)

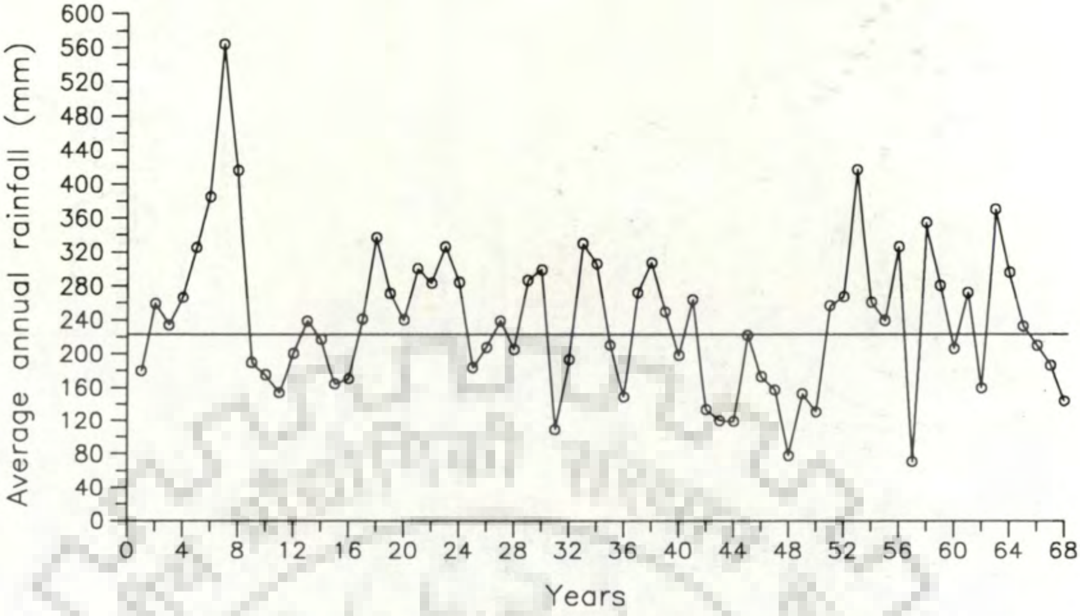


Fig. 5.5 : Average Annual Rainfall at Ahwaz for Period (1918–1985)

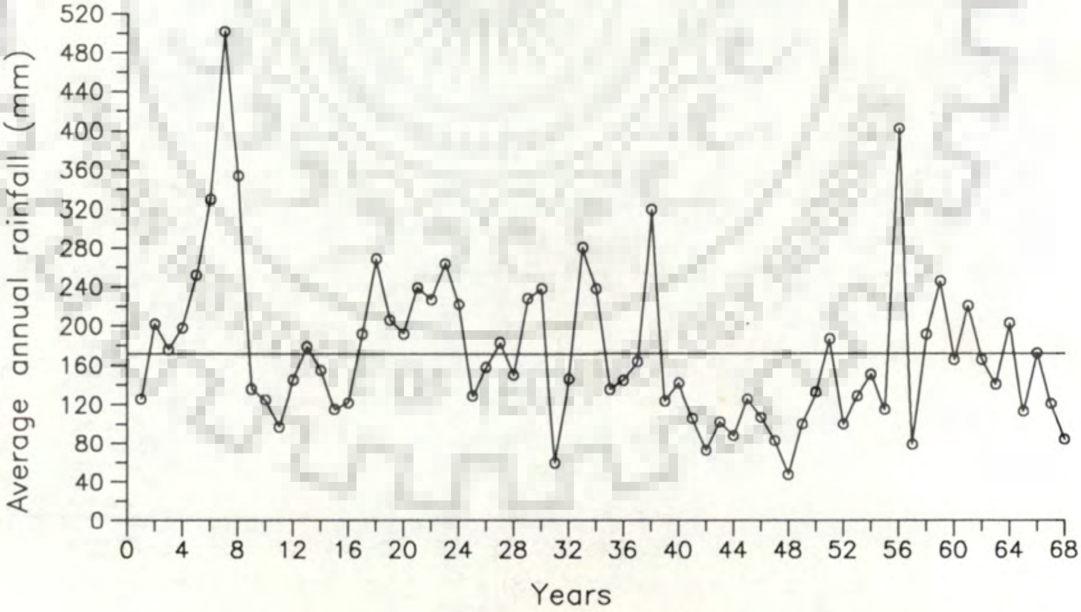


Fig. 5.6 : Average Annual Rainfall at Abadan for Period (1918–1985)

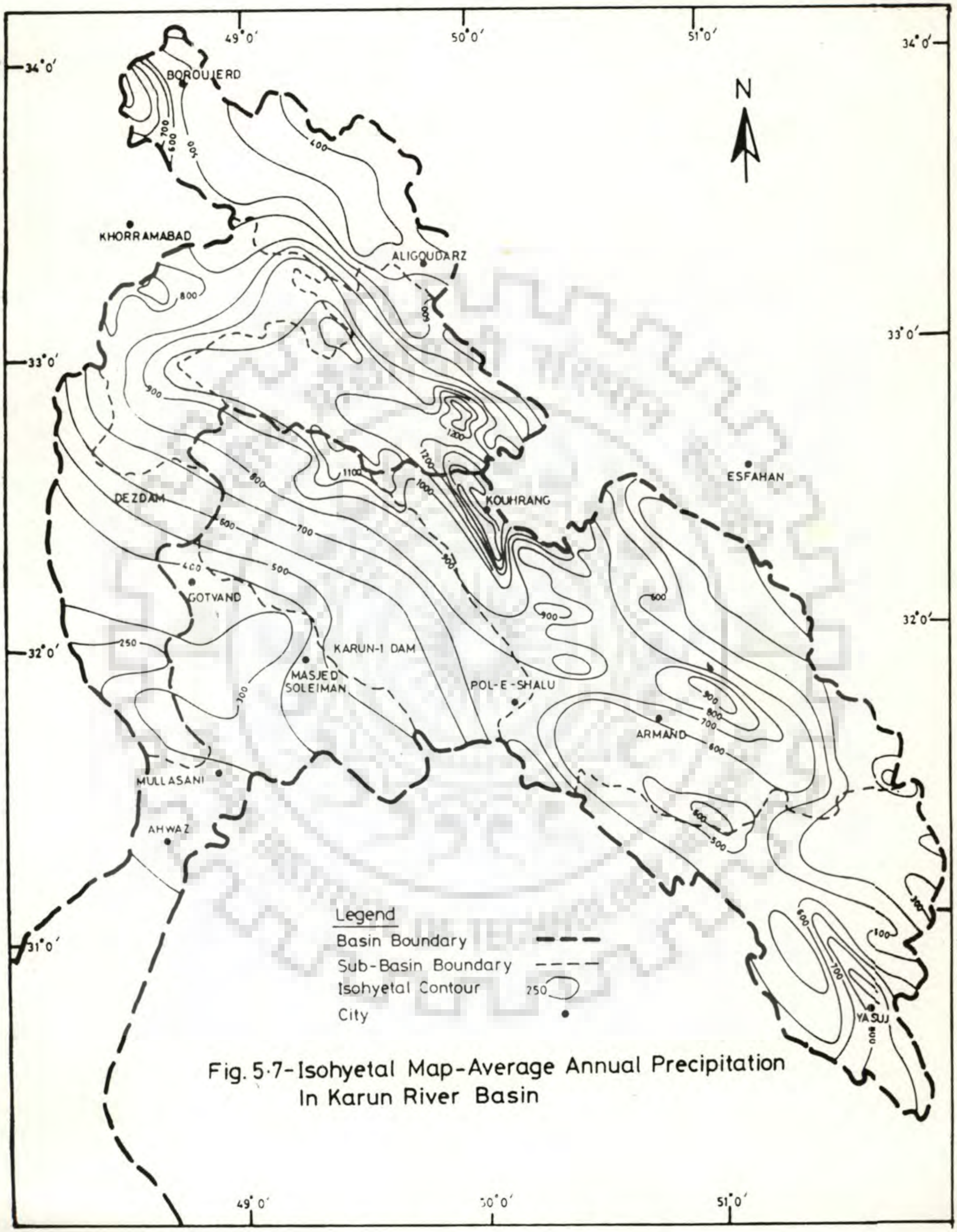


Fig. 5·7-Isohyetal Map-Average Annual Precipitation In Karun River Basin

## 5.3 STREAM FLOW

Within the Karun ~~&~~ and Dez river basins, monthly discharge data ~~is~~ are available at 19 gauging stations and dam sites. The station with longest recording period is Ahwaz with data extending from 1893-1987. After a careful checking of the data, these were extended by correlation (Hydrological Studies of Karun River Basin, 1990), to cover the period from (1950-1988). These extended records have been transferred to the dam sites, taking into account the variations in area, precipitation and other factors. The Tables 5.1 to 5.15 show the monthly yield at different sites for the period (1951-1988).

## 5.4. IRRIGATION WATER REQUIREMENT

The greatest demand on water resources of the Karun and Dez rivers is irrigation water requirement and these demands have to be investigated in depth. ~~to a great level of details.~~

Irrigation water requirements of the multi-irrigation areas are calculated based on the crop water requirements for different crop patterns. cropping

### 5.4.1 CROP WATER REQUIREMENT

Determination of consumptive use and field water requirement of different crops for this macro level study has been done on the basis of evaporative demand of crops.

The potential evapotranspiration (ETo), has been estimated by the modified Penman method (FAO. 24-revised, 1977), which is likely to give the most satisfactory results as compared to other methods. The equation is

$$ETo = C\left[W.\ Rn + (1 - W)\ .\ f(u)\ .\ (ea\text{-}ed)\right] \qquad (5.1)$$

where,

ETo = reference crop evapotranspiration (mm/day),

W = temperature-related weighting factor,

Rn = net radiation in equivalent evaporation (mm/day),

f(u) = wind -related function,

(ea-ed) = difference between the saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air, both in mbar,

C = adjustment factor to compensate for the effect of day and night weather condition (nonstandard climate)

$ET_{crop}$ can be found by : $ET_{crop} = kc.\ ETo$ (5.2)

where,

kc = crop coefficient which is used by Doorenbose and Pruit (1977).

The net irrigation requirement is determined based on a monthly period as this is a preliminary planning. The sum of net irrigation requirements for different crops over the several multi irrigation areas forms the basis for determining the irrigation demand.

To determine the total irrigation requirements, besides meeting the net irrigation requirements, water may also be required for leaching of accumulated salts from the root zone and for cultural practices. Since irrigation is never 100 percent efficient, allowances have to be made for conveyance losses and field application efficiency. In this study 80% conveyance and 40% and 60% field application efficiencies have been considered. Project efficiency (EFp) is expressed in fraction of the net irrigation requirement (IRRN).

The project irrigation supply requirement, ($V_i$) can be obtained from:

$$V_i = 10/EFp \left[\frac{A * IRRN}{1 - LR}\right]_i \qquad (5.3)$$

where :

$V_i$ = irrigation supply in month i ($m^3$/month),

EFp = project irrigation efficiency (fraction),

A = acreage under a given crop (Ha),

IRRN = net water requirement of given crop (mm/month),

LR = leaching requirement (fraction).

The Table 5.16 presents the long term average climatological data at Dezful, Ahwaz and Abadan. Since these three stations give representative values of Khuzestan Plain area, therefore, ETo values of above mentioned stations would be representative of all multi irrigation areas. Also, Table 5.17 presents the corrected monthly values of ETo for Dezful, Ahwaz and Abadan which have been used for determination of crop water requirements for all irrigation areas of the Khuzestan plains. ~~In~~ Figures 5.8 and 5.9 show average annual isoevaporation and isothermal maps respectively (Investigation of Karun River Basin, 1988) of the Karun river basin ~~are shown respectively~~.

### 5.4.2 EFFECTIVE RAINFALL

To determine the water requirements of the different irrigation areas, the effective contribution of rainfall is considered. Monthly precipitation data were generally available for Dezful, Ahwaz and Abadan for 38 years period from 1951 to 1988. To demonstrate the variations in irrigation demands, the irrigation demands and return flows are calculated for two levels of rainfall~~s~~:

- average monthly rainfall, and
- rainfall with an 80% annual probability of exceedence.

The monthly rainfall of study area with 80% dependable rainfall is shown in Table 5.18.

**Table 5.1: Monthly Yield at Karun-4 Dam Site (Up & Mid Dam Site)** Unit : In (m.c.m.)

| YEAR | APR. | MAY. | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 683.8 | 933.4 | 571.6 | 351.7 | 255.7 | 218.0 | 220.6 | 180.8 | 167.2 | 787.8 | 400.5 | 1032.6 | 483.6 |
| 1952 | 919.1 | 933.9 | 644.2 | 421.9 | 312.3 | 245.7 | 236.8 | 270.0 | 574.3 | 746.1 | 346.9 | 855.6 | 542.2 |
| 1953 | 1605.5 | 1367.4 | 805.8 | 502.3 | 362.6 | 285.2 | 288.8 | 229.7 | 612.6 | 694.7 | 327.1 | 466.8 | 629.0 |
| 1954 | 875.5 | 860.5 | 592.7 | 363.5 | 274.4 | 222.8 | 229.5 | 191.0 | 207.2 | 131.0 | 267.6 | 746.7 | 413.5 |
| 1955 | 700.3 | 828.6 | 523.0 | 346.0 | 268.0 | 198.3 | 197.8 | 199.9 | 259.1 | 266.7 | 321.7 | 791.8 | 408.4 |
| 1956 | 702.8 | 761.7 | 548.8 | 377.7 | 287.4 | 204.9 | 229.4 | 190.0 | 209.2 | 254.5 | 301.7 | 617.2 | 390.4 |
| 1957 | 1193.8 | 1359.3 | 1003.9 | 595.7 | 394.8 | 298.9 | 186.1 | 238.5 | 292.1 | 243.6 | 264.4 | 483.7 | 546.2 |
| 1958 | 579.3 | 457.7 | 319.0 | 204.9 | 172.0 | 128.0 | 115.1 | 119.2 | 311.0 | 186.6 | 223.2 | 290.0 | 258.8 |
| 1959 | 770.3 | 588.4 | 361.6 | 254.7 | 170.9 | 129.1 | 116.4 | 110.2 | 118.7 | 168.5 | 183.3 | 236.9 | 267.4 |
| 1960 | 518.3 | 583.9 | 364.3 | 203.3 | 137.4 | 112.2 | 96.4 | 113.8 | 110.2 | 144.4 | 377.9 | 318.8 | 256.7 |
| 1961 | 491.0 | 744.9 | 469.0 | 281.0 | 179.2 | 131.2 | 112.8 | 108.9 | 180.9 | 197.5 | 407.7 | 413.9 | 309.8 |
| 1962 | 461.8 | 679.0 | 426.1 | 284.4 | 199.8 | 170.6 | 150.6 | 168.5 | 183.8 | 191.8 | 262.1 | 403.6 | 298.5 |
| 1963 | 280.4 | 591.1 | 469.8 | 308.8 | 200.9 | 165.0 | 127.5 | 116.9 | 133.5 | 128.0 | 159.4 | 353.3 | 252.9 |
| 1964 | 545.3 | 420.5 | 284.2 | 167.9 | 133.9 | 122.7 | 114.6 | 115.3 | 155.8 | 185.3 | 369.9 | 543.3 | 263.2 |
| 1965 | 628.1 | 706.6 | 435.2 | 237.3 | 150.0 | 122.9 | 120.3 | 235.6 | 153.2 | 146.4 | 423.8 | 513.5 | 322.7 |
| 1966 | 614.4 | 595.9 | 417.0 | 254.7 | 168.5 | 129.4 | 133.5 | 161.2 | 135.0 | 194.1 | 228.6 | 445.6 | 289.8 |
| 1967 | 478.1 | 570.0 | 398.8 | 242.1 | 164.5 | 144.9 | 114.6 | 132.7 | 231.2 | 187.4 | 211.0 | 497.7 | 281.1 |
| 1968 | 729.1 | 845.8 | 552.3 | 365.1 | 237.3 | 171.7 | 142.3 | 188.7 | 328.1 | 293.7 | 567.4 | 1059.6 | 456.8 |
| 1969 | 1460.0 | 1170.2 | 774.1 | 520.7 | 424.3 | 300.5 | 235.6 | 250.4 | 229.1 | 233.5 | 292.9 | 417.8 | 525.8 |
| 1970 | 666.9 | 538.9 | 351.4 | 237.8 | 185.3 | 157.8 | 140.2 | 141.3 | 179.6 | 173.4 | 181.2 | 416.5 | 280.9 |
| 1971 | 706.0 | 709.0 | 427.5 | 255.0 | 173.0 | 141.4 | 131.7 | 148.3 | 257.9 | 220.6 | 258.7 | 493.5 | 326.9 |
| 1972 | 1677.5 | 1111.3 | 839.7 | 513.7 | 388.6 | 223.6 | 199.8 | 232.5 | 276.8 | 222.1 | 289.0 | 820.4 | 566.3 |
| 1973 | 747.8 | 584.2 | 396.4 | 291.7 | 1965.9 | 162.0 | 140.7 | 148.0 | 163.8 | 167.4 | 175.2 | 595.1 | 461.5 |
| 1974 | 897.5 | 699.9 | 497.4 | 332.9 | 208.1 | 185.3 | 156.0 | 150.9 | 257.4 | 396.8 | 284.3 | 564.0 | 385.9 |
| 1975 | 713.8 | 705.5 | 442.2 | 300.8 | 200.9 | 176.8 | 161.7 | 159.9 | 1840.8 | 411.9 | 913.2 | 561.9 | 549.1 |
| 1976 | 1192.2 | 1729.7 | 1257.0 | 749.4 | 458.0 | 324.4 | 257.4 | 347.8 | 275.5 | 330.0 | 326.9 | 593.3 | 653.5 |
| 1977 | 676.8 | 625.9 | 399.1 | 241.1 | 175.2 | 145.7 | 140.7 | 345.8 | 591.0 | 566.1 | 518.4 | 681.4 | 425.6 |
| 1978 | 794.9 | 663.2 | 430.7 | 282.8 | 202.8 | 142.5 | 164.3 | 185.3 | 501.6 | 345.0 | 567.6 | 535.2 | 401.3 |
| 1979 | 914.4 | 638.0 | 491.0 | 261.4 | 203.6 | 173.8 | 157.1 | 165.9 | 197.5 | 215.7 | 820.9 | 1144.9 | 448.7 |
| 1980 | 2550.1 | 1665.2 | 901.3 | 609.6 | 432.8 | 278.8 | 218.0 | 235.4 | 276.0 | 422.0 | 608.3 | 730.4 | 744.0 |
| 1981 | 1151.2 | 979.0 | 621.4 | 452.9 | 303.2 | 222.3 | 197.5 | 218.8 | 295.5 | 290.3 | 349.1 | 564.5 | 470.5 |
| 1982 | 1186.5 | 1052.6 | 609.6 | 328.6 | 249.4 | 193.6 | 214.9 | 424.8 | 316.2 | 417.3 | 407.7 | 563.2 | 497.0 |
| 1983 | 1006.8 | 1493.5 | 711.7 | 389.7 | 255.0 | 183.2 | 156.0 | 156.3 | 195.4 | 190.3 | 239.0 | 350.7 | 444.0 |
| 1984 | 1137.5 | 634.0 | 375.0 | 218.3 | 164.5 | 140.9 | 127.0 | 232.2 | 264.6 | 336.7 | 514.3 | 411.4 | 379.7 |
| 1985 | 887.9 | 524.2 | 351.7 | 211.6 | 129.9 | 103.1 | 91.8 | 106.0 | 322.2 | 295.7 | 307.4 | 446.1 | 314.8 |
| 1986 | 1190.8 | 1584.5 | 749.4 | 387.8 | 270.5 | 229.3 | 184.3 | 267.0 | 656.6 | 431.8 | 547.2 | 1338.2 | 653.1 |
| 1987 | 1431.6 | 1670.0 | 876.6 | 430.2 | 366.4 | 235.7 | 233.0 | 457.2 | 299.1 | 462.7 | 573.4 | 1472.5 | 709.0 |
| 1988 | 1120.5 | 972.1 | 610.6 | 382.1 | 308.7 | 235.3 | 208.0 | 238.1 | 199.7 | 233.4 | 395.3 | 716.5 | 468.4 |
| AVE. | 918.1 | 883.7 | 560.6 | 346.3 | 293.0 | 188.4 | 169.7 | 202.2 | 314.7 | 302.9 | 374.1 | 618.1 | 431.0 |

**Table 5.2: Monthly Yield at Karun-4 Dam Site (Down Dam Site)** **Unit: In (m.c.m.)**

| YEAR | APR. | MAY. | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 753.7 | 1028.8 | 630.0 | 387.6 | 281.8 | 240.3 | 243.1 | 199.3 | 184.3 | 868.3 | 441.4 | 1138.1 | 533.1 |
| 1952 | 1013.0 | 1029.3 | 710.0 | 465.0 | 344.2 | 270.8 | 261.0 | 297.6 | 633.0 | 822.4 | 382.3 | 943.0 | 597.6 |
| 1953 | 1769.6 | 1507.1 | 888.2 | 553.6 | 399.6 | 314.4 | 318.3 | 253.2 | 675.2 | 765.7 | 360.5 | 514.5 | 693.3 |
| 1954 | 965.0 | 948.4 | 653.3 | 400.7 | 302.4 | 245.6 | 253.0 | 210.5 | 228.4 | 144.4 | 295.0 | 823.0 | 455.8 |
| 1955 | 771.9 | 913.3 | 576.4 | 381.4 | 295.4 | 218.6 | 218.0 | 220.3 | 285.6 | 293.9 | 354.6 | 872.7 | 450.2 |
| 1956 | 774.6 | 836.5 | 602.6 | 414.6 | 317.1 | 225.0 | 251.7 | 208.7 | 229.7 | 279.7 | 331.3 | 677.8 | 429.1 |
| 1957 | 1310.8 | 1492.7 | 1102.4 | 654.1 | 433.4 | 328.1 | 204.2 | 262.1 | 320.6 | 267.5 | 290.3 | 531.1 | 599.8 |
| 1958 | 645.0 | 770.6 | 350.1 | 225.0 | 188.8 | 140.6 | 126.5 | 130.9 | 344.0 | 205.0 | 244.9 | 318.6 | 307.5 |
| 1959 | 845.8 | 646.3 | 396.9 | 279.6 | 187.5 | 142.0 | 127.8 | 120.5 | 130.4 | 185.1 | 201.4 | 260.0 | 293.6 |
| 1960 | 568.9 | 641.2 | 399.9 | 223.4 | 150.8 | 123.2 | 105.8 | 124.9 | 121.0 | 158.6 | 415.0 | 350.2 | 281.9 |
| 1961 | 539.2 | 817.7 | 515.1 | 308.6 | 196.9 | 144.1 | 123.6 | 119.8 | 198.5 | 216.7 | 447.6 | 454.6 | 340.2 |
| 1962 | 506.8 | 745.7 | 470.1 | 312.3 | 219.4 | 187.2 | 167.4 | 184.8 | 201.7 | 212.8 | 287.7 | 443.2 | 328.3 |
| 1963 | 543.2 | 649.2 | 415.9 | 239.1 | 223.1 | 181.3 | 140.0 | 128.3 | 146.7 | 140.7 | 175.0 | 387.8 | 297.5 |
| 1964 | 598.6 | 464.2 | 312.0 | 184.5 | 147.0 | 133.4 | 126.0 | 126.7 | 171.1 | 203.5 | 406.7 | 596.7 | 289.2 |
| 1965 | 689.7 | 775.7 | 477.8 | 260.3 | 164.7 | 134.7 | 132.2 | 258.7 | 168.2 | 161.0 | 465.3 | 563.8 | 354.3 |
| 1966 | 674.7 | 654.3 | 458.0 | 279.6 | 158.3 | 142.0 | 146.4 | 177.0 | 148.3 | 213.1 | 251.2 | 489.4 | 316.0 |
| 1967 | 525.0 | 625.9 | 437.9 | 266.0 | 180.5 | 159.1 | 125.7 | 145.7 | 254.0 | 205.8 | 231.7 | 546.4 | 308.6 |
| 1968 | 801.1 | 928.9 | 606.4 | 400.7 | 260.6 | 188.6 | 156.3 | 207.1 | 360.3 | 322.4 | 622.9 | 1163.3 | 501.6 |
| 1969 | 1603.0 | 1284.8 | 849.9 | 571.8 | 466.0 | 329.7 | 258.7 | 275.0 | 251.4 | 279.2 | 321.9 | 458.8 | 579.2 |
| 1970 | 732.3 | 591.9 | 385.7 | 261.1 | 203.6 | 202.8 | 182.5 | 155.3 | 197.3 | 190.5 | 198.8 | 457.5 | 313.3 |
| 1971 | 775.1 | 778.6 | 766.6 | 279.9 | 189.9 | 155.3 | 144.6 | 162.8 | 283.3 | 242.1 | 284.1 | 543.5 | 383.8 |
| 1972 | 1841.9 | 1220.3 | 921.9 | 563.5 | 694.8 | 245.6 | 219.3 | 255.3 | 304.0 | 243.9 | 317.3 | 900.7 | 644.0 |
| 1973 | 821.2 | 641.2 | 435.2 | 296.5 | 217.5 | 178.1 | 154.5 | 162.3 | 194.1 | 183.8 | 192.3 | 653.4 | 344.2 |
| 1974 | 985.4 | 768.4 | 549.1 | 365.6 | 228.5 | 203.8 | 171.3 | 166.4 | 282.5 | 435.7 | 312.1 | 619.2 | 424.0 |
| 1975 | 783.7 | 774.9 | 485.3 | 330.2 | 220.7 | 193.9 | 177.6 | 175.7 | 202.7 | 452.0 | 1002.6 | 616.9 | 451.3 |
| 1976 | 1308.9 | 1899.3 | 1380.2 | 822.8 | 503.0 | 356.0 | 282.5 | 382.1 | 302.5 | 362.1 | 358.7 | 651.4 | 717.5 |
| 1977 | 743.0 | 687.3 | 438.2 | 264.6 | 192.3 | 160.2 | 154.7 | 379.7 | 648.8 | 621.6 | 569.2 | 748.1 | 467.3 |
| 1978 | 872.9 | 726.4 | 473.0 | 312.3 | 222.6 | 156.7 | 180.4 | 203.5 | 550.8 | 379.0 | 623.1 | 587.6 | 440.7 |
| 1979 | 1003.9 | 700.7 | 539.4 | 286.9 | 223.4 | 190.7 | 172.6 | 182.2 | 229.7 | 236.9 | 901.2 | 1257.1 | 493.7 |
| 1980 | 2800.0 | 1828.3 | 989.4 | 669.3 | 476.5 | 306.1 | 239.5 | 258.4 | 303.0 | 463.4 | 668.0 | 802.0 | 817.0 |
| 1981 | 1263.9 | 1074.8 | 682.2 | 497.4 | 332.9 | 244.0 | 216.7 | 240.3 | 324.3 | 318.8 | 383.4 | 619.7 | 516.5 |
| 1982 | 1302.8 | 1155.5 | 670.1 | 360.5 | 273.7 | 212.7 | 235.9 | 466.3 | 347.3 | 458.3 | 447.6 | 618.5 | 545.8 |
| 1983 | 1105.4 | 1640.0 | 781.6 | 428.0 | 271.1 | 201.1 | 171.3 | 171.6 | 212.0 | 208.7 | 262.3 | 384.9 | 486.5 |
| 1984 | 1248.9 | 696.1 | 411.7 | 239.7 | 180.5 | 154.5 | 139.4 | 255.1 | 290.6 | 366.8 | 564.8 | 451.5 | 416.6 |
| 1985 | 974.9 | 575.6 | 386.0 | 232.2 | 142.5 | 113.0 | 100.8 | 116.4 | 351.2 | 324.8 | 337.5 | 489.9 | 345.4 |
| 1986 | 1308.7 | 2034.0 | 822.8 | 425.9 | 296.8 | 251.8 | 201.9 | 293.2 | 721.1 | 474.1 | 600.6 | 1469.4 | 741.7 |
| 1987 | 1865.0 | 1835.0 | 962.6 | 531.1 | 402.3 | 258.7 | 253.2 | 502.1 | 328.4 | 792.6 | 629.3 | 1616.6 | 831.4 |
| 1988 | 1213.9 | 1054.2 | 618.4 | 402.6 | 337.2 | 281.5 | 254.3 | 297.0 | 315.2 | 434.2 | 354.8 | 916.0 | 539.9 |
| AVE. | 1022.4 | 985.3 | 622.4 | 381.0 | 277.0 | 208.3 | 187.9 | 223.1 | 301.1 | 345.7 | 408.8 | 682.6 | 470.5 |

**Table 5.3: Monthly Yield at Karun-3 Dam Site** Unit: In (m.c.m.)

| YEAR | APR. | MAY. | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 1183.6 | 1615.6 | 989.4 | 608.8 | 442.5 | 377.4 | 381.8 | 313.1 | 289.3 | 1363.9 | 693.1 | 1787.4 | 837.2 |
| 1952 | 1591.0 | 1616.7 | 1115.0 | 730.4 | 540.5 | 425.3 | 410.1 | 467.3 | 994.3 | 1291.9 | 600.3 | 1480.8 | 938.6 |
| 1953 | 2779.1 | 2366.9 | 1394.9 | 869.4 | 627.8 | 493.9 | 499.7 | 397.9 | 1060.6 | 1202.7 | 566.4 | 808.2 | 1089.0 |
| 1954 | 1515.4 | 1489.7 | 1026.1 | 629.2 | 474.9 | 385.7 | 397.4 | 330.5 | 358.5 | 226.5 | 463.2 | 1292.4 | 715.8 |
| 1955 | 1212.2 | 1434.6 | 905.0 | 598.9 | 464.2 | 343.4 | 315.4 | 274.5 | 244.4 | 193.4 | 508.0 | 1285.6 | 648.3 |
| 1956 | 1714.2 | 3061.4 | 1911.3 | 795.5 | 549.1 | 420.5 | 368.6 | 427.7 | 600.8 | 474.1 | 523.1 | 861.6 | 975.6 |
| 1957 | 1046.5 | 777.0 | 568.9 | 399.6 | 323.0 | 259.3 | 232.8 | 233.8 | 514.8 | 338.8 | 444.0 | 574.6 | 476.1 |
| 1958 | 1608.4 | 1013.8 | 665.3 | 482.6 | 336.4 | 263.3 | 233.3 | 222.9 | 233.3 | 289.3 | 320.1 | 418.3 | 507.3 |
| 1959 | 904.0 | 911.5 | 590.9 | 366.4 | 253.1 | 213.5 | 190.8 | 209.4 | 221.9 | 262.6 | 720.3 | 794.7 | 469.9 |
| 1960 | 1096.0 | 1312.1 | 831.1 | 571.6 | 354.1 | 269.4 | 233.5 | 224.2 | 344.0 | 381.0 | 719.0 | 717.7 | 587.8 |
| 1961 | 756.4 | 1248.9 | 755.3 | 503.0 | 355.2 | 300.5 | 267.5 | 288.0 | 306.9 | 304.0 | 396.3 | 591.8 | 506.1 |
| 1962 | 713.5 | 950.3 | 729.1 | 486.7 | 326.0 | 268.4 | 220.1 | 207.6 | 231.5 | 222.1 | 266.7 | 626.2 | 437.3 |
| 1963 | 972.0 | 681.4 | 480.2 | 295.4 | 232.2 | 211.3 | 199.3 | 197.5 | 250.6 | 289.5 | 713.4 | 1078.5 | 475.1 |
| 1964 | 1207.4 | 1190.0 | 786.9 | 467.6 | 321.9 | 257.1 | 232.2 | 375.8 | 271.4 | 264.1 | 702.7 | 911.1 | 582.4 |
| 1965 | 1061.7 | 938.2 | 677.6 | 421.3 | 289.0 | 233.3 | 238.5 | 271.4 | 246.2 | 397.6 | 454.1 | .923.3 | 512.7 |
| 1966 | 937.4 | 1099.5 | 738.7 | 467.6 | 316.9 | 263.6 | 229.7 | 255.1 | 467.9 | 344.7 | 380.8 | 1029.8 | 544.3 |
| 1967 | 1458.4 | 1457.9 | 968.2 | 651.9 | 431.5 | 317.1 | 268.0 | 328.4 | 519.4 | 505.4 | 1784.1 | 1797.3 | 874.0 |
| 1968 | 2733.6 | 2031.6 | 1304.4 | 916.3 | 722.1 | 526.0 | 418.1 | 456.2 | 402.5 | 447.9 | 517.9 | 721.4 | 933.2 |
| 1969 | 1040.3 | 841.6 | 581.2 | 401.0 | 312.8 | 267.6 | 246.8 | 248.1 | 358.7 | 320.4 | 353.3 | 710.7 | 473.5 |
| 1970 | 1224.3 | 1197.8 | 733.1 | 453.2 | 319.3 | 267.0 | 242.4 | 287.2 | 441.4 | 404.1 | 471.7 | 994.0 | 586.3 |
| 1971 | 3390.9 | 2106.0 | 1488.9 | 942.5 | 676.8 | 433.9 | 378.7 | 405.9 | 473.0 | 391.1 | 488.6 | 1378.9 | 1046.3 |
| 1972 | 1236.1 | 919.2 | 647.9 | 458.0 | 349.8 | 286.3 | 254.0 | 257.1 | 277.1 | 293.2 | 340.1 | 1338.2 | 554.8 |
| 1973 | 1779.3 | 1270.6 | 897.8 | 617.9 | 401.8 | 341.2 | 298.6 | 297.3 | 483.7 | 729.9 | 554.4 | 1215.9 | 740.7 |
| 1974 | 1478.5 | 1403.7 | 929.9 | 635.9 | 440.6 | 359.4 | 321.7 | 326.3 | 388.3 | 817.3 | 2336.2 | 1588.1 | 918.8 |
| 1975 | 2723.7 | 3066.8 | 2155.6 | 1362.8 | 942.3 | 635.3 | 499.0 | 615.9 | 509.3 | 598.0 | 602.9 | 1048.5 | 1230.0 |
| 1976 | 1206.4 | 1048.6 | 714.9 | 484.5 | 369.9 | 311.2 | 298.1 | 728.4 | 1025.9 | 1976.4 | 1179.6 | 1527.7 | 906.0 |
| 1977 | 1648.8 | 1290.7 | 917.1 | 640.9 | 460.1 | 331.9 | 335.9 | 370.1 | 932.1 | 646.7 | 1150.8 | 1064.5 | 815.8 |
| 1978 | 1604.1 | 1092.0 | 887.9 | 558.4 | 425.1 | 353.8 | 323.7 | 333.1 | 484.4 | 500.5 | 1525.9 | 2390.6 | 873.3 |
| 1979 | 4252.0 | 2693.1 | 1543.3 | 1041.6 | 743.3 | 518.8 | 423.8 | 445.6 | 500.3 | 711.8 | 1138.4 | 1408.2 | 1285.0 |
| 1980 | 2038.8 | 1694.1 | 1078.1 | 780.5 | 537.0 | 409.8 | 375.1 | 396.3 | 506.5 | 493.3 | 645.9 | 1224.7 | 848.3 |
| 1981 | 2296.7 | 1747.4 | 1049.4 | 608.0 | 445.2 | 350.3 | 373.8 | 746.0 | 561.9 | 784.3 | 783.8 | 1101.1 | 904.0 |
| 1982 | 1782.2 | 2368.2 | 1201.0 | 711.4 | 481.8 | 368.5 | 317.3 | 313.1 | 358.7 | 358.2 | 428.7 | 584.8 | 772.8 |
| 1983 | 2027.8 | 1047.3 | 674.7 | 422.9 | 316.6 | 270.0 | 244.2 | 400.5 | 454.4 | 627.3 | 1137.6 | 777.6 | 700.1 |
| 1984 | 1435.4 | 883.1 | 658.4 | 452.6 | 318.7 | 267.8 | 243.4 | 267.0 | 598.8 | 563.0 | 529.8 | 803.8 | 585.1 |
| 1985 | 2218.0 | 2612.2 | 1282.7 | 739.0 | 523.9 | 429.6 | 351.0 | 468.1 | 1513.0 | 1016.3 | 996.9 | 2464.5 | 1217.9 |
| 1986 | 2529.7 | 2593.0 | 1448.7 | 849.1 | 641.2 | 444.9 | 425.1 | 705.0 | 500.3 | 1135.3 | 1057.5 | 2856.4 | 1265.5 |
| 1987 | 1955.2 | 1655.3 | 1007.1 | 675.0 | 541.0 | 450.0 | 399.2 | 466.6 | 495.1 | 681.7 | 557.3 | 1438.6 | 860.2 |
| 1988 | 1759.7 | 1526.7 | 958.9 | 600.0 | 484.8 | 369.6 | 326.6 | 374.0 | 313.6 | 366.5 | 620.8 | 1125.2 | 735.5 |
| MEAN | 1687.3 | 1533.0 | 981.4 | 623.6 | 449.8 | 349.9 | 316.2 | 366.7 | 493.0 | 584.6 | 730.9 | 1177.4 | 774.5 |

**Table 5.4: Monthly Yield at Karun-2 Dam Site** **Unit: In (m.c.m.)**

| YEAR | APR. | MAY. | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 1246.8 | 1701.9 | 1042.2 | 641.2 | 466.0 | 397.5 | 402.3 | 329.7 | 304.8 | 1436.7 | 730.2 | 1882.8 | 881.8 |
| 1952 | 1675.9 | 1702.9 | 1174.5 | 769.2 | 569.4 | 448.1 | 431.8 | 492.2 | 1047.4 | 1360.8 | 632.4 | 1559.9 | 988.7 |
| 1953 | 2927.2 | 2493.1 | 1469.4 | 915.7 | 661.3 | 520.1 | 526.4 | 419.1 | 1117.2 | 1266.7 | 596.7 | 851.2 | 1147.0 |
| 1954 | 1596.3 | 1569.3 | 1080.7 | 662.6 | 500.3 | 406.3 | 418.6 | 348.1 | 377.7 | 238.7 | 487.8 | 1361.3 | 754.0 |
| 1955 | 1276.8 | 1511.2 | 953.2 | 630.8 | 488.8 | 361.6 | 332.3 | 289.0 | 257.4 | 203.7 | 535.2 | 1354.3 | 682.9 |
| 1956 | 1805.5 | 3224.8 | 2013.4 | 837.8 | 578.3 | 443.0 | 388.3 | 450.5 | 633.0 | 499.5 | 551.1 | 907.5 | 1027.7 |
| 1957 | 1102.2 | 818.5 | 599.2 | 421.0 | 340.2 | 273.2 | 245.2 | 246.2 | 542.2 | 356.9 | 467.6 | 605.2 | 501.5 |
| 1958 | 1694.1 | 1067.9 | 700.7 | 508.4 | 354.4 | 277.2 | 245.7 | 234.8 | 245.7 | 304.8 | 337.2 | 440.6 | 534.3 |
| 1959 | 952.2 | 959.9 | 622.5 | 386.0 | 266.5 | 225.0 | 200.9 | 220.6 | 233.8 | 276.6 | 758.7 | 837.2 | 495.0 |
| 1960 | 1154.4 | 1382.1 | 875.3 | 602.1 | 373.1 | 283.9 | 246.0 | 236.1 | 362.4 | 401.2 | 757.4 | 756.1 | 619.2 |
| 1961 | 796.8 | 1315.6 | 795.5 | 529.8 | 374.2 | 316.6 | 281.8 | 303.3 | 323.2 | 320.4 | 417.6 | 623.4 | 533.2 |
| 1962 | 751.6 | 1000.9 | 767.9 | 512.6 | 343.4 | 282.6 | 231.7 | 218.8 | 243.9 | 234.1 | 281.0 | 659.7 | 460.7 |
| 1963 | 1024.0 | 717.8 | 505.9 | 311.2 | 244.5 | 222.6 | 210.0 | 208.1 | 264.1 | 305.1 | 756.7 | 1136.1 | 500.5 |
| 1964 | 1271.7 | 1253.5 | 829.0 | 492.6 | 339.1 | 270.8 | 244.7 | 395.8 | 285.9 | 278.1 | 740.3 | 959.6 | 613.4 |
| 1965 | 1118.2 | 988.3 | 713.8 | 443.8 | 304.5 | 245.6 | 251.2 | 285.9 | 259.5 | 418.9 | 478.2 | 972.5 | 540.0 |
| 1966 | 987.5 | 1158.1 | 778.1 | 492.6 | 333.7 | 277.5 | 241.8 | 268.5 | 492.7 | 363.1 | 401.0 | 1084.8 | 573.3 |
| 1967 | 1536.1 | 1535.5 | 1019.9 | 686.7 | 454.5 | 334.0 | 282.3 | 346.0 | 547.2 | 532.4 | 1879.2 | 1893.2 | 920.6 |
| 1968 | 2879.3 | 2140.0 | 1374.0 | 965.0 | 760.7 | 554.2 | 440.4 | 480.6 | 424.1 | 471.7 | 545.6 | 759.7 | 982.9 |
| 1969 | 1095.7 | 886.6 | 612.3 | 422.4 | 329.4 | 281.8 | 260.0 | 261.3 | 377.9 | 337.5 | 372.2 | 748.6 | 498.8 |
| 1970 | 1289.6 | 1261.8 | 772.2 | 477.3 | 336.4 | 281.2 | 255.3 | 302.5 | 465.0 | 425.6 | 496.9 | 1047.2 | 617.6 |
| 1971 | 3571.6 | 2218.3 | 1568.2 | 992.9 | 713.0 | 456.9 | 398.9 | 427.7 | 498.2 | 411.9 | 514.8 | 1452.6 | 1102.1 |
| 1972 | 1302.0 | 968.2 | 682.5 | 482.4 | 368.5 | 301.6 | 267.5 | 270.9 | 291.9 | 308.7 | 358.2 | 1409.5 | 584.3 |
| 1973 | 1874.1 | 1338.4 | 945.7 | 650.9 | 423.2 | 359.4 | 314.4 | 313.1 | 509.6 | 768.8 | 584.0 | 1280.7 | 780.2 |
| 1974 | 1557.2 | 1478.7 | 979.5 | 669.9 | 464.2 | 378.7 | 338.8 | 343.7 | 409.0 | 860.8 | 2460.8 | 1672.9 | 967.9 |
| 1975 | 2868.8 | 3230.4 | 2270.5 | 1435.4 | 992.6 | 669.3 | 525.7 | 648.8 | 536.5 | 629.9 | 635.0 | 1104.5 | 1295.6 |
| 1976 | 1270.6 | 1104.6 | 752.9 | 510.2 | 389.7 | 327.8 | 313.9 | 767.2 | 1080.6 | 2081.9 | 1242.6 | 1609.1 | 954.3 |
| 1977 | 1736.7 | 1359.6 | 966.1 | 675.2 | 484.8 | 349.5 | 353.8 | 389.8 | 981.8 | 681.2 | 1212.3 | 1121.3 | 859.3 |
| 1978 | 1689.5 | 1150.1 | 935.3 | 588.2 | 447.8 | 372.6 | 341.1 | 351.0 | 510.4 | 527.2 | 1607.3 | 2518.1 | 919.9 |
| 1979 | 4478.8 | 2836.7 | 1625.5 | 1097.1 | 782.9 | 546.4 | 446.3 | 469.4 | 527.0 | 749.6 | 1199.1 | 1483.4 | 1353.5 |
| 1980 | 2147.5 | 1784.4 | 1135.6 | 822.0 | 565.7 | 431.8 | 395.0 | 417.6 | 533.4 | 519.4 | 680.4 | 1290.0 | 893.6 |
| 1981 | 2419.1 | 1840.6 | 1105.4 | 640.4 | 469.0 | 369.1 | 393.7 | 785.6 | 592.0 | 826.1 | 825.6 | 1159.9 | 952.2 |
| 1982 | 1877.3 | 2494.7 | 1265.0 | 749.4 | 507.6 | 388.1 | 334.1 | 329.7 | 377.9 | 377.4 | 451.5 | 615.9 | 814.0 |
| 1983 | 2136.0 | 1103.2 | 710.6 | 445.4 | 333.5 | 284.4 | 257.1 | 421.7 | 478.5 | 660.7 | 1198.3 | 819.1 | 737.4 |
| 1984 | 1512.0 | 930.2 | 693.4 | 476.8 | 335.6 | 282.0 | 256.3 | 281.2 | 630.6 | 593.0 | 558.1 | 846.5 | 616.3 |
| 1985 | 2336.4 | 2751.5 | 1351.0 | 778.3 | 551.8 | 452.6 | 369.6 | 493.0 | 1593.6 | 1070.5 | 1050.0 | 2595.9 | 1282.8 |
| 1986 | 2664.7 | 2731.2 | 1525.9 | 894.3 | 675.5 | 468.7 | 447.6 | 742.6 | 527.0 | 1195.9 | 1114.0 | 3008.8 | 1333.0 |
| 1987 | 2059.4 | 1743.6 | 1060.9 | 710.8 | 570.0 | 474.1 | 420.4 | 491.4 | 521.5 | 718.0 | 587.1 | 1515.3 | 906.0 |
| 1988 | 1853.5 | 1608.1 | 1010.0 | 631.8 | 510.8 | 389.4 | 344.0 | 394.0 | 330.5 | 385.9 | 654.0 | 1185.3 | 774.8 |
| MEAN | 1777.3 | 1614.8 | 1033.8 | 656.8 | 473.8 | 368.6 | 333.0 | 386.2 | 519.3 | 615.8 | 769.9 | 1240.3 | 815.8 |

**Table 5.5: Monthly Yield at Karun-1 Dam Site** Unit:In (m.c.m.)

| YEAR | APR. | MAY. | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 1362.0 | 2022.2 | 1186.0 | 790.4 | 614.4 | 545.9 | 525.7 | 425.9 | 488.9 | 1954.6 | 999.2 | 2236.9 | 1096.0 |
| 1952 | 1862.8 | 2023.5 | 1357.9 | 961.0 | 732.0 | 594.3 | 562.2 | 579.1 | 847.3 | 1852.0 | 861.6 | 1837.5 | 1172.6 |
| 1953 | 3322.8 | 2888.7 | 1741.0 | 1155.7 | 836.5 | 663.7 | 678.6 | 510.1 | 881.0 | 1725.0 | 811.3 | 961.4 | 1348.0 |
| 1954 | 1769.9 | 1877.0 | 1236.3 | 819.3 | 653.0 | 554.4 | 545.9 | 443.2 | 524.1 | 331.0 | 658.1 | 1592.0 | 917.0 |
| 1955 | 1397.3 | 1813.3 | 1070.8 | 776.7 | 640.1 | 511.6 | 439.6 | 387.8 | 466.3 | 283.8 | 613.5 | 1490.4 | 824.3 |
| 1956 | 2383.0 | 3690.0 | 2447.0 | 1164.3 | 783.4 | 591.9 | 521.3 | 545.1 | 630.1 | 595.1 | 821.9 | 1067.6 | 1270.1 |
| 1957 | 1354.7 | 1054.0 | 651.1 | 549.3 | 465.2 | 423.2 | 334.4 | 352.5 | 666.7 | 421.7 | 667.4 | 672.4 | 634.4 |
| 1958 | 1792.7 | 1419.0 | 763.9 | 615.2 | 507.6 | 443.3 | 327.1 | 329.4 | 452.0 | 476.7 | 400.5 | 549.8 | 673.1 |
| 1959 | 1055.3 | 1181.7 | 596.5 | 463.9 | 421.3 | 400.7 | 275.5 | 324.5 | 488.9 | 764.6 | 1384.4 | 945.8 | 691.9 |
| 1960 | 1305.2 | 1794.8 | 977.1 | 659.2 | 519.6 | 462.8 | 381.3 | 358.0 | 486.5 | 535.8 | 855.4 | 809.7 | 762.1 |
| 1961 | 811.0 | 1706.1 | 832.2 | 651.1 | 508.9 | 459.1 | 370.4 | 381.8 | 492.0 | 418.3 | 651.9 | 699.6 | 665.2 |
| 1962 | 1009.0 | 1553.2 | 1006.3 | 675.5 | 516.1 | 455.1 | 334.6 | 358.7 | 473.6 | 324.8 | 434.4 | 855.4 | 666.4 |
| 1963 | 1210.9 | 914.7 | 593.9 | 368.5 | 379.8 | 388.4 | 290.6 | 310.5 | 473.0 | 479.3 | 794.6 | 1285.4 | 650.8 |
| 1964 | 1374.3 | 1367.3 | 822.8 | 573.2 | 483.2 | 432.0 | 338.0 | 589.4 | 499.2 | 354.1 | 1440.4 | 1246.0 | 793.3 |
| 1965 | 1209.8 | 1230.7 | 780.5 | 567.6 | 470.6 | 423.7 | 360.3 | 400.7 | 451.3 | 435.2 | 533.7 | 970.4 | 652.9 |
| 1966 | 947.4 | 1247.9 | 746.7 | 531.7 | 444.3 | 417.8 | 316.2 | 367.8 | 568.7 | 455.7 | 500.0 | 1091.8 | 636.3 |
| 1967 | 1575.4 | 1919.3 | 1190.8 | 833.0 | 602.4 | 485.6 | 381.0 | 404.4 | 676.5 | 694.7 | 2667.2 | 2472.8 | 1158.6 |
| 1968 | 3736.4 | 2967.7 | 1754.4 | 1208.0 | 873.2 | 624.1 | 534.0 | 567.6 | 495.1 | 567.6 | 710.2 | 917.6 | 1246.3 |
| 1969 | 1390.1 | 1108.9 | 570.5 | 527.6 | 444.6 | 388.4 | 352.5 | 362.9 | 489.9 | 438.0 | 482.1 | 878.7 | 619.5 |
| 1970 | 1566.9 | 1593.6 | 841.0 | 583.9 | 342.8 | 350.9 | 324.0 | 417.3 | 648.0 | 645.4 | 777.6 | 1316.7 | 784.0 |
| 1971 | 3599.8 | 2579.3 | 1754.4 | 1229.4 | 841.0 | 610.7 | 456.2 | 453.6 | 593.6 | 531.4 | 679.1 | 1661.5 | 1249.2 |
| 1972 | 1481.2 | 1116.9 | 835.7 | 570.5 | 447.3 | 356.2 | 337.0 | 334.4 | 342.1 | 409.5 | 565.1 | 1980.3 | 731.4 |
| 1973 | 2576.6 | 1877.6 | 1138.3 | 800.8 | 565.1 | 474.1 | 406.9 | 394.0 | 679.1 | 948.7 | 860.5 | 1604.4 | 1027.2 |
| 1974 | 2011.5 | 2046.3 | 1403.5 | 908.0 | 658.9 | 519.6 | 464.0 | 469.2 | 650.6 | 1482.6 | 3317.8 | 2350.9 | 1356.9 |
| 1975 | 3516.7 | 3433.7 | 2726.6 | 1840.1 | 1296.3 | 865.1 | 705.0 | 790.6 | 526.2 | 806.1 | 777.6 | 326.6 | 1467.5 |
| 1976 | 423.2 | 972.3 | 476.8 | 527.6 | 648.2 | 731.2 | 450.5 | 804.0 | 841.1 | 2342.4 | 1430.5 | 1898.4 | 962.2 |
| 1977 | 1746.6 | 1449.3 | 1013.8 | 779.7 | 600.0 | 504.9 | 472.5 | 460.9 | 899.4 | 1000.3 | 1781.5 | 1255.8 | 997.1 |
| 1978 | 1851.0 | 1419.0 | 980.6 | 703.3 | 569.4 | 508.1 | 435.5 | 438.8 | 581.9 | 822.2 | 2104.7 | 2709.9 | 1093.7 |
| 1979 | 4906.3 | 3000.9 | 1787.3 | 1296.9 | 930.2 | 677.9 | 592.5 | 586.6 | 609.6 | 1232.5 | 1762.0 | 1848.9 | 1602.6 |
| 1980 | 2686.2 | 2173.3 | 1324.2 | 1040.8 | 766.3 | 606.1 | 554.7 | 521.3 | 576.2 | 833.6 | 1003.9 | 1563.8 | 1137.5 |
| 1981 | 2626.7 | 2121.8 | 1262.3 | 802.4 | 631.0 | 533.0 | 508.6 | 824.5 | 622.1 | 1078.0 | 1166.4 | 1370.1 | 1128.9 |
| 1982 | 2110.0 | 3028.2 | 1734.8 | 1064.1 | 706.3 | 536.8 | 471.5 | 458.0 | 534.2 | 497.9 | 560.1 | 676.3 | 1031.5 |
| 1983 | 2085.9 | 1370.8 | 743.5 | 525.8 | 441.7 | 418.9 | 344.5 | 492.7 | 624.7 | 840.3 | 1525.9 | 1092.0 | 875.6 |
| 1984 | 1938.1 | 1201.8 | 803.5 | 554.7 | 458.5 | 441.4 | 347.1 | 374.8 | 547.5 | 720.1 | 825.8 | 1349.4 | 771.9 |
| 1985 | 2147.5 | 3178.7 | 1537.1 | 949.5 | 722.4 | 586.8 | 466.3 | 524.6 | 955.2 | 1314.1 | 1169.0 | 2968.6 | 1376.6 |
| 1986 | 2696.3 | 2847.7 | 1689.8 | 1077.0 | 811.6 | 596.2 | 546.7 | 848.6 | 577.0 | 1978.0 | 1522.8 | 3634.8 | 1568.9 |
| 1987 | 2269.1 | 2094.5 | 1227.8 | 909.9 | 715.9 | 594.1 | 538.9 | 528.5 | 555.2 | 885.9 | 671.1 | 1649.3 | 1053.3 |
| 1988 | 2168.7 | 1939.7 | 1157.3 | 777.3 | 627.5 | 514.5 | 454.1 | 486.5 | 501.3 | 531.1 | 891.9 | 1374.5 | 952.0 |
| AVE. | 1981.0 | 1927.0 | 1175.4 | 811.4 | 623.1 | 518.2 | 440.7 | 479.2 | 592.5 | 842.3 | 1055.3 | 1442.5 | 990.7 |

**Table 5.6: Monthly Yield at Godar-e-Landar Run-of-River " Tunnel Scheme " Unit: In (m.c.m.)**

| YEAR | APR. | MAY. | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 1215.5 | 1104.3 | 853.3 | 628.9 | 593.8 | 606.7 | 399.2 | 403.8 | 400.2 | 696.0 | 1116.4 | 1499.7 | 793.1 |
| 1952 | 1521.9 | 1897.1 | 1157.3 | 763.3 | 594.6 | 596.7 | 394.5 | 394.5 | 410.6 | 1305.1 | 1251.7 | 2004.1 | 1024.3 |
| 1953 | 2122.4 | 1899.8 | 1281.9 | 914.9 | 670.1 | 593.8 | 391.4 | 579.6 | 1613.5 | 1264.4 | 1078.5 | 1980.8 | 1199.3 |
| 1954 | 3876.2 | 2633.4 | 1565.3 | 1086.1 | 777.0 | 603.2 | 494.8 | 526.2 | 1323.7 | 1191.0 | 995.6 | 898.6 | 1330.9 |
| 1955 | 1989.8 | 1689.5 | 1084.2 | 688.6 | 593.8 | 596.5 | 397.9 | 397.4 | 401.5 | 601.3 | 685.3 | 1801.4 | 910.6 |
| 1956 | 1558.6 | 1704.8 | 1066.3 | 735.0 | 594.3 | 595.4 | 395.5 | 397.1 | 399.4 | 596.7 | 593.3 | 1513.0 | 845.8 |
| 1957 | 2934.2 | 2664.7 | 2060.0 | 1096.8 | 675.5 | 593.0 | 392.4 | 480.8 | 817.5 | 670.3 | 897.4 | 1129.9 | 1201.0 |
| 1958 | 1329.6 | 1075.6 | 758.8 | 593.8 | 595.9 | 611.7 | 411.6 | 417.8 | 439.6 | 595.1 | 600.3 | 600.0 | 669.2 |
| 1959 | 2008.5 | 1257.5 | 798.2 | 604.8 | 591.7 | 602.1 | 403.8 | 408.0 | 414.2 | 634.3 | 626.5 | 647.2 | 749.7 |
| 1960 | 470.1 | 637.7 | 663.7 | 591.7 | 601.6 | 624.3 | 424.1 | 437.0 | 463.4 | 686.4 | 691.8 | 622.1 | 576.2 |
| 1961 | 1379.1 | 1595.0 | 905.0 | 595.7 | 592.2 | 622.5 | 427.7 | 416.3 | 424.8 | 629.3 | 638.9 | 609.1 | 736.3 |
| 1962 | 882.3 | 1540.9 | 857.9 | 595.4 | 592.7 | 603.4 | 404.4 | 410.1 | 416.8 | 610.2 | 631.7 | 638.7 | 682.0 |
| 1963 | 452.4 | 977.9 | 894.3 | 594.1 | 593.0 | 606.4 | 407.7 | 413.7 | 422.2 | 636.1 | 668.2 | 702.2 | 614.0 |
| 1964 | 491.0 | 441.9 | 420.0 | 606.4 | 623.3 | 654.6 | 450.7 | 470.2 | 493.3 | 741.6 | 727.6 | 675.2 | 566.3 |
| 1965 | 811.3 | 867.5 | 803.5 | 594.3 | 594.6 | 606.4 | 423.5 | 416.5 | 406.9 | 609.4 | 636.3 | 615.9 | 615.5 |
| 1966 | 967.7 | 948.4 | 707.4 | 594.1 | 596.5 | 611.5 | 412.1 | 416.8 | 418.6 | 630.6 | 649.0 | 665.4 | 634.8 |
| 1967 | 778.6 | 1424.1 | 939.0 | 594.9 | 594.6 | 609.6 | 408.8 | 417.1 | 412.4 | 602.4 | 619.2 | 638.4 | 669.9 |
| 1968 | 1716.3 | 1819.7 | 1123.3 | 784.8 | 594.9 | 594.1 | 399.4 | 398.1 | 475.1 | 827.4 | 3418.6 | 2283.3 | 1202.9 |
| 1969 | 4034.7 | 2916.0 | 1653.1 | 1128.9 | 869.1 | 635.6 | 491.7 | 527.5 | 457.2 | 568.2 | 668.2 | 891.9 | 1236.8 |
| 1970 | 1249.7 | 1019.9 | 707.4 | 581.7 | 599.7 | 619.5 | 419.9 | 427.7 | 436.8 | 652.1 | 682.0 | 693.4 | 674.1 |
| 1971 | 509.4 | 1319.4 | 800.0 | 591.1 | 588.7 | 604.5 | 409.8 | 429.5 | 459.6 | 639.4 | 659.4 | 1093.8 | 675.4 |
| 1972 | 3759.1 | 2458.0 | 1658.7 | 1012.4 | 732.3 | 596.5 | 453.3 | 526.2 | 654.2 | 580.9 | 601.1 | 1630.6 | 1221.9 |
| 1973 | 1342.1 | 1016.2 | 823.9 | 603.7 | 597.8 | 598.9 | 401.0 | 405.4 | 407.7 | 630.1 | 685.8 | 864.2 | 698.1 |
| 1974 | 2267.8 | 1633.8 | 1159.5 | 751.3 | 594.3 | 586.6 | 386.7 | 387.8 | 425.3 | 767.5 | 756.3 | 1449.2 | 930.5 |
| 1975 | 1662.5 | 1682.8 | 1149.3 | 817.7 | 604.2 | 605.1 | 398.4 | 398.4 | 473.3 | 997.9 | 2869.3 | 2050.0 | 1142.4 |
| 1976 | 3346.7 | 3732.9 | 2697.7 | 1646.4 | 1188.7 | 807.3 | 651.6 | 780.5 | 684.5 | 776.3 | 776.6 | 1311.6 | 1533.4 |
| 1977 | 2580.6 | 1315.4 | 905.8 | 628.9 | 596.7 | 604.0 | 398.1 | 744.9 | 1250.4 | 2715.9 | 1437.0 | 1796.0 | 1247.8 |
| 1978 | 2101.7 | 1440.4 | 1083.9 | 829.5 | 631.0 | 587.1 | 388.3 | 525.7 | 1295.5 | 831.5 | 1359.8 | 1212.0 | 1023.9 |
| 1979 | 1841.9 | 1149.0 | 962.6 | 656.5 | 593.8 | 597.0 | 397.4 | 396.6 | 431.3 | 713.6 | 2026.9 | 2662.0 | 1035.7 |
| 1980 | 4497.3 | 2736.0 | 1616.1 | 1022.1 | 756.4 | 598.9 | 508.6 | 548.5 | 593.3 | 927.4 | 1399.9 | 1738.2 | 1411.9 |
| 1981 | 2228.4 | 1874.3 | 1213.9 | 839.7 | 604.2 | 593.0 | 392.7 | 476.7 | 605.5 | 659.1 | 992.5 | 1786.7 | 1022.2 |
| 1982 | 2882.2 | 2136.8 | 1245.2 | 745.7 | 593.8 | 589.2 | 459.6 | 938.3 | 728.1 | 986.8 | 1090.7 | 1361.6 | 1146.5 |
| 1983 | 1968.4 | 2462.8 | 1484.9 | 941.7 | 654.3 | 588.4 | 400.2 | 507.5 | 596.4 | 600.0 | 594.9 | 701.1 | 958.4 |
| 1984 | 2346.3 | 1190.3 | 818.5 | 590.9 | 588.7 | 597.3 | 397.9 | 408.0 | 402.5 | 778.4 | 1387.0 | 944.3 | 870.8 |
| 1985 | 2242.6 | 3319.6 | 1605.2 | 991.5 | 754.2 | 612.8 | 487.0 | 547.9 | 997.4 | 1372.5 | 1220.8 | 3100.0 | 1437.6 |
| 1986 | 2815.8 | 2973.8 | 1764.5 | 1124.7 | 847.4 | 622.7 | 570.8 | 886.2 | 602.6 | 2065.6 | 1590.2 | 3795.7 | 1638.3 |
| 1987 | 2369.6 | 2187.2 | 1282.2 | 950.0 | 747.5 | 620.3 | 562.7 | 551.8 | 579.8 | 925.1 | 700.9 | 1722.4 | 1100.0 |
| 1988 | 2264.9 | 2025.7 | 1208.5 | 811.8 | 655.4 | 537.3 | 474.3 | 508.0 | 523.6 | 554.7 | 931.3 | 1435.4 | 994.2 |
| MEAN | 1968.9 | 1757.1 | 1152.1 | 787.6 | 654.4 | 608.8 | 433.9 | 492.7 | 598.9 | 849.2 | 1025.2 | 1362.2 | 974.3 |

Table 5.7: Monthly Yield at Godar-e-Landar Run-of-River "Up Dam Site" Unit: In (m.c.m)

| YEAR | APR. | MAY. | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 1242.8 | 1129.5 | 873.4 | 644.4 | 606.7 | 621.1 | 409.8 | 417.1 | 414.2 | 714.6 | 1141.5 | 1532.9 | 812.3 |
| 1952 | 1555.6 | 1938.6 | 1183.9 | 782.4 | 609.1 | 609.6 | 405.6 | 406.4 | 423.0 | 1333.8 | 1279.9 | 2056.0 | 1048.7 |
| 1953 | 2168.4 | 1941.3 | 1311.1 | 936.4 | 687.0 | 607.5 | 403.3 | 594.1 | 1648.8 | 1292.6 | 1102.9 | 2024.1 | 1226.5 |
| 1954 | 3957.1 | 2689.9 | 1600.3 | 1111.3 | 796.0 | 618.7 | 508.0 | 539.4 | 1353.3 | 1218.0 | 1018.4 | 919.4 | 1360.8 |
| 1955 | 2033.2 | 1726.5 | 1109.4 | 705.5 | 607.5 | 608.0 | 409.0 | 408.5 | 416.0 | 616.9 | 702.2 | 1840.8 | 932.0 |
| 1956 | 1592.8 | 1742.3 | 1090.9 | 753.2 | 608.8 | 606.9 | 405.6 | 407.2 | 410.1 | 612.2 | 608.9 | 1550.0 | 865.7 |
| 1957 | 2993.9 | 2721.8 | 2104.7 | 1122.0 | 692.4 | 605.9 | 404.4 | 494.0 | 837.0 | 686.6 | 918.1 | 1155.5 | 1228.0 |
| 1958 | 1359.3 | 1100.3 | 777.8 | 607.5 | 606.9 | 622.2 | 421.2 | 427.4 | 460.9 | 609.6 | 617.9 | 618.7 | 685.8 |
| 1959 | 2051.9 | 1285.9 | 817.4 | 620.3 | 603.2 | 612.6 | 413.4 | 416.8 | 423.0 | 651.1 | 637.6 | 661.2 | 766.2 |
| 1960 | 494.7 | 661.3 | 679.8 | 603.2 | 611.5 | 633.4 | 432.1 | 446.6 | 479.0 | 701.9 | 723.2 | 646.4 | 592.8 |
| 1961 | 1411.0 | 1631.1 | 926.5 | 610.7 | 603.2 | 638.0 | 443.2 | 425.9 | 436.8 | 643.9 | 662.0 | 631.2 | 755.3 |
| 1962 | 903.7 | 1575.2 | 878.5 | 610.4 | 604.2 | 613.9 | 413.9 | 420.2 | 429.2 | 620.8 | 645.9 | 655.5 | 697.6 |
| 1963 | 474.3 | 1005.7 | 915.7 | 608.5 | 604.0 | 616.3 | 416.5 | 422.5 | 432.3 | 646.2 | 678.8 | 720.6 | 628.5 |
| 1964 | 516.1 | 460.1 | 434.4 | 617.4 | 632.4 | 662.9 | 458.8 | 478.2 | 505.2 | 760.0 | 753.2 | 701.7 | 581.7 |
| 1965 | 843.2 | 893.5 | 822.8 | 608.8 | 606.1 | 616.8 | 439.1 | 429.8 | 417.1 | 619.5 | 657.1 | 638.7 | 632.7 |
| 1966 | 991.5 | 970.4 | 724.8 | 607.7 | 607.5 | 621.9 | 422.2 | 427.4 | 428.7 | 642.6 | 663.0 | 693.6 | 650.1 |
| 1967 | 805.1 | 1456.0 | 961.0 | 609.3 | 605.6 | 620.0 | 417.6 | 427.2 | 423.0 | 613.5 | 632.4 | 666.7 | 686.5 |
| 1968 | 1755.2 | 1859.3 | 1149.3 | 803.8 | 609.3 | 605.1 | 410.6 | 408.8 | 499.0 | 863.7 | 3490.9 | 2337.2 | 1232.7 |
| 1969 | 4118.8 | 2978.6 | 1693.8 | 1154.1 | 887.4 | 649.2 | 501.8 | 536.3 | 469.7 | 579.3 | 688.2 | 912.1 | 1264.1 |
| 1970 | 1273.6 | 1040.6 | 722.9 | 590.1 | 610.1 | 628.6 | 428.7 | 437.3 | 448.7 | 664.6 | 696.2 | 711.8 | 687.8 |
| 1971 | 550.4 | 1344.0 | 809.1 | 604.0 | 597.8 | 612.8 | 419.4 | 445.0 | 489.1 | 669.0 | 698.8 | 1124.7 | 697.0 |
| 1972 | 3839.5 | 2502.7 | 1679.4 | 1022.3 | 752.4 | 611.2 | 466.6 | 539.4 | 675.5 | 596.4 | 618.7 | 1657.6 | 1246.8 |
| 1973 | 1352.6 | 1028.5 | 844.0 | 621.9 | 612.3 | 608.8 | 409.8 | 414.2 | 415.8 | 644.6 | 715.9 | 910.1 | 714.9 |
| 1974 | 2324.3 | 1675.9 | 1190.0 | 767.4 | 608.0 | 593.5 | 392.4 | 392.9 | 446.1 | 788.2 | 779.4 | 1476.1 | 952.9 |
| 1975 | 1684.4 | 1715.2 | 1175.8 | 839.7 | 622.5 | 621.9 | 411.6 | 412.4 | 488.3 | 1022.3 | 2930.8 | 2095.1 | 1168.3 |
| 1976 | 3417.9 | 3812.2 | 2756.6 | 1683.9 | 1217.1 | 827.9 | 669.3 | 800.6 | 703.0 | 796.3 | 796.5 | 1342.4 | 1568.6 |
| 1977 | 2615.7 | 1346.4 | 928.6 | 646.3 | 611.2 | 616.8 | 408.2 | 767.0 | 1280.4 | 2772.1 | 1471.5 | 1837.5 | 1275.2 |
| 1978 | 2149.1 | 1477.4 | 1111.3 | 848.8 | 645.5 | 598.1 | 398.9 | 537.6 | 1323.0 | 851.0 | 1397.3 | 1243.4 | 1048.4 |
| 1979 | 1891.2 | 1182.0 | 988.6 | 673.3 | 607.5 | 608.5 | 408.0 | 407.2 | 446.3 | 728.6 | 2070.7 | 2729.9 | 1061.8 |
| 1980 | 4616.5 | 2811.8 | 1660.3 | 1052.6 | 778.3 | 615.0 | 521.8 | 562.5 | 608.3 | 948.7 | 1433.1 | 1778.4 | 1448.9 |
| 1981 | 2286.3 | 1922.3 | 1245.7 | 863.2 | 620.3 | 605.9 | 404.6 | 489.1 | 621.0 | 674.2 | 1011.9 | 1818.5 | 1046.9 |
| 1982 | 2947.0 | 2186.6 | 1275.7 | 763.9 | 608.3 | 600.2 | 471.5 | 960.3 | 744.9 | 1009.8 | 1113.8 | 1393.5 | 1173.0 |
| 1983 | 2019.0 | 2529.5 | 1520.0 | 963.2 | 669.3 | 600.0 | 410.3 | 517.6 | 607.6 | 611.2 | 608.1 | 718.8 | 981.2 |
| 1984 | 2404.1 | 1220.8 | 838.6 | 603.7 | 599.2 | 606.4 | 405.9 | 420.4 | 416.5 | 796.8 | 1420.2 | 967.3 | 891.7 |
| 1985 | 2278.5 | 3372.6 | 1630.9 | 1007.3 | 766.3 | 622.7 | 494.8 | 556.5 | 1013.5 | 1394.2 | 1240.3 | 3149.5 | 1460.6 |
| 1986 | 2860.8 | 3021.2 | 1792.9 | 1142.6 | 861.1 | 632.6 | 580.1 | 900.5 | 612.2 | 2098.5 | 1615.6 | 3856.4 | 1664.5 |
| 1987 | 2407.3 | 2222.3 | 1302.5 | 965.3 | 759.6 | 630.2 | 571.8 | 560.6 | 589.2 | 939.9 | 712.0 | 1749.9 | 1117.5 |
| 1988 | 2301.0 | 2057.8 | 1227.8 | 824.7 | 665.9 | 545.9 | 481.9 | 516.1 | 531.9 | 563.5 | 946.3 | 1458.3 | 1010.1 |
| MEAN | 2012.8 | 1795.7 | 1177.8 | 805.3 | 668.5 | 620.5 | 444.5 | 504.5 | 614.9 | 868.3 | 1050.0 | 1394.2 | 996.4 |

**Table 5.8: Monthly Yield at Godar-e-Landar Run-of-River "Down Dam Site"** Unit: In (m.c.m.)

| YEAR | APR. | MAY. | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 1255.6 | 1141.5 | 883.1 | 651.9 | 612.8 | 627.8 | 415.0 | 423.3 | 420.7 | 723.2 | 1153.4 | 1548.7 | 821.4 |
| 1952 | 1523.5 | 1958.4 | 1196.4 | 791.2 | 615.8 | 615.8 | 411.1 | 412.1 | 429.0 | 1347.6 | 1293.4 | 2080.9 | 1056.3 |
| 1953 | 2190.4 | 1961.1 | 1325.0 | 946.5 | 695.0 | 613.9 | 409.0 | 600.8 | 1665.4 | 1306.1 | 1114.6 | 2044.6 | 1239.4 |
| 1954 | 3995.6 | 2716.7 | 1617.0 | 1123.3 | 804.9 | 626.2 | 514.3 | 545.6 | 1367.3 | 1230.9 | 1029.0 | 929.2 | 1375.0 |
| 1955 | 2053.8 | 1744.2 | 1121.4 | 713.5 | 613.9 | 613.9 | 414.5 | 413.9 | 422.8 | 624.4 | 710.2 | 1859.8 | 942.2 |
| 1956 | 1609.2 | 1760.2 | 1102.7 | 761.7 | 615.5 | 612.6 | 410.3 | 411.9 | 415.2 | 619.7 | 616.4 | 1567.6 | 875.3 |
| 1957 | 3023.4 | 2748.8 | 2125.8 | 1134.0 | 700.4 | 612.0 | 410.1 | 500.3 | 846.3 | 694.4 | 927.9 | 1167.7 | 1240.9 |
| 1958 | 1373.5 | 1112.1 | 786.6 | 613.9 | 612.3 | 627.0 | 425.6 | 431.8 | 471.0 | 616.4 | 626.2 | 627.8 | 693.7 |
| 1959 | 2072.5 | 1299.6 | 826.8 | 627.8 | 608.8 | 617.4 | 417.8 | 420.9 | 427.2 | 659.1 | 643.1 | 667.7 | 774.1 |
| 1960 | 506.5 | 672.3 | 687.5 | 608.8 | 616.0 | 637.7 | 436.0 | 451.0 | 486.5 | 709.4 | 738.2 | 658.1 | 600.7 |
| 1961 | 1426.0 | 1647.8 | 936.6 | 617.6 | 608.5 | 645.5 | 450.7 | 430.3 | 442.5 | 650.6 | 673.1 | 641.5 | 764.2 |
| 1962 | 913.9 | 1591.5 | 888.4 | 617.4 | 609.9 | 618.7 | 418.3 | 424.8 | 435.2 | 626.0 | 652.9 | 663.6 | 705.0 |
| 1963 | 484.8 | 1019.1 | 925.9 | 615.2 | 609.3 | 620.9 | 420.7 | 426.6 | 437.0 | 650.9 | 684.0 | 729.1 | 635.3 |
| 1964 | 528.2 | 469.3 | 441.1 | 622.7 | 636.7 | 666.9 | 462.7 | 482.1 | 510.9 | 768.5 | 765.4 | 714.1 | 589.0 |
| 1965 | 858.2 | 905.8 | 832.2 | 615.5 | 611.7 | 621.7 | 446.6 | 436.0 | 421.7 | 624.2 | 666.9 | 649.3 | 640.8 |
| 1966 | 1003.1 | 980.8 | 733.1 | 614.2 | 612.8 | 626.7 | 426.9 | 432.6 | 433.4 | 648.3 | 669.5 | 707.1 | 657.4 |
| 1967 | 817.7 | 1471.0 | 971.5 | 616.0 | 610.9 | 624.9 | 421.7 | 431.8 | 428.2 | 619.0 | 638.7 | 680.1 | 694.3 |
| 1968 | 1773.6 | 1878.1 | 1161.6 | 812.6 | 616.0 | 610.4 | 416.0 | 413.9 | 510.4 | 881.0 | 3525.1 | 2362.9 | 1246.8 |
| 1969 | 4159.0 | 3008.6 | 1713.4 | 1166.2 | 895.9 | 655.7 | 506.5 | 540.4 | 475.6 | 584.8 | 697.8 | 921.5 | 1277.1 |
| 1970 | 1285.1 | 1050.5 | 730.4 | 594.1 | 615.1 | 632.9 | 432.9 | 441.7 | 454.4 | 670.6 | 703.2 | 720.3 | 694.3 |
| 1971 | 568.6 | 1355.8 | 813.4 | 610.1 | 602.1 | 616.8 | 423.8 | 452.6 | 503.1 | 683.0 | 717.7 | 1139.2 | 707.2 |
| 1972 | 3877.8 | 2523.9 | 1689.3 | 1026.9 | 762.0 | 618.4 | 472.8 | 545.6 | 685.6 | 603.9 | 627.0 | 1670.5 | 1258.6 |
| 1973 | 1357.4 | 1034.4 | 853.6 | 630.5 | 619.0 | 613.4 | 413.9 | 418.3 | 419.6 | 651.4 | 730.2 | 931.8 | 722.8 |
| 1974 | 2351.1 | 1696.0 | 1204.5 | 775.1 | 614.4 | 597.0 | 395.0 | 395.3 | 455.9 | 798.1 | 790.6 | 1489.1 | 963.5 |
| 1975 | 1694.9 | 1730.8 | 1188.4 | 850.1 | 631.0 | 630.0 | 417.8 | 418.9 | 495.6 | 1033.9 | 2960.1 | 2116.6 | 1180.7 |
| 1976 | 3451.9 | 3849.7 | 2784.7 | 1701.9 | 1230.7 | 837.8 | 677.5 | 810.0 | 711.5 | 805.9 | 806.1 | 1356.9 | 1585.4 |
| 1977 | 2632.3 | 1361.2 | 939.3 | 654.6 | 617.9 | 623.0 | 412.9 | 777.3 | 1294.7 | 2799.1 | 1487.8 | 1857.2 | 1288.1 |
| 1978 | 2171.6 | 1495.1 | 1124.1 | 858.2 | 652.2 | 603.4 | 404.1 | 543.3 | 1336.2 | 860.3 | 1415.2 | 1258.4 | 1060.2 |
| 1979 | 1914.5 | 1197.8 | 1000.9 | 681.4 | 613.9 | 614.2 | 413.2 | 412.4 | 453.6 | 735.9 | 2091.7 | 2762.0 | 1074.3 |
| 1980 | 4673.3 | 2847.9 | 1681.2 | 1067.1 | 788.8 | 622.7 | 528.0 | 568.9 | 615.6 | 958.8 | 1448.9 | 1797.6 | 1466.6 |
| 1981 | 2313.6 | 1945.1 | 1260.7 | 874.2 | 628.1 | 612.0 | 410.3 | 495.1 | 628.6 | 681.4 | 1026.4 | 1833.8 | 1059.1 |
| 1982 | 2977.8 | 2210.5 | 1290.2 | 772.5 | 615.0 | 605.6 | 477.2 | 970.7 | 753.0 | 1021.0 | 1124.9 | 1408.8 | 1185.6 |
| 1983 | 2043.1 | 2561.4 | 1536.6 | 973.3 | 676.3 | 605.6 | 415.0 | 522.3 | 613.0 | 616.6 | 614.3 | 727.1 | 992.0 |
| 1984 | 2431.5 | 1235.3 | 848.2 | 609.9 | 604.0 | 610.7 | 409.8 | 426.4 | 423.0 | 805.3 | 1436.0 | 978.5 | 901.5 |
| 1985 | 2295.4 | 3397.6 | 1642.9 | 1014.8 | 772.2 | 627.3 | 498.4 | 560.6 | 1021.0 | 1404.6 | 1249.6 | 3173.1 | 1471.5 |
| 1986 | 2882.0 | 3043.7 | 1806.0 | 1151.2 | 867.5 | 637.2 | 584.2 | 906.9 | 616.6 | 2114.0 | 1627.8 | 3885.1 | 1676.9 |
| 1987 | 2425.3 | 2238.6 | 1312.4 | 972.5 | 765.2 | 635.0 | 575.9 | 564.8 | 593.3 | 946.9 | 717.2 | 1762.8 | 1125.8 |
| 1988 | 2318.2 | 2073.3 | 1237.2 | 830.8 | 670.7 | 549.9 | 485.5 | 520.0 | 535.8 | 567.6 | 953.3 | 1469.1 | 1017.6 |
| MEAN | 2032.5 | 1814.1 | 1190.0 | 813.7 | 675.1 | 626.0 | 449.5 | 510.0 | 622.5 | 877.4 | 1061.9 | 1409.5 | 1006.9 |

Table 5.9: Monthly Yield at Gotvand Diversion Dam Site Unit: In (m.c.m.)

| YEAR | APR. | MAY. | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 1564.7 | 2064.8 | 1259.1 | 816.1 | 604.8 | 525.2 | 500.0 | 440.9 | 437.0 | 1573.9 | 1242.1 | 2584.5 | 1134.4 |
| 1952 | 2199.2 | 2066.1 | 1413.9 | 980.8 | 724.5 | 583.1 | 531.1 | 630.1 | 1859.5 | 1072.6 | 1005.7 | 2401.5 | 1289.0 |
| 1953 | 4000.7 | 2522.8 | 1731.0 | 1180.1 | 856.0 | 639.1 | 542.0 | 512.4 | 2410.0 | 1316.7 | 1088.9 | 1321.9 | 1510.1 |
| 1954 | 2185.6 | 2024.3 | 1420.6 | 966.6 | 708.4 | 560.1 | 487.8 | 429.2 | 591.5 | 637.4 | 804.6 | 2133.0 | 1079.1 |
| 1955 | 1671.1 | 1786.0 | 1307.1 | 861.1 | 638.8 | 497.6 | 420.4 | 407.2 | 435.7 | 708.9 | 678.3 | 1789.0 | 933.4 |
| 1956 | 2643.6 | 2917.3 | 1981.5 | 1191.4 | 804.3 | 604.8 | 489.9 | 552.1 | 870.9 | 699.8 | 953.9 | 1200.1 | 1242.5 |
| 1957 | 1411.5 | 1135.6 | 819.6 | 626.7 | 433.9 | 377.7 | 339.6 | 337.0 | 966.8 | 601.3 | 769.8 | 834.6 | 721.2 |
| 1958 | 2134.7 | 1344.6 | 862.4 | 658.9 | 479.4 | 396.4 | 357.7 | 347.3 | 349.9 | 629.9 | 479.5 | 632.4 | 722.8 |
| 1959 | 1221.4 | 1143.7 | 766.0 | 506.2 | 391.0 | 337.5 | 308.4 | 362.9 | 404.4 | 730.9 | 1656.3 | 1233.8 | 755.2 |
| 1960 | 1682.0 | 1864.2 | 1068.7 | 691.0 | 484.8 | 385.7 | 343.2 | 335.4 | 474.6 | 628.3 | 1106.3 | 1028.0 | 841.0 |
| 1961 | 1017.5 | 1737.7 | 956.2 | 632.9 | 462.6 | 379.0 | 335.9 | 361.6 | 497.1 | 417.8 | 619.5 | 747.0 | 680.4 |
| 1962 | 1029.3 | 1369.7 | 997.2 | 612.3 | 425.1 | 349.8 | 307.4 | 311.6 | 369.4 | 375.1 | 411.1 | 830.0 | 615.6 |
| 1963 | 1250.0 | 824.4 | 602.9 | 402.0 | 313.9 | 275.3 | 253.5 | 248.8 | 475.9 | 846.5 | 1276.6 | 1295.7 | 672.1 |
| 1964 | 1603.8 | 1500.7 | 1030.9 | 663.2 | 488.3 | 388.4 | 316.5 | 644.6 | 432.3 | 436.8 | 1359.5 | 1350.4 | 851.3 |
| 1965 | 1399.2 | 1248.9 | 845.3 | 573.2 | 444.9 | 371.5 | 367.0 | 391.1 | 335.1 | 517.9 | 583.2 | 1214.9 | 691.0 |
| 1966 | 1147.2 | 1342.9 | 910.7 | 589.0 | 429.1 | 358.4 | 331.0 | 373.2 | 803.3 | 466.6 | 609.1 | 1361.6 | 726.8 |
| 1967 | 1934.9 | 2069.9 | 1315.6 | 829.5 | 587.4 | 445.7 | 377.7 | 499.7 | 784.3 | 907.5 | 3899.1 | 2655.0 | 1358.9 |
| 1968 | 4586.5 | 3269.3 | 1939.4 | 1240.6 | 904.5 | 638.5 | 547.9 | 596.2 | 514.0 | 691.0 | 828.4 | 998.4 | 1396.2 |
| 1969 | 1431.3 | 1131.4 | 764.1 | 551.5 | 467.9 | 421.3 | 387.2 | 378.4 | 568.9 | 448.4 | 563.8 | 938.8 | 671.1 |
| 1970 | 2010.7 | 1768.8 | 950.8 | 596.7 | 489.6 | 406.0 | 369.1 | 605.8 | 1024.4 | 797.3 | 971.2 | 1432.6 | 951.9 |
| 1971 | 4448.0 | 2809.9 | 1866.8 | 1203.9 | 726.9 | 626.5 | 558.1 | 577.8 | 785.1 | 573.6 | 751.2 | 1897.9 | 1402.1 |
| 1972 | 1618.8 | 1196.7 | 797.1 | 584.2 | 431.8 | 354.6 | 319.3 | 304.8 | 328.7 | 548.2 | 899.4 | 2287.4 | 805.9 |
| 1973 | 2952.7 | 1922.0 | 1175.8 | 833.0 | 595.9 | 460.7 | 389.1 | 362.1 | 959.6 | 1077.0 | 1106.3 | 1697.2 | 1127.6 |
| 1974 | 2095.3 | 2143.3 | 1355.8 | 879.6 | 614.2 | 507.0 | 443.2 | 523.1 | 725.2 | 1882.8 | 4601.6 | 2843.2 | 1551.2 |
| 1975 | 4472.1 | 4253.8 | 2859.2 | 1821.3 | 1298.5 | 874.8 | 688.2 | 750.6 | 530.1 | 974.1 | 937.5 | 370.7 | 1652.6 |
| 1976 | 445.2 | 1061.7 | 446.0 | 545.6 | 636.1 | 681.4 | 436.2 | 908.0 | 1834.6 | 1821.7 | 1858.5 | 2197.8 | 1072.7 |
| 1977 | 2052.2 | 14939.0 | 1104.0 | 805.7 | 590.1 | 476.5 | 454.9 | 484.2 | 2066.1 | 963.2 | 2360.0 | 1463.4 | 2313.3 |
| 1978 | 2184.2 | 1463.2 | 1074.0 | 731.7 | 559.0 | 480.2 | 423.5 | 457.0 | 805.6 | 849.7 | 2822.4 | 3124.9 | 1248.0 |
| 1979 | 6056.7 | 3041.1 | 1800.7 | 1305.7 | 926.7 | 682.5 | 556.8 | 639.2 | 916.0 | 1112.0 | 2332.3 | 2141.0 | 1792.5 |
| 1980 | 3243.0 | 2215.6 | 1383.7 | 1058.2 | 759.6 | 597.0 | 524.6 | 558.8 | 782.8 | 856.7 | 1248.0 | 1815.4 | 1253.6 |
| 1981 | 3167.7 | 2164.1 | 1327.7 | 827.6 | 621.7 | 510.0 | 485.5 | 933.4 | 965.3 | 1011.7 | 1481.3 | 1594.3 | 1257.5 |
| 1982 | 2512.9 | 3068.1 | 1753.5 | 1080.7 | 698.5 | 514.5 | 454.1 | 480.6 | 616.9 | 642.3 | 614.8 | 801.7 | 1103.2 |
| 1983 | 2482.3 | 1415.0 | 860.3 | 560.1 | 428.8 | 374.2 | 346.3 | 523.3 | 975.6 | 861.1 | 1995.1 | 1276.6 | 1008.2 |
| 1984 | 2294.9 | 1246.5 | 914.4 | 588.2 | 446.2 | 401.0 | 348.4 | 377.7 | 1065.8 | 784.1 | 994.3 | 1113.5 | 881.2 |
| 1985 | 2560.3 | 3218.4 | 1575.4 | 969.8 | 714.9 | 574.0 | 449.7 | 563.0 | 2287.7 | 1164.1 | 1484.7 | 3420.1 | 1581.8 |
| 1986 | 3255.6 | 2887.9 | 1713.1 | 1093.6 | 805.7 | 585.5 | 517.9 | 963.2 | 786.7 | 1588.6 | 1990.7 | 4181.2 | 1697.5 |
| 1987 | 2714.6 | 2136.8 | 1296.6 | 929.4 | 708.2 | 582.6 | 511.1 | 567.9 | 699.8 | 890.4 | 772.9 | 1912.9 | 1143.6 |
| 1988 | 2587.1 | 1982.3 | 1233.1 | 803.3 | 618.2 | 488.0 | 1068.2 | 439.3 | 515.8 | 486.0 | 663.3 | 1088.9 | 997.8 |
| MEAN | 2349.2 | 2323.6 | 1249.5 | 836.6 | 613.7 | 492.4 | 444.4 | 504.7 | 848.8 | 857.7 | 1311.1 | 1663.5 | 1124.6 |

**Table 5.10: Monthly Yield Between Gotvand Diversion Dam and Shushtar** **Unit : In (m.c.m.)**

| YEAR | APR. | MAY. | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 30.3 | 9.4 | 4.0 | 2.1 | 1.6 | 1.6 | 2.6 | 26.2 | 43.3 | 55.0 | 60.9 | 42.0 | 23.2 |
| 1952 | 34.6 | 11.0 | 4.6 | 2.4 | 1.9 | 1.9 | 3.1 | 30.1 | 49.8 | 63.0 | 69.7 | 48.0 | 26.7 |
| 1953 | 39.6 | 12.3 | 5.4 | 2.9 | 2.1 | 2.1 | 3.4 | 31.6 | 52.6 | 66.9 | 73.9 | 50.8 | 28.6 |
| 1954 | 41.8 | 13.1 | 5.6 | 2.9 | 2.1 | 2.1 | 2.6 | 25.7 | 42.8 | 54.2 | 59.9 | 41.2 | 24.5 |
| 1955 | 34.0 | 10.7 | 4.6 | 2.4 | 1.9 | 1.6 | 2.3 | 23.1 | 38.1 | 48.5 | 53.7 | 36.8 | 21.5 |
| 1956 | 30.5 | 9.6 | 4.0 | 2.1 | 1.6 | 1.6 | 2.1 | 21.0 | 34.7 | 44.3 | 49.0 | 33.7 | 19.5 |
| 1957 | 27.9 | 8.8 | 3.7 | 2.1 | 1.6 | 1.3 | 2.3 | 21.5 | 35.5 | 45.1 | 50.0 | 34.5 | 19.5 |
| 1958 | 28.4 | 8.8 | 3.7 | 2.1 | 1.6 | 1.3 | 1.8 | 16.8 | 28.0 | 35.3 | 39.1 | 27.0 | 16.2 |
| 1959 | 22.2 | 7.0 | 2.9 | 1.6 | 1.1 | 1.1 | 2.9 | 27.0 | 44.6 | 56.8 | 62.7 | 43.0 | 22.7 |
| 1960 | 35.6 | 11.2 | 4.8 | 2.7 | 1.9 | 1.9 | 2.1 | 18.9 | 31.4 | 39.7 | 44.1 | 30.3 | 18.7 |
| 1961 | 24.9 | 7.8 | 3.2 | 1.9 | 1.3 | 1.3 | 1.6 | 16.3 | 27.0 | 34.5 | 38.1 | 26.2 | 15.3 |
| 1962 | 21.7 | 6.7 | 2.9 | 1.6 | 1.1 | 1.1 | 1.3 | 13.2 | 22.0 | 28.0 | 30.8 | 21.3 | 12.6 |
| 1963 | 17.7 | 5.6 | 2.4 | 1.3 | .8 | .8 | 2.3 | 21.5 | 35.5 | 45.1 | 50.0 | 34.5 | 18.1 |
| 1964 | 28.4 | 8.8 | 3.7 | 2.1 | 1.6 | 1.3 | 2.3 | 21.8 | 35.8 | 45.6 | 50.3 | 34.7 | 19.7 |
| 1965 | 28.7 | 8.8 | 3.7 | 2.1 | 1.6 | 1.3 | 1.6 | 14.5 | 24.1 | 30.6 | 34.0 | 23.3 | 14.5 |
| 1966 | 19.3 | 6.2 | 2.4 | 1.3 | 1.1 | 1.1 | 2.3 | 22.0 | 36.5 | 46.4 | 51.3 | 35.3 | 18.8 |
| 1967 | 29.2 | 9.1 | 3.7 | 2.1 | 1.6 | 1.6 | 4.9 | 46.7 | 77.5 | 98.2 | 108.9 | 74.9 | 38.2 |
| 1968 | 61.9 | 19.3 | 8.3 | 4.6 | 3.2 | 3.2 | 2.1 | 18.7 | 31.1 | 39.4 | 43.5 | 30.1 | 22.1 |
| 1969 | 24.6 | 7.8 | 3.2 | 1.9 | 1.3 | 1.3 | 2.3 | 21.8 | 36.0 | 45.6 | 50.5 | 34.7 | 19.3 |
| 1970 | 28.7 | 8.8 | 3.7 | 2.1 | 1.6 | 1.6 | 3.4 | 31.6 | 52.6 | 66.6 | 73.9 | 50.8 | 27.1 |
| 1971 | 41.8 | 13.1 | 5.6 | 2.9 | 2.1 | 2.1 | 2.1 | 19.7 | 32.7 | 41.5 | 45.9 | 31.6 | 20.1 |
| 1972 | 26.0 | 8.0 | 3.5 | 1.9 | 1.3 | 1.3 | 3.1 | 29.5 | 48.7 | 61.9 | 68.7 | 47.2 | 25.1 |
| 1973 | 38.8 | 12.3 | 5.1 | 2.7 | 2.1 | 1.9 | 2.9 | 28.5 | 47.2 | 59.9 | 66.4 | 45.6 | 26.1 |
| 1974 | 37.8 | 11.8 | 5.1 | 2.7 | 2.1 | 1.9 | 5.7 | 53.9 | 89.4 | 113.5 | 125.7 | 86.6 | 44.7 |
| 1975 | 71.2 | 22.5 | 9.4 | 5.1 | 3.7 | 3.7 | .3 | 1.0 | 1.8 | 2.3 | 2.6 | 1.8 | 10.5 |
| 1976 | 1.6 | .5 | .3 | .0 | .0 | .0 | 2.6 | 24.4 | 40.4 | 51.3 | 57.0 | 39.1 | 18.1 |
| 1977 | 32.4 | 10.2 | 4.3 | 2.4 | 1.6 | 1.6 | 3.1 | 31.1 | 51.6 | 65.6 | 72.6 | 50.0 | 27.2 |
| 1978 | 41.2 | 12.9 | 5.4 | 2.9 | 2.1 | 2.1 | 3.6 | 36.3 | 60.1 | 76.2 | 84.5 | 58.1 | 32.1 |
| 1979 | 47.9 | 15.0 | 6.4 | 3.5 | 2.7 | 2.4 | 3.6 | 35.5 | 58.8 | 74.6 | 82.7 | 57.0 | 32.5 |
| 1980 | 46.9 | 14.7 | 6.2 | 3.5 | 2.4 | 2.4 | 2.9 | 28.0 | 46.4 | 59.1 | 65.3 | 44.8 | 26.9 |
| 1981 | 37.0 | 11.5 | 4.8 | 2.7 | 1.9 | 1.9 | 3.1 | 30.8 | 51.1 | 64.8 | 71.8 | 49.5 | 27.6 |
| 1982 | 40.7 | 12.9 | 5.4 | 2.9 | 2.1 | 2.1 | 2.1 | 19.2 | 31.9 | 40.4 | 44.6 | 30.8 | 19.6 |
| 1983 | 25.2 | 8.0 | 3.5 | 1.9 | 1.3 | 1.3 | 2.9 | 27.7 | 46.1 | 58.6 | 64.8 | 44.6 | 23.8 |
| 1984 | 36.7 | 11.5 | 4.8 | 2.7 | 1.9 | 1.9 | 2.3 | 24.1 | 39.7 | 50.5 | 55.7 | 38.4 | 22.5 |
| 1985 | 31.6 | 9.9 | 4.3 | 2.4 | 1.6 | 1.6 | 2.9 | 28.8 | 47.7 | 60.4 | 66.9 | 46.1 | 25.3 |
| 1986 | 38.0 | 11.8 | 5.1 | 2.7 | 2.1 | 1.9 | 3.6 | 34.0 | 56.2 | 71.3 | 79.1 | 54.4 | 30.0 |
| 1987 | 44.7 | 14.2 | 5.9 | 3.2 | 2.4 | 2.4 | 2.3 | 23.1 | 38.4 | 48.5 | 53.7 | 37.1 | 23.0 |
| 1988 | 30.5 | 9.6 | 4.0 | 2.1 | 1.6 | 1.6 | 2.3 | 22.8 | 37.8 | 48.2 | 53.4 | 36.8 | 20.9 |
| MEAN | 33.7 | 10.6 | 4.5 | 2.4 | 1.8 | 1.7 | 2.6 | 25.5 | 42.2 | 53.6 | 59.4 | 40.9 | 23.2 |

**Table 5.11: Monthly Yield of Dez River at Tale Zang** **Unit: In (m.c.m.)**

| YEAR | APR. | MAY. | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 1041.6 | 1426.5 | 771.9 | 445.4 | 299.7 | 242.9 | 226.3 | 214.4 | 265.9 | 1113.0 | 705.0 | 1715.4 | 705.7 |
| 1952 | 1451.4 | 1427.3 | 858.7 | 526.6 | 366.7 | 276.9 | 242.6 | 337.5 | 815.7 | 1059.4 | 618.5 | 1394.2 | 781.3 |
| 1953 | 2646.8 | 2001.8 | 1052.3 | 619.2 | 426.1 | 325.4 | 294.5 | 282.0 | 867.3 | 993.0 | 586.8 | 689.7 | 898.8 |
| 1954 | 1375.4 | 1330.1 | 797.4 | 459.1 | 321.7 | 249.1 | 187.9 | 213.3 | 602.6 | 265.2 | 711.0 | 1287.4 | 650.0 |
| 1955 | 1402.4 | 1569.3 | 909.6 | 580.4 | 400.2 | 242.9 | 175.7 | 164.3 | 205.3 | 316.5 | 465.0 | 940.9 | 614.4 |
| 1956 | 1668.6 | 2111.1 | 1338.9 | 660.0 | 416.5 | 275.3 | 243.6 | 317.5 | 465.5 | 444.8 | 528.0 | 892.2 | 780.2 |
| 1957 | 941.5 | 720.8 | 462.3 | 302.9 | 215.3 | 170.3 | 149.6 | 145.2 | 603.9 | 339.8 | 429.2 | 624.2 | 425.4 |
| 1958 | 1826.9 | 995.0 | 567.3 | 377.7 | 252.0 | 185.6 | 147.5 | 156.8 | 189.0 | 362.6 | 284.1 | 310.3 | 471.2 |
| 1959 | 854.9 | 924.6 | 489.1 | 297.8 | 200.3 | 149.5 | 121.0 | 145.2 | 227.1 | 556.2 | 1065.3 | 663.8 | 474.6 |
| 1960 | 1070.8 | 1385.8 | 654.1 | 432.8 | 292.2 | 198.7 | 162.3 | 161.5 | 303.3 | 373.5 | 691.0 | 517.4 | 520.3 |
| 1961 | 603.7 | 1313.8 | 565.9 | 341.8 | 217.0 | 176.2 | 151.9 | 160.7 | 246.2 | 286.9 | 537.6 | 490.7 | 424.4 |
| 1962 | 905.6 | 1363.3 | 804.1 | 425.3 | 275.6 | 197.4 | 155.0 | 199.1 | 256.3 | 253.2 | 381.3 | 701.4 | 493.1 |
| 1963 | 981.1 | 622.7 | 411.4 | 249.1 | 178.1 | 142.0 | 121.0 | 122.3 | 235.9 | 376.9 | 860.5 | 925.6 | 435.6 |
| 1964 | 1015.4 | 830.0 | 516.4 | 321.9 | 233.8 | 170.1 | 147.2 | 448.4 | 307.7 | 247.5 | 1268.0 | 1031.1 | 544.8 |
| 1965 | 889.5 | 865.7 | 572.6 | 361.6 | 248.8 | 179.7 | 168.7 | 211.5 | 163.0 | 214.4 | 324.3 | 585.5 | 398.8 |
| 1966 | 580.1 | 731.2 | 469.5 | 272.1 | 184.3 | 139.5 | 122.6 | 168.2 | 357.2 | 292.4 | 353.3 | 669.8 | 361.7 |
| 1967 | 1096.8 | 1434.8 | 795.8 | 448.6 | 291.1 | 200.3 | 161.5 | 285.1 | 434.9 | 556.8 | 1863.4 | 2599.8 | 847.4 |
| 1968 | 3776.5 | 2224.4 | 1133.0 | 665.0 | 446.2 | 311.5 | 238.2 | 260.8 | 224.5 | 367.0 | 501.6 | 535.5 | 890.3 |
| 1969 | 739.0 | 677.1 | 382.5 | 269.4 | 174.1 | 134.5 | 124.4 | 119.5 | 269.6 | 183.8 | 256.3 | 924.3 | 354.5 |
| 1970 | 1622.0 | 1577.3 | 671.2 | 367.5 | 233.6 | 163.4 | 131.9 | 335.9 | 837.7 | 538.1 | 648.5 | 843.4 | 664.2 |
| 1971 | 2701.2 | 1897.4 | 1261.3 | 731.7 | 456.9 | 314.4 | 216.4 | 449.2 | 692.1 | 385.4 | 587.6 | 1226.8 | 910.0 |
| 1972 | 971.7 | 767.4 | 485.3 | 318.2 | 230.9 | 181.9 | 136.9 | 136.9 | 169.8 | 303.8 | 555.5 | 1455.9 | 476.2 |
| 1973 | 2133.3 | 1351.5 | 811.8 | 475.1 | 304.8 | 248.8 | 180.1 | 166.7 | 320.9 | 506.0 | 521.8 | 958.8 | 665.0 |
| 1974 | 1086.6 | 1188.1 | 713.3 | 471.9 | 231.1 | 190.4 | 151.1 | 157.3 | 305.6 | 1041.5 | 2042.8 | 1088.1 | 722.3 |
| 1975 | 2414.3 | 2424.5 | 1412.1 | 871.6 | 682.2 | 462.3 | 287.7 | 275.0 | 260.2 | 338.5 | 514.3 | 665.6 | 884.0 |
| 1976 | 857.4 | 709.8 | 534.3 | 299.4 | 186.1 | 154.0 | 220.8 | 484.2 | 766.2 | 992.5 | 777.9 | 1440.9 | 618.6 |
| 1977 | 1189.5 | 858.7 | 625.4 | 395.9 | 259.3 | 218.3 | 210.5 | 221.6 | 1066.9 | 663.3 | 1268.0 | 892.9 | 655.9 |
| 1978 | 1406.4 | 1009.8 | 613.1 | 386.8 | 251.2 | 202.0 | 176.5 | 219.0 | 387.8 | 589.7 | 1318.3 | 1854.6 | 701.3 |
| 1979 | 3806.8 | 1910.5 | 967.7 | 614.4 | 439.3 | 324.1 | 271.6 | 373.5 | 470.4 | 885.4 | 1255.3 | 1482.4 | 1066.8 |
| 1980 | 2351.9 | 1600.3 | 853.3 | 568.9 | 415.7 | 311.5 | 273.2 | 304.8 | 345.3 | 610.9 | 750.6 | 1217.5 | 800.3 |
| 1981 | 1995.7 | 1465.4 | 804.3 | 455.9 | 317.7 | 247.2 | 217.5 | 503.9 | 452.8 | 621.8 | 826.8 | 1036.5 | 745.5 |
| 1982 | 1656.6 | 2278.2 | 1244.1 | 666.1 | 386.8 | 235.7 | 228.1 | 273.5 | 344.7 | 331.3 | 384.9 | 461.4 | 707.6 |
| 1983 | 1371.1 | 977.9 | 529.5 | 309.6 | 180.5 | 134.7 | 143.3 | 248.8 | 569.7 | 485.2 | 945.6 | 922.5 | 568.2 |
| 1984 | 1719.3 | 874.8 | 620.9 | 314.7 | 202.2 | 175.2 | 147.2 | 169.0 | 506.0 | 400.7 | 633.0 | 671.8 | 536.2 |
| 1985 | 1283.0 | 2272.4 | 914.9 | 501.1 | 367.2 | 259.3 | 187.9 | 239.2 | 684.3 | 681.7 | 616.9 | 2187.6 | 849.6 |
| 1986 | 1877.6 | 1767.7 | 940.1 | 543.7 | 375.0 | 260.1 | 213.3 | 588.4 | 355.1 | 1383.1 | 1021.5 | 2843.9 | 1014.1 |
| 1987 | 1746.3 | 1514.6 | 803.3 | 517.5 | 341.0 | 251.0 | 229.7 | 247.8 | 282.5 | 487.3 | 401.8 | 1137.9 | 663.4 |
| 1988 | 1775.8 | 1398.1 | 763.3 | 433.9 | 273.2 | 197.1 | 194.4 | 262.8 | 284.9 | 369.6 | 637.6 | 1022.0 | 634.4 |
| MEAN | 1548.3 | 1363.2 | 766.4 | 455.3 | 304.6 | 223.7 | 188.4 | 257.1 | 424.8 | 532.1 | 740.5 | 1076.6 | 656.7 |

Table 5.12 : Monthly Yield at Dez Dam Site

Unit: In (m.c.m.)

| YEAR | APR. | MAY. | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 1083.1 | 1483.6 | 802.7 | 463.1 | 311.5 | 252.6 | 235.4 | 222.9 | 276.6 | 1157.6 | 733.3 | 1784.1 | 733.9 |
| 1952 | 1509.5 | 1484.4 | 893.0 | 547.5 | 381.1 | 287.9 | 252.2 | 351.0 | 848.4 | 1101.9 | 643.3 | 1450.0 | 812.5 |
| 1953 | 2752.6 | 2081.9 | 1094.4 | 644.2 | 443.3 | 338.3 | 306.1 | 293.4 | 902.0 | 1032.7 | 610.4 | 717.5 | 934.7 |
| 1954 | 1430.5 | 1383.1 | 829.2 | 477.3 | 334.5 | 259.0 | 195.4 | 221.9 | 626.7 | 275.5 | 739.5 | 1338.8 | 676.0 |
| 1955 | 1458.4 | 1631.9 | 946.0 | 603.7 | 416.2 | 252.6 | 182.7 | 171.1 | 213.6 | 329.2 | 483.7 | 978.5 | 639.0 |
| 1956 | 1735.6 | 2195.8 | 1392.5 | 686.5 | 433.1 | 286.3 | 253.5 | 330.2 | 484.2 | 462.7 | 549.2 | 927.9 | 811.5 |
| 1957 | 979.2 | 749.7 | 481.0 | 315.0 | 223.9 | 177.0 | 155.5 | 150.9 | 628.3 | 353.3 | 446.6 | 649.0 | 442.5 |
| 1958 | 1899.8 | 1034.7 | 589.8 | 392.7 | 261.9 | 192.8 | 153.4 | 163.0 | 196.5 | 376.9 | 295.5 | 322.7 | 490.0 |
| 1959 | 889.0 | 961.5 | 508.6 | 309.9 | 208.4 | 155.6 | 126.0 | 151.1 | 236.1 | 578.5 | 1107.8 | 690.5 | 493.6 |
| 1960 | 1113.7 | 1441.2 | 680.3 | 450.2 | 304.0 | 206.5 | 168.7 | 168.0 | 315.4 | 388.5 | 718.8 | 538.1 | 541.1 |
| 1961 | 628.1 | 866.5 | 588.7 | 355.4 | 225.8 | 180.2 | 147.9 | 166.9 | 256.1 | 298.3 | 559.1 | 510.4 | 441.4 |
| 1962 | 941.7 | 1417.7 | 836.2 | 442.5 | 286.9 | 205.4 | 161.2 | 207.1 | 266.5 | 263.3 | 396.3 | 729.4 | 512.8 |
| 1963 | 1020.5 | 647.6 | 428.0 | 259.0 | 185.3 | 147.8 | 126.0 | 127.3 | 245.2 | 391.9 | 895.0 | 962.7 | 453.0 |
| 1964 | 1056.1 | 863.2 | 537.0 | 334.8 | 243.2 | 177.0 | 153.2 | 466.3 | 319.9 | 257.4 | 1318.6 | 1072.3 | 566.6 |
| 1965 | 925.1 | 900.2 | 595.7 | 376.0 | 259.0 | 187.0 | 175.5 | 219.8 | 169.5 | 222.9 | 337.2 | 608.9 | 414.7 |
| 1966 | 603.2 | 760.7 | 488.3 | 282.8 | 191.8 | 145.2 | 127.5 | 175.0 | 371.4 | 304.0 | 367.5 | 696.5 | 376.2 |
| 1967 | 1140.7 | 1492.1 | 827.6 | 466.6 | 302.9 | 208.4 | 168.0 | 296.5 | 452.3 | 579.1 | 1937.8 | 2703.7 | 881.3 |
| 1968 | 3927.6 | 2313.3 | 1178.2 | 691.8 | 463.9 | 323.8 | 247.8 | 271.1 | 233.3 | 381.8 | 521.5 | 556.8 | 925.9 |
| 1969 | 768.4 | 704.2 | 397.7 | 280.2 | 181.1 | 139.8 | 129.3 | 124.2 | 280.5 | 191.0 | 266.5 | 961.4 | 368.7 |
| 1970 | 1686.9 | 1640.3 | 698.0 | 381.9 | 242.9 | 169.8 | 137.1 | 349.4 | 871.2 | 559.6 | 674.4 | 877.1 | 690.7 |
| 1971 | 2809.1 | 1973.4 | 1311.9 | 760.9 | 475.1 | 327.0 | 225.0 | 467.3 | 719.8 | 401.0 | 610.9 | 1276.0 | 946.5 |
| 1972 | 1010.6 | 797.9 | 504.9 | 330.8 | 240.0 | 189.4 | 142.6 | 142.3 | 176.5 | 316.0 | 577.5 | 1514.0 | 495.2 |
| 1973 | 2218.5 | 1405.4 | 844.2 | 494.4 | 316.9 | 258.7 | 187.4 | 173.4 | 333.6 | 526.2 | 542.8 | 997.1 | 691.6 |
| 1974 | 1130.3 | 1235.5 | 741.9 | 490.7 | 240.3 | 197.9 | 157.1 | 163.6 | 317.8 | 1083.2 | 2124.4 | 1131.7 | 751.2 |
| 1975 | 2511.0 | 2521.4 | 1468.6 | 906.4 | 709.5 | 480.8 | 299.1 | 285.9 | 270.6 | 352.3 | 534.7 | 692.3 | 919.4 |
| 1976 | 891.6 | 738.2 | 555.8 | 311.2 | 193.6 | 160.2 | 229.7 | 503.6 | 797.0 | 1032.4 | 809.0 | 1498.4 | 643.4 |
| 1977 | 1236.9 | 893.0 | 650.6 | 411.7 | 269.7 | 227.1 | 218.8 | 230.4 | 1109.6 | 690.0 | 1318.8 | 928.7 | 682.1 |
| 1978 | 1462.7 | 1050.2 | 637.7 | 402.3 | 261.4 | 210.0 | 183.5 | 227.6 | 403.3 | 613.3 | 1370.9 | 1929.0 | 729.3 |
| 1979 | 3958.9 | 1986.8 | 1006.3 | 638.8 | 456.9 | 336.9 | 282.5 | 388.5 | 489.4 | 920.9 | 1305.3 | 1541.5 | 1109.4 |
| 1980 | 2445.9 | 1664.6 | 887.4 | 591.7 | 432.3 | 323.8 | 284.3 | 317.0 | 359.3 | 635.3 | 780.7 | 1266.2 | 832.4 |
| 1981 | 2075.5 | 1524.0 | 836.5 | 474.1 | 330.2 | 257.1 | 226.0 | 523.8 | 471.0 | 646.7 | 859.8 | 1078.0 | 775.2 |
| 1982 | 1722.7 | 2369.3 | 1293.9 | 692.6 | 402.3 | 245.1 | 237.2 | 284.3 | 358.5 | 344.5 | 400.2 | 479.8 | 735.9 |
| 1983 | 1426.0 | 1017.0 | 550.7 | 322.2 | 187.8 | 140.3 | 149.0 | 258.9 | 592.5 | 504.7 | 983.4 | 959.6 | 591.0 |
| 1984 | 1588.1 | 909.9 | 645.8 | 327.3 | 210.3 | 182.1 | 153.2 | 175.7 | 426.2 | 416.8 | 658.1 | 698.5 | 557.7 |
| 1985 | 1334.1 | 2363.2 | 951.6 | 520.9 | 381.9 | 269.7 | 195.4 | 248.8 | 711.8 | 708.9 | 641.5 | 2275.3 | 883.6 |
| 1986 | 1952.6 | 1838.5 | 977.6 | 565.4 | 390.0 | 270.5 | 221.9 | 612.0 | 369.4 | 1438.3 | 1062.5 | 2957.7 | 1054.7 |
| 1987 | 1816.2 | 1575.2 | 835.4 | 538.1 | 354.6 | 260.9 | 238.7 | 257.6 | 293.9 | 506.7 | 417.8 | 1183.5 | 689.9 |
| 1988 | 1846.8 | 1454.1 | 793.9 | 451.3 | 284.2 | 204.9 | 202.2 | 273.5 | 296.3 | 384.4 | 663.3 | 1062.7 | 659.8 |
| MEAN | 1610.2 | 1417.7 | 797.0 | 473.5 | 316.8 | 232.6 | 195.9 | 267.4 | 441.8 | 553.4 | 770.1 | 1119.6 | 683.0 |

**Table 5.13: Monthly Yield of Dez River at Dezful** **Unit: In (m.c.m.)**

| YEAR | APR. | MAY. | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 20.9 | 28.4 | 15.5 | 8.8 | 5.9 | 4.8 | 4.7 | 4.1 | 5.2 | 22.3 | 14.0 | 34.2 | 14.1 |
| 1952 | 28.9 | 28.7 | 17.1 | 10.4 | 7.2 | 5.6 | 4.9 | 6.7 | 16.3 | 21.3 | 12.4 | 28.0 | 15.6 |
| 1953 | 53.0 | 39.9 | 21.2 | 12.3 | 8.6 | 6.4 | 6.0 | 5.7 | 17.4 | 20.0 | 11.7 | 13.7 | 18.0 |
| 1954 | 27.6 | 26.5 | 15.8 | 9.1 | 6.4 | 5.1 | 3.9 | 4.1 | 12.2 | 5.2 | 14.3 | 25.7 | 13.0 |
| 1955 | 28.1 | 31.3 | 18.2 | 11.5 | 8.0 | 4.8 | 3.6 | 3.4 | 4.1 | 6.2 | 9.3 | 18.9 | 12.3 |
| 1956 | 33.5 | 42.3 | 26.8 | 13.1 | 8.3 | 5.6 | 4.9 | 6.5 | 9.3 | 8.8 | 10.6 | 17.9 | 15.6 |
| 1957 | 18.7 | 14.5 | 9.4 | 6.2 | 4.3 | 3.5 | 2.9 | 2.9 | 12.2 | 6.7 | 8.6 | 12.4 | 8.5 |
| 1958 | 36.4 | 19.8 | 11.2 | 7.5 | 5.1 | 3.7 | 2.9 | 3.1 | 3.9 | 7.3 | 5.7 | 6.2 | 9.4 |
| 1959 | 17.1 | 18.5 | 9.9 | 5.9 | 4.0 | 2.9 | 2.3 | 2.9 | 4.7 | 11.1 | 21.3 | 13.2 | 9.5 |
| 1960 | 21.4 | 27.9 | 13.1 | 8.6 | 5.9 | 4.0 | 3.4 | 3.4 | 6.0 | 7.5 | 13.7 | 10.4 | 10.4 |
| 1961 | 12.1 | 26.2 | 11.2 | 6.7 | 4.3 | 3.5 | 3.1 | 3.1 | 4.9 | 5.7 | 10.9 | 9.8 | 8.5 |
| 1962 | 18.2 | 27.3 | 16.1 | 8.6 | 5.6 | 4.0 | 3.1 | 3.9 | 5.2 | 5.2 | 7.5 | 14.0 | 9.9 |
| 1963 | 19.6 | 12.6 | 8.3 | 5.1 | 3.5 | 2.9 | 2.3 | 2.3 | 4.7 | 7.5 | 17.1 | 18.4 | 8.7 |
| 1964 | 20.4 | 16.6 | 10.4 | 6.4 | 4.8 | 3.5 | 2.9 | 9.1 | 6.2 | 4.9 | 25.4 | 20.7 | 10.9 |
| 1965 | 17.7 | 17.4 | 11.5 | 7.2 | 5.1 | 3.5 | 3.4 | 4.1 | 3.4 | 4.1 | 6.5 | 11.7 | 8.0 |
| 1966 | 11.5 | 14.7 | 9.4 | 5.4 | 3.7 | 2.7 | 2.3 | 3.4 | 7.3 | 6.0 | 7.0 | 13.5 | 7.2 |
| 1967 | 22.0 | 28.7 | 15.8 | 8.8 | 5.9 | 4.0 | 3.4 | 5.7 | 8.8 | 11.1 | 37.3 | 52.1 | 17.0 |
| 1968 | 75.5 | 44.5 | 22.8 | 13.4 | 8.8 | 6.2 | 4.7 | 5.2 | 4.4 | 7.3 | 10.1 | 10.6 | 17.8 |
| 1969 | 14.7 | 13.7 | 7.8 | 5.4 | 3.5 | 2.7 | 2.6 | 2.3 | 5.4 | 3.6 | 5.2 | 18.4 | 7.1 |
| 1970 | 32.4 | 31.6 | 13.4 | 7.2 | 4.6 | 3.2 | 2.6 | 6.7 | 16.8 | 10.9 | 13.0 | 16.8 | 13.3 |
| 1971 | 54.1 | 38.0 | 25.2 | 14.7 | 9.1 | 6.2 | 4.4 | 9.1 | 13.7 | 7.8 | 11.7 | 24.6 | 18.2 |
| 1972 | 19.6 | 15.3 | 9.6 | 6.4 | 4.6 | 3.7 | 2.9 | 2.9 | 3.4 | 6.0 | 11.1 | 29.0 | 9.5 |
| 1973 | 42.6 | 27.1 | 16.3 | 9.4 | 6.2 | 5.1 | 3.6 | 3.4 | 6.5 | 10.1 | 10.4 | 19.2 | 13.3 |
| 1974 | 21.7 | 23.8 | 14.2 | 9.4 | 4.6 | 3.7 | 3.1 | 3.1 | 6.2 | 20.7 | 41.0 | 21.8 | 14.4 |
| 1975 | 48.2 | 48.5 | 28.1 | 17.4 | 13.7 | 9.4 | 5.7 | 5.4 | 5.2 | 6.7 | 10.4 | 13.2 | 17.7 |
| 1976 | 17.1 | 14.2 | 10.7 | 5.9 | 3.7 | 2.9 | 4.4 | 9.6 | 15.3 | 20.0 | 15.6 | 28.8 | 12.4 |
| 1977 | 23.8 | 17.1 | 12.6 | 8.0 | 5.1 | 4.3 | 4.1 | 4.4 | 21.3 | 13.2 | 25.4 | 17.9 | 13.1 |
| 1978 | 28.1 | 20.1 | 12.3 | 7.8 | 5.1 | 4.0 | 3.6 | 4.4 | 7.8 | 11.9 | 26.4 | 37.1 | 14.1 |
| 1979 | 76.1 | 38.3 | 19.3 | 12.3 | 8.8 | 6.4 | 5.4 | 7.5 | 9.3 | 17.6 | 25.1 | 29.5 | 21.3 |
| 1980 | 47.1 | 31.9 | 17.1 | 11.5 | 8.3 | 6.2 | 5.4 | 6.0 | 7.0 | 12.2 | 15.0 | 24.4 | 16.0 |
| 1981 | 39.9 | 29.2 | 16.1 | 9.1 | 6.4 | 5.1 | 4.4 | 10.1 | 9.1 | 12.4 | 16.6 | 20.7 | 14.9 |
| 1982 | 33.2 | 45.5 | 24.9 | 13.4 | 7.8 | 4.8 | 4.7 | 5.4 | 7.0 | 6.7 | 7.8 | 9.3 | 14.2 |
| 1983 | 27.3 | 19.6 | 10.7 | 6.2 | 3.7 | 2.7 | 2.9 | 4.9 | 11.4 | 9.6 | 18.9 | 18.4 | 11.4 |
| 1984 | 34.3 | 17.4 | 12.3 | 6.2 | 4.0 | 3.5 | 2.9 | 3.4 | 10.1 | 8.0 | 12.7 | 13.5 | 10.7 |
| 1985 | 25.7 | 45.5 | 18.2 | 9.9 | 7.2 | 5.1 | 3.9 | 4.9 | 13.7 | 13.7 | 12.4 | 43.8 | 17.0 |
| 1986 | 37.5 | 35.4 | 18.7 | 37.8 | 7.5 | 5.1 | 4.1 | 11.7 | 7.0 | 27.7 | 20.5 | 56.8 | 22.5 |
| 1987 | 34.8 | 30.3 | 16.1 | 10.4 | 6.7 | 5.1 | 4.7 | 4.9 | 5.7 | 9.8 | 8.0 | 22.8 | 13.3 |
| 1988 | 35.6 | 27.9 | 15.3 | 8.6 | 5.4 | 4.0 | 3.9 | 5.2 | 5.7 | 7.3 | 12.7 | 20.5 | 12.7 |
| MEAN | 31.0 | 27.3 | 15.3 | 9.8 | 6.1 | 4.5 | 3.8 | 5.1 | 8.5 | 10.6 | 14.8 | 21.5 | 13.2 |

**Table 5.14: Monthly Yield of Shavor River at Shavor** **Unit : In (m.c.m.)**

| YEAR | APR. | MAY. | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 28.4 | 31.1 | 31.6 | 30.5 | 28.9 | 30.3 | 34.2 | 40.2 | 38.6 | 32.1 | 29.8 | 23.6 | 31.6 |
| 1952 | 56.0 | 62.4 | 54.4 | 50.9 | 58.7 | 53.3 | 50.5 | 45.9 | 39.1 | 32.7 | 36.5 | 38.6 | 48.2 |
| 1953 | 49.3 | 42.9 | 39.1 | 38.3 | 45.3 | 44.2 | 40.4 | 41.0 | 36.5 | 32.1 | 36.5 | 34.2 | 40.0 |
| 1954 | 34.0 | 37.8 | 30.8 | 32.9 | 36.4 | 36.4 | 35.3 | 35.3 | 39.4 | 40.4 | 43.0 | 40.2 | 36.8 |
| 1955 | 54.9 | 51.2 | 46.6 | 44.2 | 49.3 | 53.0 | 46.9 | 48.7 | 37.3 | 33.4 | 23.1 | 29.3 | 43.2 |
| 1956 | 31.3 | 33.7 | 28.4 | 28.1 | 28.4 | 32.9 | 28.8 | 30.3 | 30.1 | 28.0 | 30.6 | 34.0 | 30.4 |
| 1957 | 37.5 | 34.8 | 28.7 | 26.2 | 25.2 | 26.2 | 28.5 | 29.8 | 30.8 | 32.4 | 32.4 | 36.3 | 30.7 |
| 1958 | 39.6 | 31.9 | 31.9 | 32.4 | 37.0 | 35.9 | 31.9 | 36.5 | 31.9 | 32.9 | 28.0 | 25.1 | 32.9 |
| 1959 | 29.5 | 29.2 | 26.8 | 26.5 | 27.3 | 29.5 | 31.6 | 33.2 | 31.6 | 33.4 | 35.5 | 27.0 | 30.1 |
| 1960 | 30.3 | 31.9 | 27.6 | 27.3 | 26.8 | 31.3 | 33.4 | 37.1 | 31.9 | 32.1 | 29.8 | 24.9 | 30.4 |
| 1961 | 28.1 | 29.5 | 24.9 | 26.5 | 26.0 | 27.9 | 30.3 | 31.1 | 25.7 | 30.8 | 28.8 | 25.7 | 27.9 |
| 1962 | 28.4 | 28.7 | 23.6 | 24.4 | 24.9 | 31.6 | 34.7 | 35.3 | 26.2 | 25.7 | 26.2 | 23.8 | 27.8 |
| 1963 | 25.7 | 26.0 | 25.7 | 23.3 | 20.4 | 23.3 | 27.5 | 34.5 | 31.6 | 27.0 | 36.0 | 30.6 | 27.6 |
| 1964 | 33.2 | 32.7 | 25.7 | 27.3 | 24.9 | 17.7 | 29.0 | 35.3 | 29.8 | 28.5 | 37.1 | 33.7 | 29.6 |
| 1965 | 34.6 | 31.9 | 26.5 | 24.9 | 26.8 | 32.4 | 32.9 | 33.2 | 28.0 | 30.1 | 32.4 | 32.7 | 30.5 |
| 1966 | 33.5 | 34.8 | 32.9 | 29.2 | 24.9 | 24.9 | 30.6 | 36.3 | 34.7 | 30.8 | 30.8 | 28.3 | 31.0 |
| 1967 | 29.2 | 30.3 | 28.1 | 28.1 | 28.4 | 30.5 | 33.7 | 38.4 | 37.6 | 36.3 | 49.2 | 31.1 | 33.4 |
| 1968 | 98.0 | 44.7 | 32.7 | 31.9 | 36.4 | 32.7 | 35.3 | 38.4 | 34.7 | 46.9 | 41.2 | 33.2 | 42.2 |
| 1969 | 37.0 | 37.2 | 30.0 | 29.7 | 30.3 | 32.1 | 32.4 | 35.8 | 33.2 | 35.3 | 33.4 | 34.5 | 33.4 |
| 1970 | 45.8 | 36.7 | 32.1 | 33.5 | 32.9 | 34.3 | 35.3 | 34.0 | 38.9 | 37.3 | 41.5 | 36.8 | 36.6 |
| 1971 | 51.4 | 39.6 | 36.7 | 32.4 | 30.3 | 35.4 | 34.2 | 39.1 | 37.1 | 36.8 | 37.1 | 37.1 | 37.3 |
| 1972 | 40.2 | 36.7 | 34.8 | 32.1 | 31.6 | 33.5 | 32.1 | 34.7 | 35.5 | 35.8 | 35.3 | 34.5 | 34.7 |
| 1973 | 59.7 | 38.0 | 35.1 | 32.9 | 36.7 | 35.9 | 35.3 | 39.9 | 38.4 | 36.3 | 34.2 | 34.7 | 38.1 |
| 1974 | 36.4 | 40.2 | 37.5 | 37.8 | 36.7 | 37.2 | 38.4 | 35.5 | 33.4 | 36.8 | 41.2 | 34.7 | 37.2 |
| 1975 | 37.5 | 36.4 | 34.3 | 38.0 | 37.5 | 38.3 | 35.5 | 34.2 | 36.8 | 35.8 | 35.8 | 31.6 | 36.0 |
| 1976 | 32.1 | 31.3 | 30.0 | 31.9 | 34.6 | 41.2 | 38.4 | 36.5 | 37.8 | 34.0 | 31.9 | 29.0 | 34.1 |
| 1977 | 34.8 | 35.1 | 33.2 | 30.5 | 33.7 | 32.1 | 29.3 | 29.8 | 39.1 | 30.8 | 48.0 | 35.0 | 34.3 |
| 1978 | 36.4 | 38.6 | 36.7 | 34.6 | 37.8 | 35.4 | 35.0 | 34.2 | 35.0 | 38.9 | 47.4 | 46.9 | 38.1 |
| 1979 | 49.0 | 33.7 | 41.0 | 42.1 | 42.6 | 42.1 | 38.4 | 35.8 | 33.2 | 31.4 | 31.4 | 36.5 | 38.1 |
| 1980 | 44.5 | 44.2 | 38.6 | 35.6 | 38.3 | 39.9 | 35.0 | 32.1 | 31.1 | 35.8 | 30.1 | 32.7 | 36.5 |
| 1981 | 31.3 | 33.2 | 33.2 | 34.3 | 35.9 | 37.2 | 44.3 | 50.8 | 50.5 | 44.6 | 41.0 | 53.9 | 40.9 |
| 1982 | 54.6 | 47.7 | 46.9 | 48.5 | 52.8 | 54.6 | 53.7 | 43.3 | 37.3 | 35.0 | 38.1 | 41.2 | 46.1 |
| 1983 | 42.9 | 39.9 | 41.2 | 45.8 | 62.1 | 67.5 | 62.2 | 55.0 | 46.9 | 37.1 | 35.3 | 49.5 | 48.8 |
| 1984 | 54.9 | 48.7 | 41.5 | 45.5 | 50.6 | 58.4 | 57.5 | 49.5 | 59.1 | 46.1 | 50.8 | 54.2 | 51.4 |
| 1985 | 65.1 | 65.6 | 55.4 | 49.3 | 53.6 | 54.1 | 58.6 | 60.7 | 49.5 | 35.3 | 43.0 | 49.8 | 53.3 |
| 1986 | 60.0 | 56.2 | 43.9 | 51.7 | 62.1 | 71.2 | 74.9 | 67.7 | 49.5 | 44.3 | 39.7 | 62.2 | 57.0 |
| 1987 | 71.0 | 57.0 | 48.2 | 54.6 | 58.9 | 67.0 | 65.6 | 65.8 | 57.5 | 48.2 | 40.7 | 59.6 | 57.9 |
| 1988 | 80.1 | 73.9 | 56.0 | 55.7 | 59.7 | 72.0 | 63.2 | 59.6 | 47.7 | 39.4 | 34.2 | 45.4 | 57.3 |
| MEAN | 43.8 | 39.9 | 35.6 | 35.5 | 37.8 | 39.8 | 39.9 | 40.4 | 37.5 | 35.3 | 36.2 | 36.6 | 38.2 |

**Table 5.15: Monthly Yield of Karun River at Ahwaz** Unit: In (m.c.m.)

| YEAR | APR. | MAY. | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 2854.6 | 3639.9 | 2117.8 | 1308.9 | 872.1 | 708.7 | 623.1 | 628.3 | 748.6 | 2409.0 | 2300.7 | 4754.5 | 1913.9 |
| 1952 | 4093.4 | 3642.4 | 2379.2 | 1621.2 | 1120.9 | 820.9 | 662.8 | 938.3 | 3047.4 | 2327.4 | 1942.7 | 3856.1 | 2204.4 |
| 1953 | 7706.6 | 5154.6 | 2962.3 | 1978.3 | 1342.4 | 980.6 | 789.3 | 798.9 | 3263.1 | 2226.5 | 1812.1 | 1885.7 | 2575.0 |
| 1954 | 3864.1 | 3386.3 | 2194.4 | 1362.0 | 954.0 | 728.8 | 644.9 | 663.6 | 974.6 | 1119.7 | 1413.7 | 3304.0 | 1717.5 |
| 1955 | 2941.4 | 3274.9 | 1942.4 | 1284.0 | 926.7 | 630.0 | 529.5 | 551.3 | 602.4 | 1082.2 | 1297.3 | 3075.7 | 1511.5 |
| 1956 | 5381.2 | 6555.1 | 4036.6 | 1994.3 | 1230.2 | 815.3 | 618.2 | 869.4 | 1654.5 | 1329.4 | 1840.1 | 2124.7 | 2370.7 |
| 1957 | 2836.7 | 1947.5 | 1303.8 | 867.0 | 556.0 | 425.9 | 415.2 | 480.0 | 1888.0 | 1191.8 | 1437.5 | 1235.6 | 1215.4 |
| 1958 | 3920.4 | 2585.5 | 1475.3 | 987.5 | 645.5 | 472.5 | 407.2 | 433.1 | 510.9 | 1235.3 | 742.9 | 959.8 | 1198.0 |
| 1959 | 2095.8 | 2170.8 | 1220.5 | 710.3 | 463.1 | 374.2 | 351.2 | 423.0 | 747.8 | 1464.0 | 3303.0 | 1850.7 | 1264.5 |
| 1960 | 2713.5 | 3242.5 | 1799.9 | 1068.1 | 671.5 | 517.7 | 466.0 | 491.2 | 732.5 | 1282.3 | 1926.9 | 1544.6 | 1371.4 |
| 1961 | 1491.3 | 3087.4 | 1579.5 | 1053.7 | 649.0 | 509.2 | 454.1 | 539.1 | 767.5 | 1189.0 | 1397.3 | 1296.5 | 1167.8 |
| 1962 | 1980.7 | 2820.1 | 1844.3 | 1098.1 | 664.0 | 499.5 | 415.2 | 492.2 | 649.3 | 1114.8 | 831.0 | 1646.7 | 1171.3 |
| 1963 | 2480.7 | 1704.3 | 1064.4 | 535.7 | 375.2 | 345.8 | 367.3 | 395.0 | 647.0 | 1237.4 | 2861.8 | 2614.3 | 1219.1 |
| 1964 | 2884.6 | 2495.5 | 1565.0 | 910.7 | 594.3 | 446.8 | 419.1 | 959.0 | 814.4 | 1138.1 | 3449.2 | 2525.6 | 1516.9 |
| 1965 | 2478.3 | 2256.6 | 1500.4 | 900.5 | 567.6 | 427.5 | 443.2 | 577.2 | 507.5 | 1202.7 | 1089.4 | 1905.9 | 1154.7 |
| 1966 | 1828.3 | 2286.6 | 1449.3 | 834.6 | 512.1 | 413.8 | 395.3 | 510.9 | 1259.2 | 1218.8 | 1001.8 | 2178.8 | 1157.4 |
| 1967 | 3382.3 | 3460.0 | 2125.0 | 1386.6 | 846.6 | 570.0 | 462.9 | 723.4 | 1492.7 | 1491.7 | 6767.7 | 6035.5 | 2395.4 |
| 1968 | 9305.6 | 4966.8 | 2943.6 | 2123.2 | 1519.5 | 1006.0 | 661.5 | 839.0 | 901.2 | 1333.1 | 1566.1 | 1545.6 | 2392.6 |
| 1969 | 2220.4 | 1941.3 | 1152.0 | 728.3 | 491.0 | 412.5 | 411.9 | 448.4 | 903.3 | 1133.2 | 755.3 | 2086.6 | 1057.0 |
| 1970 | 3818.9 | 3330.1 | 1687.7 | 958.1 | 589.8 | 451.3 | 414.5 | 734.3 | 2079.8 | 1414.7 | 1765.9 | 2375.8 | 1635.1 |
| 1971 | 8679.4 | 4687.7 | 3323.6 | 2265.1 | 1467.0 | 884.4 | 607.8 | 993.3 | 1874.0 | 1308.4 | 1678.6 | 3474.6 | 2603.7 |
| 1972 | 2862.4 | 2126.9 | 1358.2 | 890.0 | 632.1 | 502.5 | 429.0 | 478.0 | 575.7 | 1193.1 | 1320.9 | 3743.9 | 1342.7 |
| 1973 | 5415.7 | 3160.8 | 2058.6 | 1375.6 | 822.3 | 668.5 | 506.0 | 556.2 | 1222.1 | 1603.4 | 1678.8 | 2857.9 | 1827.2 |
| 1974 | 3397.6 | 3127.6 | 1978.3 | 1398.1 | 769.5 | 613.6 | 500.5 | 578.3 | 1022.0 | 2003.6 | 8215.3 | 3575.1 | 2265.0 |
| 1975 | 7250.7 | 6332.0 | 4317.6 | 3122.5 | 2208.1 | 1360.1 | 775.5 | 1033.4 | 1158.9 | 1411.1 | 1759.7 | 2199.6 | 2744.1 |
| 1976 | 2646.0 | 2206.5 | 1499.1 | 902.4 | 594.9 | 498.5 | 541.2 | 1392.7 | 3007.5 | 2716.7 | 3423.3 | 3993.2 | 1951.8 |
| 1977 | 3806.5 | 2638.5 | 1855.9 | 1289.4 | 841.6 | 614.4 | 565.1 | 698.8 | 3381.0 | 1651.1 | 4336.4 | 2547.4 | 2018.8 |
| 1978 | 4064.5 | 2585.7 | 1805.2 | 1149.0 | 776.7 | 621.7 | 524.9 | 654.7 | 1344.5 | 1509.8 | 5178.0 | 5818.8 | 2169.5 |
| 1979 | 1624.8 | 5350.9 | 3032.8 | 2237.3 | 1541.2 | 1013.2 | 695.7 | 953.1 | 1522.8 | 1835.7 | 4285.9 | 3881.8 | 3164.6 |
| 1980 | 6131.4 | 3904.3 | 2328.1 | 1768.0 | 1194.0 | 847.7 | 654.5 | 821.4 | 1307.7 | 1518.7 | 2313.1 | 3240.3 | 2169.1 |
| 1981 | 5984.3 | 3813.8 | 2233.8 | 1330.9 | 906.9 | 679.0 | 604.5 | 1434.4 | 1602.4 | 1712.8 | 2736.4 | 2805.1 | 2153.7 |
| 1982 | 4705.7 | 5398.3 | 2952.7 | 1810.6 | 1067.1 | 688.1 | 564.3 | 693.1 | 1039.4 | 1252.5 | 1158.9 | 1244.4 | 1881.2 |
| 1983 | 4646.2 | 2501.1 | 1444.5 | 823.9 | 506.2 | 416.2 | 425.9 | 763.3 | 1619.2 | 1524.1 | 3671.6 | 2179.6 | 1710.1 |
| 1984 | 4280.4 | 2205.9 | 1535.8 | 876.9 | 542.1 | 468.5 | 429.0 | 524.9 | 1764.9 | 1428.7 | 1849.9 | 1858.5 | 1480.4 |
| 1985 | 4798.6 | 5661.6 | 2651.9 | 1600.6 | 1101.1 | 803.3 | 558.6 | 828.1 | 3739.5 | 1900.5 | 2742.6 | 6400.4 | 2732.2 |
| 1986 | 6156.3 | 5082.5 | 2884.4 | 1834.2 | 1289.6 | 825.2 | 645.7 | 1483.1 | 1314.1 | 2427.4 | 3663.5 | 7898.9 | 2958.7 |
| 1987 | 5099.4 | 3766.4 | 2181.3 | 1527.5 | 1087.2 | 819.9 | 637.4 | 835.9 | 1173.4 | 1560.4 | 1446.9 | 3432.6 | 1964.0 |
| 1988 | 4850.9 | 3495.6 | 2074.2 | 1284.8 | 899.9 | 636.9 | 545.4 | 750.6 | 828.1 | 1278.6 | 2022.0 | 2814.7 | 1790.1 |
| MEAN | 4386.3 | 3473.5 | 2101.6 | 1347.3 | 890.5 | 645.2 | 530.6 | 736.0 | 1412.9 | 1525.7 | 2447.0 | 2967.6 | 1872.0 |

**Table 5.16 : Long-Term Average Climatological Data for Dezful, Ahwaz and Abadan**

| | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | DEZFUL | | | | | | |
| $T_{min}$ (C$^{o}$) | 5.6 | 7.8 | 10.5 | 15.1 | 20.8 | 24.3 | 30.6 | 20.5 | 28.0 | 22.3 | 10.8 | 7.1 |
| $T_{max}$ (C$^{o}$) | 17.2 | 19.7 | 24.3 | 29.6 | 37.2 | 43.2 | 45.6 | 44.7 | 41.5 | 34.8 | 26.7 | 19.4 |
| Sunshine (h) | 4.5 | 5.8 | 6.3 | 7.3 | 9.2 | 11.0 | 10.6 | 10.4 | 9.9 | 7.9 | 5.6 | 4.3 |
| Wind (Km/d) | 141.7 | 185.4 | 214.8 | 249.9 | 278.7 | 266.0 | 213.6 | 211.5 | 180.4 | 150.2 | 119.5 | 126.4 |
| RH (%) | 72.0 | 67.0 | 56.0 | 47.0 | 32.0 | 22.0 | 24.0 | 26.0 | 25.0 | 36.0 | 54.0 | 70.0 |
| $RH_{max}$ (%) | 78.0 | 79.0 | 71.0 | 60.0 | 42.0 | 29.0 | 28.0 | 31.0 | 32.0 | 47.0 | 65.0 | 76.0 |
| Barometric Pressure (Mbar) | 1002.9 | 1000.9 | 994.5 | 998.1 | 991.5 | 984.8 | 980.9 | 983.0 | 989.4 | 996.5 | 1001.3 | 1003.1 |
| | | | | | | AHWAZ | | | | | | |
| $T_{min}$ (C$^{o}$) | 6.5 | 8.1 | 11.8 | 16.5 | 21.7 | 24.7 | 26.9 | 26.0 | 22.1 | 17.5 | 12.0 | 7.7 |
| $T_{max}$ (C$^{o}$) | 17.6 | 20.4 | 25.5 | 31.8 | 38.8 | 44.3 | 45.9 | 45.5 | 42.3 | 36.0 | 26.5 | 19.4 |
| Sunshine (h) | 5.4 | 5.8 | 6.5 | 7.1 | 9.0 | 10.6 | 10.6 | 10.1 | 9.9 | 8.2 | 5.9 | 5.2 |
| Wind (Km/d) | 180.4 | 183.2 | 252.3 | 266.3 | 286.2 | 311.1 | 270.9 | 247.7 | 215.9 | 178.6 | 172.2 | 166.7 |
| RH (%) | 72.0 | 64.0 | 53.0 | 43.0 | 32.0 | 25.0 | 26.0 | 30.0 | 31.0 | 40.0 | 53.0 | 68.0 |
| $RH_{max}$ (%) | 84.0 | 80.0 | 71.0 | 64.0 | 50.0 | 42.0 | 45.0 | 50.0 | 51.0 | 60.0 | 71.0 | 82.0 |
| Barometric Pressure (Mbar) | 1017.5 | 1015.7 | 1012.6 | 1008.9 | 1005.0 | 998.4 | 994.7 | 996.6 | 1002.8 | 1010.4 | 1015.4 | 1017.5 |
| | | | | | | ABADAN | | | | | | |
| $T_{min}$ (C$^{o}$) | 7.5 | 8.8 | 12.3 | 16.9 | 22.2 | 25.6 | 26.5 | 27.1 | 23.7 | 18.9 | 13.8 | 8.9 |
| $T_{max}$ (C$^{o}$) | 18.3 | 21.1 | 25.9 | 31.7 | 38.5 | 43.1 | 44.5 | 44.7 | 42.2 | 36.0 | 26.8 | 19.9 |
| Sunshine (h) | 5.6 | 6.9 | 7.4 | 7.7 | 9.2 | 10.5 | 10.3 | 9.8 | 9.7 | 8.8 | 6.7 | 5.0 |
| Wind (Km/d) | 249.5 | 274.0 | 307.6 | 306.8 | 332.4 | 402.1 | 380.8 | 336.7 | 265.0 | 203.7 | 223.0 | 225.9 |
| RH (%) | 72.0 | 64.0 | 54.0 | 47.0 | 36.0 | 30.0 | 32.0 | 33.0 | 36.0 | 47.0 | 59.0 | 71.0 |
| $RH_{max}$ (%) | 84.0 | 79.0 | 72.0 | 66.0 | 53.0 | 42.0 | 43.0 | 44.0 | 51.0 | 64.0 | 75.0 | 83.0 |
| Barometric Pressure (Mbar) | 1018.3 | 1016.4 | 1013.3 | 1010.0 | 1006.3 | 1000.2 | 996.2 | 997.9 | 1004.1 | 1011.4 | 1016.4 | 1018.5 |

**Table 5.17 : Corrected Monthly Values of (ETo) for Reference Crop at Dezful, Ahwaz and Abadan**

|  | Jan. | Feb. | Mar | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DEZFUL** |  |  |  |  |  |  |  |  |  |  |  |  |
| Penman ETo (mm/d) | 1.94 | 2.86 | 4.74 | 6.96 | 10.17 | 11.96 | 10.99 | 10.34 | 8.44 | 5.67 | 3.13 | 1.94 |
| Adjustment factor | 0.92 | 0.94 | 0.94 | 0.94 | 0.88 | 0.86 | 0.89 | 0.87 | 0.86 | 0.89 | 0.92 | 0.92 |
| Corrected Penman ETo(mm/d) | 1.90 | 2.70 | 4.50 | 6.50 | 8.90 | 10.30 | 9.80 | 9.00 | 7.30 | 5.00 | 2.90 | 1.80 |
| Average monthly ETo (mm) | 55.30 | 75.30 | 138.10 | 196.30 | 277.40 | 308.60 | 303.20 | 278.90 | 217.80 | 156.40 | 86.40 | 55.30 |
| **AHWAZ** |  |  |  |  |  |  |  |  |  |  |  |  |
| Penman ETo (mm/d) | 2.25 | 3.21 | 5.48 | 7.42 | 10.55 | 12.78 | 12.19 | 10.94 | 9.03 | 6.17 | 3.84 | 2.33 |
| Adjustment factor | 0.92 | 0.94 | 0.93 | 0.95 | 0.92 | 0.90 | 0.93 | 0.95 | 0.94 | 0.94 | 0.93 | 0.92 |
| Corrected Penman ETo(mm/d) | 2.10 | 3.00 | 5.10 | 7.00 | 9.70 | 11.50 | 11.30 | 10.40 | 8.50 | 5.80 | 2.50 | 2.10 |
| Average monthly ETo (mm) | 64.20 | 84.50 | 158.00 | 211.50 | 300.90 | 345.10 | 351.40 | 322.20 | 254.60 | 179.80 | 107.10 | 66.50 |
| **ABADAN** |  |  |  |  |  |  |  |  |  |  |  |  |
| Penman ETo (mm/d) | 2.69 | 3.99 | 6.14 | 8.08 | 11.06 | 14.05 | 13.60 | 12.37 | 9.73 | 6.39 | 4.18 | 2.64 |
| Adjustment factor | 0.90 | 0.92 | 0.94 | 0.96 | 0.93 | 0.86 | 0.87 | 0.87 | 0.92 | 0.96 | 0.93 | 0.91 |
| Corrected Penman ETo(mm/d) | 2.40 | 3.70 | 5.80 | 7.80 | 10.30 | 12.10 | 11.80 | 10.80 | 9.00 | 6.10 | 3.10 | 2.40 |
| Average monthly ETo (mm) | 75.10 | 102.80 | 178.90 | 232.70 | 318.90 | 362.50 | 366.80 | 333.60 | 268.50 | 190.20 | 113.30 | 74.50 |

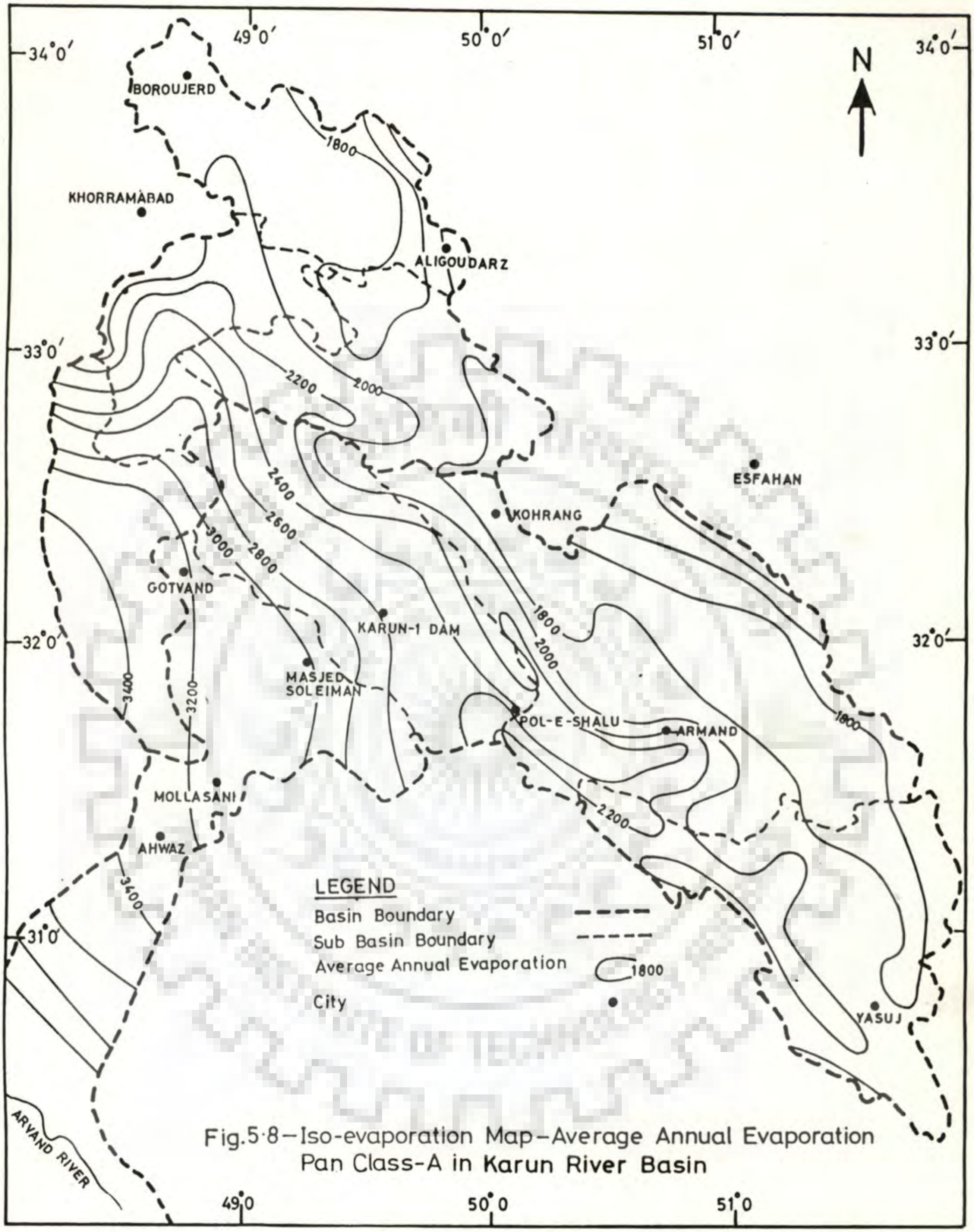


Fig.5·8—Iso-evaporation Map—Average Annual Evaporation Pan Class-A in Karun River Basin

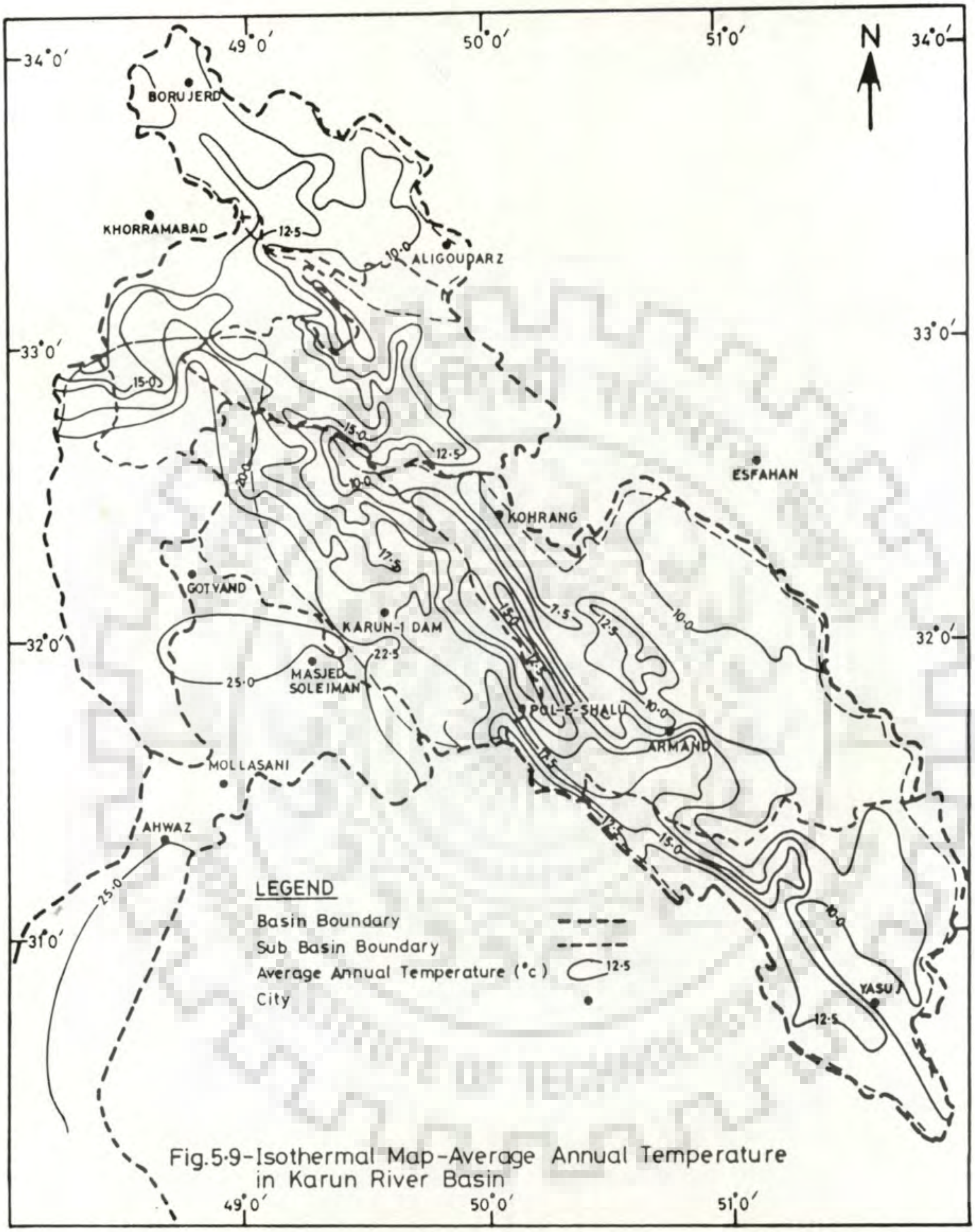


Fig.5·9-Isothermal Map-Average Annual Temperature in Karun River Basin

**Table 5.18 : Monthly Rainfall of Plain Area (80 % Dependable Rainfall) Unit : mm**

| NO. | STATION | MONTH |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | JAN. | FEB. | MAR. | APR. | MAY | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. |
| 1. | DEZFUL | 71.9 | 55.6 | 36.8 | 25.6 | 10.7 | 1.8 | 0.0 | 0.0 | 0.9 | 9.3 | 33.9 | 62.5 |
| 2. | AHWAZ | 38.0 | 10.4 | 27.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 20.3 | 63.8 |
| 3. | ABADAN | 12.4 | 12.1 | 2.0 | 29.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 36.3 | 15.9 |

### 5.4.3 REPRESENTATIVE CROPS

The following representative crops or crop combinations were selected for the purpose of study :

Winter Planted
Wheat
Barley
Tomato /Eggplant
Spring cucumber
Watermelon/Melon
Onions/Garlic
Barseem/Fababean
Winter Vegetables
Potato

Perennial
Alfaalfa
Tree Fruit
Sugar cane
Date Palm

Summer Planted
Rice
Autumn Vegetables
Watermelon/Melon
Vetch and Black-Eye Been
Corn
Sugar cane
Sudan grass

### 5.5 MUNICIPAL AND INDUSTRIAL (M & I) WATER DEMAND

Municipal and Industrial (M & I) water demands are considered in two stages of developments. The estimated demands of M & I water for existing development and future full development (after 25 years) for cities which are located in the river basin are given in Tables 5.19 and 5.20.

### 5.6 EXISTING DEVELOPMENT

The waters of both the rivers (Karun and Dez) have been used for thousands of years for irrigation on Khuzestan plain. However, it is only in the last 50 years or so that the potential for hydropower and regulation of the rivers in the mountains has been recognized.

The Dez river was developed first and the Dez concrete arch dam with a height of 203 meter was commissioned in 1965. This dam is functioning as a multipurpose project generating hydropower and has the capability to regulate the Dez river thereby permitting modern irrigation of some 108000 ha near the town of Dezful. Shortly thereafter, in 1967 to 1969 studies of Karun river identified a significant potential for hydropower and concluded that regulation of the river would permit development of irrigation for a further 130000 to 150000 ha of land. The Karun -1, a

Table 5.19 : Municipal and Industrial Water Demands-(m.c.m.) Existing Development

| Location | MONTHS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. |
| Gotvand | 10.2 | 13.3 | 7.5 | 6.8 | 7.3 | 7.2 | 7.8 | 12.3 | 12.2 | 11.5 | 10.9 | 9.6 |
| Shushtar | 3.1 | 3.1 | 3.1 | 3.7 | 3.7 | 3.7 | 2.8 | 2.8 | 2.8 | 2.6 | 2.6 | 2.6 |
| Ahwaz | 24.3 | 24.3 | 24.3 | 28.6 | 28.6 | 28.6 | 22.1 | 22.1 | 22.1 | 20.7 | 20.7 | 20.7 |
| Mared/ Khorramshahr/ Abadan | 5.6 | 5.6 | 5.6 | 7.3 | 7.3 | 7.3 | 4.9 | 4.9 | 4.9 | 4.3 | 4.3 | 4.3 |
| Dezful | 14.2 | 9.1 | 8.2 | 6.9 | 5.2 | 6.1 | 5.2 | 11.8 | 10.5 | 11.6 | 14.2 | 11.1 |
| Total | 57.4 | 55.4 | 48.7 | 53.3 | 52.1 | 52.9 | 42.8 | 53.9 | 52.5 | 50.7 | 52.7 | 48.3 |

Table 5.20: Municipal and Industrial Water demands-(m.c.m.) Full Development

| Location | MONTHS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. |
| Gotvand | 14.9 | 18.9 | 11.3 | 10.9 | 11.4 | 11.3 | 11.4 | 17.2 | 17.0 | 16.3 | 15.6 | 13.0 |
| Shushtar | 26.1 | 15.4 | 15.4 | 16.5 | 16.5 | 16.5 | 14.7 | 14.7 | 14.7 | 29.9 | 29.9 | 29.9 |
| Ahwaz | 73.8 | 59.4 | 59.4 | 71.0 | 71.0 | 71.0 | 53.8 | 53.8 | 53.8 | 65.0 | 65.0 | 63.0 |
| Mared/ Khorramshahr/ Abadan | 15.1 | 15.1 | 15.1 | 17.9 | 17.9 | 17.9 | 13.9 | 13.9 | 13.9 | 12.8 | 12.8 | 12.4 |
| Dezful | 31.6 | 25.4 | 24.3 | 19.6 | 17.4 | 18.5 | 17.1 | 25.1 | 23.5 | 33.3 | 36.5 | 32.9 |
| Total | 161.5 | 134.2 | 125.5 | 135.9 | 134.2 | 135.2 | 110.9 | 124.7 | 122.9 | 157.3 | 159.8 | 151.2 |

concrete arch dam of 170m height with a power station having an installed capacity of 1000 MW was commissioned in 1976 (Karun-2 and Karun-3 Development Projects, Definition Report, 1984).

## 5.7 DEVELOPMENT POTENTIAL

Based on the developmental potential, investigated (The Initial Karun River Project Feasibility Report, 1968), the Karun river can be divided into four major Zones, as shown in Figures 5.10 and 5.11.

**Zone1 :** From Arvand Rud (mouth of river) to Gotvand km 360, the development potential includes irrigation, municipal and industrial water supply. This reach has a length of 360 km measured along the river and it is not suitable for power generation or for providing storage schemes.

**Zone2 :** From Km 360 to Km 490 (Karun-1 dam site/Shahid Abbaspour Dam), river flows in steep-sided valley through the foothills of the Zagross mountains. Although a number of potential dam sites exist on this reach, but geological formations are not suitable for high storage dams. Thus, this length of the river should be considered for development by a series of run-of-river power installations.

**Zone3 :** The most important stretch of the river from a development point of view is that from km 490 to km 670. Here the river has a considerable long-term average discharge and a relatively steep slope. The river drops some 450 m along this reach and with a long term average flow of approximately 300 $m^3$/sec, this has very considerable hydropower potential. In addition, the topography of the river valley is such that dams would retain reservoir storages of adequate size to give significant regulation of river flows. So far, three main dam sites were identified in this stretch of the river, which can provide almost complete regulation of the river.

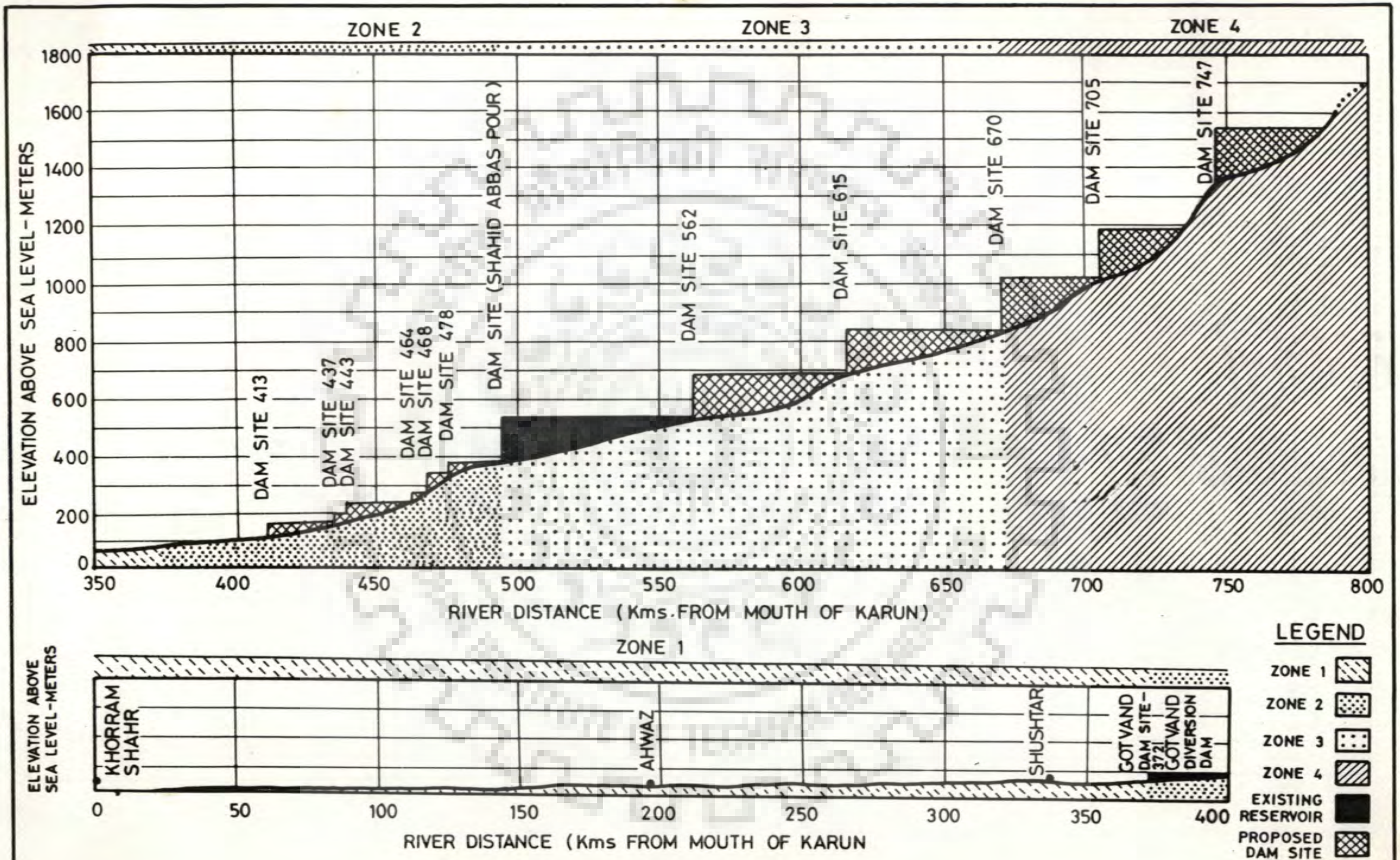


Fig. 5·10 : Karun River Profile

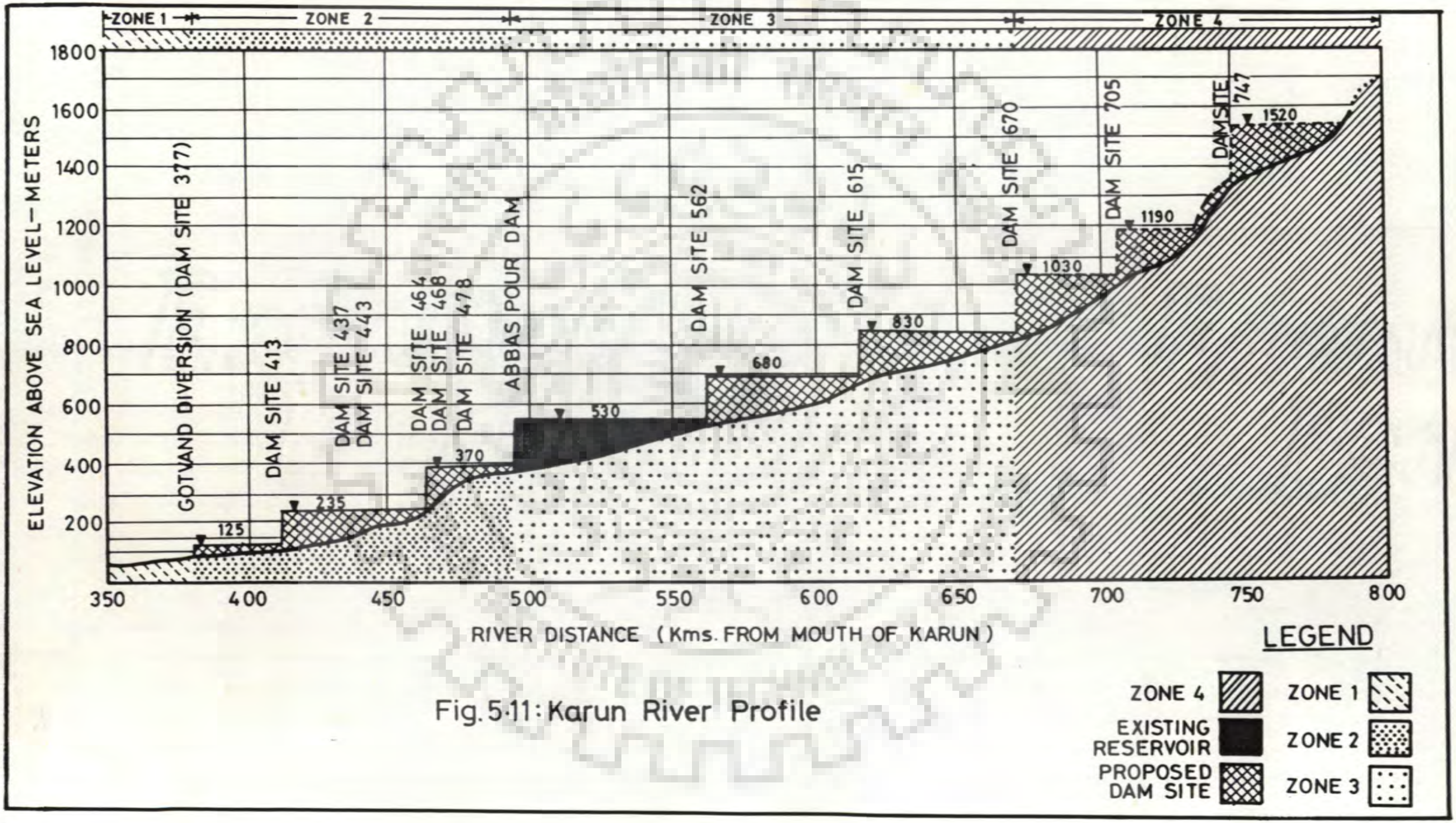


Fig. 5·11: Karun River Profile

**Zone4 :** The headwaters of the river above km 670 include a number of major tributaries such as the Khersan, Bazuft and Vanak rivers. Several potential dam sites have been identified at km 670, km 705 and km 747. In this study, proposal of dam sites at Km 705 and Km 747 have not been considered as these are not currently under investigation by the project authorities.

## 5.8 STATEMENT OF THE PROBLEM

The constantly increasing demand for a significant quantity and quality of water properly distributed in time and space, has forced planners to contemplate and propose ever more comprehensive, complex and ambitious plans for water resources systems. The specific decision problem under consideration is a multi reservoir, multi purpose and multi irrigation area system,where in, an optimal combination of reservoirs is to be determined to meet the current and forecasted growth in demand of water for irrigation, hydropower, flood control,and municipal & industrial water supply. It is imperative to organize this effort in a well balanced form, allocating resources to those projects at the level that offers the highest potential pay off. An effective strategic model should be able to support the development of logistics to provide the top managers with a better understanding of decisions on design of new facilities and the expansion of the existing water supply system.

The problem now is to develop a suitable methodology to identify the combination of multi reservoir alternatives to maximize the economic benefits, satisfying the system and the resource constraints. The methodology is applied to the Karun river system in Iran. It is noted that except Karun -1 and Dez reservoirs and their diversions which are existing in the Karun river system,several other potential dam sites on the Karun river between Km 360 (Gotvand diversion dam) and Km 747 are proposed, as follows:

Initially, three run-of-river hydropower sites at Km 464, 466 and 477 which are called Tunnel scheme, Up Dam Site and Down Dam Sites respectively, and storage hydropower sites at Km 562 (Karun-2) and Km 615 (Karun-3) and Km 670 (Karun-4) are proposed. Based on preliminary investigations (Karun-2,3 Development Project, Power Studies, 1986), it is found that for each storage site there were alternative schemes, i.e.,

i) a single high dam at Karun-2 with a gross head of 300 meter, or two lower dams at Karun -2 and Karun-3,

ii) Three possible sites between Km 544 and 564 at Karun-2,and

iii) Three possible sites between Km 666 to 670 at Karun-4, which are named Karun-4 up & mid and down dam sites.

These investigations finally proposed 3 potential reservoir sites and one run-of-river hydropower site which are to be developed. The Table 5.21 gives the details of these dam sites. Monthly distribution of reservoir evaporation for different dam sites are shown in Table 5.22.

Since the Karun river system is partially developed, in terms of irrigation utilization, the potential irrigation area of the total system is classified in the two developmental categories:

- Case 1. Existing development with an irrigation area of 326000 ha, and
- Case 2. Full development with major projects with an irrigation area of 450000 ha.

Based on above categories several Multi Irrigation areas with different crop patterns as well as with different irrigation water requirements have been identified by the project authorities. The Figures 5.12 and 5.13. schematically show the entire Karun river system and multi irrigation areas for existing and full development scenarios respectively. The details of irrigation potential are given in Tables 5.23 and 5.24. Also, Volume vs Elevation and Area Curves for reservoir at each of the Dam

Sites are shown in Figures 5.14 to 5.33. It is required to examine the technical feasibility, economical viability of this basin development. There can be various alternatives depending upon the configurations of the reservoir/sites in the basin. In the first instance, alternative combinations, capacities and project targets of 5 major dams, i.e., Karun-1, Karun-2, Karun-3, Karun-4, Dez, and Godar-e-Landar run-of-river hydroplant are proposed to be investigated.

The various proposed alternative configurations of the above system to be studied are shown in Table 5.25, based on various project proposals and engineering considerations. These are to be analyzed using the approach mentioned in the Chapter-1, for deciding the optimal system configuration and the optimal project targets.

**Table 5.21: Pertinent Features of Dam Sites in Karun River Basin**

| NO. | Description | Site | CA (Km$^2$) | Annual Catchment Yield (m.c.m.) | Storage(m.c.m.) | | |
|---|---|---|---|---|---|---|---|
| | | | | | Live | Dead | Gross |
| 1. | Karun-4 Dam Site* | 1 | 14590 | 470.5 | 860 | 1176 | 2036 |
| 2. | Karun-3 Dam Site* | 2 | 22913 | 774.5 | 1345 | 930 | 2275 |
| 3. | Karun-2 Dam Site* | 3 | 24120 | 815.8 | 2373 | 2300 | 4673 |
| 4. | Karun-1 Dam Site | 4 | 25852 | 990.7 | 1740 | 1280 | 3020 |
| 5. | Godar-e-Landar Run-of-river Hydropower Plant* | 5 | 26997 | 974.3 | - | - | - |
| 6. | Dez Dam Site | 6 | 17429 | 683.0 | 2510 | 830 | 3340 |

* Under investigation.

Table 5.22 : Monthly Distribution of Reservoir Evaporation at Karun River Dam Sites Unit:In mm

| NO. | Dam Site | Jan. | Feb. | Mar | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Karun-4 Dam Site | 48.9 | 60.7 | 72.8 | 117.0 | 164.0 | 214.1 | 257.0 | 279.3 | 237.9 | 163.5 | 82.5 | 58.7 | 1754.6 |
| 2. | Karun-3 Dam Site | 40.0 | 48.3 | 70.0 | 94.4 | 166.0 | 264.0 | 277.0 | 265.0 | 235.0 | 165.0 | 95.5 | 57.8 | 1778.0 |
| 3. | Karun-2 Dam Site | 40.0 | 48.3 | 70.0 | 94.4 | 166.0 | 264.0 | 277.0 | 265.0 | 235.0 | 165.0 | 95.5 | 57.8 | 1778.0 |
| 4. | Karun-1 Dam Site | 35.5 | 40.3 | 55.2 | 87.2 | 142.9 | 234.2 | 292.3 | 298.3 | 253.9 | 166.7 | 94.4 | 48.5 | 1749.3 |
| 5. | Godar-e-Landar Run-of-river Hydropower Plant | 54.4 | 50.2 | 72.8 | 110.3 | 187.5 | 267.7 | 281.1 | 275.7 | 261.3 | 197.1 | 123.9 | 72.8 | 1954.8 |
| 6. | Dez Dam Site | 59.7 | 67.0 | 92.9 | 137.4 | 210.8 | 303.0 | 342.6 | 326.0 | 299.0 | 216.4 | 132.7 | 75.9 | 2263.4 |

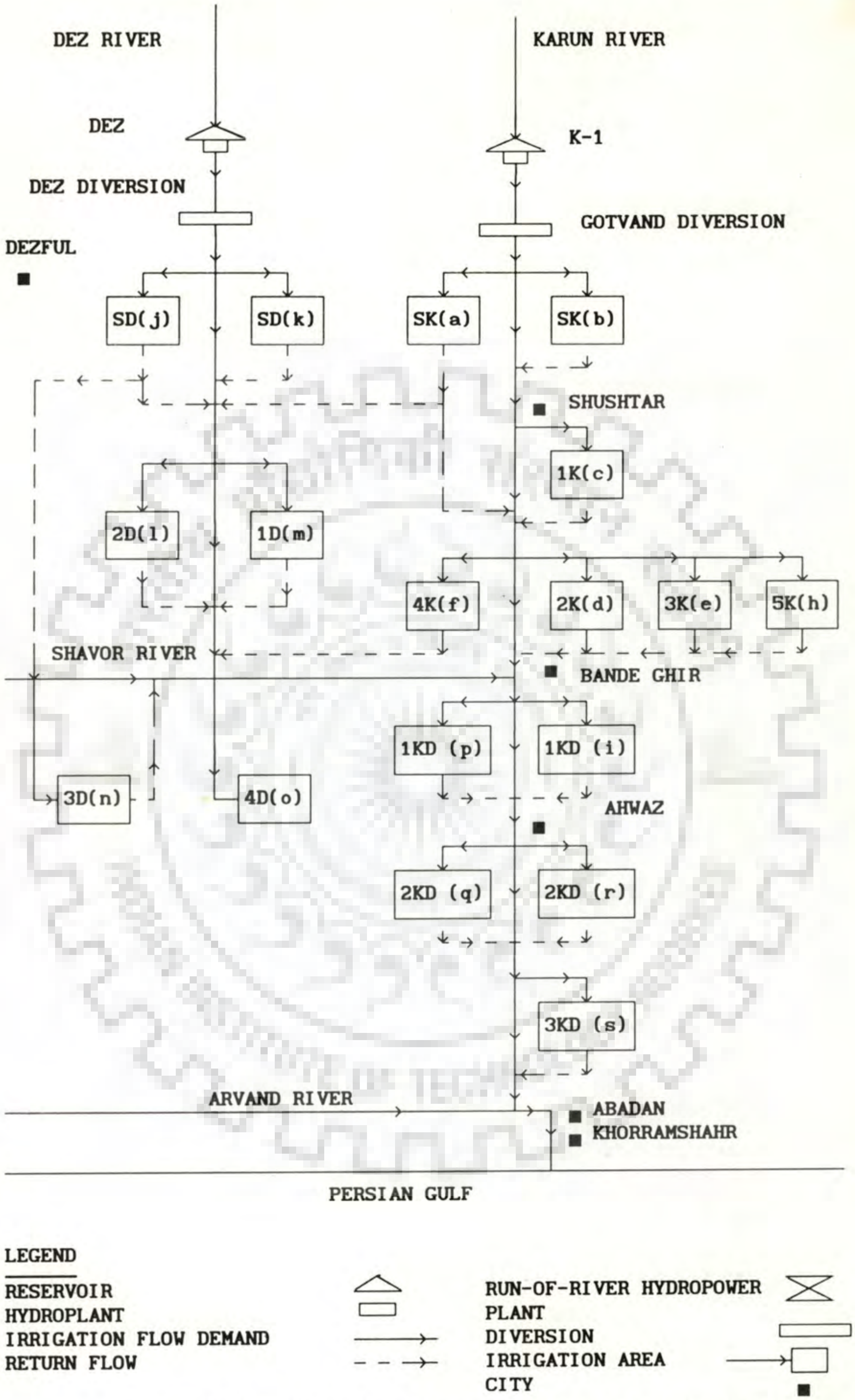


Fig. 5.12 : Schematic Diagram of Karun River System - Existing Development

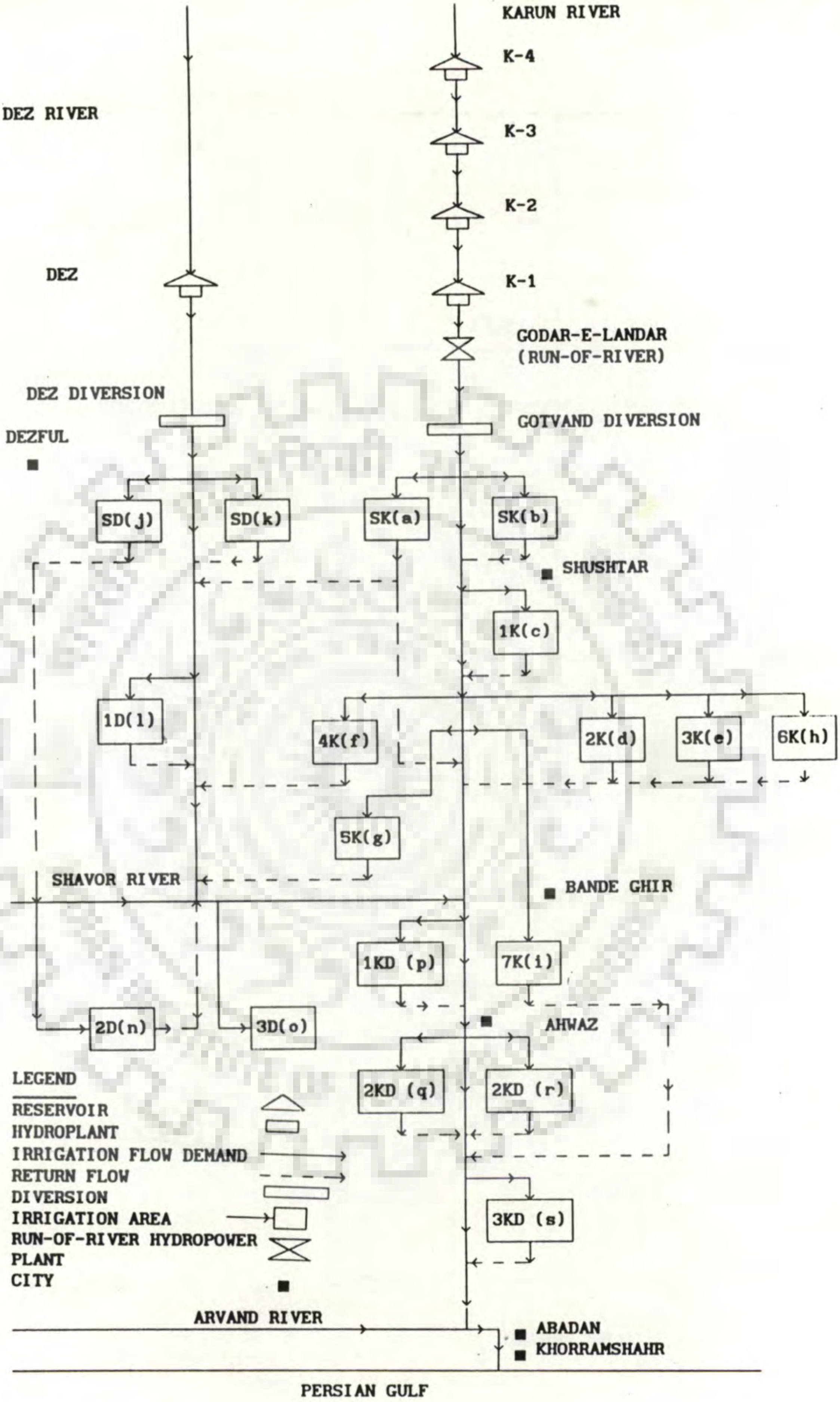


Fig. 5.13 : Schematic Diagram of Karun River System-Full Development

Table 5.23 : **Potential of Self & Multi Irrigation Areas of Karun River Basin (Existing Development)**

| NO. | Irrigation Area | Total Cultivable Area (ha) | Total Annual Irrigation requirement in m.c.m. |
|---|---|---|---|
| 1. | SK (Self Karun) | 14000 | 252.0 |
| 2. | 1K | 70 | 1.5 |
| 3. | 2K | 20930 | 376.0 |
| 4. | 3K | 6900 | 124.0 |
| 5. | 4K | 14260 | 257.0 |
| 6. | 5K | 1760 | 32.0 |
| 7. | SD (Self Dez) | 100100 | 1802.0 |
| 8. | 1D | 15990 | 288.0 |
| 9. | 2D | 16220 | 292.0 |
| 10 | 3D | 16100 | 290.0 |
| 11. | 4D | 1800 | 32.0 |
| 12. | 1KD | 30250 | 786.0 |
| 13. | 2KD | 61410 | 1597.0 |
| 14. | 3KD | 26000 | 676.0 |
| | | 325790 | 6805.5 |

Table 5.24 : **Potential of Self & Multi Irrigation Areas of Karun River Basin (Full Development)**

| NO. | Irrigation Area | Total Cultivable Area (ha) | Total Annual Irrigation requirement in m.c.m. |
|---|---|---|---|
| 1. | SK (Self Karun) | 40000 | 720.0 |
| 2. | 1K | 170 | 3.0 |
| 3. | 2K | 6900 | 124.0 |
| 4. | 3K | 25800 | 465.0 |
| 5. | 4K | 1495 | 27.0 |
| 6. | 5K | 33700 | 607.0 |
| 7. | 6K | 4715 | 85.0 |
| 8. | 7K | 17000 | 306.0 |
| 9. | SD (Self Dez) | 105700 | 1902.0 |
| 10. | 1D | 20470 | 368.0 |
| 11. | 2D | 17710 | 319.0 |
| 12. | 3D | 15640 | 282.0 |
| 13. | 1KD | 25900 | 673.0 |
| 14. | 2KD | 92230 | 2398.0 |
| 15. | 3KD | 41500 | 1079.0 |
| | | 448930 | 9359.0 |

**Table 5.25: Proposed alternative Configurations for reserviors/sites in Karun River Basin**

| Site Aalternatives | Karun-1 Dam | Karun-2 Dam | Karun-3 Dam | Karun-4 Dam | Dez Dam | Godar-e-Landar Run-of-river Power plant |
|---|---|---|---|---|---|---|
| 1 | YES | YES | YES | YES | YES | YES |
| 2 | YES | NO | YES | YES | YES | YES |
| 3 | YES | YES | NO | YES | YES | YES |
| 4 | YES | YES | YES | NO | YES | YES |
| 5 | YES | YES | NO | NO | YES | YES |
| 6 | YES | NO | YES | NO | YES | YES |
| 7 | YES | NO | NO | YES | YES | YES |
| 8 | YES | NO | NO | NO | YES | YES |

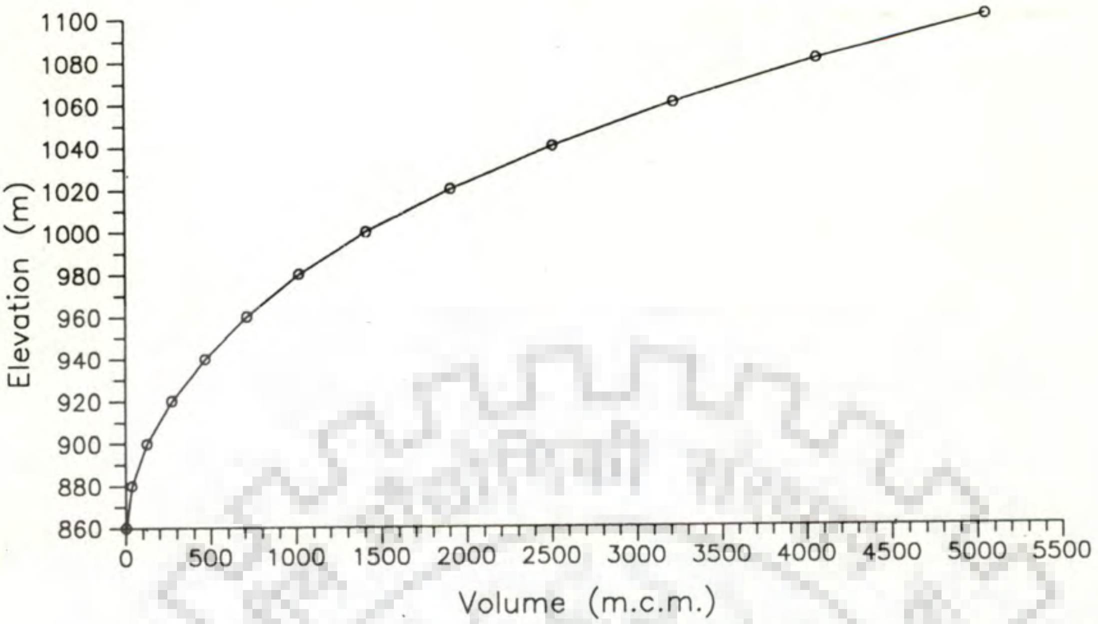


Fig. 5.14 : Reservoir Volume vs Elevation for Karun-4 (Up Dam Site)

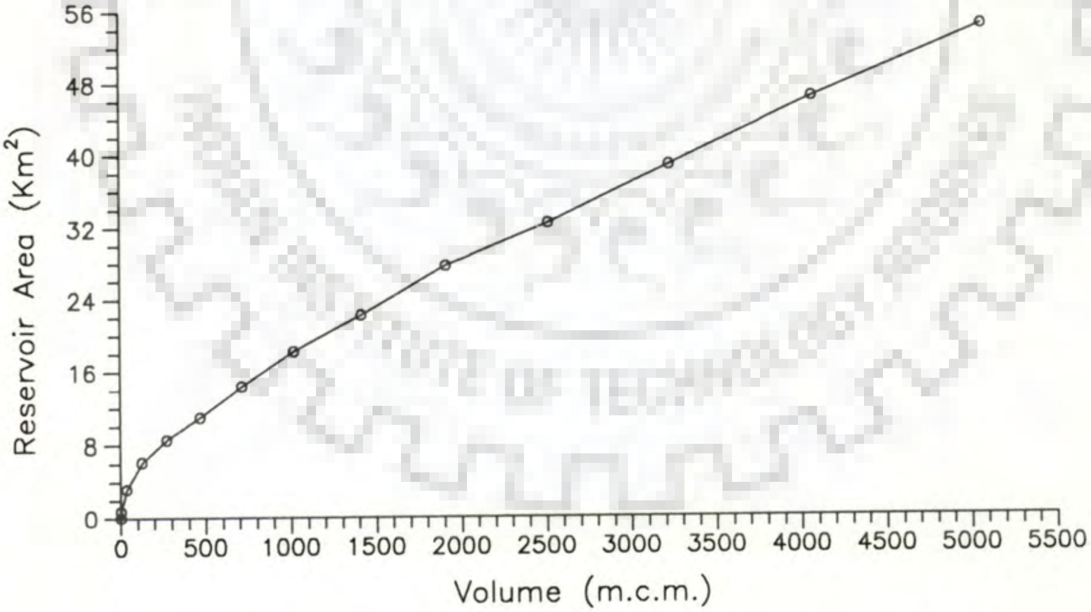


Fig. 5.15 : Reservoir Volume vs Area for Karun-4 (Up Dam Site)

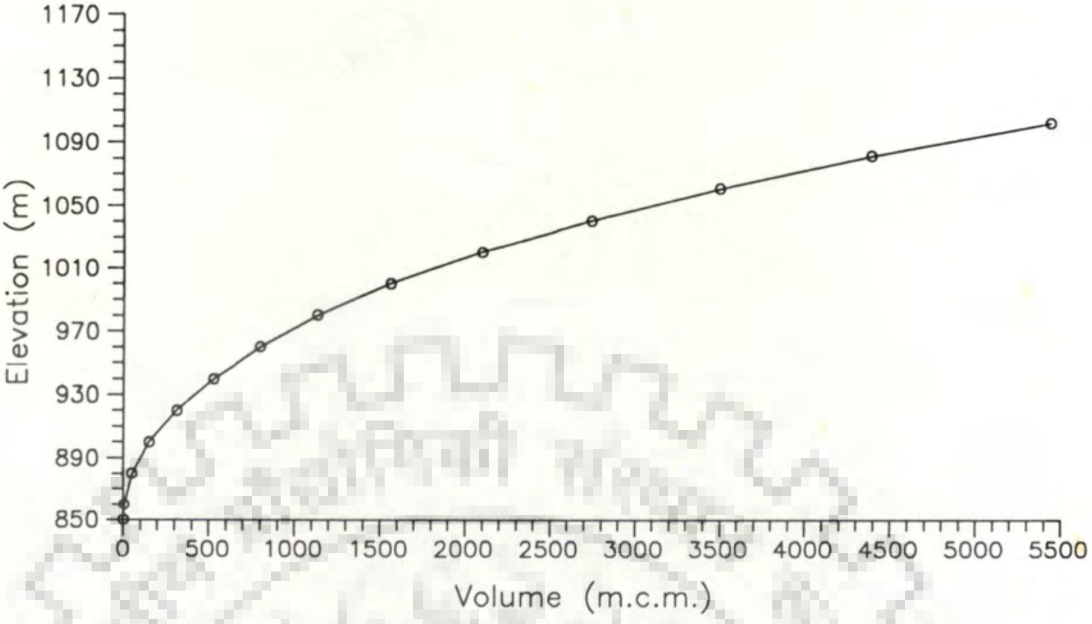


Fig. 5.16 : Reservoir Volume vs Elevation for Karun-4 (Mid Dam Site)

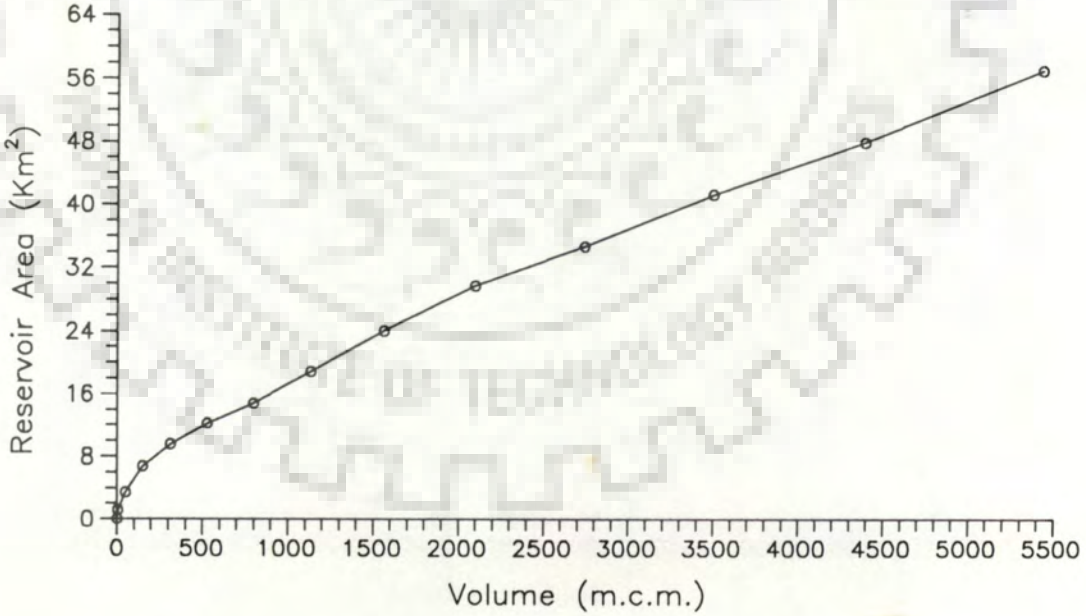


Fig. 5.17 : Reservoir Volume vs Area for Karun-4 (Mid Dam Site)

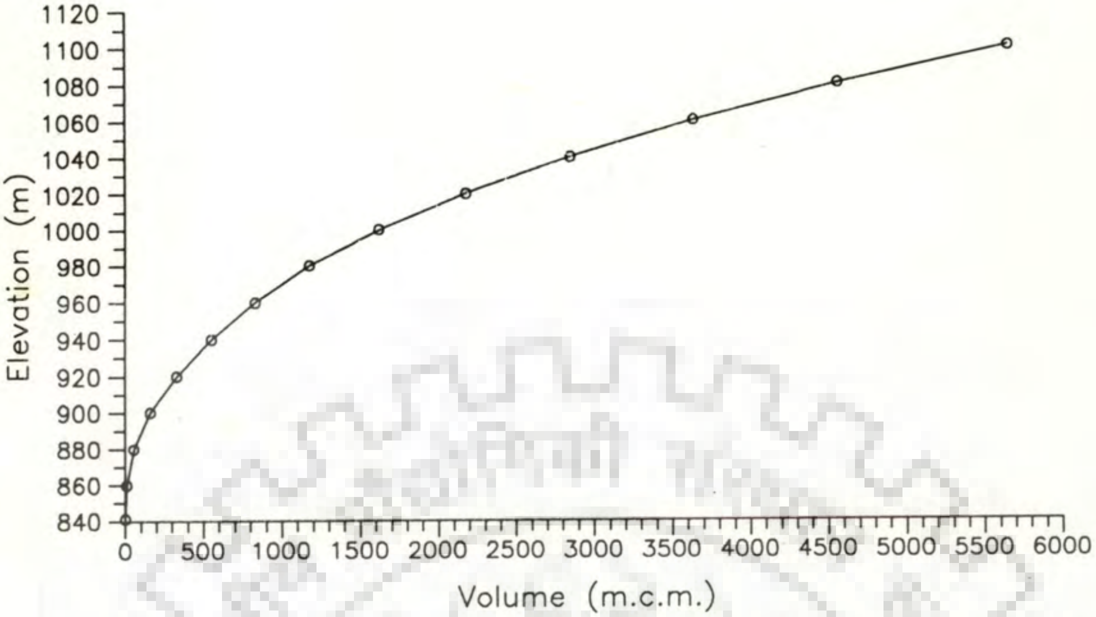


Fig. 5.18 : Reservoir Volume vs Elevation for Karun-4 (Down Dam Site)

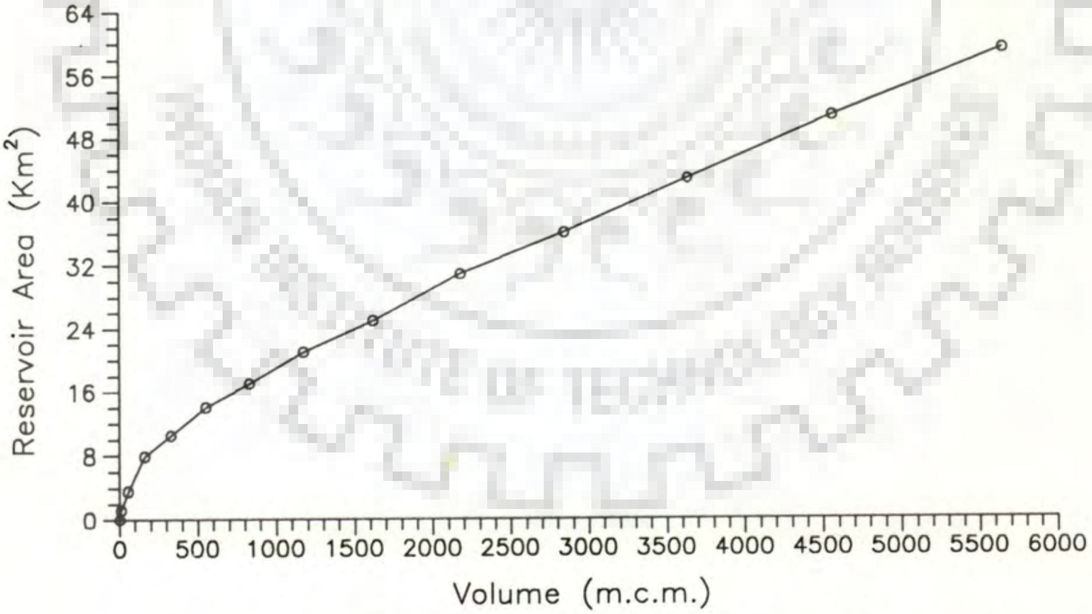


Fig. 5.19 : Reservoir Volume vs Area for Karun-4 (Down Dam Site)

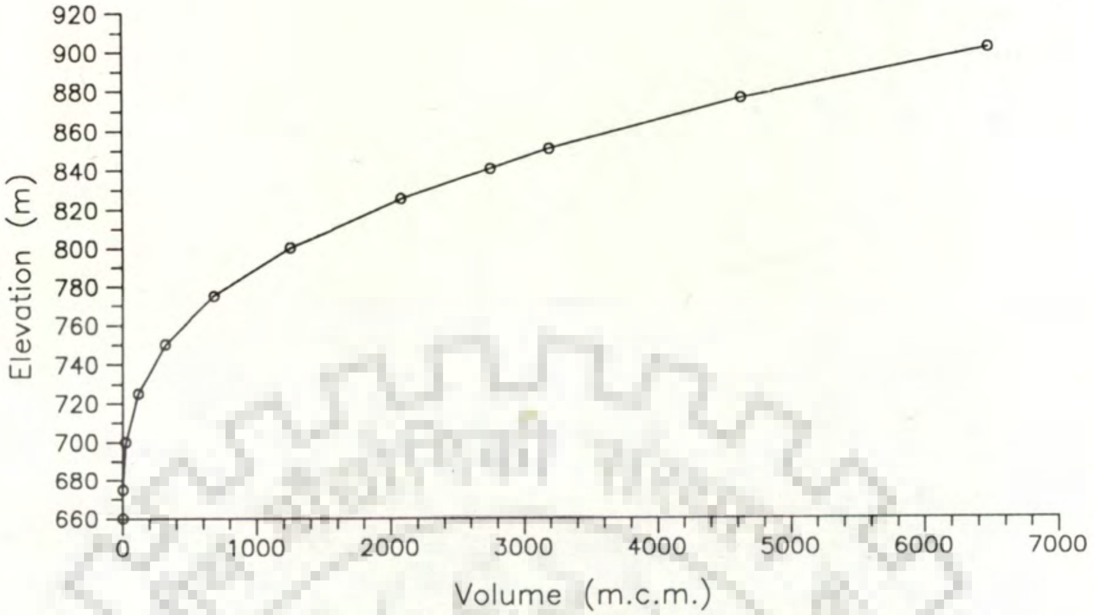


**Fig. 5.20 : Reservoir Volume vs Elevation for Karun-3 Dam Site**

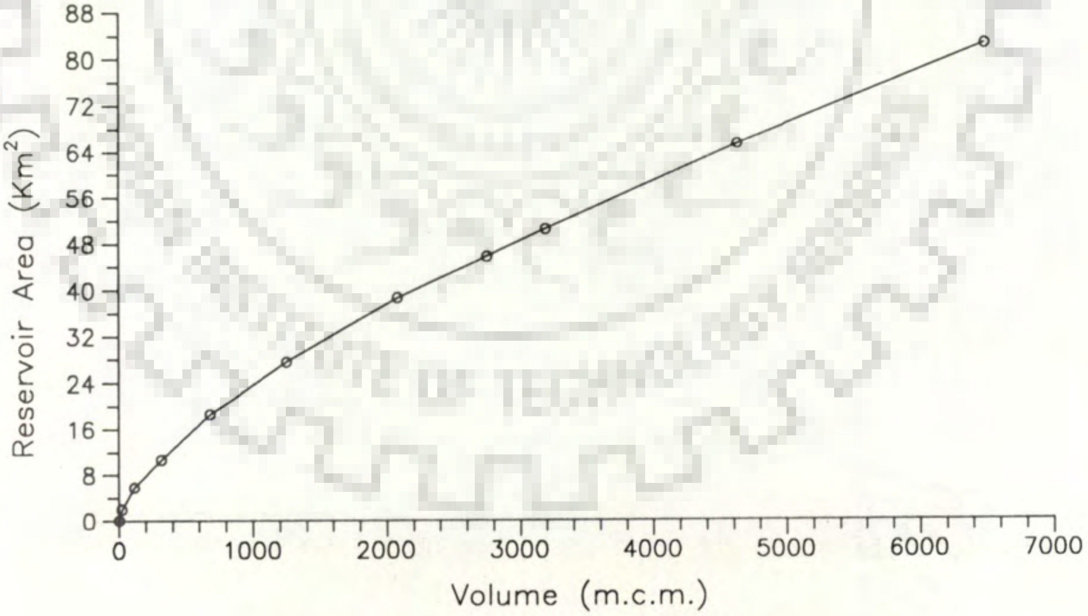


**Fig. 5.21 : Reservoir Volume vs Area for Karun-3 Dam Site**

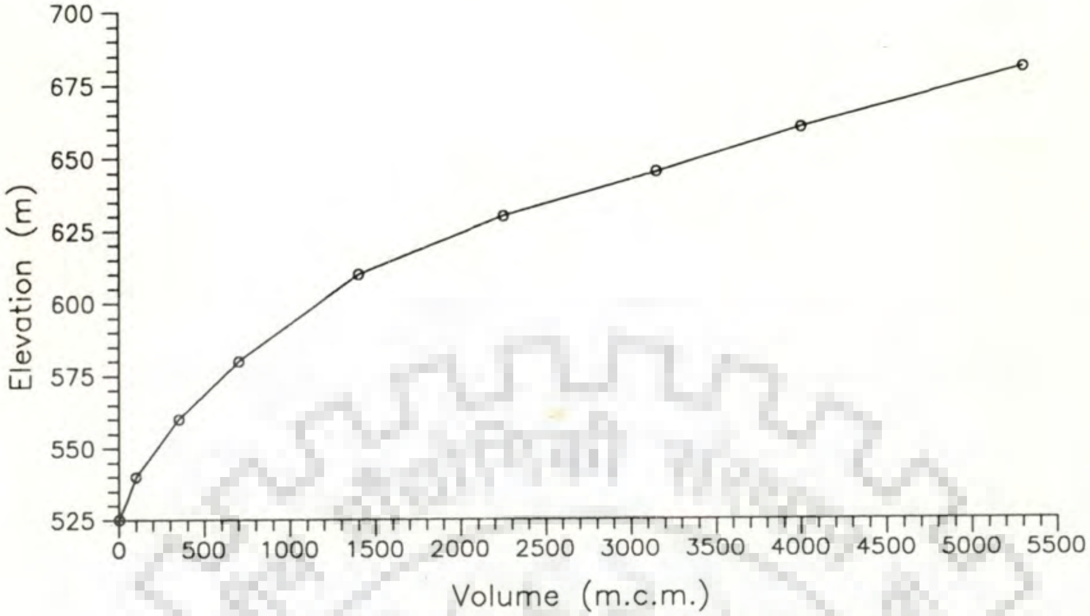


Fig. 5.22 : Reservoir Volume vs Elevation for Karun-2 Dam Site

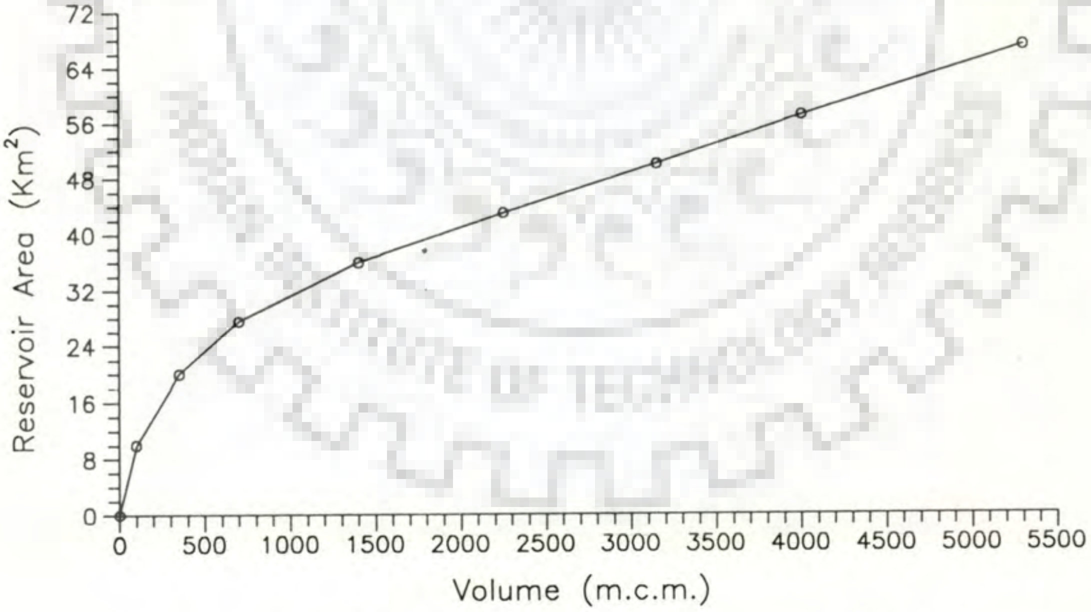


Fig. 5.23 : Reservoir Volume vs Area for Karun-2 Dam Site

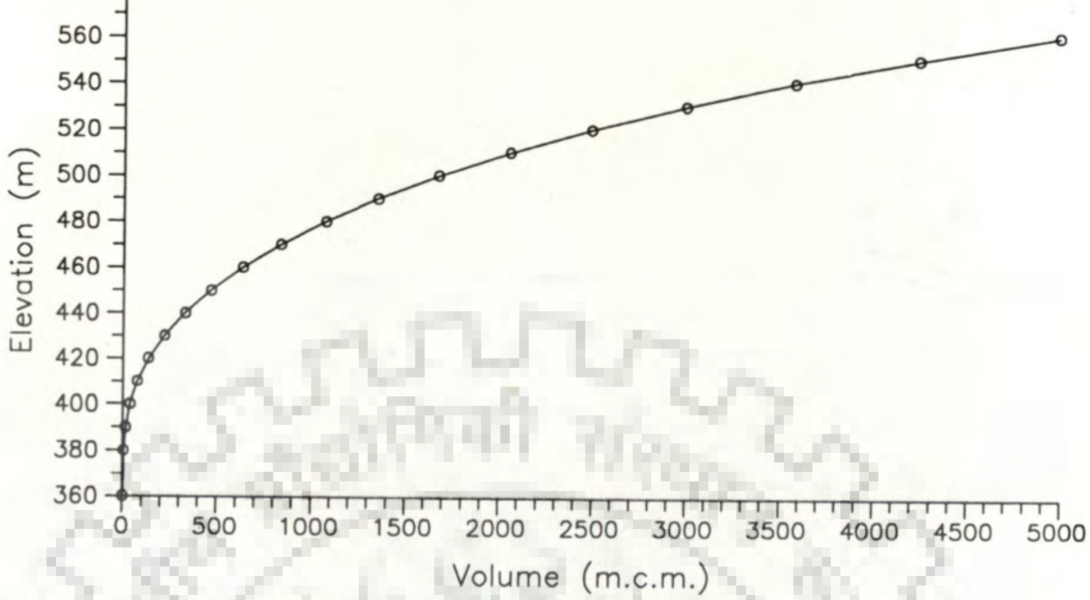


**Fig. 5.24 : Reservoir Volume vs Elevation for Karun-1 Dam Site**

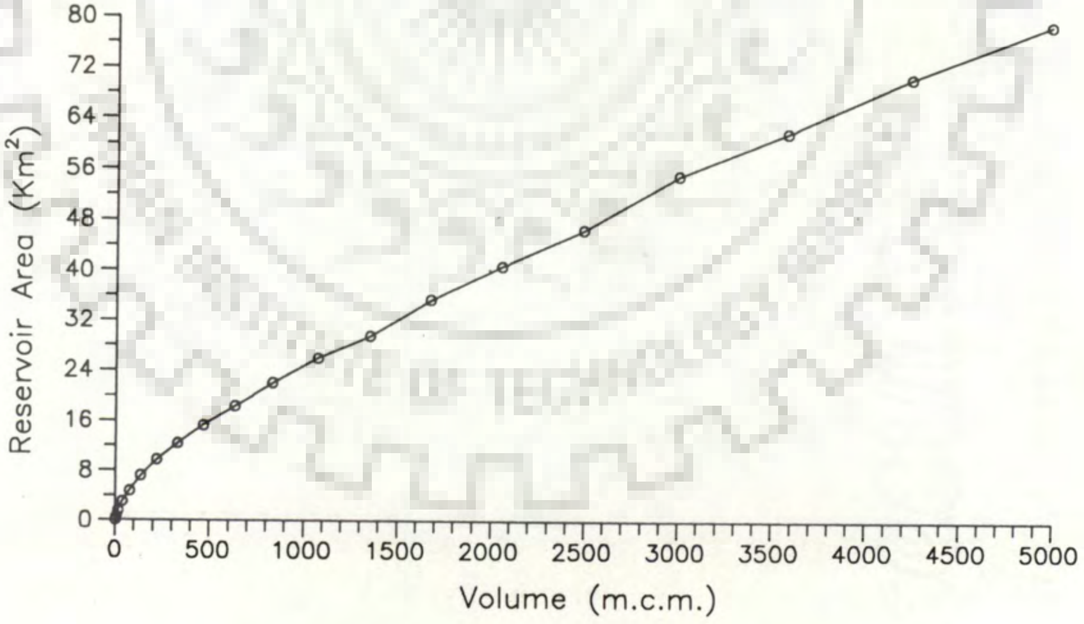


**Fig. 5.25 : Reservoir Volume vs Area for Karun-1 Dam Site**

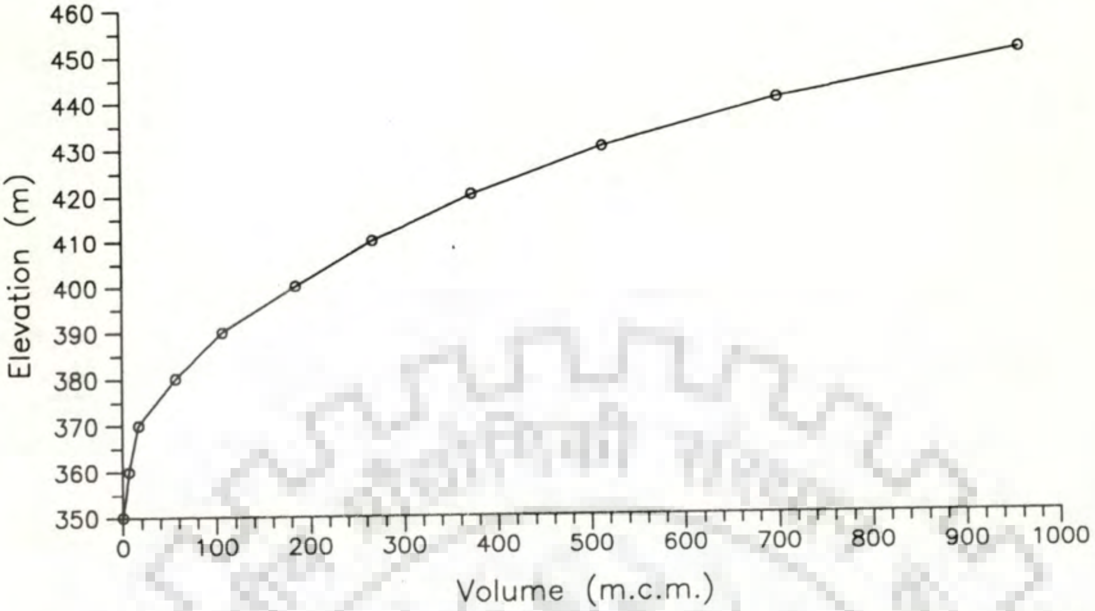


Fig. 5.26 : Reservoir Volume vs Elevation for Godar-e-Landar (Tunnel Scheme)

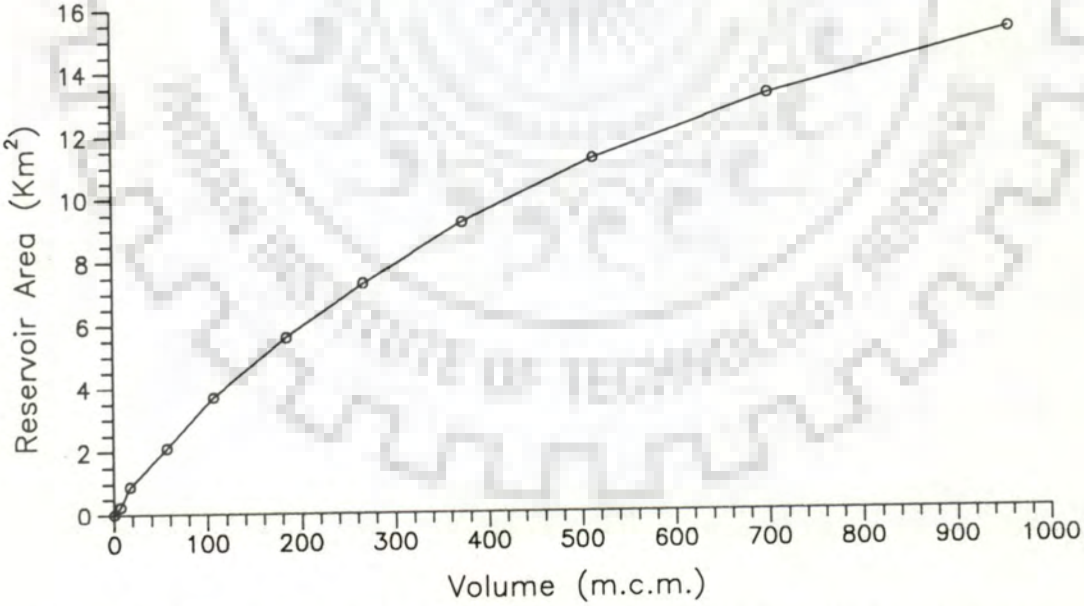


Fig. 5.27 : Reservoir Volume vs Area for Godar-e-Landar (Tunnel Scheme)

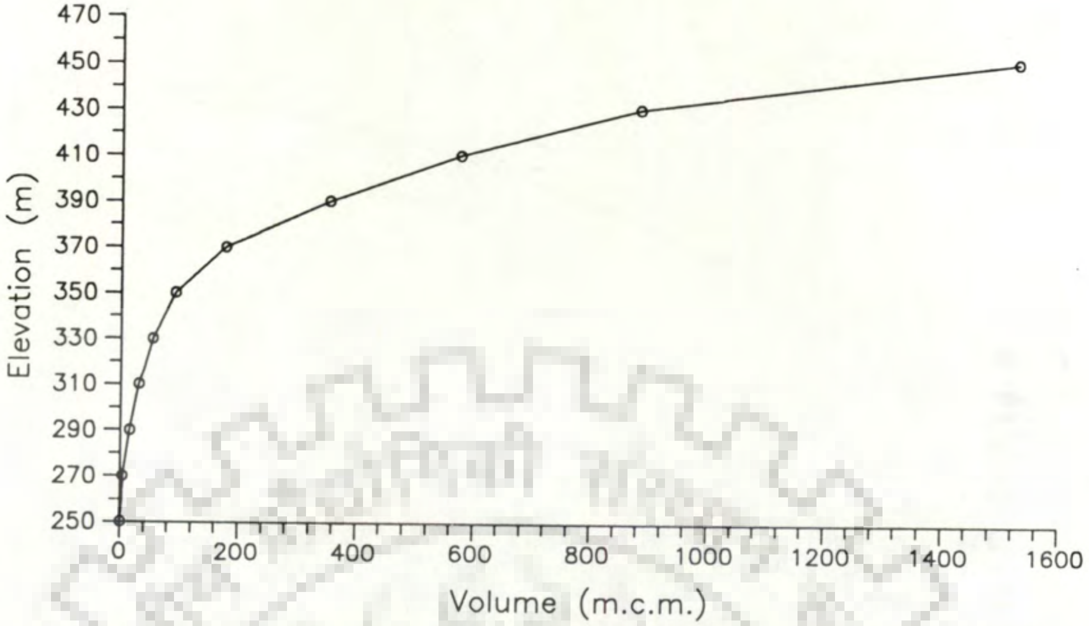


Fig. 5.28 : Reservoir Volume vs Elevation for Godar-e-Landar (Up Dam Site)

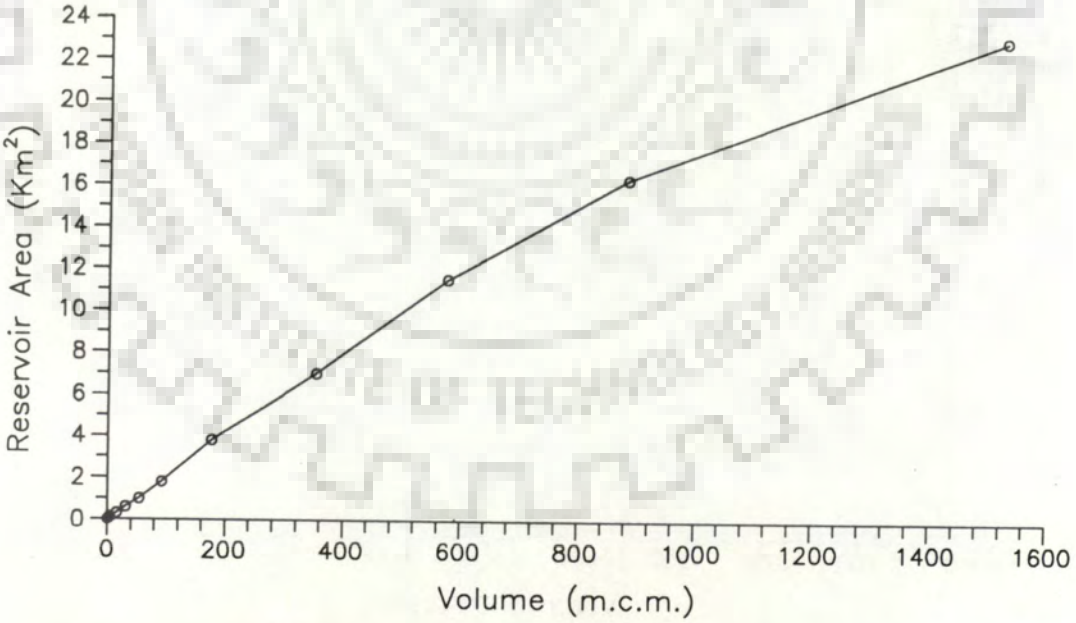


Fig. 5.29 : Reservoir Volume vs Area for Godar-e-Landar (Up Dam Site)

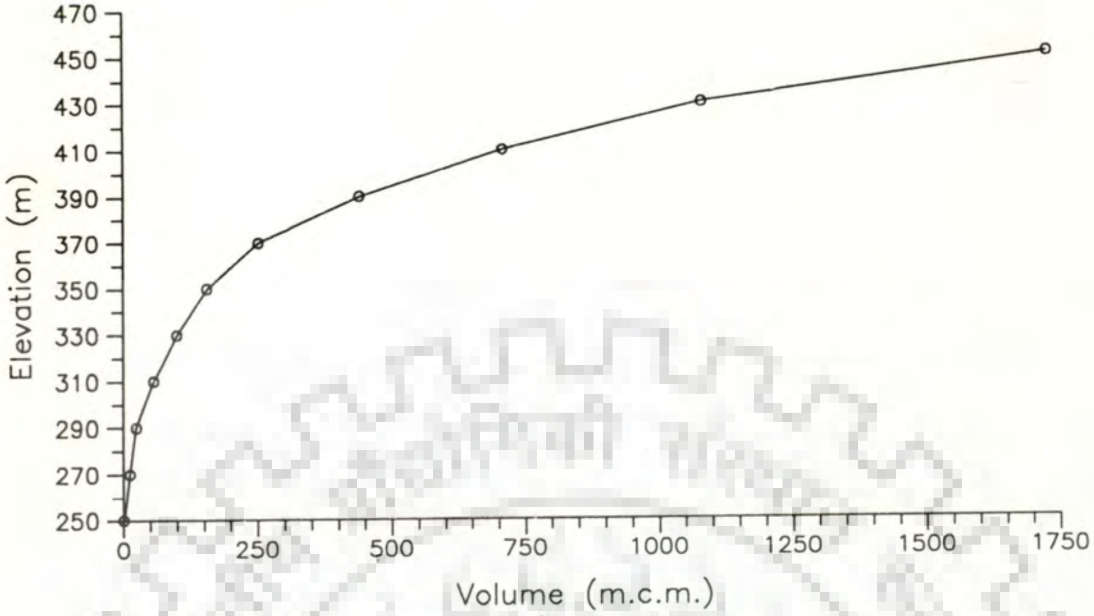


**Fig. 5.30 : Reservoir Volume vs Elevation for Godar-e-Landar (Down Dam Site)**

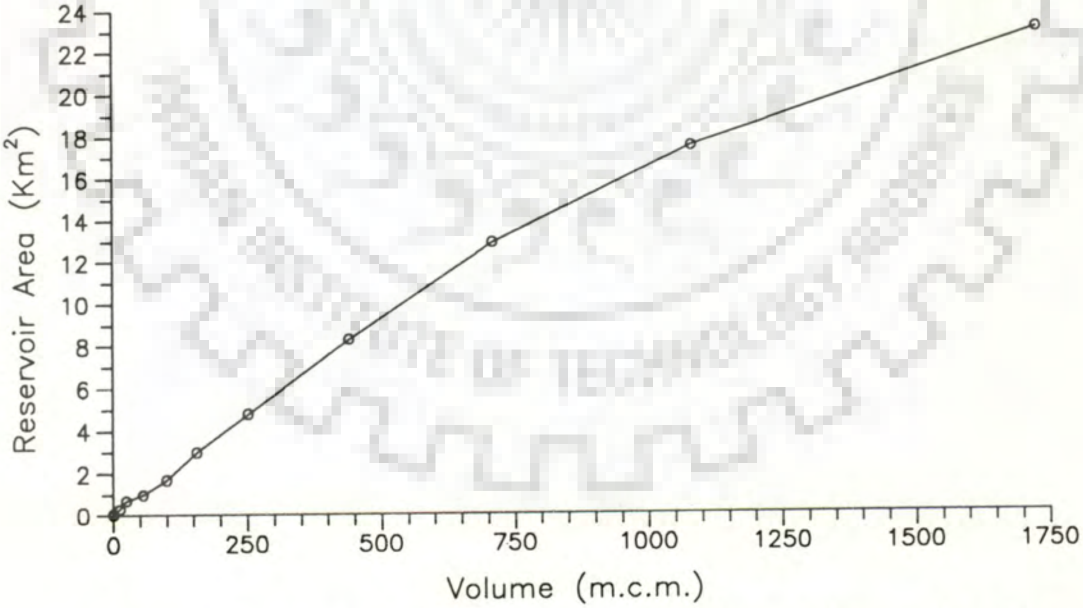


**Fig.5.31 : Reservoir Volume vs Area for Godar-e-Landar (Down Dam Site)**

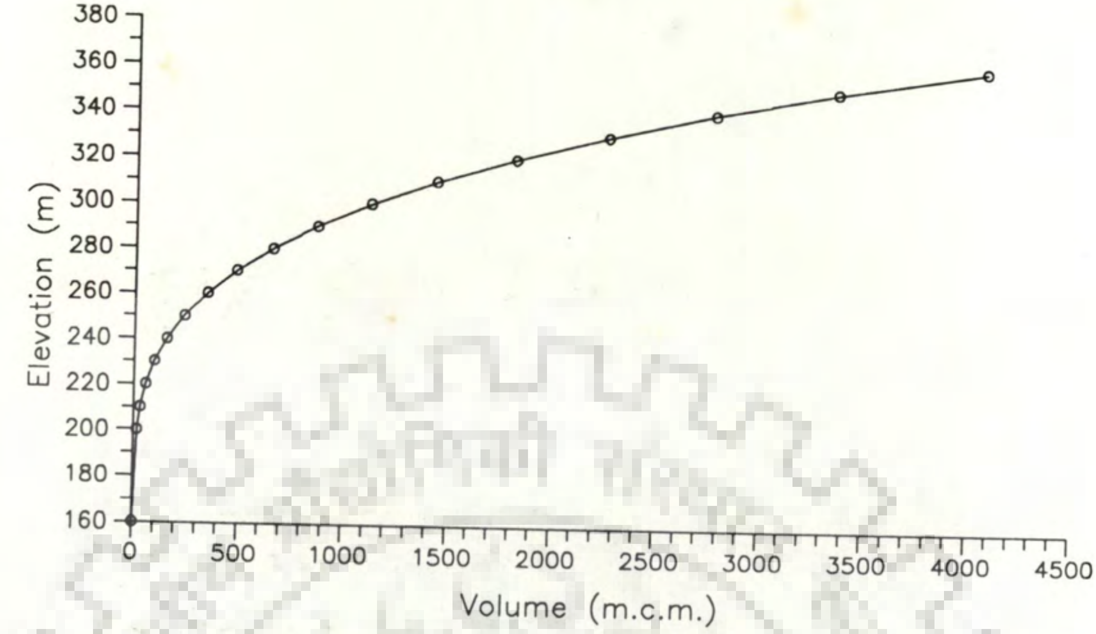


**Fig. 5.32 : Reservoir Volume vs Elevation for Dez Dam Site**

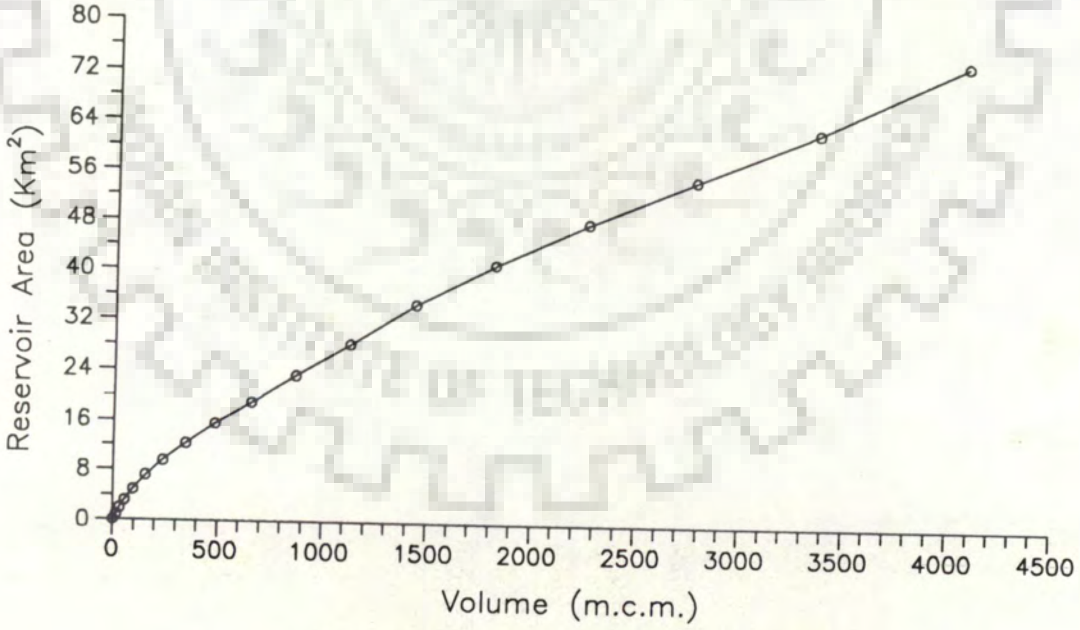


**Fig. 5.33 : Reservoir Volume vs Area for Dez Dam Site**

# CHAPTER-VI

# DEVELOPMENT OF SOFTWARE FOR INPUT DATA MATRIX GENERATION FOR LINEAR PROGRAMMING MODEL

## (INDEMAG PACKAGE)

Chapter 7 - VI

# DEVELOPMENT OF SOFTWARE FOR INPUT DATA MATRIX GENERATION FOR LINEAR PROGRAMMING MODEL (INDMAG PACKAGE)

## 6.1 INTRODUCTION

Computer technology has already exerted a major impact on water resources. It can not be doubted that such an impact will continue to accelerate with the further growth and evolution of computer technology. Increasingly ambitious computations will be made possible by increasingly powerful and effective machines and by new software production methods (Bugliarello, 1987). Meanwhile, computer packages for addressing water resources problems are being developed and implemented which incorporate advance computer-based capabilities for several purposes. But procedure of utilization of these packages vary from packages to packages as well as from problem to problem (Bhattacharya, 1987 ; Srivastava, 1991; and Suryawanshi, 1987). Standard Linear Programming packages like MPS (Mathematical Programming System) of the IBM computers (Mathematical programming system-extended, 1972), and LINGO, of LINDO systems Inc./are efficient and generalized computer packages.These packages cater the needs for all types of operation research problems in linear programming.In a very standard format the input data matrix of the non-zero elements of the set of constraint equations is fed to the computer.This technique may be simple and fool proof but the data handling is extensive.In fact, a few number of users in the field of systems analysis can have access to these computer packages.In spite of the availability of several computer programmes for linear programming in the books or otherwise, the data feeding is extensive.These programmes are neither very efficient nor generalized with regard to feeding of the input data matrix. The entire matrix of zero and non-zero elements of the constraint equations are to be prepared on paper and is then fed as the input data (Srivastava, 1991). In this chapter a generalised computer algorithm has been presented to generate the input data matrix of the non zero elements for the set of constraint equations of the Linear Programming Model presented in Chapter 3 of a complex water resources system. This has to be appended as a subroutine sub programme to the main computer programme on linear programming (Appendix 6.I).

## 6.2 THE INPUT DATA IN MATRIX FORM

The modeled constraint equations and the objective function given in Chapter 3 are rewritten below, by arranging the variables in the following sequence:

$O_{i,t}$ , $S_{i,t-1}$, $S_{i,t}$ , $Y_i$ , $Sp_{i,t}$ , $Ymax_{i,t}$, $O^0_{i,t}$ ,

$O^{j\,=\,i\,+\,L\,+\,1}_{i,\,t}$ , ................, $O^{j\,=\,i\,+\,L\,+\,Q}_{i,\,t}$ ,$Ir_i$ ,

$Ir^i_{j\,=}$, .........., $Ir^i_{j\,=}$, $H_i$ , $E_i$, $E^T_{i,t}$ and $E_{i,t}$ .

where,

i = $i^{th}$ reservoir / site,

L = number of parallel reservoirs (excluding $i^{th}$ reservoir), i.e., total number of parallel reservoirs are,(L + 1). In case there is no reservoir in parallel, L=0,

Q = total number of multi-irrigation areas,

j = $j^{th}$ multi-irrigation areas, and

t = any time period.

### 6.2.1 Reservoir Constraints

$$O_{i,t} - (1-a_{i,t})\, S_{i,t-1} + (1+a_{i,t})\, S_{i,t} = F_{i,t} + P_{i,t} + I_{i,t}$$

$$-Ao_i\, e^0_{i,t} - O^d_{i,t} - O^m_{i,t} \qquad \text{for all i and t} \qquad (3.4)$$

$$S_{i,t-1} - Y_i \leq 0 \qquad \text{for all i and t} \qquad (3.7)$$

$$S_{i,t-1} \geq Yd_i \qquad \text{for all i and t} \qquad (3.8)$$

### 6.2.2 Flood Control Constraint

$$S_{i,t-1} - Ymax_{i,t} \leq 0 \qquad \text{for all i and t} \qquad (3.18)$$

### 6.2.3 Irrigation Constraints

$$-O^0_{p,t} + K_{p,t}\, Ir_p \leq I''_{p,t} \qquad \text{for all p and t} \qquad (3.19)$$

where, p = i, i+1, ..........., i+L .

$$-\left\{\sum_{p=i}^{i+L} O^j_{p,t}\right\} + \left\{\sum_{p=i}^{i+L} K_{j,t}\, Ir^p_j\right\} \leq I''_{j,t} \qquad \text{for all j and t} \qquad (3.20)$$

where,

j= i + L + 1, i + L + 2, ..........., i + L + Q .

$$O_{p,t} - Sp_{p,t} - O^0_{p,t} - \left\{\sum_{j=i+L+1}^{i+L+Q} O^j_{p,t}\right\} = 0 \qquad \text{for all p and t} \qquad (3.21)$$

$$Ir_j - \sum_{p=1}^{i+L} Ir^p_j = 0 \qquad \text{for all j} \qquad (3.22)$$

### 6.2.4 Hydroelectric Energy Constraints

$$-(C_f\ e_i\ He_{i,t}) * O_{i,t} + E^T_{i,t} = 0 \qquad \text{for all i and t} \qquad (3.23)$$

$$-(\alpha_{i,t}\, h_{i,t})\, H_i + E^T_{i,t} = 0 \qquad \text{for all i and t} \qquad (3.24)$$

$$-\eta_{i,t}\, E_i + E^T_{i,t} - \hat{E}_{i,t} = 0 \qquad \text{for all i and t} \qquad (3.25)$$

### 6.2.5 The Objective Function

$$\text{Max} : \left[\sum_t \left(a_{4,i} - C'_{1,i} - Om'_{1,i}\right)\right] Y_i - \left[\sum_t \left(a_{4,i}\ Ymax_{i,t}\right)\right] +$$

$$\left[a_{2,i} - \left(C'_{2,i} + Om'_{2,i}\right)\right] Ir_i - \left(C'_{3,i} + Om'_{3,i}\right) H_i + a_{3,i}\ E_i \qquad (3.26)$$

Also, further we may put,

$$b_{i,t} = \left(1 - \bar{a}_{i,t}\right) ; \qquad d_{i,t} = \left(1 + \bar{a}_{i,t}\right) ;$$

$$X_{i,t} = F_{i,t} + P_{i,t} + I_{i,t} - Ao_i\ e^0_{i,t} - O^d_{i,t} - O^m_{i,t} \quad \text{in Equation} \qquad (3.4)$$

$$R_{i,t} = C_f\ e_i\ He_{i,t} \quad \text{in Equation} \qquad (3.23)$$

$$T_{i,t} = \alpha_{i,t}\ h_{i,t} \quad \text{in Equation} \qquad (3.24)$$

and

$$M_i = \left(\sum_t a_{4,i}\right) - \left(C'_{1,i} + Om'_{1,i}\right) ; \qquad U_i = a_{4,i} ;$$

$$V_i = a_{2,i} - \left(C'_{2,i} + Om'_{2,i}\right) ;$$

$Z_i = \left(C'_{3,i} + Om'_{3,i}\right)$ ; and $D_i = a_{3,i}$ , in the objective function.

### 6.2.6 The Data Matrix in Detached Coefficient Form

In order to explain the principle of the computer algorithm the above constraint equations are opened and have been written for 2 reservoirs and 2 multi-irrigation areas, i.e., i =1, L = 1, Q = 2, and t=2 (Figure 6.1).

### 6.2.6.1 Reservoir constraints for site 1, and time periods t=1 & 2

Here, i = 1, and the constraint equations are,

$$O_{1,1} - b_1 S_{1,0} + d_{1,1} S_{1,1} = X_{1,1} \qquad \text{for } t = 1 \tag{6-4-1-1}$$

$$O_{1,2} + d_{1,2} S_{1,0} - b_{1,2} S_{1,1} = X_{1,2} \qquad \text{for } t = 2 \tag{6-4-1-2}$$

Since there is no U/S reservoir $F_{1,1} = I_{1,1}$ and $F_{1,2} = I_{1,2}$ in $X_{1,1}$ and respectively. Also, it is assumed that, $S_{1,2} = S_{1,0}$

$$S_{1,0} - Y_1 \leq 0 \qquad \text{for } t = 1 \tag{6-7-1-1}$$

$$S_{1,1} - Y_1 \leq 0 \qquad \text{for } t = 2 \tag{6-7-1-2}$$

$$S_{1,0} \geq Yd_1 \qquad \text{for } t = 1 \tag{6-8-1-1}$$

$$S_{1,1} \geq Yd_1 \qquad \text{for } t = 2 \tag{6-8-1-2}$$

It is assumed that flood provision is only for first time period, i.e.,

$$S_{1,0} - Ymax_{1,1} \leq 0 \qquad \text{for } t = 1 \tag{6-18-1-1}$$

### 6.2.6.2 Irrigation constraints for sites 1 & 2, multi-irrigation areas 3 & 4, and time periods t = 1 & 2

Since, reservoirs 1 and 2 are parallel with each other, i=1 for reservoir 1, and here,

p = i, ........, i + L, or p = 1 to 2, and

j = i + L + 1, ...., i + L + Q , or j = 3 to 4, and the constraint equations are,

$$-O^0_{1,1} + K_{1,1} Ir_1 \leq I''_{1,1} \qquad \text{for } t = 1 \tag{6-19-1-1}$$

$$-O^0_{1,2} + K_{1,2} Ir_1 \leq I''_{1,2} \qquad \text{for } t = 2 \tag{6-19-1-2}$$

$$-O^{3}_{1,1} + K_{3,1}\, Ir^{1}_{3} \leq I''_{3,1} \qquad \text{for } t = 1 \qquad (6\text{-}20\text{-}1\text{-}1)$$

$$-O^{3}_{1,2} + K_{3,2}\, Ir^{1}_{3} + \leq I''_{3,2} \qquad \text{for } t = 2 \qquad (6\text{-}20\text{-}1\text{-}2)$$

$$O_{1,1} - Sp_{1,1} - O^{0}_{1,1} - O^{3}_{1,1} - O^{4}_{1,1} = 0 \qquad \text{for } t = 1 \qquad (6\text{-}21\text{-}1\text{-}1)$$

$$O_{1,2} - Sp_{1,2} - O^{0}_{1,2} - O^{3}_{1,2} - O^{4}_{1,2} = 0 \qquad \text{for } t = 2 \qquad (6\text{-}21\text{-}1\text{-}2)$$

$$-O^{0}_{2,1} + K_{2,1}\, Ir_{2} \leq I''_{2,1} \qquad \text{for } t = 1 \qquad (6\text{-}19\text{-}2\text{-}1)$$

$$-O^{0}_{2,2} + K_{2,2}\, Ir_{2} \leq I''_{2,2} \qquad \text{for } t = 2 \qquad (6\text{-}19\text{-}2\text{-}2)$$

$$-O^{4}_{1,1} + K_{4,1}\, Ir^{1}_{4} - O^{4}_{2,1} + K_{4,1}\, Ir^{2}_{4} \leq I''_{4,1} \qquad \text{for } t = 1 \qquad (6\text{-}20\text{-}2\text{-}1)$$

$$-O^{4}_{1,2} + K_{4,2}\, Ir^{1}_{4} - O^{4}_{2,2} + K_{4,2}\, Ir^{2}_{4} \leq I''_{4,2} \qquad \text{for } t = 2 \qquad (6\text{-}20\text{-}2\text{-}2)$$

$$O_{2,1} - Sp_{2,1} - O^{0}_{2,1} - O^{4}_{2,1} = 0 \qquad \text{for } t = 1 \qquad (6\text{-}21\text{-}2\text{-}1)$$

$$O_{2,2} - Sp_{2,2} - O^{0}_{2,2} - O^{4}_{2,2} = 0 \qquad \text{for } t = 2 \qquad (6\text{-}21\text{-}2\text{-}2)$$

$$Ir_{3} - Ir^{1}_{3} = 0 \qquad (6\text{-}22\text{-}1\text{-}1)$$

$$Ir_{4} - Ir^{1}_{4} - Ir^{2}_{4} = 0 \qquad (6\text{-}22\text{-}1\text{-}2)$$

### 6.2.6.3 Hydroelectric constraints for site 1, & time periods t=1 & 2

Here, i = 1, and the constraint equations are,

$$- R_{1,1}{*}\, O_{1,1} + E^{T}_{1,1} = 0 \qquad \text{for } t = 1 \qquad (6\text{-}23\text{-}1\text{-}1)$$

$$- R_{1,2}{*}\, O_{1,2} + E^{T}_{1,2} = 0 \qquad \text{for } t = 2 \qquad (6\text{-}23\text{-}1\text{-}2)$$

$-T_{1,1}{}^{*}\ H_1 + E^{T}_{1,1} = 0$ for $t = 1$ (6-24-1-1)

$-T_{1,2}{}^{*}\ H_1 + E^{T}_{1,2} = 0$ for $t = 2$ (6-24-1-2)

$-\eta_{1,1}\ E_1 + E^{T}_{1,1} - \hat{E}_{1,1} = 0$ for $t = 1$ (6-25-1-1)

$-\eta_{1,2}\ E_1 + E^{T}_{1,2} - \hat{E}_{1,2} = 0$ for $t = 2$ (6-25-1-2)

### 6.2.6.4 Reservoir constraints for site 2, and time periods t = 1 & 2

Here, $i = 2$, and the constraint equations are,

$O_{2,1} - b_{2,1}\ S_{2,0} + d_{2,1}\ S_{2,1} = X_{2,1}$ for $t = 1$ (6-4-2-1)

$O_{2,2} + d_{2,2}\ S_{2,0} - b_{2,2}\ S_{2,1} = X_{2,2}$ for $t = 2$ (6-4-2-2)

Since there is no U/S reservoir $F_{2,1} = I_{2,1}$ and $F_{2,2} = I_{2,2}$ in $X_{2,1}$ and $X_{2,2}$ respectively. Also, it is assumed that, $S_{2,2} = S_{2,0}$

$S_{2,0} - Y_2 \leq 0$ for $t = 1$ (6-7-2-1)

$S_{2,1} - Y_2 \leq 0$ for $t = 2$ (6-7-2-2)

$S_{2,0} \geq Yd_2$ for $t = 1$ (6-8-2-1)

$S_{2,1} \geq Yd_2$ for $t = 2$ (6-8-2-2)

It is assumed that flood provision is only for first time period, i.e.,

$S_{2,0} - Ymax_{2,1} \leq 0$ for $t = 1$ (6-18-2-1)

### 6.2.6.5 Hydroelectric constraints for site 2, and time periods t=1 & 2

Here, i=2, and the constraint equations are,

$$-R_{2,1} * O_{2,1} + E^{T}_{2,1} = 0 \qquad \text{for } t = 1 \qquad (6\text{-}23\text{-}2\text{-}1)$$

$$-R_{2,2} * O_{2,2} + E^{T}_{2,2} = 0 \qquad \text{for } t = 2 \qquad (6\text{-}23\text{-}2\text{-}2)$$

$$-T * H_2 + E^{T}_{2,1} = 0 \qquad \text{for } t = 1 \qquad (6\text{-}24\text{-}2\text{-}1)$$

$$-T_{2,2} * H_2 + E^{T}_{2,2} = 0 \qquad \text{for } t = 2 \qquad (6\text{-}24\text{-}2\text{-}2)$$

$$-\eta_{2,1} E_2 + E^{T}_{2,1} - E_{2,1} = 0 \qquad \text{for } t = 1 \qquad (6\text{-}25\text{-}2\text{-}1)$$

$$-\eta_{2,2} E_2 + E^{T}_{2,2} - E_{2,2} = 0 \qquad \text{for } t = 2 \qquad (6\text{-}25\text{-}2\text{-}2)$$

### 6.2.6.6 The objective function

The objective function coefficients can be written in the following manner:

$$\left[M_1 Y_1 - a_{4,1} \, Ymax_{1,1} + V_1 \, Ir_1 - Z_1 H_1 + a_{3,1} E_1\right] +$$

$$\left[M_2 Y_2 - a_{4,2} \, Ymax_{2,1} + V_2 \, Ir_2 - Z_2 H_2 + a_{3,2} E_2\right] + \left[V_3 \, Ir_3\right] + \left[V_4 \, Ir_4\right] \quad (6.26)$$

The data Matrix in Detached Coefficient Form is given in Table 6.1.

## 6.3 AlGORITHM FOR CREATION OF DATA MATRIX

Based on the Detached Coefficients in Matrix Form of Table 6.1, a computer algorithm is presented below to create the desired Input Data Matrix for the Linear Programming Model. This computer algorithm based computer programme can be appended as a subroutine sub-programme to a available computer programme on Linear Programming. Before producing the algorithm, the following variables are defined below.

ICOLR or $C^{R}_{i,r}1$ = a Column Index Number (CIN), defining the location of a particular design variable($Y_i$) and/or stating location of a set of series of time variant variables

$$(O_{i,t}, S_{i,t-}, Sp_{i,t-1}, Ymax_{i,t}, O^{0}_{i,t}$$

$O^{j=i+L+1}_{i,t}, \ldots\ldots\ldots, O^{j=i+L+Q}_{i,t})$concerning $i^{th}$ reservoir,

ICOLI or $C^{I}_{i,r}2$ = a Column Index Number (CIN), defining the location of a particular design variable,

$(Ir_i, Ir^{i}_{j=i+L+1}, \ldots, Ir^{i}_{j=i+L+Q})$ concerning irrigation from $i^{th}$ reservoir,

ICOLP or $C^{P}_{i,r}3$ = a Column Index Number (CIN), defining the location of a particular design variable $(H_i, E_i)$ and/or starting location of a set of series of time variant variables $(E^{T}_{i,t}, \bar{E}_{i,t})$ concerning hydropower from $i^{th}$ reservoir,

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,

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

IROW = a counter for the total number of rows in the problem,

JCOL = a counter for the time increment (increment for the column number for the variables /parameters varying with time). A temporary variable,

JROW = a counter for the time increment (increment for the row number). A temporary variable,

A = the Coefficient Matrix,

B = the Right Hand Side Matrix,

C = the Objective Function Matrix,

CODE = the variable defining the natur eof a constraint equation, and

MM = total time period for which the model is to be run.

The various Column Index Numbers, CIN's, are defined below in Table 6.2. Looking at the 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 with time increments.For example, in the continuity equation for a reservoir the variables $S_{i,t-1}$, $S_{i,t}$, and $O_{i,t}$, and parameter $X_{i,t}$have this property, as seen from Table 6.1 (refer Equation 6-4-1-1, and 6-4-1-2 for reservoir 1 and Equation 6-4-2-1, and 6-4-2-2 for reservoir 2). This property has been utilized in the algorithm presented here, and further this logic can be easily programmed on computer. A general flow chart of the entire algorithm (computer programme flow chart)has been shown in Figure 6.2.As a sample a detailed flow chart of the algorithm for generating the non-zero coefficients of the Continuity Equation (3.4) (computer programme flow chart) is given in Figure 6.3.The detailed computer programme is given in Appendix 6.I.A.

A sample data for the problem above explained is given in Table 6.3.The main features of this computer algorithm (computer programme), now named as **INDMAG PACKAGE**, are as follows.

(1) The computer programme is very general and can be applied
   (a) to any single reservoir or to any multi-reservoir systems
   (b) to any single or multipurpose reservoir, and
   (c) to any configuration, consisting of reservoirs in series and parallel.

(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 data A, B, C, CODE, NLET, NGET, NET, M, and K are generated by the algorithm.

Where,

NLET = the number of less than equal to constraints,

NGET = the number of greater than equal to constraints,

NET = the number of equal to constraints,

M = the total number of constraints, and

K = the total number of variables.

(5) For using this computer programme, firstly, define the problem to be solved, and the set of system constraints involved. Secondly, choose the sequence of the variables which are to be used and then define the sequence of CIN's and their values (VCIN). The CIN of a variable not considered will be zero.

To explain the above, the sample data for a single purpose irrigation reservoir, a single purpose hydropower reservoir, and two hydropower reservoirs in series are given in Appendices 6.II, 6.III, and 6.IV respectively.

(6) The modifications (additions/deletions)in the input data file already created (Appendix 6.III), due to the exclusion and/or inclusion of constraint equations and/or variables, arising out of any omission/error, at any stage for a large size problem are very simple here as compared to MPS and

LINGO.This is because in latter packages the changes required are to be thoroughly searched in the already existing data file, which is cumbersome.

(7) The input data file for each of the reservoirs of the system problem can be prepared individually and tested and then can be added together with minor changes for multi-reservoir problem.

(8) The above software package is very convenient and can be used repetitively for any number of times without any hesitation due to its simplicity in data feeding as compared to other available softwares.

(9) At last, the above approach is feasible, efficient, flexible, fool proof and requires very small input data and time. The Table 6.4 compares the statistics of the extent of the size of input data file, in each of the packages.

**Sample Input data for INDMAG PACKAGE :**

In order to explain the flexibility in the input data for INDMAG Computer Package on linear programming a sample input data for two multi-purpose reservoirs in parallel form with two multi-irrigation areasis presented in Table 6.3.

The Coefficients of Matrices [A], [B] and [C] for two multi-purpose parallel reservoirs with two multi-irrigation areas is presented in Table 6.1. It shows that the number of constraint equations in matrix [A] is equal to 40, also the number of variables which is contributed in this matrix is equal to 45.

## Table 6.1: Cofficients of the Matrices [A], [B], [C] for Two Parallel Reservoirs with Two Multi Irrigation Areas.

| COL. NO. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VAR. | $O_{1,1}$ | $O_{1,2}$ | $S_{1,0}$ | $S_{1,1}$ | $Y_1$ | $Sp_{1,1}$ | $Sp_{1,2}$ | $Ymax_{1,1}$ | $O^0_{1,1}$ | $O^0_{1,2}$ | $O^3_{1,1}$ | $O^3_{1,2}$ | $O^4_{1,1}$ | $O^4_{1,2}$ | $Ir_1$ | $Ir^1_3$ | $Ir^1_4$ | $H_1$ | $E_1$ | $E^T_{1,1}$ | $E^T_{1,2}$ | $\bar{E}_{1,1}$ | $\bar{E}_{1,2}$ | $O_{2,1}$ | $O_{2,2}$ | $S_{2,0}$ | $S_{2,1}$ | $Y_2$ | $Sp_{2,1}$ | $Sp_{2,2}$ | $Ymax_{2,1}$ | $O^0_{2,1}$ | $O^0_{2,2}$ | $O^4_{2,1}$ | $O^4_{2,2}$ | $Ir_2$ | $Ir^2_4$ | $H_2$ | $E_2$ | $E^T_{2,1}$ | $E^T_{2,2}$ | $\bar{E}_{2,1}$ | $\bar{E}_{2,2}$ | $Ir_3$ | $Ir_4$ | SIGN | RHS [B] |
| CIN | $C^R_{1,1}$ | | $C^R_{1,2}$ | | $C^R_{1,3}$ | $C^R_{1,4}$ | | $C^R_{1,5}$ | $C^R_{1,6}$ | | $C^R_{1,7}$ | | $C^R_{1,8}$ | | $C^I_{1,1}$ | $C^I_{1,2}$ | $C^I_{1,3}$ | $C^P_{1,1}$ | $C^P_{1,2}$ | $C^P_{1,3}$ | | $C^P_{1,4}$ | | $C^R_{2,1}$ | | $C^R_{2,2}$ | | $C^R_{2,3}$ | $C^R_{2,4}$ | | $C^R_{2,5}$ | $C^R_{2,6}$ | | $C^R_{2,7}$ | | $C^I_{2,1}$ | $C^I_{2,2}$ | $C^P_{2,1}$ | $C^P_{2,2}$ | $C^P_{2,3}$ | | $C^P_{2,4}$ | | $C^I_{3,1}$ | $C^I_{4,1}$ | | |
| VCIN | 1 | | 3 | | 5 | 6 | | 8 | 9 | | 11 | | 13 | | 15 | 15 | 17 | 18 | 19 | 20 | | 22 | | 24 | | 26 | | 28 | 29 | | 31 | 32 | | 34 | | 36 | 37 | 38 | 39 | 40 | | 42 | | 44 | 45 | | |
| Equations | | | | | | | | | | | | | | | | | | | | Coefficient Matrix [A] | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6-19-1-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | $K_{1,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | $I^*_{1,1}$ |
| 6-19-1-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 | 0 | $K_{1,2}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | $I^*_{1,2}$ |
| 6-19-2-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 | $K_{2,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | $I^*_{2,1}$ |
| 6-19-2-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | $K_{2,2}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | $I^*_{2,2}$ |
| 6-20-1-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 | 0 | $K_{3,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | $I^*_{3,1}$ |
| 6-20-1-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 | $K_{3,2}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | $I^*_{3,2}$ |
| 6-20-2-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 | $K_{4,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | $K_{4,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | $I^*_{4,1}$ |
| 6-20-2-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | $K_{4,2}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | $K_{4,2}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | $I^*_{4,2}$ |
| 6-21-1-1 | 1 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | -1 | 0 | -1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-21-1-2 | 0 | 1 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | -1 | 0 | -1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-21-2-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | -1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-21-2-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | -1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-22-1-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | = | 0 |
| 6-22-1-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | = | 0 |
| 6-4-1-1 | 1 | 0 | $-b_{1,1}$ | $d_{1,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | $X_{1,1}$ |
| 6-4-1-2 | 0 | 1 | $d_{1,2}$ | $-b_{1,2}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | $X_{1,2}$ |
| 6-7-1-1 | 0 | 0 | 1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | 0 |
| 6-7-1-2 | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | 0 |
| 6-8-1-1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≥ | $Yd_1$ |
| 6-8-1-2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≥ | $Yd_1$ |
| 6-18-1-1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | 0 |
| 6-23-1-1 | $-R_{1,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-23-1-2 | 0 | $-R_{1,2}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-24-1-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $-T_{1,1}$ | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-24-1-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -T1,2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-25-1-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $-q_{1,1}$ | 1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-25-1-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $-q_{1,2}$ | 0 | 1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-4-2-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | $-b_{2,1}$ | $d_{2,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | $X_{2,1}$ |
| 6-4-2-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | $d_{2,2}$ | $-b_{2,2}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | $X_{2,2}$ |
| 6-7-2-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | 0 |
| 6-7-2-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | 0 |
| 6-8-2-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≥ | $Yd_2$ |
| 6-8-2-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≥ | $Yd_2$ |
| 6-18-2-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | 0 |
| 6-23-2-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $-R_{2,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-23-2-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $-R_{2,2}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | = | 0 |
| 6-24-2-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $-T_{2,1}$ | 0 | 1 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-24-2-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $-T_{2,2}$ | 0 | 0 | 1 | 0 | 0 | 0 | 0 | = | 0 |
| 6-25-2-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $-q_{2,1}$ | 1 | 0 | -1 | 0 | 0 | 0 | = | 0 |
| 6-25-2-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $-q_{2,2}$ | 0 | 1 | 0 | -1 | 0 | 0 | = | 0 |
| | | | | | | | | | | | | | | | | | | | | Coefficient Matrix [C] | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6-26 | 0 | 0 | 0 | 0 | $M_1$ | 0 | 0 | $-a_{4,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | $V_1$ | 0 | 0 | $-Z_1$ | $a_{3,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $M_2$ | 0 | 0 | $-a_{4,2}$ | 0 | 0 | 0 | 0 | $V_2$ | 0 | $-Z_2$ | $a_{3,2}$ | 0 | 0 | 0 | 0 | $V_3$ | $V_4$ | | |

CIN = Column Index Number , VCIN = Value of CIN,RHS represents CODE. M = Number of constraint equations in Matrix [A],and K= Total Number of Variables.

Here ,M = 40 , & K = 45.

Note : All the parameters ,$b_{1,t}$,$d_{1,t}$ ,$X_{1,t}$ ,$R_{1,t}$ ,$T_{1,t}$ ,$M_1$, $V_1$ ,$Z_1$ ,and $D_1$ in the matrices [A],[B],and [C] are known quantities and are computed in the computer programme, INDMAG, from the Basic Input Data.

Table 6.2: Definition of Column Index Numbers

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| V | $O_{i,1}$ | $S_{i,0}$ | $Y_i$ | $Sp_{i,1}$ | $Ymax_{i,1}$ | $O^0_{i,1}$ | $O^{j=i+L+1}_{i,1}$ | $\ldots O^{j=i+L+Q}_{i,1}$ |
| CIN | ICOLR(i,1) | ICOLR(i,2) | ICOLR(i,3) | ICOLR(i,4) | ICOLR(i,5) | ICOLR(i,6) | ICOLR(i,7) | ... ICOLR(i,7+Q-1) |
| | $C^R_{i,1}$ | $C^R_{i,2}$ | $C^R_{i,3}$ | $C^R_{i,4}$ | $C^R_{i,5}$ | $C^R_{i,6}$ | $C^R_{i,7}$ | $\ldots C^R_{i,7+Q-1}$ |
| V | $Ir_i$ | $Ir^i_{j=i+L+1}$ | | ........... | $Ir^i_{j=i+L+Q}$ | | | |
| CIN | ICOLI(i,1) | ICOLI(i,2) | | ........... | ICOL I(i,2+Q-1) | | | |
| | $C^I_{i,1}$ | $C^I_{i,2}$ | | ........... | $C^I_{i,2+Q-1}$ | | | |
| V | $H_i$ | $E_i$ | $E^T_{i,1}$ | | $\hat{E}_{i,1}$ | | | |
| CIN | ICOLP(i,1) | ICOLP(i,2) | ICOLP(i,3) | | ICOLP(i,4) | | | |
| | $C^P_{i,1}$ | $C^P_{i,2}$ | $C^P_{i,3}$ | | $C^P_{i,4}$ | | | |

V = Variable, CIN = Column Index Number.

**Table 6.3: Sample Input Data File for INDMAG PACKAGE for Two Parallel Reservoirs With Two Multi-irrigation Areas**

| Input Parameter/Variable (Read Statement) | Input Parameter/Variable (Data to be Given) |
|---|---|
| IGEN | 1 |
| IPRNT | 0 |
| NTYPE NOPT | 1 0 |
| NRE | 4 |
| MM | 2 |
| SITNA | KARUN-1 |
| SITNO | SITE-4 |
| IRENO | 1 |
| NOS | 0 |
| NSURC | - |
| NFLM | 1 |
| IFLM | 1 -1 |
| MMFS | 1 1 |
| FLOW | 1530 533 |
| FLOW1 | 2*0 |
| FLOW2 | 2*0 |
| P | 2*0 |
| WS | 12.1 13.4 |
| NVAR | 23 |
| ITHMI | -1 |
| NCOLR NCOLI NCOLP | 8 3 4 |
| ICOLR | 1 3 5 6 8 9 11 13 |
| ICOLI | 15 16 17 |
| ICOLP | 18 19 20 22 |
| XK1 | 0.78 0.22 |
| XK3 | .156 .044 |
| IRP | 1 |
| IRFMI | 1 |
| LRFMI | 1 |
| QSFMI | 2 |
| IRJP | 1 1 |
| | -1 1 |
| YD | 1280 |
| XNETA | 0.506 0.494 |
| COEFF EFFCI | 2.6 0.885 |
| ALPHA | 0.64 0.61 |
| HEAD | 2*160 |
| TIME | 2*720 |
| C11 OM11 | 17.85 1.95 |
| A2 C21 OM21 | 10 4.31 0.93 |
| A3 C31 OM31 | 0.15 46.3 25.2 |
| A4 | 5 |
| A0 AA | 30 0.01 |
| ET | 0.21 0.09 |
| ISAL | -1 |
| NVAAL | - |
| IUP ILO IEQ | - |
| UL LM EQU | - |
| EQ | 7*1 |
| G | 0 |
| IBAR | 0 |

**Table 6.3 continued**

| | |
|---|---|
| SITNA | DEZ |
| SITNO | SITE-5 |
| IRENO | 2 |
| NOS | 0 |
| NSURC | - |
| NFLM | 1 |
| IFLM | 1 -1 |
| MMFS | 1 1 |
| FLOW | 896.7 403 |
| FLOW1 | 2*0 |
| FLOW2 | 2*0 |
| P | 2*0 |
| WS | 8.3 10.7 |
| NVAR | 43 |
| ITHMI | -1 |
| NCOLR NCOLI NCOLP | 7 2 4 |
| ICOLR | 24 26 28 29 31 32 34 |
| ICOLI | 36 37 |
| ICOLP | 38 39 40 42 |
| XK1 | 0.75 0.25 |
| XK3 | 0.075 0.025 |
| IRP | 1 |
| IRFMI | -1 |
| LRFMI | - |
| QSFMI | - |
| IRJP | - |
| YD | 930 |
| XNETA | 0.506 0.494 |
| COEFF EFFCI | 2.6 .885 |
| ALPHA | 0.64 0.61 |
| HEAD | 2*180 |
| TIME | 2*720 |
| C11 OM11 | 16.8 1.80 |
| A2 C21 OM21 | 10 19.3 4.10 |
| A3 C31 OM31 | 0.15 72 39.2 |
| A4 | 5 |
| A0 AA | 22 0.067 |
| ET | 0.21 0.09 |
| ISAL | 1 |
| NVAAL | 5 1 |
| IUP ILO IEQ | -1 -1 2 |
| UL LM EQU | 0 0 2500 |
| EQ | 7*1 |
| G | 0 |
| IBAR | 0 |
| SITNA | MULTI-IRRIGATION AREA |
| SITNO | MIR-1 |
| IRENO | 3 |
| NOS | 0 |
| NSURC | - |
| NFLM | 0 |
| IFLM | - |
| MMFS | - |
| FLOW | 220 156 |
| FLOW1 | 2*0 |
| FLOW2 | 2*0 |
| P | 2*0 |

**Table 6.3 continued**

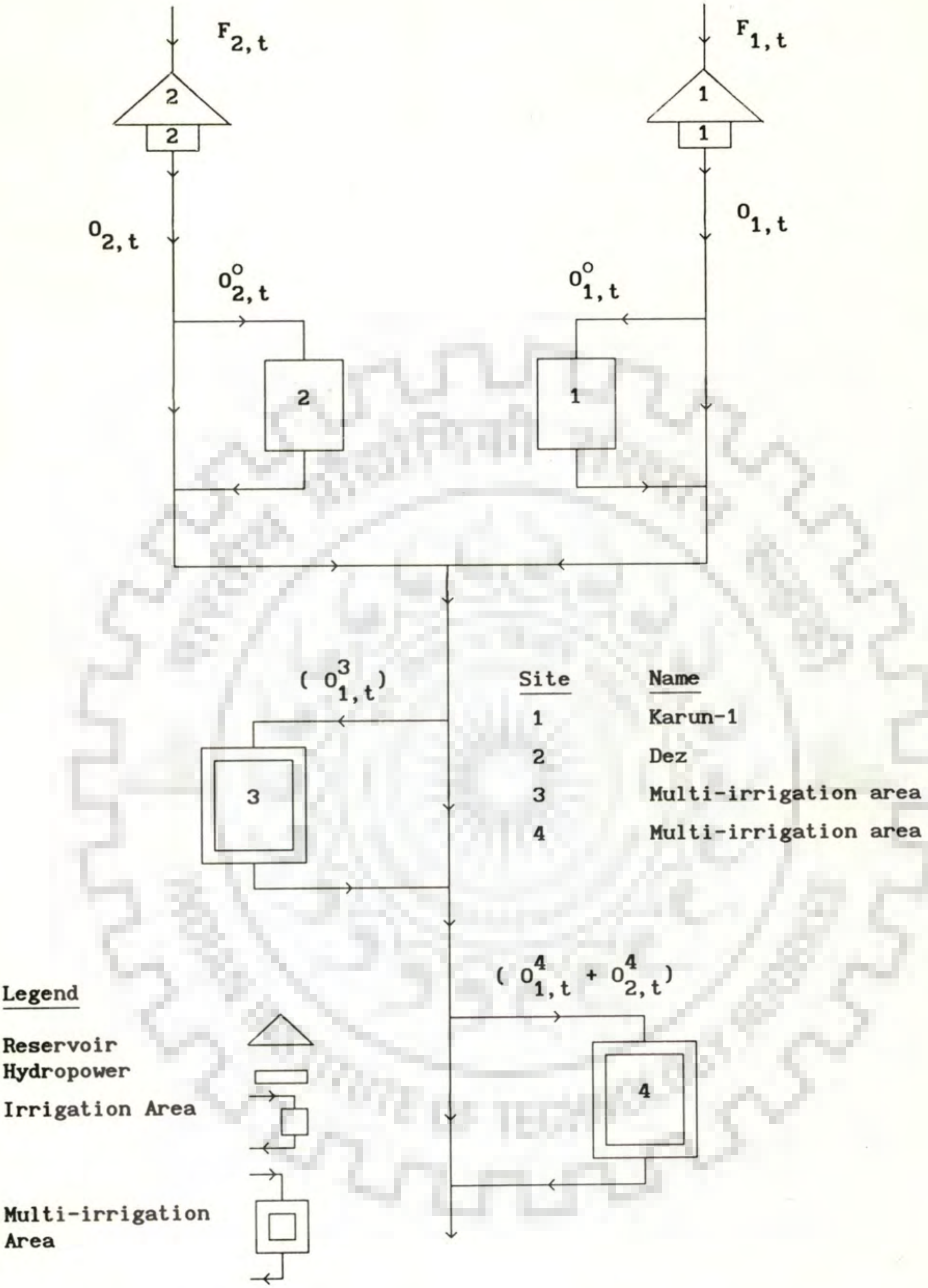
| | |
|---|---|
| WS | 2*0 |
| NVAR | 44 |
| ITHMI | 1 |
| NCOLR NCOLI NCOLP | 0 1 0 |
| ICOLR | - |
| ICOLI | 44 |
| ICOLP | - |
| XK1 | 0.7 0.3 |
| XK3 | 2*0 |
| IRP | -1 |
| IRFMI | -1 |
| LRFMI | - |
| QSFMI | - |
| IRJP | - |
| YD | 0 |
| XNETA | - |
| COEFF EFFCI | - |
| ALPHA | - |
| HEAD | - |
| TIME | - |
| C11 OM11 | - |
| A2 C21 OM21 | 12 2.2 0.80 |
| A3 C31 OM31 | - |
| A4 | - |
| A0 AA | 2*0 |
| ET | 2*0 |
| ISAL | -1 |
| NVAAL | - |
| IUP ILO IEQ | - |
| UL LM EQU | - |
| EQ | 7*0 |
| G | 0 |
| IBAR | 0 |
| SITNA | MULTI-IRRIGATION AREA |
| SITNO | MIR-2 |
| IRENO | 4 |
| NOS | 0 |
| NSURC | - |
| NFLM | 0 |
| IFLM | - |
| MMFS | - |
| FLOW | 280 120 |
| FLOW1 | 2*0 |
| FLOW2 | 2*0 |
| P | 2*0 |
| WS | 2*0 |
| NVAR | 45 |
| ITHMI | 1 |
| NCOLR NCOLI NCOLP | 0 1 0 |
| ICOLR | - |
| ICOLI | 45 |
| ICOLP | - |
| XK1 | 0.65 0.35 |
| XK3 | 2*0 |
| IRP | -1 |
| IRFMI | -1 |
| LRFMI | - |

**Table 6.3 continued**

| | |
|---|---|
| QSFMI | - |
| IRJP | - |
| YD | 0 |
| XNETA | - |
| COEFF EFFCI | - |
| ALPHA | - |
| HEAD | - |
| TIME | - |
| C11 OM11 | - |
| A2 C21 OM21 | 9 2.3 0.7 |
| A3 C31 OM31 | - |
| A4 | - |
| A0 AA | 2*0 |
| ET | 2*0 |
| ISAL | -1 |
| NVAAL | - |
| IUP ILO IEQ | - |
| UL LM EQU | - |
| EQ | 7*0 |
| G | 0 |
| IBAR | 0 |
| 1PRNT | 0 |
| IDSCO | - |
| IRDC IPDC | - |
| TIRRI | - |
| THPRE | - |

**Table 6.4: Statistics of the Input Data Files for Various Computer Packages on Linear Programming**

| Problem | No.of Time Periods MM | No. of Constraints Equations, M | No. of Variables, K | Non-zero Coefficients in Matrices [A], [B], and [C] | Size of Input Data File in terms of Number of Data Lines Package | | |
|---|---|---|---|---|---|---|---|
| | | | | | INDMAG | MPS | LINGO |
| Hydropower Reservoir | 2 | 12 | 11 | 33 | 37 | 39 | 14 |
| | 12 | 72 | 51 | 204 | 37 | 236 | 79 |
| Irrigation Reservoir | 2 | 10 | 10 | 30 | 36 | 39 | 14 |
| | 12 | 60 | 50 | 204 | 36 | 236 | 79 |
| Multiple and Multi-Purpose Reservoir Table 6.3 | 12 | 240 | 270 | 762 | 141 | 716 | 241 |



| Site | Name |
|---|---|
| 1 | Karun-1 |
| 2 | Dez |
| 3 | Multi-irrigation area |
| 4 | Multi-irrigation area |

Figure 6.1 Two parallel Reservoirs with 2 Multi-irrigation Areas

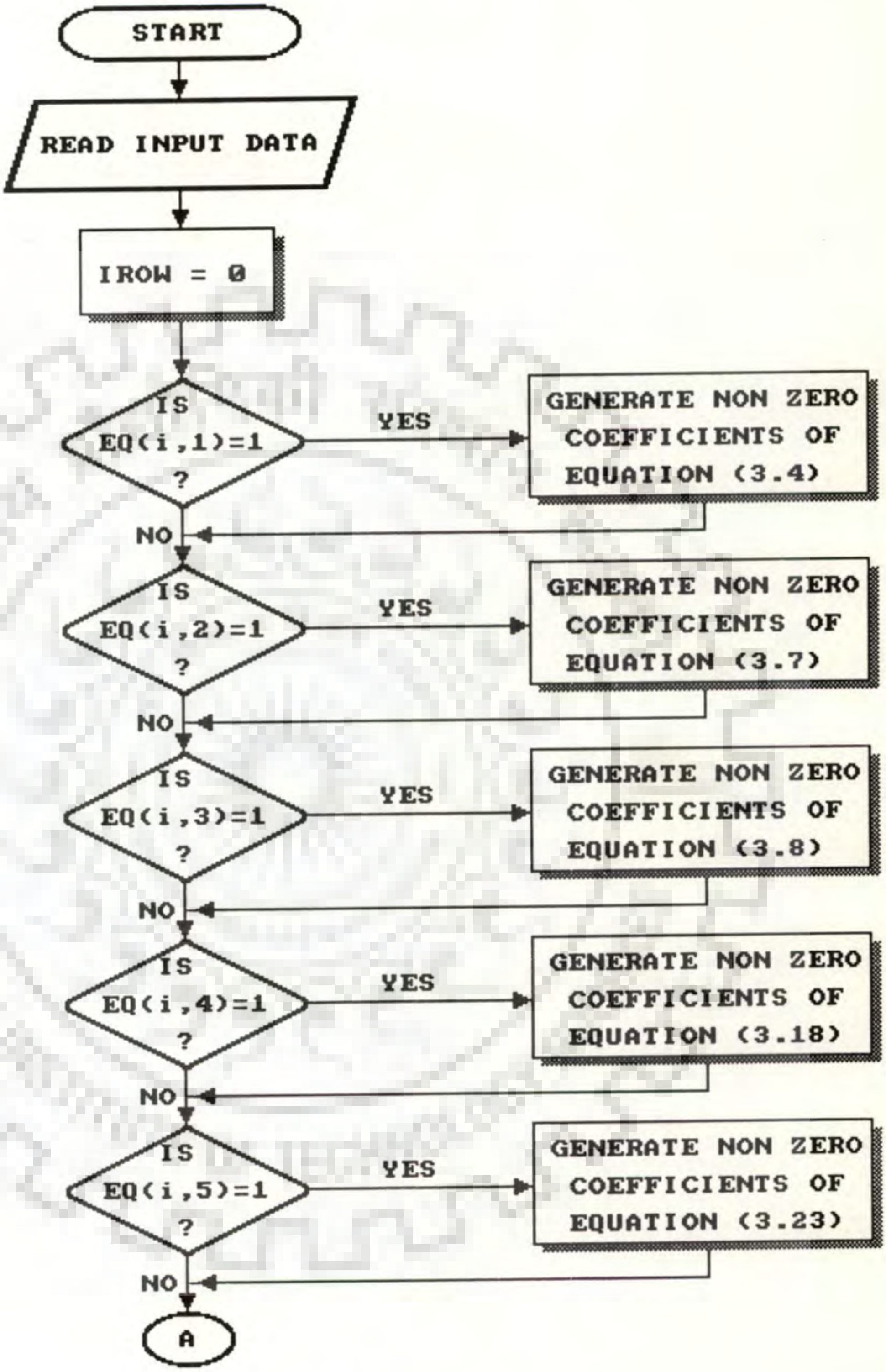


**Fig.6.2 General Flow Chart for Generation of Coefficients of Input Data Matrix for Linear Programming Model (INDMAG PACKAGE)**

Fig.6.2 continued

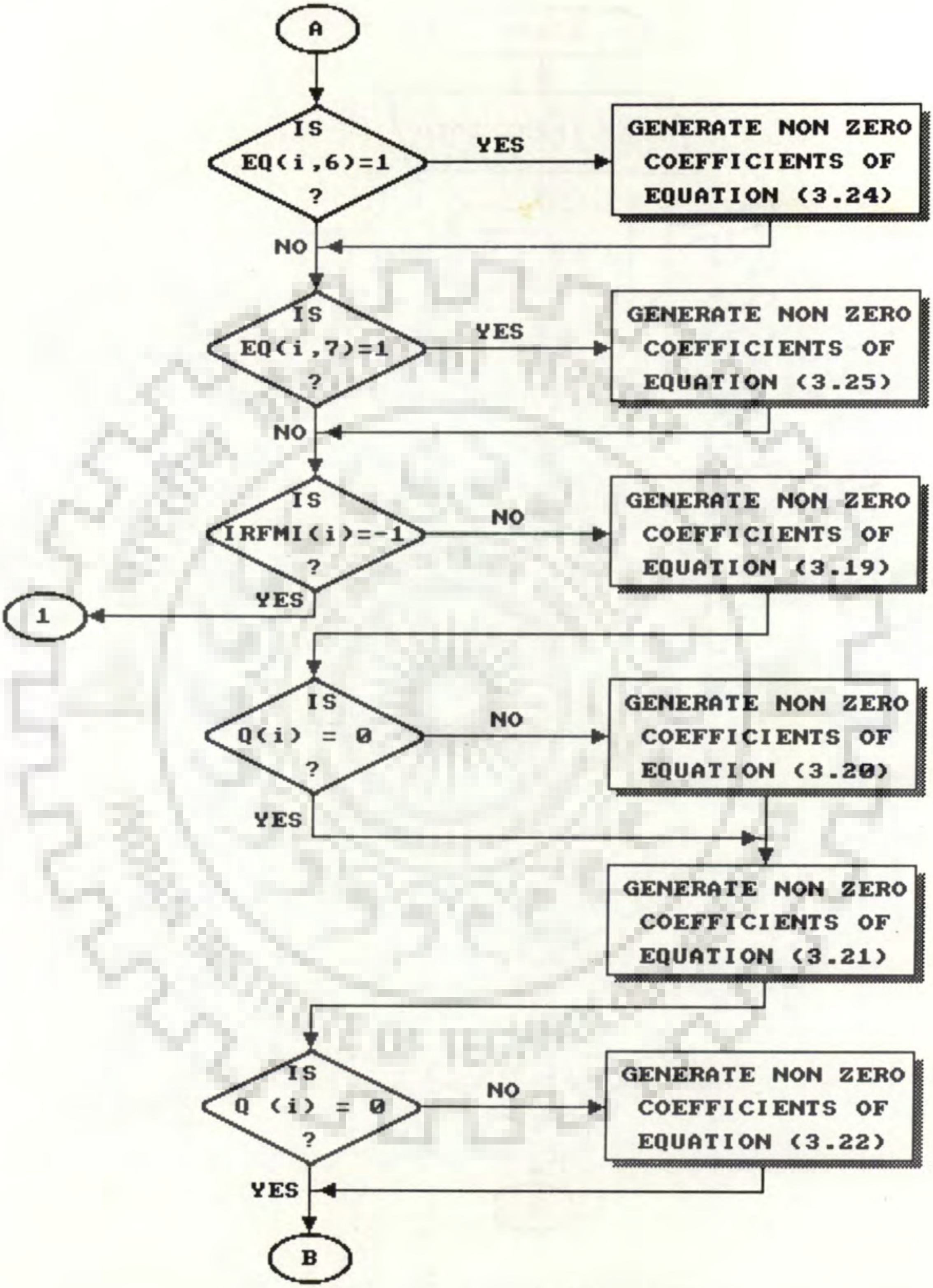
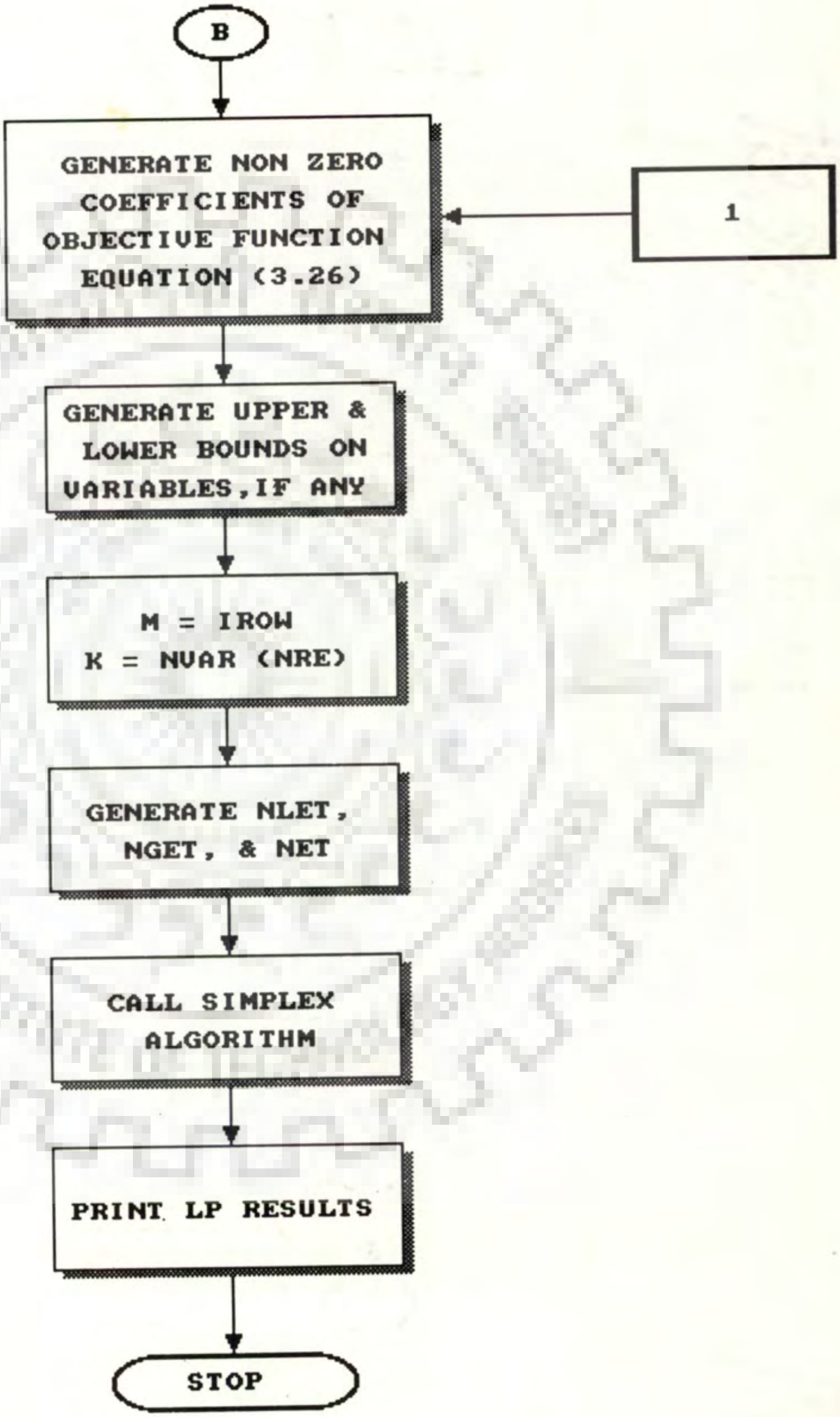


Fig.6.2 continued



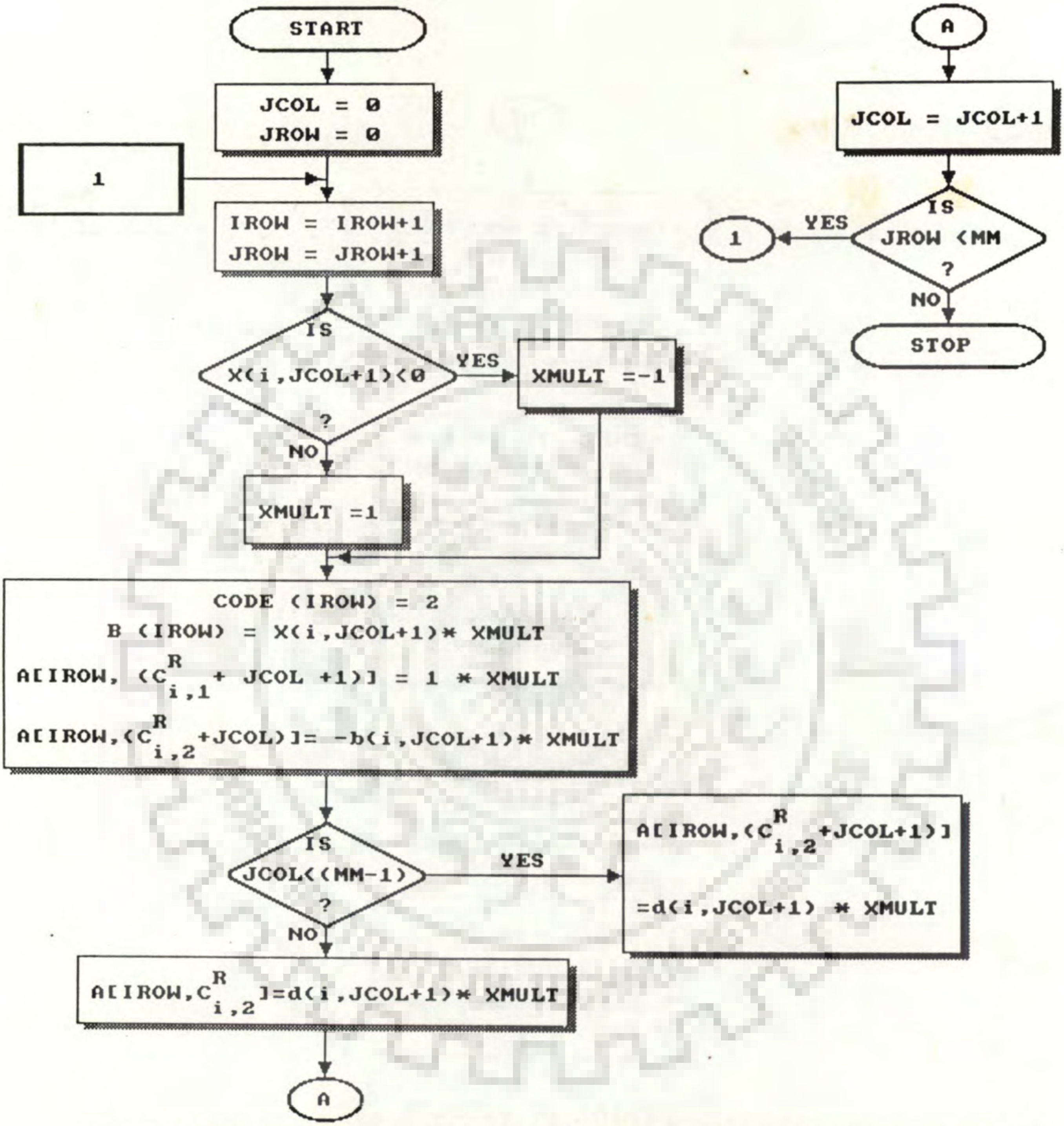


Fig.6.3 Flow Chart for Generation of Non-Zero Coefficients for Continuity Equation (3.4) in (INDMAG PACKAGE)

# CHAPTER-VII

# COMPUTATION, RESULTS AND DISCUSSION

## Chapter-VII

# COMPUTATION, RESULTS AND DISCUSSION

### 7.1 GENERAL

Both analytical and simulation models were applied for the design of the problem to find the optimal configuration of the reservoirs and the optimal sizes of reservoirs and projects targets. The analytical mathematical model (Linear programming model) was used to find a reasonably small set of possible optimal design alternatives. A suitable algorithm was developed for multi purpose, multiple reservoirs as well as for multi irrigation areas to create the Input Data Matrix, and was attached to the main computer programme containing the Simplex algorithm for the computation of the above Linear Programming screening model. At this stage the large number of alternative combinations could be reduced to a less number of alternative designs, and could indicate a path on the response surface. It may be then possible to use the simulation technique for further analysis, to obtain the near optimal design variables.

Computation of LP model was done on the basis of the monthly flows, using an average flow, and 90% and, 70% dependable flow as a representative year depending upon the type of the project. The simulation model considered 12 monthly flows and thirty eight years of data were used. The flood storages in Karun-1 reservoir were 750, 600, 540 and 20 m.c.m. in the months of February, March, April and May respectively. For Dez reservoir the flood storages were 820, 800, and 40 m.c.m. in the months of March, April and May respectively. It is noted that all input data required for the computation of LP and simulation models are given in Chapter 5. Basic data were obtained from Mahab Ghodss Consulting Engineers Company Various Project Reports, 1968 to 1993). The computations were done on TATA ELXI Power series 3220 computer and PC. (GENIUS 386).

## 7.2 COST, BENEFIT AND LOSS FUNCTIONS

### 7.2.1 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 (James and Lee, 1971). These functions were developed from the data obtained from numerous volumes of reports in the Master Plan for the Karun river system.

The system 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 model 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.

Since the value of capital cost of the projects were not at the level of present time, therefore, to evaluate the present value of the capital cost of each project including dam, power plant, and irrigation diversions, suitable inflation rate up to 1994 was considered and the present value of the capital cost of dam, power plant irrigation were calculated. For Karun-1 project (i=4) considering 7% constant inflation rate from 1970 to 1994 calculations are as follows:

**(1) Present value of dam capital cost**

$$F = P\left(\frac{F}{P}, i_f\ \%, n\right) = P\,(1 + i_f)^n$$

$$(K_{4,1})_{24} = 116129 * 10^6\ (1+0.07)^{24} = 589049 * 10^6 \text{ Rials}$$

**(2) Present value of irrigation and diversion capital cost**

$$(K_{4,2})_{24} = 308539 * 10^6 \text{ Rials}$$

**(3) Present value of power plant capital cost**

$$(K_{4,3})_{24} = 504882 * 10^6 \text{ Rials}$$

### 7.2.2 Cost, Benefit, and Loss Functions for Linear Programming Model

For linear programming unit capital costs were calculated from the given project provisions and then unit annual cost of each item was calculated.

#### 7.2.2.1 Computation of unit annual cost of reservoir

Unit annual costs were calculated from the capital costs of the reservoir, subjected to the following items,

**(i)** Unit annual interest on capital cost = $( i^r_{i,1} * CC_{i,1})$

**(ii)** Unit annual depreciation cost = $\left[\dfrac{i^d_{i,1}}{(1 + i^d_{i,1})^n - 1}\right] * CC_{i,1}$

**(iii)** Unit annual operation and maintenance cost = $(i^{om}_{i,1} * CC_{i,1})$

Unit annual cost can be defined as the sum of unit annual interest on capital cost, unit annual depreciation cost, and unit annual operation and maintenance cost, i.e.,

$$C_{i,1} = CC_{i,1} \left[ i^r_{i,1} + \frac{i^d_{i,1}}{(1 + i^d_{i,1})^n - 1} \right] + CC_{i,1}\, i^{om}_{i,1}$$

$$= C'_{i,1} + Om'_{i,1}$$

where,

$$CC_{i,1} = \frac{K_{i,1}}{Y_i}$$

$K_{i,1}$ = capital cost of $i^{th}$ reservoir,

$CC_{i,1}$ = unit capital cost of $i^{th}$ reservoir,

$C_{i,1}$ = unit annual cost function of $i^{th}$ reservoir,

$i^{r}_{i,1}$ = annual rate for calculating annual interest on capital cost of reservoir,

$i^{d}_{i,1}$ = annual rate for calculating annual depreciation on capital cost of reservoir using sinking fund method,

$i^{om}_{i,1}$ = annual rate for calculating annual operation & maintenance on the capital cost of reservoir,

$C'_{i,1}$ = unit annual capital cost of reservoir, and

$Om'_{i,1}$ = unit annual OM cost of reservoir.

For example the capital cost of Karun-1 reservoir (i=4) is Rials 589049 * $10^6$ (based on price level of 1994), and gross storage of the reservoir (up to top of the dam )is 3020 m.c.m. The values of $i^{r}_{4,1}$, $i^{d}_{4,1}$, and $i^{om}_{4,1}$ are 7%, 1%, and 1% respectively. Hence

**Unit capital cost of reservoir :**

$$CC_{4,1} = \left(\frac{589049}{3020}\right) * 10^6 = 195 * 10^6 \text{ Rials/m.c.m.}$$

**(i)** **Unit annual interest on capital cost:**

$$\left[(0.07 * 195 * 10^6)\right] = 13.65 * 10^6 \text{ Rials/m.c.m.}$$

**(ii)** **Unit annual depreciation cost:**

$$\left[\frac{0.01}{(1 + 0.01^{38})-1}\right] * 195 * 10^6$$

$= 4.2 * 10^6$ Rials/m.c.m.

Here it is assumed that n = 38 years.

$i^{r}_{i,2}$ = annual rate for calculating annual interest on capital cost of irrigation,

$i^{d}_{i,2}$ = annual rate for calculating annual depreciation on capital cost of irrigation using sinking fund method,

$i^{om}_{i,2}$ = annual rate for calculating annual operation & maintenance on the capital cost of irrigation,

$C'_{i,2}$ = unit annual capital cost of irrigation, and

$Om'_{i,2}$ = unit annual OM cost of irrigation.

Capital cost of the irrigation is Rials 308539 * $10^6$ (based on price level of 1994), & and annual water requirement for irrigation is 540 m.c.m. The values of $i^{r}_{4,2}$, $i^{d}_{4,2}$, and $i^{om}_{4,2}$ are 7%, 2%, and 2% respectively. Hence

**Unit capital cost of irrigation:**

$$CC_{4,2} = \left(\frac{308539}{6638}\right) * 10^6 = 46.5 * 10^6 \text{ Rials/m.c.m.}$$

**(i)** **Unit annual interest on capital cost:**

$$\left[(0.07) * (46.5 * 10^6)\right] = 3.3 * 10^6 \text{ Rials/m.c.m.}$$

**(ii)** **Unit annual depreciation cost:**

$$\left[\frac{0.01}{(1 + 0.01^{38}) -1}\right] * 46.5 * 10^6 = 1.01 * 10^6 \text{ Rials/m.c.m.}$$

Here it is assumed that n=38 years.

**(iii)** **Unit annual operation and maintenance cost:**

$$\left[(0.02) * (46.5 * 10^6)\right] = 0.93 * 10^6 \text{ Rials/m.c.m.}$$

Therefore, unit annual cost of irrigation $= \left[(i) + (ii)\right] + (iii)$

**(iii) Unit annual operation and maintenance cost:**

$$\left[(0.01) * (195 * 10^6)\right] = 1.95 * 10^6 \text{ Rials/m.c.m.}$$

Therefore,

$$\text{unit annual cost of reservoir} = \left[(\text{i}) + (\text{ii})\right] + (\text{iii})$$

$$\left[(13.65 * 10^6) + (4.2 * 10^6)\right] + (1.95 * 10^6) = (17.85 * 10^6 + 1.95 * 10^6)$$

$$= 19.8 * 10^6 \text{ Rials/m.c.m.}$$

or $C'_{4,1} = 17.85 * 10^6$ Rials/m.c.m.,

and $Om'_{4,1} = 1.95 * 10^6$ Rials/m.c.m.

### 7.2.2.2 Computation of unit annual cost of irrigation

Similarly unit annual cost of irrigation can be defined as :

$$C_{i,2} = CC_{i,2}\left[i^r_{i,2} + \frac{i^d_{i,2}}{(1+i^d_{i,2})^n - 1}\right] + CC_{i,2}\, i^{om}_{i,2}$$

$$= C'_{i,2} + Om'_{i,2}$$

where,

$$CC_{i,2} = \frac{K_{i,2}}{Ir_i}$$

and

$K_{i,2}$ = capital cost of $i^{th}$ irrigation site/area,

$CC_{i,2}$ = uuit capital cost of $i^{th}$ irrigation site/area,

$C_{i,2}$ = unit annual cost function of $i^{th}$ irrigation site/area,

$$\left[(3.3 * 10^6) + (1.01 * 10^6)\right] + (0.93 * 10^6) = (4.31 * 10^6 + 0.93 * 10^6)$$

$$= 5.24 * 10^6 \text{ Rials/m.c.m.}$$

or $C'_{4,2} = 4.31 * 10^6$ Rials/m.c.m.,

and $Om'_{4,2} = 0.93 * 10^6$ Rials/m.c.m.

### 7.2.2.3 Computation of unit annual cost of hydropower plant

Unit annual cost of hydropower plant can be defined:

$$C_{i,3} = CC_{i,3} \left[ i^r_{i,3} + \frac{i^d_{i,3}}{(1 + i^d_{i,3})^n - 1} \right] + CC_{i,3}\, i^{om}_{i,3}$$

$$= C'_{i,3} + Om'_{i,3}$$

where,

$$CC_{i,3} = \frac{K_{i,3}}{H_i}$$

$K_{i,3}$ = capital cost of hydropower plant at $i^{th}$ site,

$CC_{i,3}$ = unit capital cost of hydropower plant at $i^{th}$ site,

$C_{i,3}$ = unit annual cost function of hydropower plant at $i^{th}$ site,

$i^r_{i,3}$ = annual rate for calculating annual interest on capital cost of hydropower,

$i^d_{i,3}$ = annual rate for calculating annual depreciation on capital cost of hydropower, using sinking fund method,

$i^{om}_{i,3}$ = annual rate for calculating annual operation & maintenance on the capital cost of hydropower plant at $i^{th}$ site,

$H_i$ = power plant capacity in MW at $i^{th}$site,

$C'_{i,3}$ = unit annual capital cost of hydropower plant, and

$Om'_{i,3}$ = unit annual OM cost of hydropower plant.

Capital cost of the power plant is Rials 504882 * $10^6$ (based on price level of 1994), & and total power plant capacity is 1000 MW. The values of $i^{r}_{4,3}$, $i^{d}_{4,3}$, and $i^{om}_{4,3}$ are 7%, 2%, and 5% respectively, hence

**Unit capital cost of hydropower plant:**

$$CC_{4,3} = \left(\frac{504882}{1000}\right) * 10^6 = 504.9 * 10^6 \text{ Rials/MW.}$$

**(i) Unit annual interest on capital cost:**

$$\left[(0.07) * (504.9 * 10^6)\right] = 35.3 * 10^6 \text{ Rials/MW.}$$

**(ii) Unit annual depreciation cost:**

$$\left[\frac{0.02}{(1 + 0.02)^{38} - 1}\right] * 504.9 * 10^6 = 9.0 * 10^6 \text{ Rials/MW.}$$

It is assumed that n = 38 years.

**(iii) Unit annual operation and maintenance cost:**

$$\left[(0.05\ ) * (504.9 * 10^6)\right] = 25.2 * 10^6 \text{ Rials/MW.}$$

Therefore, unit annual cost of hydropower plant = $\left[\text{(i)} + \text{(ii)}\right] + \text{(iii)}$

$$5.3 * 10^6) + (9.0 * 10^6)\Big] + (25.2 * 10^6) = (44.3 * 10^6 + 25.2 * 10^6)$$

$$= 79.5 * 10^6 \text{ Rials/MW.}$$

or $C'_{4,3} = 44.3 * 10^6$ Rials/MW.

and $Om'_{4,3} = 25.2 * 10^6$ Rials/MW.

#### 7.2.2.4 Values of cost, benefit and loss functions of LP Model

Based on the above methodology, the values of economical parameters of different projects, are calculated and the result are presented in Table 7.1.

**Table 7.1: Values of economical parameters for Linear Programming Model**

**Rials * $10^6$**

| Reservoir<br>i | K-4<br>1 | K-3<br>2 | K-2<br>3 | K-1<br>4 | R-O-R<br>5 | DEZ<br>6 |
|---|---|---|---|---|---|---|
| $C'_{i,1}$ | 147.40 | 148.00 | 80.70 | 17.85 | - | 16.80 |
| $Om'_{i,1}$ | 16.00 | 16.10 | 8.80 | 1.95 | - | 1.80 |
| $C'_{i,2}$ | - | - | - | 4.31 | - | 19.30 |
| $Om'_{i,2}$ | - | - | - | 0.93 | - | 4.10 |
| $a_2$ | - | - | - | 10.00 | - | 10.00 |
| $C'_{i,3}$ | 122.50 | 57.30 | 233.50 | 46.30 | 416.90 | 72.00 |
| $Om'_{i,3}$ | 66.70 | 31.50 | 127.20 | 25.20 | 237.00 | 39.20 |
| $a_3$ | 0.30 | 0.25 | 0.25 | 0.25 | 0.30 | 0.15 |
| $a_4$ | 10.00 | 10.00 | 10.00 | 5.00 | - | 5.00 |

### 7.2.3 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 also 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, (Table 7.2), and also Figures (7.1 to 7.26) show the functional relationships of the data used in this study.

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

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

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 system.

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 4.

### 7.2.4 Reservoir Volume vs Reservoir Elevation and Reservoir Volume vs Reservoir Area Curves for Simulation

Relationship, of volume vs elevation and area of each reservoir are developed and for the five reservoir storage projects these are shown in Tables 7.3 and 7.4 respectively.

**Table 7.2: Functional Relationship Developed for Different Dam Sites**

| Site | Independent Variable | Dependent Variable | Coefficients |
|---|---|---|---|
| K-4 | Reservoir Capacity | Capital Cost of Reservoir | a0 = 545.579<br>a1 = 1.8589822<br>a2 = -0.000285568<br>a3 = 1.74605E-008 |
| K-4 | Reservoir Capacity | OM Cost of Reservoir | a0 = 5.20432<br>a1 = 0.0197592<br>a2 = -3.55671E-006<br>a3 = 2.76598E-010 |
| K-4 | Power Plant Capacity | Capital Cost of Power Plant | a0 = 303.091<br>a1 = 1.45891<br>a2 = -0.000339648<br>a3 = 8.12214E-008 |
| K-4 | Power Plant Capacity | OM Cost of Power Plant | a0 = 15.1867<br>a1 = 0.0727399<br>a2 = -1.66151E-005<br>a3 = 3.86844E-009 |
| K-3 | Reservoir Capacity | Capital Cost of Reservoir | a0 = 757.406<br>a1 = 1.42838<br>a2 = -7.81206E-005<br>a3 = 3.08513E-009 |
| K-3 | Reservoir Capacity | OM Cost of Reservoir | a0 = 7.47569<br>a1 = 0.0143747<br>a2 = -8.0495E-007<br>a3 = 3.2714E-011 |

Where a0, a1, a2 and a3 are the coefficients of polynomial equations. All volumetric values are in m.c.m.; all costs are in Rials $10^6$; all plant capacities are in MW.

**Table 7.2: continued**

| Site | Independent Variable | Dependent Variable | Coefficients |
|---|---|---|---|
| K-3 | Power Plant Capacity | Capital Cost of Power Plant | a0 = 545.884<br>a1 = 1.65424<br>a2 = 0.000207173<br>a3 = -2.45782E-008 |
| K-3 | Power Plant Capacity | OM Cost of Power Plant | a0 = 27.055<br>a1 = 0.0834022<br>a2 = 9.94212E-006<br>a3 = -1.159E-009 |
| K-2 | Reservoir Capacity | Capital Cost of Reservoir | a0 = 412.472<br>a1 = 1.4467<br>a2 = -0.000238202<br>a3 = 2.10304E-008 |
| K-2 | Reservoir Capacity | OM Cost of Reservoir | a0 = 4.03859<br>a1 = 0.0148571<br>a2 = -2.73661E-006<br>a3 = 2.68544E-010 |
| K-2 | Power Plant Capacity | Capital Cost of Power Plant | a0 = 105.373<br>a1 = 2.93729<br>a2 = -0.000462186<br>a3 = -3.72211-008 |
| K-2 | Power Plant Capacity | OM Cost of Power Plant | a0 = 5.26863<br>a1 = 0.146865<br>a2 = -2.3193E-005<br>a3 = -1.86108E-009 |

**Table 7.2: continued**

| Site | Independent Variable | Dependent Variable | Coefficients |
|---|---|---|---|
| K-1 | Reservoir Capacity | Capital Cost of Reservoir | a0 = 34.0132<br>a1 = 0.211825<br>a2 = -2.77768E-005<br>a3 = 1.7701E-009 |
| K-1 | Reservoir Capacity | OM Cost of Reservoir | a0 = 0.0336752<br>a1 = 0.000212637<br>a2 = -2.77013E-008<br>a3 = 1.66186E-012 |
| K-1 | Annual Irrigation | Capital Cost of Irrigation | a0 = 16.4243<br>a1 = 0.0693478<br>a2 = -5.37352E-006<br>a3 = 2.71958E-10 |
| K-1 | Annual Irrigation | OM Cost of Irrigation | a0 = 0.408289<br>a1 = 0.00124764<br>a2 = -5.46823E-008<br>a3 = -1.07415E-014 |
| K-1 | Power Plant Capacity | Capital Cost of Power Plant | a0 = 30.7688<br>a1 = 0.652351<br>a2 = -0.000160429<br>a3 = -1.83026E-008 |
| K-1 | Power Plant Capacity | OM Cost of Power Plant | a0 = 1.74987<br>a1 = 0.0363192<br>a2 = -2.21688E-005<br>a3 = 9.3499E-009 |

**Table 7.2: continued**

| Site | Independent Variable | Dependent Variable | Coefficients |
|---|---|---|---|
| Dez | Reservoir Capacity | Capital Cost of Reservoir | a0 = 31.8654<br>a1 = 0.247984<br>a2 = -3.24945E-005<br>a3 = 3.11586E-009 |
| Dez | Reservoir Capacity | OM Cost of Reservoir | a0 = 0.19404<br>a1 = 0.00263214<br>a2 = -3.6957E-007<br>a3 = 3.41304E-011 |
| Dez | Annual Irrigation | Capital Cost of Irrigation | a0 = 28.4295<br>a1 = 0.218481<br>a2 = -2.07183E-005<br>a3 = 2.2782E-009 |
| Dez | Annual Irrigation | OM Cost of Irrigation | a0 = 0.556525<br>a1 = 0.00443552<br>a2 = -4.93582E-007<br>a3 = 7.00355E-011 |
| Dez | Power Plant Capacity | Capital Cost of Power Plant | a0 = 23.4717<br>a1 = 0.899987<br>a2 = -0.000343172<br>a3 = 6.98417E-008 |
| Dez | Power Plant Capacity | OM Cost of Power Plant | a0 = 1.21212<br>a1 = 0.0443957<br>a2 = -1.52875E-005<br>a3 = 2.16895E-009 |

**Table 7.3: Functional Relationship of Volume vs Elevation at Dam Sites**

| Site | Independent Variable | Dependent Variable | Coefficients |
|---|---|---|---|
| K-4 | Reservoir Capacity | Reservoir Elevation | a0 = 861.4277<br>a1 = 0.1761322<br>a2 = $-0.7791817*10^{-4}$<br>a3 = $0.1678200*10^{-7}$<br>a4 = $-0.1273204*10^{-11}$ |
| K-3 | Reservoir Capacity | Reservoir Elevation | a0 = 685.6182<br>a1 = 0.1804962<br>a2 = $-0.8368492*10^{-4}$<br>a3 = $0.1710941*10^{-7}$<br>a4 = $-0.11897115*10^{-11}$ |
| K-2 | Reservoir Capacity | Reservoir Elevation | a0 = 529.2402<br>a1 = 0.09342957<br>a2 = $-0.4109740*10^{-4}$<br>a3 = $0.9647920*10^{-8}$<br>a4 = $-0.7922552*10^{-12}$ |
| K-1 | Reservoir Capacity | Reservoir Elevation | a0 = 387.0791<br>a1 = 0.1695938<br>a2 = $-0.9513646*10^{-4}$<br>a3 = $0.2450179*10^{-7}$<br>a4 = $-0.2180034*10^{-11}$ |
| Dez | Reservoir Capacity | Reservoir Elevation | a0 = 199.4976<br>a1 = 0.1985207<br>a2 = $-0.1305118*10^{-3}$<br>a3 = $0.3885361*10^{-7}$<br>a4 = $-0.4029221*10^{-11}$ |

Where ,a0, a1, a2, a3,and a4 are the coefficients of polynomial equations.All volumes ,and elevation are in m.c.m.& meters respectively

**Table 7.4: Functional Relationship of Volume vs Area at Dam Stes**

| Site | Independent Variable | Dependent Variable | Coefficients |
|---|---|---|---|
| K-4 | Reservoir Capacity | Reservoir Area | a0 = 2.085449<br>a1 = 0.02111959<br>a2 = $-0.5795620*10^{-5}$<br>a3 = $0.1116177*10^{-8}$<br>a4 = $-0.7725764*10^{-13}$ |
| K-3 | Reservoir Capacity | Reservoir Area | a0 = 1.007202<br>a1 = 0.03124523<br>a2 = $-0.9516254*10^{-5}$<br>a3 = $0.1811031*10^{-8}$<br>a4 = $-0.1214723*10^{-12}$ |
| K-2 | Reservoir Capacity | Reservoir Area | a0 = 3.111938<br>a1 = 0.05115986<br>a2 = $-0.2834853*10^{-4}$<br>a3 = $0.7146809*10^{-8}$<br>a4 = $-0.1214723*10^{-12}$ |
| K-1 | Reservoir Capacity | Reservoir Area | a0 = 1.5744341<br>a1 = 0.03354454<br>a2 = $-0.1277495*10^{-4}$<br>a3 = $0.3388323*10^{-8}$<br>a4 = $-0.3120559*10^{-12}$ |
| Dez | Reservoir Capacity | Reservoir Area | a0 = 1.189636<br>a1 = 0.03252220<br>a2 = $-0.8011586*10^{-5}$<br>a3 = $0.1158014*10^{-8}$ |

Where, a0, a1, a2, a3, and a4 are the coefficients of polynomial equations. All volumes, and areas are in m.c.m. & Km$^2$ respectively.

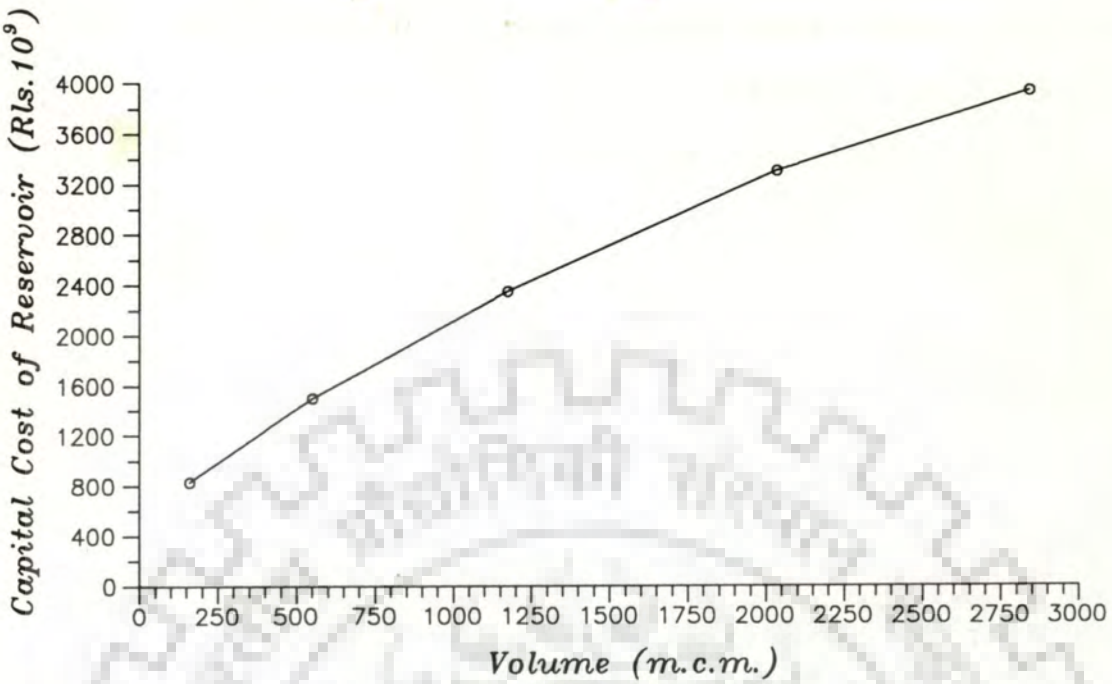


*Fig.7.1:Reservoir Volume vs Capital Cost of Reservoir for Karun-4 Dam Site*

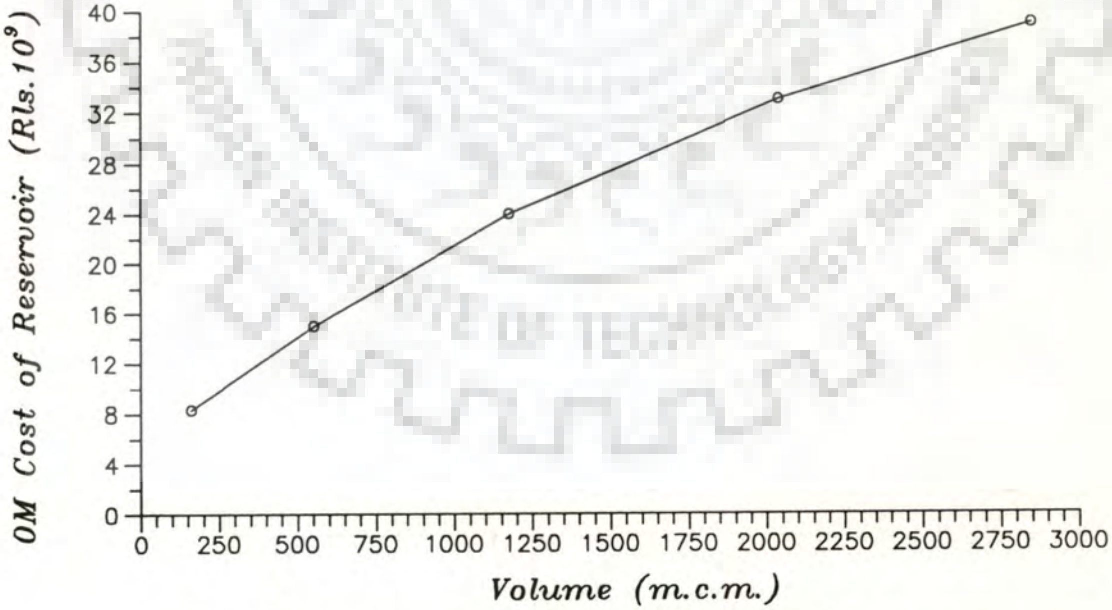


*Fig.7.2:Reservoir Volume vs OM Cost of Reservoir for Karun-4 Dam Site*

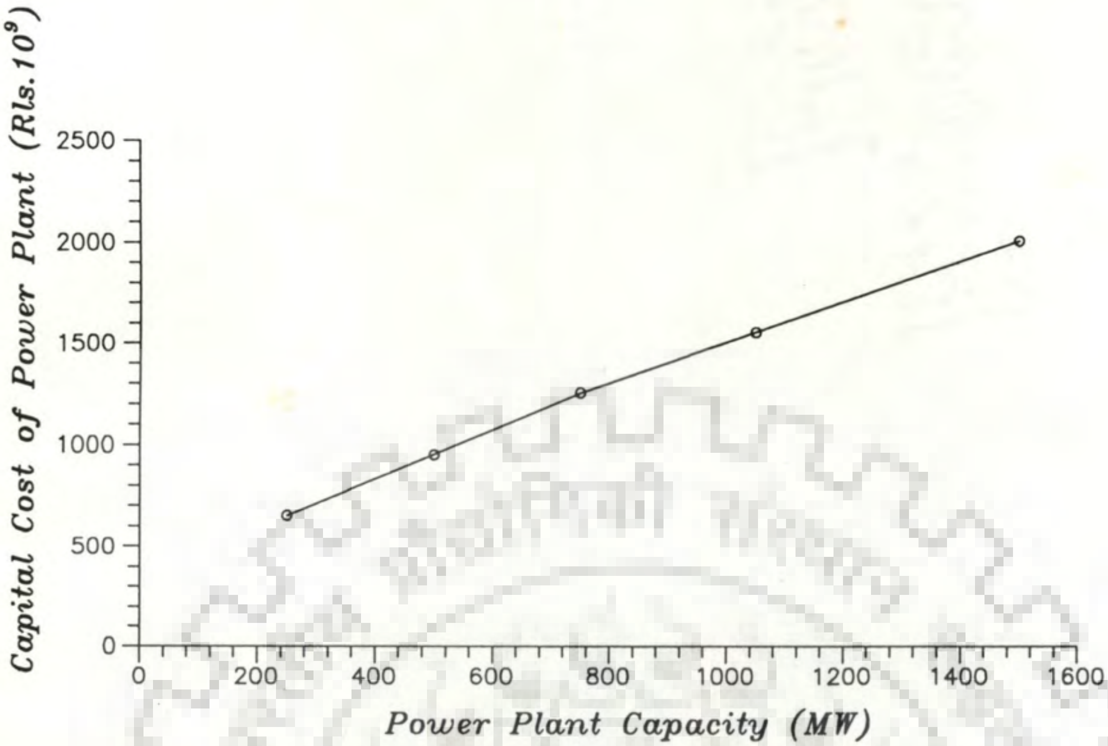


*Fig.7.3:Power Plant Capacity vs Capital Cost for Karun-4 Dam Site*

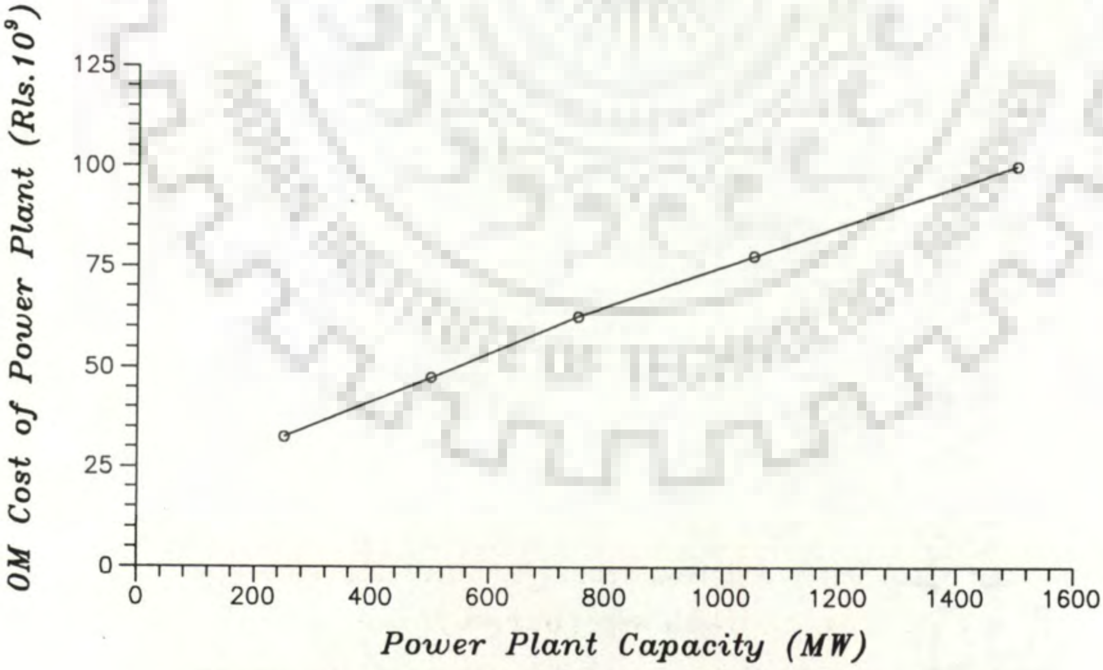


*Fig.7.4:Power Plant Capacity vs OM Cost for Karun-4 Dam Site*

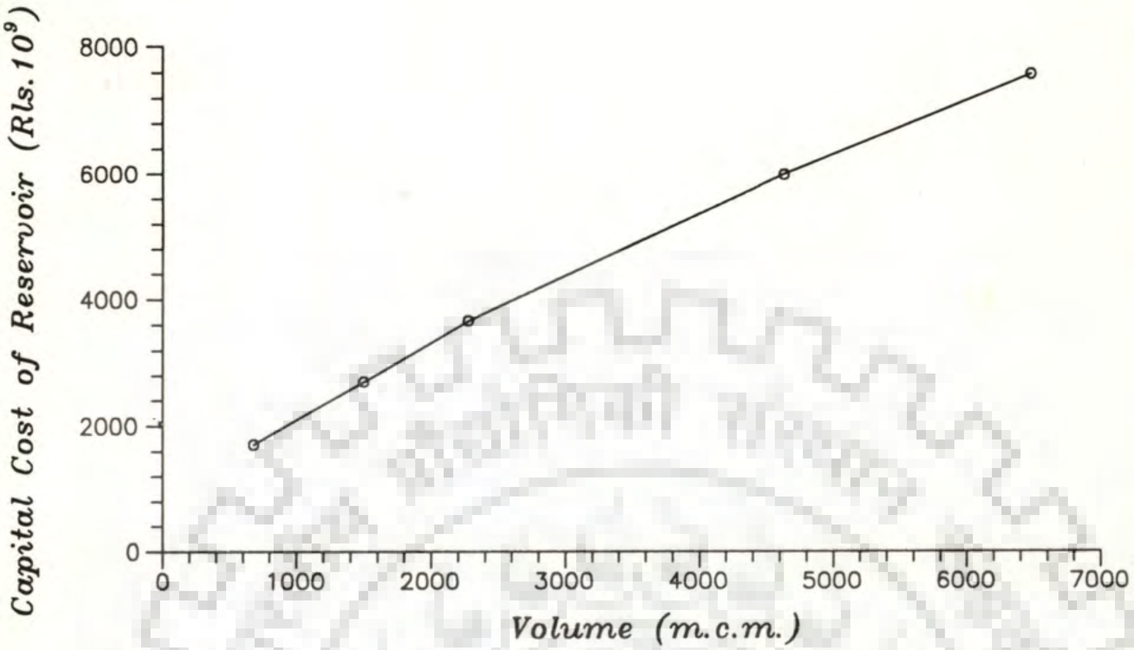


*Fig.7.5:Reservoir Volume vs Capital Cost of Reservoir for Karun-3 Dam Site*

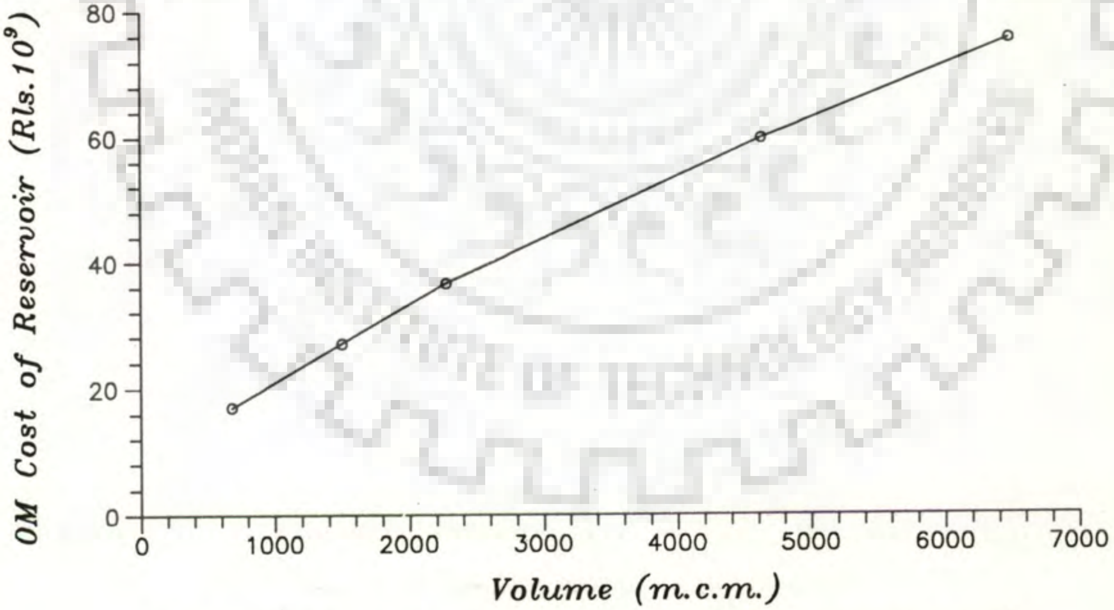


*Fig.7.6:Reservoir Volume vs OM Cost of Reservoir for Karun-3 Dam Site*

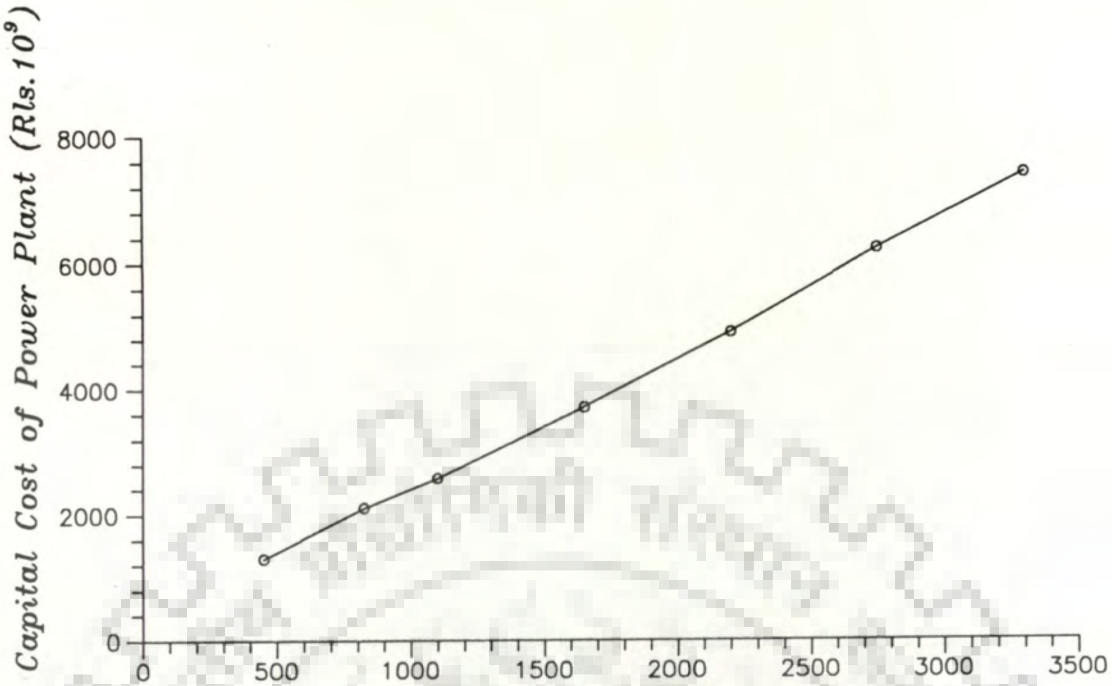


*Fig.7.7:Power Plant Capacity vs Capital Cost for Karun-3 Dam Site*

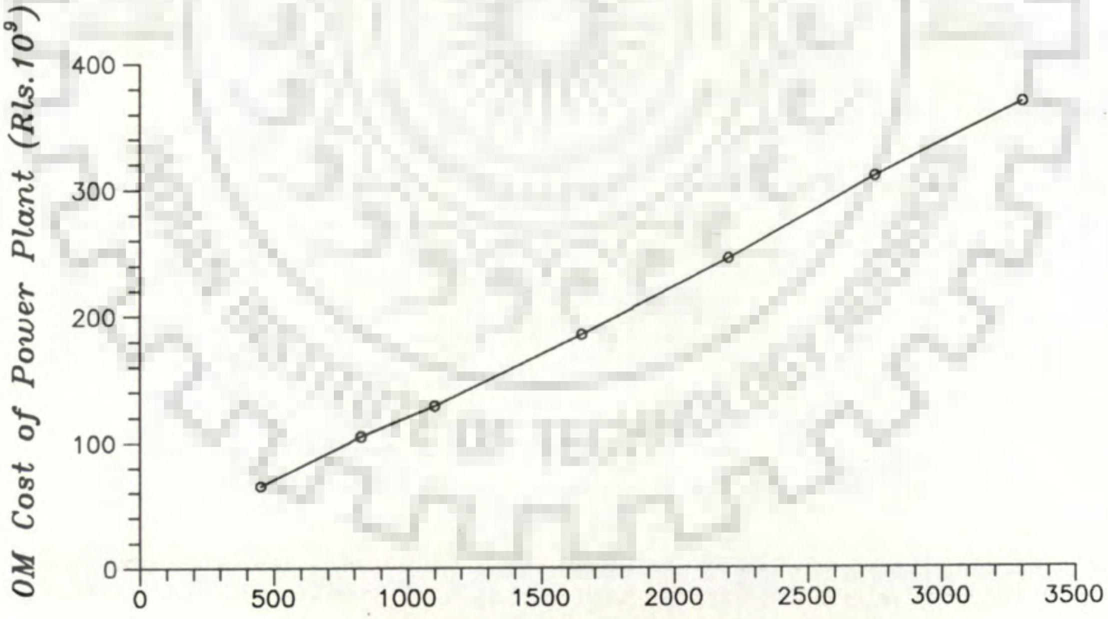


*Fig.7.8:Power Plant Capacity vs OM Cost for Karun-3 Dam Site*

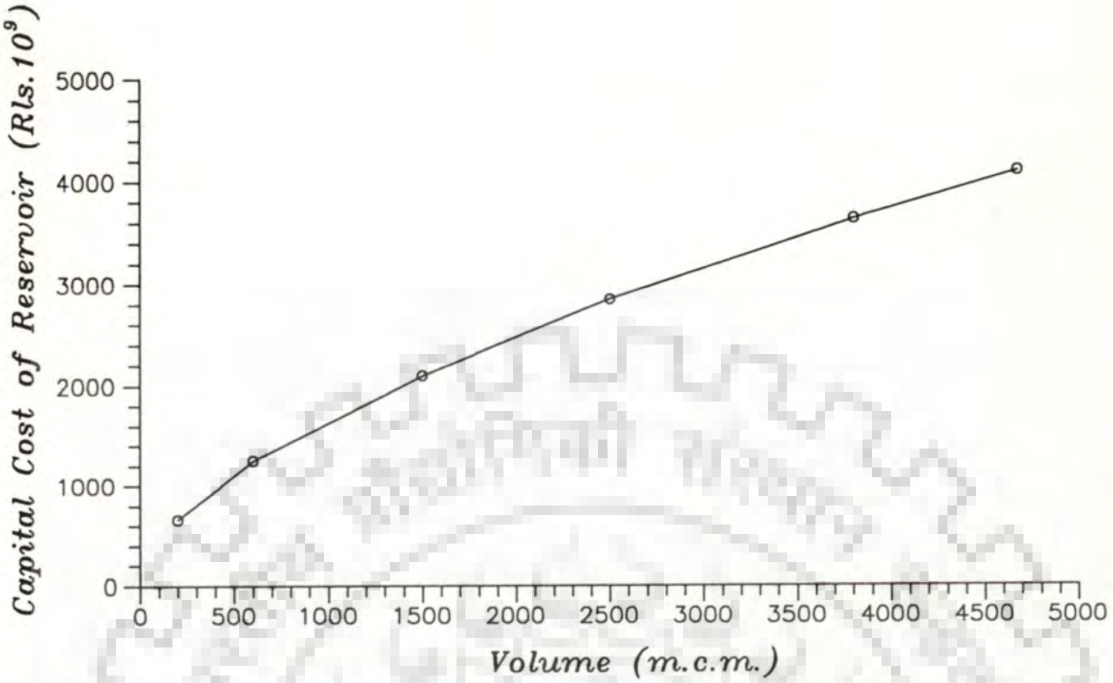


*Fig.7.9:Reservoir Volume vs Capital Cost of Reservoir for Karun−2 Dam Site*

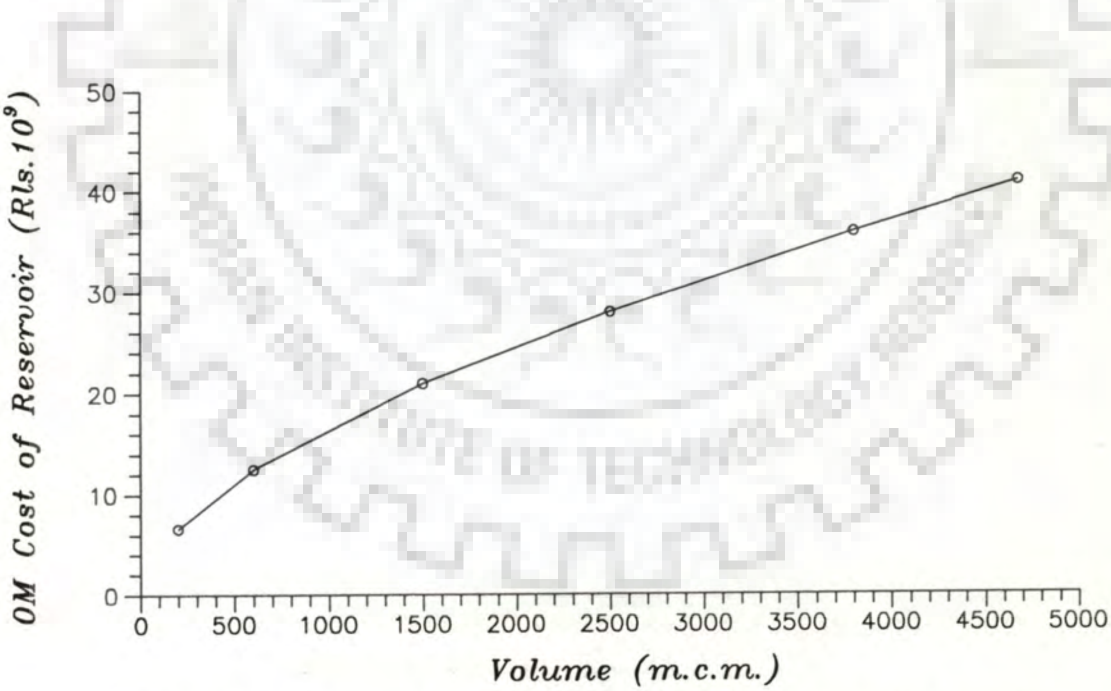


*Fig.7.10:Reservoir Volume vs OM Cost of Reservoir for Karun−2 Dam Site*

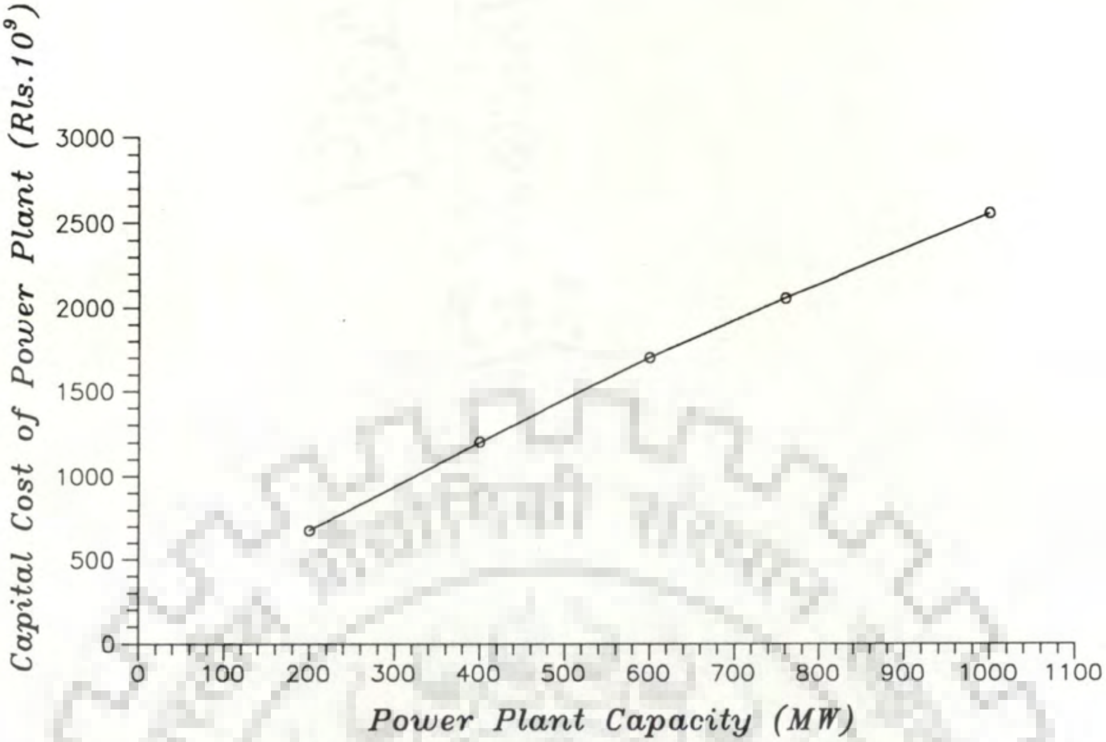


*Fig.7.11:Power Plant Capacity vs Capital Cost for Karun-2 Dam Site*

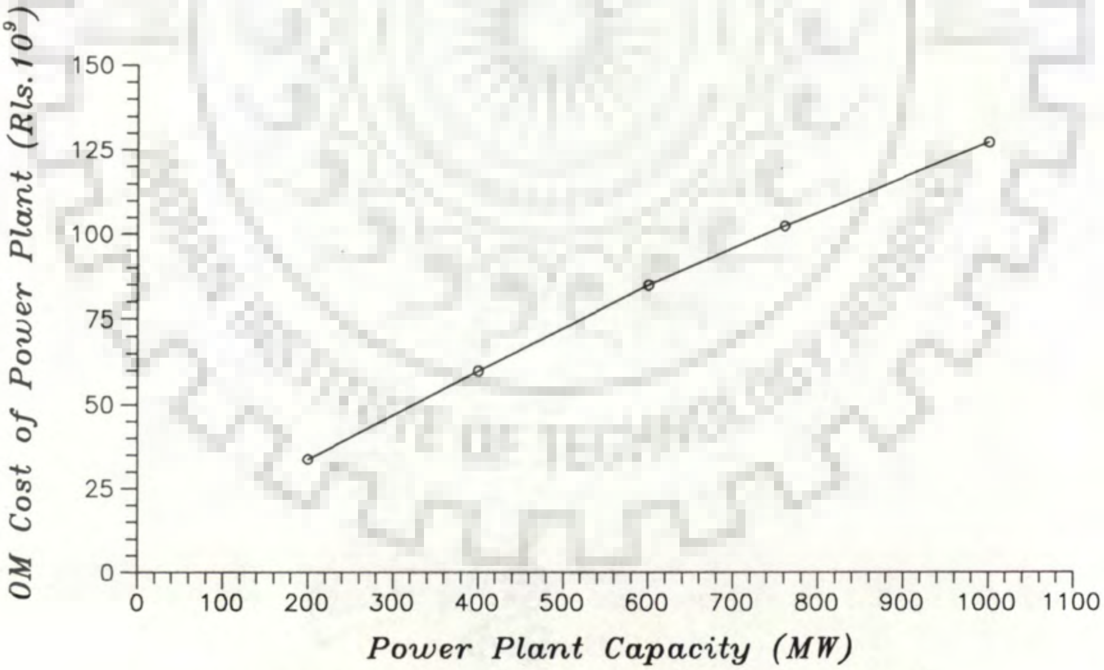


*Fig.7.12:Power Plant Capacity vs OM Cost for Karun-2 Dam Site*

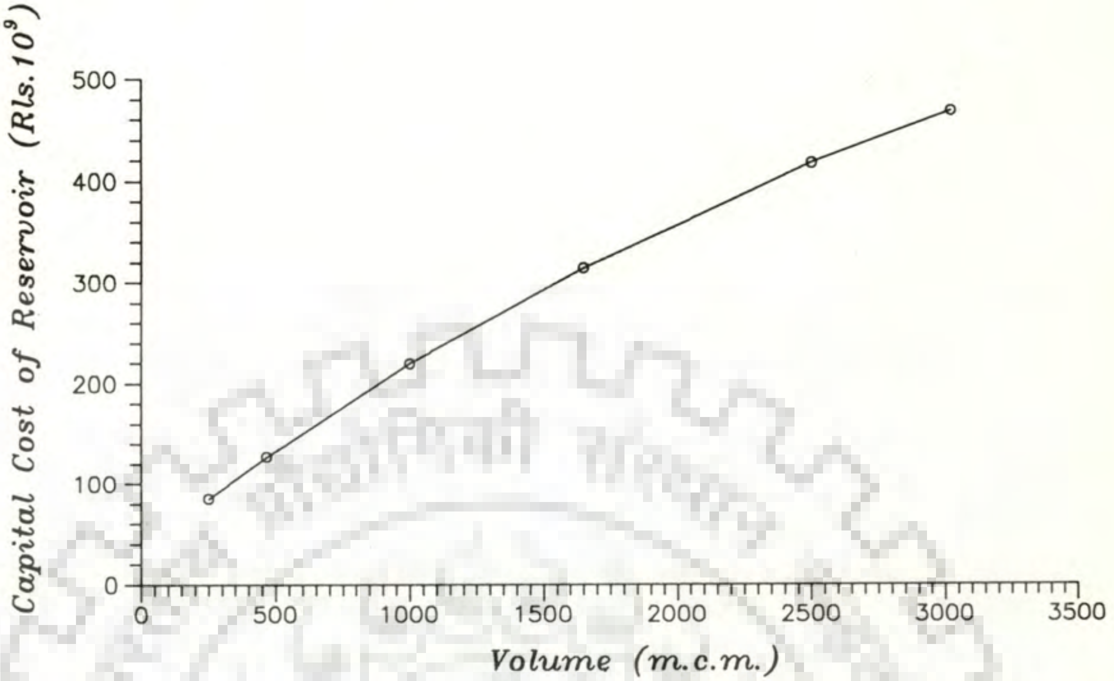


*Fig.7.13:Reservoir Volume vs Capital Cost of Reservoir for Karun-1 Dam Site*

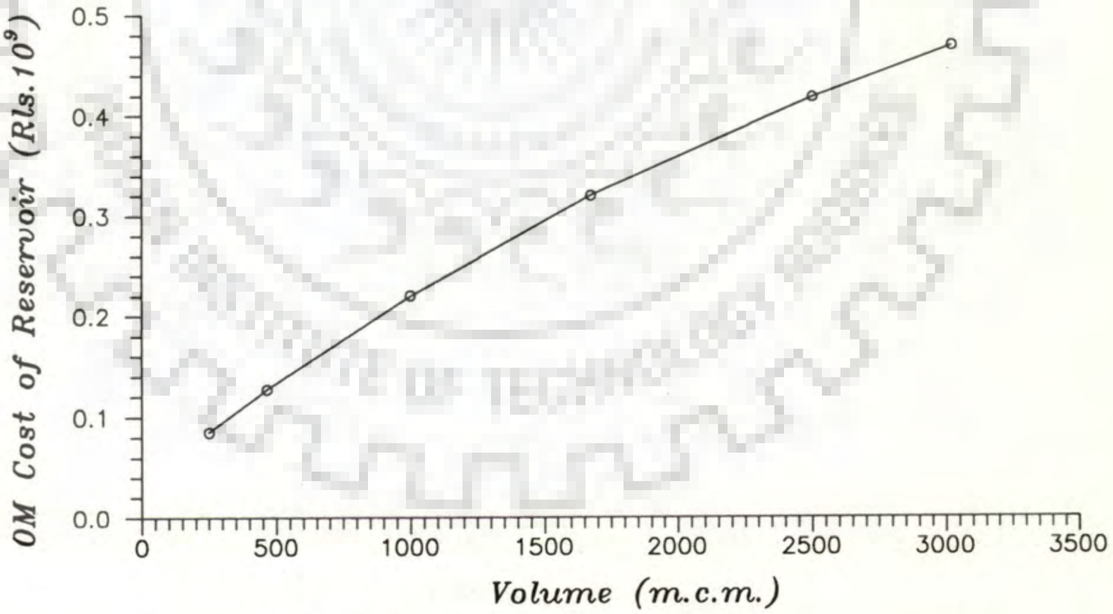


*Fig.7.14:Reservoir Volume vs OM Cost of Reservoir for Karun-1 Dam Site*

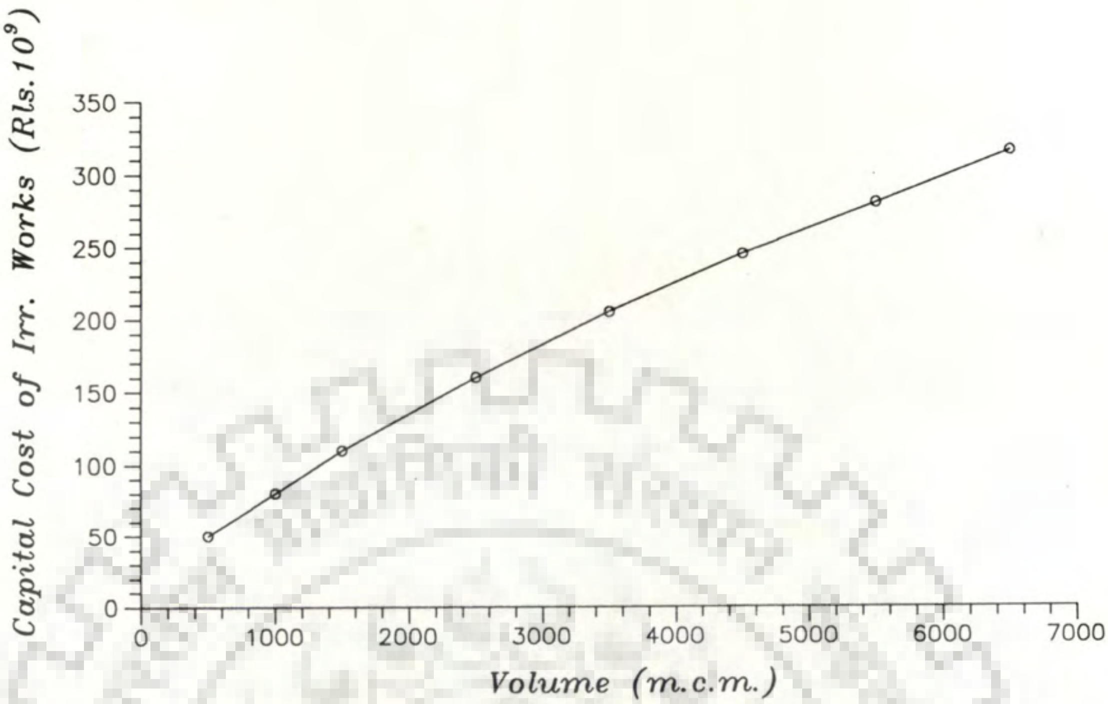


*Fig.7.15:Annual Irrigation vs Capital Cost for Karun-1 Dam Site*

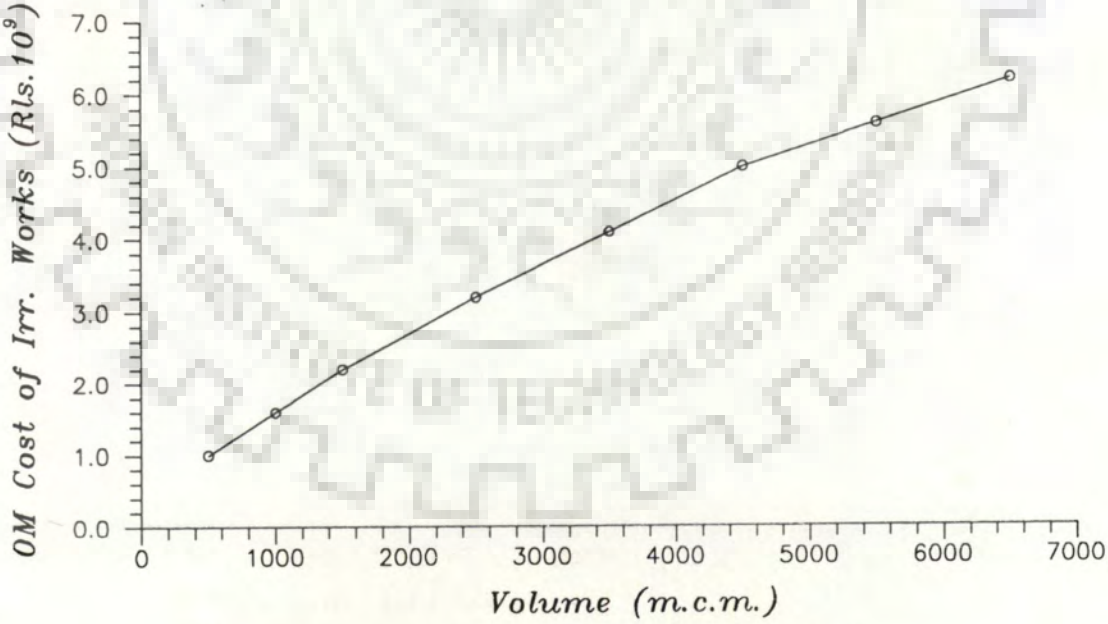


*Fig.7.16:Annual Irrigation vs OM Cost for Karun-1 Dam Site*

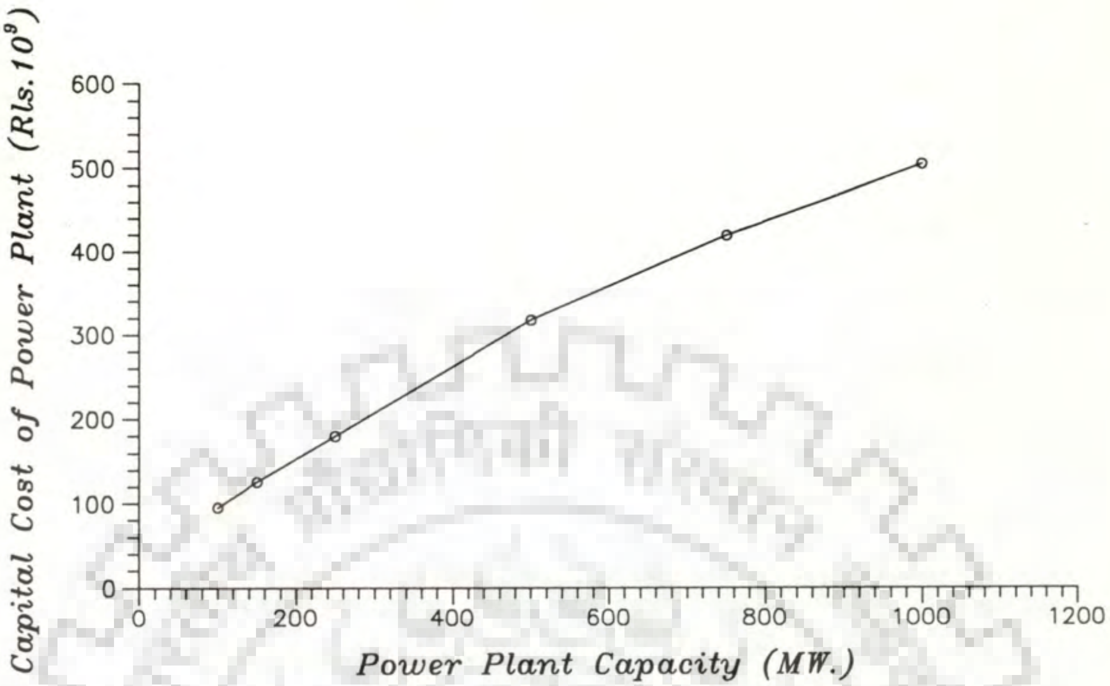


*Fig.7.17:Power Plant Capacity vs Capital Cost for Karun-1 Dam Site*

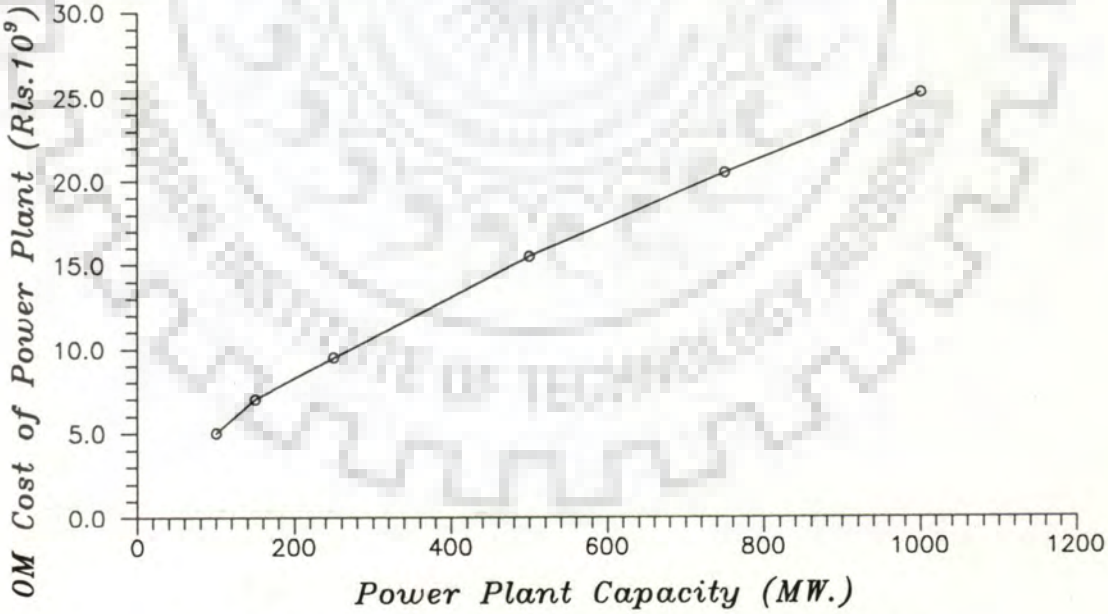


*Fig.7.18:Power Plant Capacity vs OM Cost for Karun-1 Dam Site*

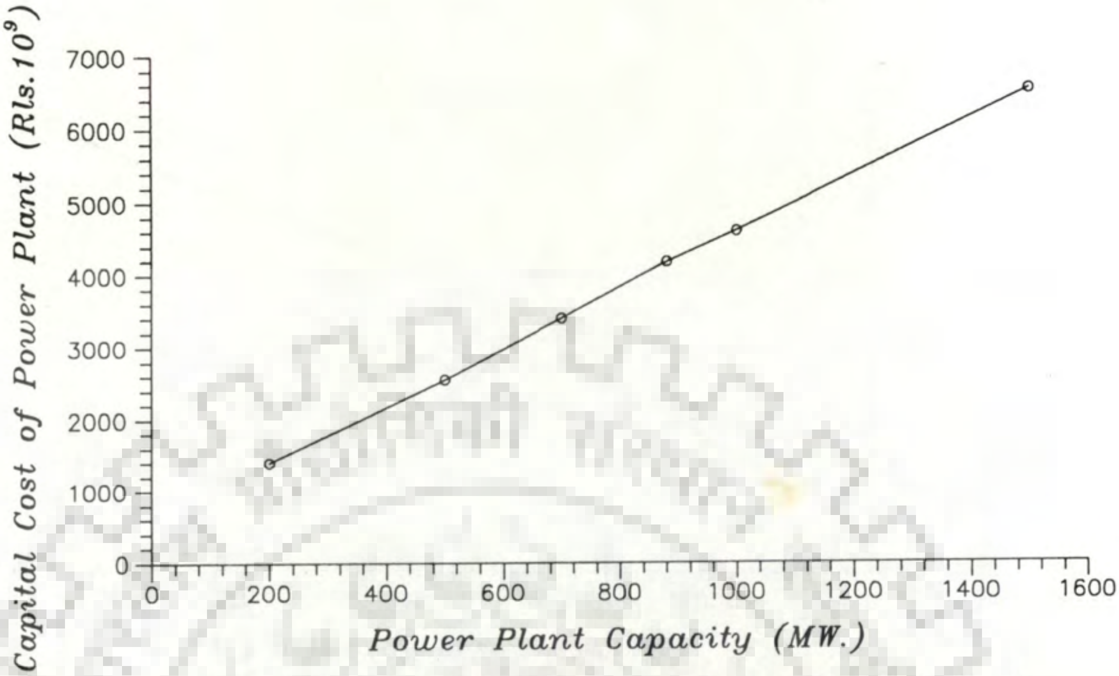


Fig.7.19:Power Plant Capacity vs Capital Cost for Godar-e-Landar (Run-of-River)

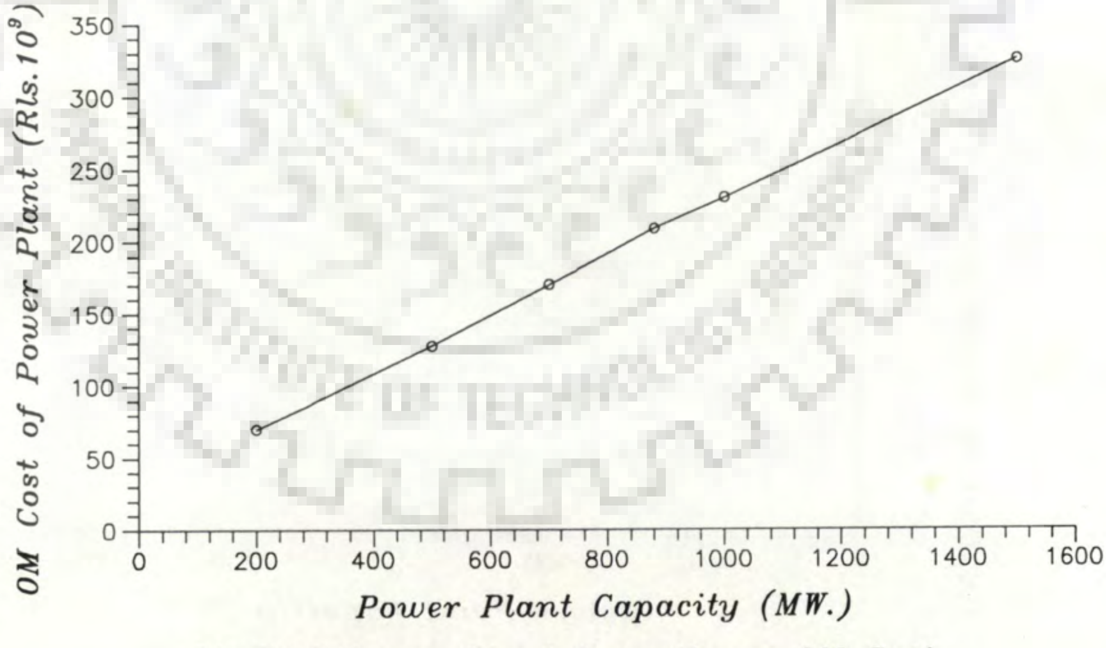


Fig.7.20:Power Plant Capacity vs OM Cost for Godar-e-Landar (Run-of-River)

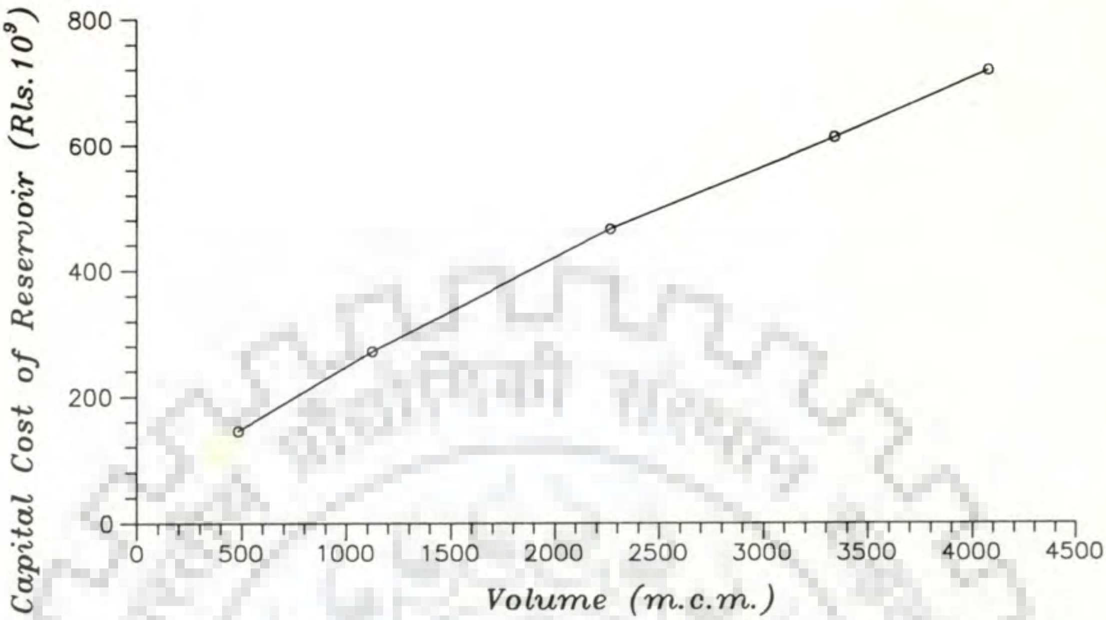


*Fig.7.21:Reservoir Volume vs Capital Cost of Reservoir for Dez Dam Site*

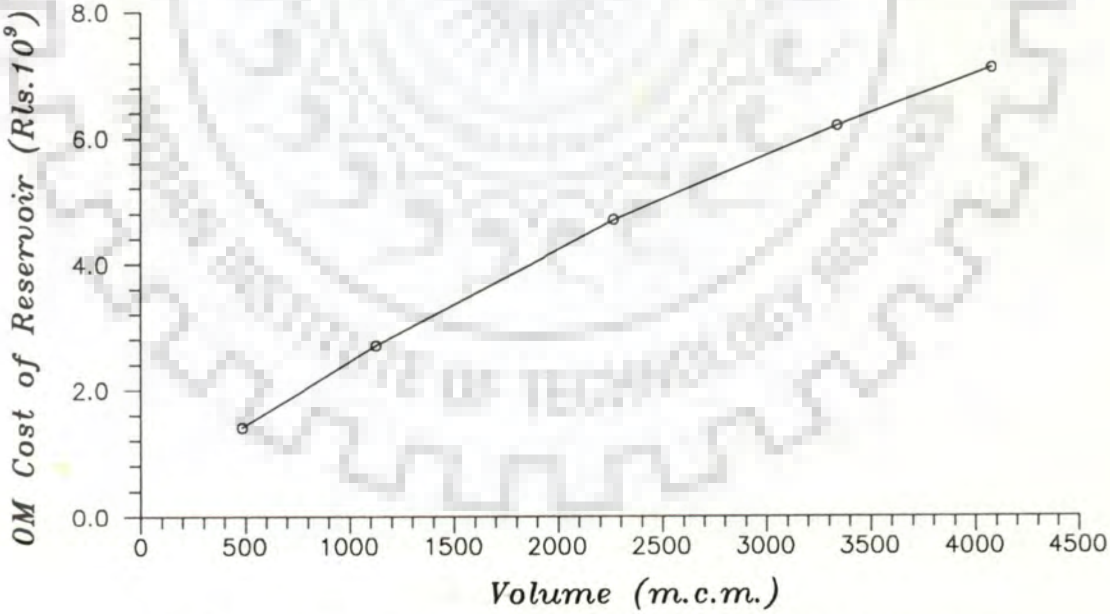


*Fig.7.22:Reservoir Volume vs OM Cost of Reservoir for Dez Dam Site*

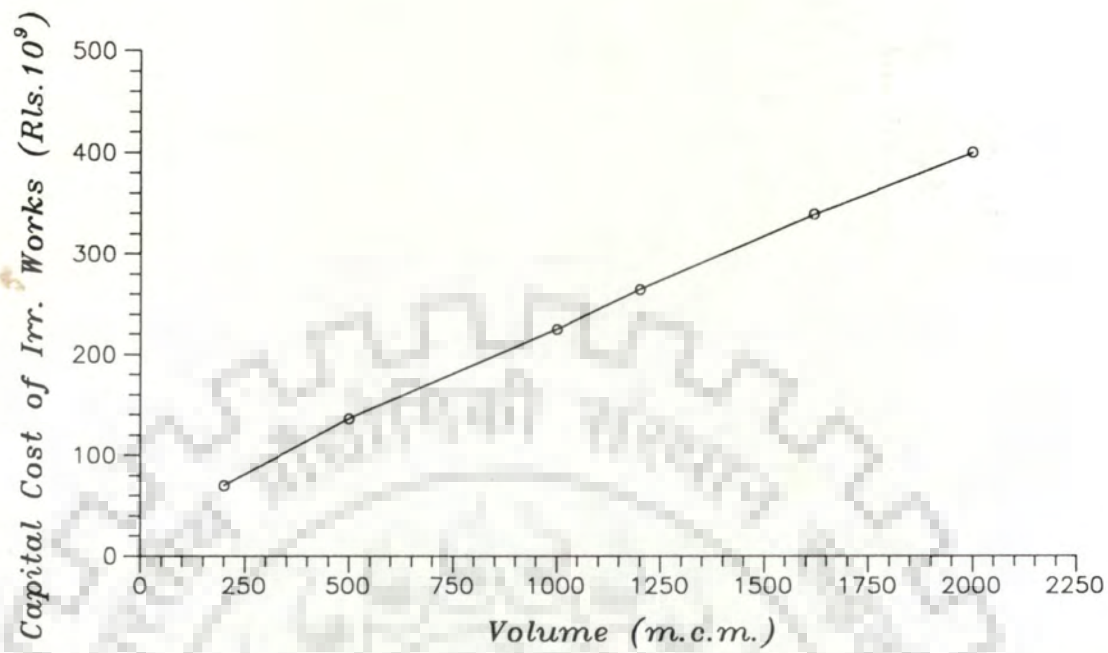


*Fig.7.23:Annual Irrigation vs Capital Cost for Dez Dam Site*

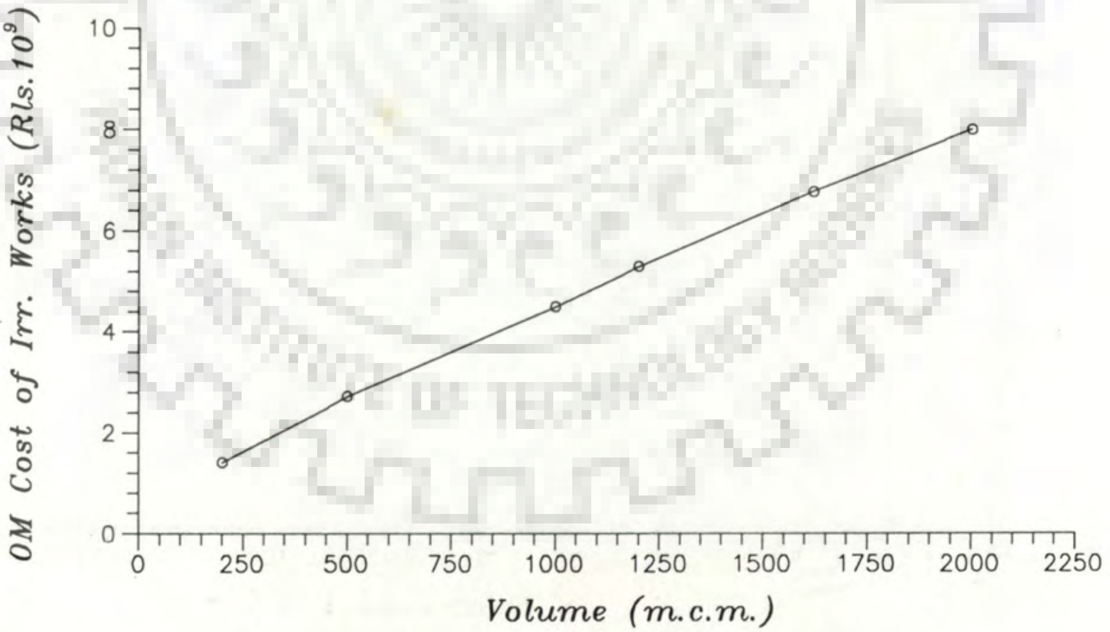


*Fig.7.24:Annual Irrigation vs OM Cost for Dez Dam Site*

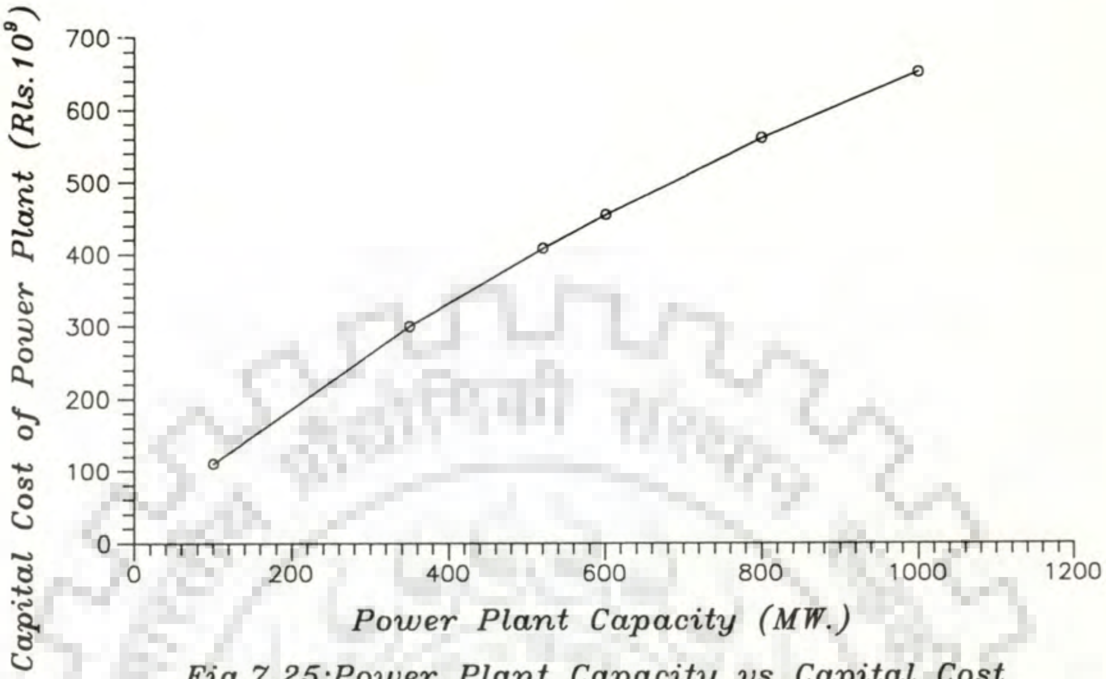


*Fig.7.25:Power Plant Capacity vs Capital Cost for Dez Dam Site*

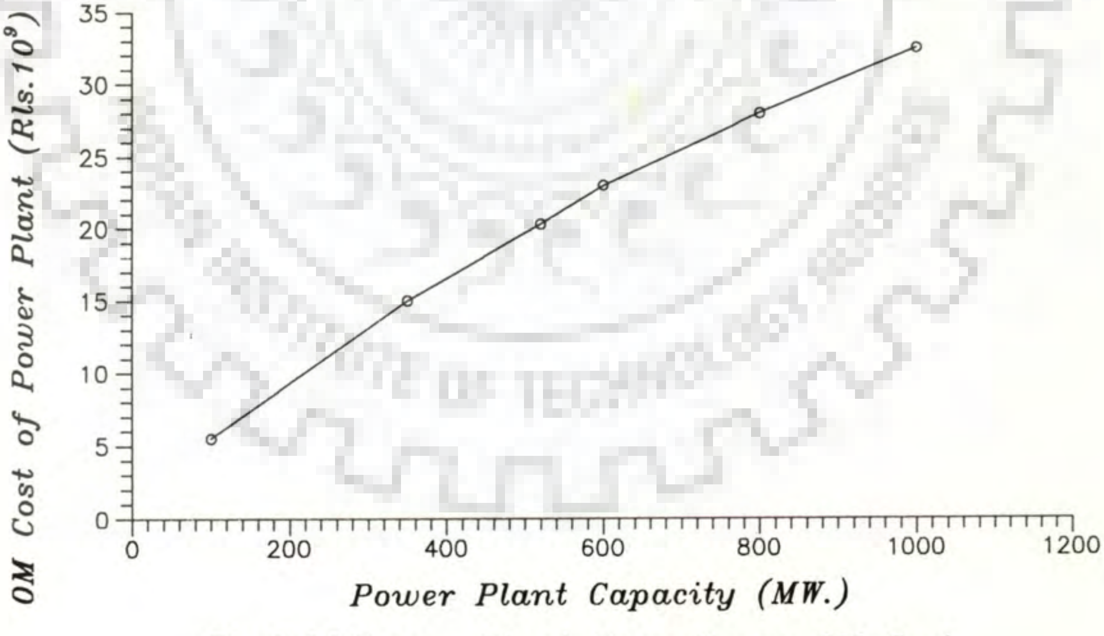


*Fig.7.26:Power Plant Capacity vs OM Cost for Dez Dam Site*

## 7.3 SOLUTION METHODOLOGY

The Linear Programming Model (LP Model), Chapter-3, was used to analyze all possible alternative configurations of the reservoir system for preliminary screening and design of projects with respect to the economical considerations. Simulation model (Chapter-4) was then used to screen and eliminate clearly inferior alternatives based on economical, project dependability and other considerations. Therefore, a combined model is developed to analyze the physical and economic efficiencies of a large number of alternative development options as follows:

### 7.3.1 Deciding Configuration and Sizing of Reservoirs For Future Development

In the first instance the multi irrigation areas at Karun-1 and Dez have been clubbed individually for deciding the reservoir configuration and the project sizes and targets for future development scenario.

### 7.3.2 Sizing of Irrigation Including Multi-Irrigation Areas

Thereafter, the self and the multi-irrigation areas are unclubbed and both the existing and the future development scenarios have been considered and analyzed for sizing the various irrigation areas.

Ultimately, the results of the optimization - simulation screening models were used to develop appropriate methodology for decision making purposes for a large complex water resources system.

## 7.4 COMPUTATION FOR DECIDING CONFIGURATION AND SIZING OF RESERVOIRS FOR FUTURE DEVELOPMENT

The optimization and simulation screening models are proposed to be applied using the following methodology.

### 7.4.1 Strategy For LP Computation

The linear programming model was used as a preliminary screening model. In this model, constraints were written only for one year. The decision variables were namely $O_{i,t}$ ; $S_{i,t}$; $Y_i$; $Ir_i$; $H_i$; and $E_i$. Average monthly flows and monthly flows of 70% or 90% dependable flow year were used as the input, as shown in Table 7.5, 7.6, and 7.7. The values of $K_{i,t}$ for 12 time period are given in Table 7.8 and 7.9 for the existing and the future development respectively. The reservoir storage at the end of the year is same as at the beginning of the same year, i.e., $S_{12}= S_0$.

A few more constraints were added on the basis of some design criterias:

(i) Based on agreement between neighbor province (Esfahan) and neighbor basin (Karkheh irrigation project) water has to be transfered from the Karun river to above mentioned province and basin as follow:

- 25 $m^3$/sec from the source point of Karun river by Kouhrang tunnel towards Esfahan province. It is noted that, these diversions remained constant for two development scenarios. Table 7.10 shows the pattern of monthly distribution of these diversion requirements.

(ii) It also recommended that total power plant capacity of Karun river system should not exceed 8000 MW.

The load factors are given in Table 7.11. The number of hours $h_t$, on an average, in a month are taken at 720.

**Table 7.5: Mean Flows at Dam Sites** **Unit:In (m.c.m.)**

| Time period | Mean monhly flows at Dam sites | | | | | |
|---|---|---|---|---|---|---|
| | K-4 | K-3 | K-2 | K-1 | R-O-R | Dez |
| t | i =1 | i =2 | i =3 | i =4 | i =5 | i =6 |
| 1 | 1022.4 | 1687.3 | 1777.3 | 1981.0 | 1968.9 | 1610.2 |
| 2 | 985.3 | 1533.0 | 1614.8 | 1927.0 | 1757.1 | 1417.7 |
| 3 | 622.4 | 981.4 | 1033.8 | 1175.4 | 1152.1 | 797.0 |
| 4 | 381.0 | 623.6 | 656.8 | 811.4 | 787.6 | 473.5 |
| 5 | 277.0 | 449.8 | 473.8 | 623.2 | 654.4 | 316.8 |
| 6 | 208.9 | 349.9 | 368.6 | 518.2 | 608.8 | 232.6 |
| 7 | 187.9 | 316.2 | 333.0 | 440.7 | 433.9 | 195.9 |
| 8 | 223.1 | 366.7 | 386.2 | 479.2 | 492.3 | 267.4 |
| 9 | 301.1 | 493.0 | 519.8 | 592.5 | 598.9 | 441.8 |
| 10 | 345.7 | 584.6 | 615.8 | 842.3 | 849.2 | 553.4 |
| 11 | 408.8 | 730.9 | 769.9 | 1055.3 | 1025.2 | 770.1 |
| 12 | 682.5 | 1177.4 | 1240.3 | 1442.5 | 1362.2 | 1119.6 |
| Total | 5646.0 | 9294.0 | 9789.6 | 11888.4 | 1691.6 | 8196.0 |

Table 7.6: Flows of Different Dependabilities at Karun River Dam Sites Unit:In (m.c.m.)

| | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Karun-4 Dam Site** | | | | | | | | | | | | |
| AVE. = | 1022.4 | 985.3 | 622.4 | 381.0 | 277.0 | 208.3 | 187.9 | 223.1 | 301.1 | 345.7 | 408.8 | 682.6 |
| %90 = | 543.2 | 649.2 | 415.9 | 239.1 | 223.1 | 181.3 | 140.0 | 128.3 | 146.7 | 140.7 | 175.0 | 387.8 |
| **Karun-3 Dam Site** | | | | | | | | | | | | |
| AVE. = | 1687.3 | 1533.0 | 981.4 | 623.6 | 449.8 | 349.9 | 316.2 | 366.7 | 493.0 | 584.6 | 730.9 | 1177.4 |
| %90 = | 972.0 | 681.4 | 480.2 | 295.4 | 232.2 | 211.3 | 199.3 | 197.5 | 250.6 | 289.5 | 713.4 | 1078.5 |
| **Karun-2 Dam Site** | | | | | | | | | | | | |
| AVE. = | 1777.3 | 1614.8 | 1033.8 | 656.8 | 473.8 | 368.6 | 333.0 | 386.2 | 519.3 | 615.8 | 769.9 | 1240.3 |
| %90 = | 1024.0 | 717.8 | 505.9 | 311.2 | 244.5 | 222.6 | 210.0 | 208.1 | 264.1 | 305.1 | 756.7 | 1136.1 |
| **Karun-1 Dam Site** | | | | | | | | | | | | |
| AVE. = | 1981.0 | 1927.0 | 1175.4 | 811.4 | 623.1 | 518.2 | 440.7 | 479.2 | 592.5 | 842.3 | 1055.3 | 1442.5 |
| %70 = | 1938.1 | 1201.8 | 803.5 | 554.7 | 458.5 | 441.4 | 347.1 | 374.8 | 547.5 | 720.1 | 825.8 | 1349.4 |
| %90 = | 1210.9 | 914.7 | 593.9 | 368.5 | 379.8 | 388.4 | 290.6 | 310.5 | 473.0 | 479.3 | 794.6 | 1285.4 |
| **Godar-e-Landar Run of River (Tunnel Scheme)** | | | | | | | | | | | | |
| AVE. = | 1968.9 | 1757.1 | 1152.1 | 787.6 | 654.4 | 608.8 | 433.9 | 492.7 | 598.9 | 849.2 | 1025.2 | 1362.2 |
| %90 = | 811.3 | 867.5 | 803.5 | 594.3 | 594.6 | 606.4 | 423.5 | 416.5 | 406.9 | 609.4 | 636.3 | 615.9 |

**Table 7.7: Flows of Dez Dam Site With different dependabilities** **Unit:In (m.c.m.)**

| | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Dez Dam Site** | | | | | | | |
| AVE. = | 1610.2 | 1417.7 | 797.0 | 473.5 | 316.8 | 232.6 | 195.9 | 267.4 | 441.8 | 553.4 | 770.1 | 1119.6 |
| %70 = | 1588.1 | 909.9 | 645.8 | 327.3 | 210.3 | 182.1 | 153.2 | 175.7 | 426.2 | 416.8 | 658.1 | 698.5 |
| %90 = | 628.1 | 866.5 | 588.7 | 355.4 | 225.8 | 180.2 | 147.9 | 166.9 | 256.1 | 298.3 | 559.1 | 510.4 |

**Table 7.8: Values of $K_{i,t}$ at Different Sites (Existing Development)**

| Time period | Percentage of total annual irrigation requirement $K_{i,t}$ | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SK | SD | 1K | 2K | 3K | 4K | 5K | 1D | 2D | 3D | 4D | 1KD | 2KD | 3KD |
| t | i=1 | i=2 | i=3 | i=4 | i=5 | i=6 | i=7 | i=8 | i=9 | i=10 | i=11 | i=12 | i=13 | i=14 |
| 1* | 8.7 | 12.8 | 20.0 | 20.6 | 20.9 | 21.3 | 17.0 | 21.3 | 13.4 | 17.2 | 17.7 | 20.4 | 19.8 | 13.1 |
| 2 | 12.2 | 13.4 | 20.0 | 18.1 | 19.5 | 18.8 | 17.8 | 18.5 | 14.8 | 15.5 | 17.2 | 16.8 | 17.5 | 13.1 |
| 3 | 15.2 | 11.1 | 20.0 | 9.8 | 10.9 | 9.3 | 13.3 | 9.5 | 13.5 | 10.3 | 10.3 | 8.3 | 9.4 | 13.1 |
| 4 | 16.3 | 11.1 | 20.0 | 5.5 | 5.7 | 4.5 | 8.9 | 5.2 | 12.2 | 7.0 | 6.3 | 4.3 | 5.2 | 13.1 |
| 5 | 14.9 | 12.0 | 20.0 | 4.5 | 4.3 | 4.0 | 6.7 | 4.5 | 10.3 | 7.2 | 5.2 | 3.6 | 4.3 | 11.4 |
| 6 | 10.8 | 11.3 | 0.0 | 4.0 | 3.3 | 4.0 | 5.2 | 4.1 | 7.9 | 7.5 | 5.7 | 3.7 | 3.9 | 7.6 |
| 7 | 5.9 | 7.1 | 0.0 | 3.8 | 2.7 | 3.6 | 4.4 | 3.3 | 5.6 | 6.2 | 5.1 | 3.6 | 3.3 | 5.5 |
| 8 | 3.6 | 4.8 | 0.0 | 6.0 | 5.5 | 6.0 | 4.4 | 5.1 | 4.4 | 6.2 | 5.7 | 5.8 | 5.1 | 3.7 |
| 9 | 2.5 | 3.1 | 0.0 | 5.2 | 5.2 | 5.3 | 3.7 | 5.2 | 3.5 | 4.5 | 5.7 | 6.7 | 6.0 | 3.1 |
| 10 | 2.0 | 2.0 | 0.0 | 3.5 | 3.5 | 3.6 | 3.0 | 3.4 | 2.2 | 2.9 | 3.4 | 4.5 | 4.3 | 3.1 |
| 11 | 2.3 | 2.9 | 0.0 | 4.5 | 4.3 | 4.6 | 3.7 | 4.7 | 3.0 | 3.6 | 5.1 | 6.9 | 6.3 | 3.1 |
| 12 | 5.6 | 8.4 | 0.0 | 14.5 | 14.2 | 15.0 | 11.9 | 15.2 | 9.2 | 11.9 | 12.6 | 15.4 | 14.9 | 10.0 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

* Month of April

Table 7.9: Values of $K_{i,t}$ at Different Sites (Full Development)

| Time period | Percentage of total annual irrigation requirement $K_{i,t}$ | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SK<br>i=4 | SD<br>i=5 | 1K<br>i=6 | 2K<br>i=7 | 3K<br>i=8 | 4K<br>i=9 | 5K<br>i=10 | 6K<br>i=11 | 7K<br>i=12 | 1D<br>i=13 | 2D<br>i=14 | 3D<br>i=15 | 1KD<br>i=16 | 2KD<br>i=17 |
| 1 | 8.7 | 12.8 | 14.3 | 20.6 | 20.1 | 20.9 | 12.3 | 17.1 | 19.0 | 11.2 | 16.7 | 17.5 | 10.8 | 19.4 |
| 2 | 12.2 | 13.4 | 14.3 | 19.2 | 17.8 | 18.7 | 14.2 | 17.1 | 16.8 | 13.8 | 15.2 | 16.7 | 12.4 | 17.3 |
| 3 | 15.2 | 11.1 | 20.4 | 10.7 | 9.8 | 8.8 | 13.2 | 13.0 | 9.3 | 14.2 | 10.3 | 10.1 | 12.6 | 9.4 |
| 4 | 16.3 | 11.1 | 14.3 | 5.8 | 5.6 | 4.4 | 12.9 | 9.1 | 5.2 | 14.0 | 7.2 | 6.0 | 13.6 | 5.1 |
| 5 | 14.9 | 12.0 | 7.1 | 4.3 | 4.6 | 4.4 | 12.2 | 7.2 | 3.8 | 12.4 | 7.3 | 5.4 | 12.8 | 4.0 |
| 6 | 10.8 | 11.3 | 7.1 | 3.4 | 4.0 | 4.3 | 9.0 | 5.6 | 3.5 | 9.1 | 7.6 | 5.8 | 9.5 | 4.0 |
| 7 | 5.9 | 7.1 | 7.1 | 2.9 | 4.0 | 3.3 | 5.5 | 4.7 | 3.8 | 6.3 | 6.4 | 5.0 | 5.7 | 3.3 |
| 8 | 3.6 | 4.8 | 7.1 | 5.8 | 6.3 | 6.6 | 4.7 | 4.7 | 6.0 | 4.4 | 6.4 | 5.9 | 4.8 | 5.4 |
| 9 | 2.5 | 3.1 | 0.0 | 5.8 | 5.8 | 6.6 | 3.1 | 3.5 | 6.8 | 2.4 | 5.0 | 5.7 | 3.7 | 6.7 |
| 10 | 2.0 | 2.0 | 0.0 | 3.4 | 3.3 | 3.3 | 1.9 | 2.4 | 4.6 | 1.7 | 2.8 | 3.8 | 2.5 | 4.5 |
| 11 | 2.3 | 2.9 | 0.0 | 4.5 | 4.7 | 4.4 | 2.7 | 3.8 | 6.5 | 2.7 | 3.8 | 5.4 | 3.7 | 6.4 |
| 12 | 5.6 | 8.4 | 7.1 | 13.6 | 14.0 | 14.3 | 8.2 | 11.5 | 14.7 | 7.8 | 11.3 | 12.7 | 7.9 | 14.5 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

Note : Sites i = 1 to 3 are hydropower site.

Table 7.10: Monthly Pattern of Diversion Out of The Basin Unit:In (m.c.m.)

| Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Ave. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 67.0 | 67.0 | 67.0 | 67.0 | 67.0 | 67.0 | 65.0 | 65.0 | 65.0 | 65.0 | 65.0 | 65.0 | 66.0 |
| 53.5 | - | - | - | - | - | - | - | 52.0 | 52.0 | 52.0 | 52.0 | 21.8 |
| 120.5 | 67.0 | 67.0 | 67.0 | 67.0 | 67.0 | 65.0 | 65.0 | 117.0 | 117.0 | 117.0 | 117.0 | 87.8 |

**Table 7.11: Monthly Pattern of Load Factors**

| Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.58 | 0.60 | 0.64 | 0.67 | 0.70 | 0.66 | 0.59 | 0.58 | 0.61 | 0.62 | 0.63 | 0.62 |

With respect to above consideration, strategy of LP computation is follows:

First of all the reservoirs in the system are to be sequenced in ascending order from the upper most reservoir towards the down stream. To achieve a preliminary ~~the~~ rough design of reservoirs, each reservoir is approximately dimensioned by LP model iterations in the following steps.

(i) LP model was applied individually to each reservoir by using average, 90% or 70% dependable flow years inflows depending upon the type of project, to find the values of reservoir capacity and other design variables like hydropower plant capacity, annual firm energy which is generated by the plant, and annual firm irrigation capability of each reservoir, for fixing the ranges of design variables at each site.

(ii) Again LP model has to be applied individually for each reservoir by using the above mentioned dependabilities using intermediate catchment inflows, to fix the ranges of design variables at each site.

(iii) Since in this system, reservoirs are in series and parallel form, therefore, LP Model has been applied to the reservoir system according to the various alternative configurations which could be formed by different combinations of reservoirs also refer Table 5.25.

### 7.4.2 Strategy For Simulation Computation

Based on the preliminary design LP screening model, simulation model was used to refine and test the feasibility of the results of LP model, by fixing the ranges of the variables in terms of upper and lower bounds, and selecting various combinations of variables between these bounds of design variables and applying simulation for entire period (38 years), accordingly, many alternatives are simulated and ultimately the picking up of better alternatives is made based on the comparison of the following criteria~~s~~.

- Present value of net benefits, $PW_{nb}$, calculated for the period of simulation (38 years).
- The annual firm target is defined in terms of number and amount of annual deficits of each use, i.e, 100%, 90% and 75% successes or project dependabilities for water supply, hydropower and irrigation respectively during entire period for single purpose reservoir and about 100% and 70% success or project dependabilities for water supply and irrigation in a multi-purpose reservoir.
- Number of times that reservoir is full during entire period.
- Number of times that reservoir is empty in the critical months of the year (during entire period).
- Amount and number of average annual spill.

### 7.4.3 Computation

### 7.4.3.1 Computation For Reservoir-1

According to the above methodology the computations of LP model were carried out as follows:

**Computation for reservoir-1 as an individual project.**

**(i)** LP model was applied to the reservoir-1 (Karun-4) as an individual project with average monthly inflows, and 90% dependable years flow (as it is a hydropower reservoir), to find the values of design variables. In this case, there is no upstream reservoir, so the natural inflow to the reservoir is taken as the total natural catchment inflow up to the dam site. The Table

7.12.1 shows the values of variables which have been obtained from the model results.

**Table 7.12.1: Results of LP Model for Individual Project (Reservoir-1)**

| Reservoir Under Consideration | Inflow | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|
| | | Y | Ir | H | E | |
| Res.-1 (K-4) | Average | 2633 | - | 356 | 1832 | 177.6 |
| | 90% | 2077 | - | 217 | 1121 | 33.5 |

Where,

Y = Reservoir capacity (m.c.m.)

Ir = Annual irrigation water (m.c.m.)

H = Hydropower plant capacity (MW)

E = Annual energy generation (Gwhr)

**(ii)** On the basis of the results of preliminary screening by LP model the ranges on design variables were put in terms of upper and lower bounds. The first set of values of the upper and lower bounds on the variables are fixed on the basis of following criteria~~s~~:

- It is evident that the results of LP model using average inflows give higher estimates of design variables, which may put upper bounds on these variables for further simulation.
- On the other hand results of LP model using 90% dependable year's flow (as it is hydropower site), may put lower bounds on the values of the design variables.

Therefore, on the basis of the above mentioned criteria~~s~~, the upper and lower bounds on the values of design variables were fixed and are presented in Table 7.12.2. Then the selection of a number of design alternatives were made between the intervals of the above bounds using systematic sampling. The increments for Y and H were 100 m.c.m. and 50 MW respectively. Then simulation model was applied to each of the mentioned alternatives and the model was run on the monthly basis for thirty eight years of data. In every alternative the value of E was varied till 90% project dependability was obtained (i.e., 4 number of failure years or 34 years success out 38 years simulation). A successful year means that the annual demand is met without any shortfall. According to the comparison criterias mentioned earlier out of 35 simulated design alternatives a few number of better alternatives were selected and are given in Table 7.12.3. From the results it is found that for a large value of Y the increase in the present value of net benefit is not much, and hence higher reservoir capacity is not advisable. Again by selecting a second set of ranges for variables as given in Table 7.12.4 on the basis of above results, a number of 5 more alternative designs were simulated. The increments for Y, were 50 m.c.m.. The value of H was fixed equal to 350 MW, because with smaller values of H, the annual firm energy, E, decreases and with higher values there is no much change in E values. The best possible alternative which is satisfying the feasibility criterias was picked up, the results are presented in Table 7.12.5. It is found from the results that the value of E is close to the value of E obtained from LP model with 90% dependable year's flow, see Table 7.12.1.

**Table 7.12.2: First Set of Upper & Lower Bounds on Design Variables for Individual Project (Reservoir-1)**

| Reservoir Under Consideration | Design Variable | | |
|---|---|---|---|
| | Y | Ir | H |
| Res.-1 (K-4) | 2600* | – | 400* |
| | 2000** | – | 200** |

* Upper bound    ** Lower bound

**Table 7.12.3: A Few Selected Alternatives from Simulation from First Sample for Individual Project (Reservoir-1)**

| Reservoir Under Consideration | Design Variables For Better Selected Alternatives | | | | Total present value of net benefits in Rials $10^9$ ($PW_{nb}$) |
|---|---|---|---|---|---|
| | Y | Ir | H | E | |
| Res.-1 (K-4) | 2400 | - | 350 | 1520 | 6562.3 |
| | 2200 | - | 350 | 1435 | 6499.4 |
| | 2100 | - | 350 | 1379 | 6466.3 |
| | 2000 | - | 350 | 1311 | 6424.5 |

**Table 7.12.4: Second Set of Upper & Lower Bounds on Design Variables for Individual Project (Reservoir-1)**

| Reservoir Under Consideration | Design Variable | | |
|---|---|---|---|
| | Y | Ir | H |
| Res.-1 (K-4) | 2200 | – | 350 |
| | 2000 | – | 350 |

**Table 7.12.5: Results of Simulation from Second Sample for Individual Project (Reservoir-1)**

| Reservoir Under Consideration | Design Variable | | | | | Ave. Ann. Ener. Def. | No.of Ann. Ener. Def. | Ave. Ann. Spill | $PW_{nb}$ Rials $10^9$ |
|---|---|---|---|---|---|---|---|---|---|
| | Y | Ir | H | E | $\bar{E}$ | | | | |
| Res.-1 (K-4) | 2050 | - | 350 | 1343 | 573 | 9.5 | 4 | 2341 | 6449 |

$\bar{E}$ = Annual secondary energy generation (GWhr)

### 7.4.3.2 Computation For Reservoir-2

For reservoir-2, all possible alternative configurations of reservoirs which it can form with U/S reservoir-1 were tested with LP and simulation models as follows:

### 1. Computation for reservoir-2 as an individual project

Following the process of individual project computation for reservoir-1, computations were also carried out for reservoir-2 (Karun-3) in two steps:

(i) Initially, it is assumed that there is no reservoir upstream of reservoir-2, so the entire natural catchment inflow contribution up to this site is taken as the natural inflow for analysis for reservoir-2. This is done because U/S reservoir-1 has only hydropower. Results of LP model are presented in Table 7.13.1.

**Table 7.13.1: Results of LP Model for Individual Project (Reservoir-2)**

| Reservoir Under Consideration | Inflow | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|
| | | Y | Ir | H | E | |
| Res.-2 (K-3) | Average | 3281 | - | 642 | 3308 | 283.7 |
| | 90% | 2578 | - | 384 | 1980 | 61.6 |

(ii) In an another effort made by LP model using intermediate catchment flow between reservoir-1 and reservoir-2 (Karun-4 and Karun-3) the capability as well as contribution of the intermediate catchment flow in estimation of the values of design variables at reservoir-2 was determined as shown in Table 7.13.2.

(iii) Based on the results at this site and considering the procedure which was used for fixing the ranges of design variables at reservoir-1, the ranges on design variables for reservoir-2 are fixed and are given in Table 7.13.3.

Then, by choosing certain increments a number of design alternatives were formed between the ranges of the above bounds using systematic sampling, and the increments for Y, H were selected as 100 m.c.m., 50 MW, respectively for further investigation by simulation as follows:

Simulation model was applied to each of the selected alternatives. Out of 54 simulated design alternatives a few number of better alternatives were selected on the basis of the comparison criterias mentioned earlier, and the result are given in Table 7.13.4. Based on the results as given in this table it may be seen that the competition of better alternatives are in the ranges of 2200 m.c.m. and 2400 m.c.m. for the value of Y. Therefore, by selecting a new set of ranges for variables (Table 7.13.5), a 5 number of alternative designs were simulated. The increments for Y was 50 m.c.m. The best attractive alternative design among all alternatives is selected, and the final results are given in Table 7.13.6.

**Table 7.13.2: Results of LP Model for Individual Project Reservoir-2)**
**(With Intermediate Catchment Flows)**

| Reservoir Under Consideration | Inflow | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|
| | | Y | Ir | H | E | |
| Res.-2 (K-3) | Average | 1831 | - | 260 | 1339 | 29.9 |
| | 90% | 1332 | - | 149 | 766 | 6.7 |

**2. Computation for integration of reservoir-2 with U/S reservoir-1**

Following the process of integrated reservoirs studies, computation were done as follows:

(i) Again LP model was used for integrated reservoir-2 and reservoir-1 (Karun-3 and 4). In this case the natural inflow to the second reservoir is taken as the contribution of the intermediate catchment natural inflow. Tables

7.13.7, and 7.13.8 show the results of LP model in integrated case of reservoir-2 and reservoir-1 with average and 90% results of dependable inflows respectively.

**(ii)** Simulation was applied to these integrated reservoirs by keeping the features of the U/S reservoir same, i.e., reservoir-1 (Karun-4) as finalised earlier by simulation (Table 7.12.5). The results of integrated studies are given in Table 7.13.9. It is seen from this table that reservoir capacity of Karun-3 (reservoir-2) has reduced to 2200 m.c.m. from 2250 m.c.m. of Table 7.13.6, which may be expected sometimes in integrated system.

**Table 7.13.3 : First Set of Upper & Lower Bounds on Design Variables for Individual Project (Reservoir-2)**

| Reservoir Under Consideration | Design Variable | | |
|---|---|---|---|
| | Y | Ir | H |
| Res.-2 (K-3) | 2500 | – | 650 |
| | 2000 | – | 200 |

**Table 7.13.4: A Few Selected Alternatives from Simulation for Individual Project (Reservoir-2)**

| Reservoir Under Consideration | Design Variables for better Selected Alternatives | | | | Total present value of net benefits in Rials $10^9$ ($PW_{nb}$) |
|---|---|---|---|---|---|
| | Y | Ir | H | E | |
| Res.-2 (K-3) | 2500 | – | 650 | 2072 | 9357.1 |
| | 2400 | – | 650 | 2015 | 9280.6 |
| | 2300 | – | 650 | 1946 | 9195.3 |
| | 2200 | – | 650 | 1886 | 9111.9 |
| | 2100 | – | 650 | 1819 | 9029.7 |
| | 2000 | – | 650 | 1760 | 8942.1 |

**Table 7.13.5: Second Set of Upper & Lower Bounds on Design Variables for Individual Project (Reservoir-2)**

| Reservoir Under Consideration | Design Variable | | |
|---|---|---|---|
| | Y | Ir | H |
| Res.-2<br>(K-3) | 2400 | - | 650 |
| | 2200 | - | 650 |

**Table 7.13.6: Results of Simulation From Second Sample for Individual Project (Reservoir-2)**

| Reservoir Under Consideration | Design Variable | | | | | Ave. Ann. Ener. Def. | No.of Ann. Ener. Def. | Ave. Ann. Spill | $PW_{nb}$ Rials $10^9$ |
|---|---|---|---|---|---|---|---|---|---|
| | Y | Ir | H | E | $\bar{E}$ | | | | |
| Res.-2<br>(K-3) | 2250 | - | 650 | 1916 | 1172 | 24.0 | 4 | 4223 | 9152 |

**Table 7.13.7: Results of LP Model for Integrated Reservoirs for Average Flows (Reservoirs-2 and 1)**

| Reservoir Under Consideration | Other possible Alternative Reservoir Configurations | Res. No. | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | |
| Res.-2<br>(K-3) | 2,1<br>(K-3,4) | 1 | 2633 | - | 356 | 1832 | 662.3 |
| | | 2 | 1831 | - | 639 | 3294 | |

Table 7.13.8: Results of LP Model for Integrated Reservoirs for 90% Dependable Inflows (Reservoirs-2 and 1)

| Reservoir Under Consideration | Other possible Alternative Reservoir Configurations | Res. No. | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | |
| Res.-2<br>(K-3) | 2,1<br>(K-3,4) | 1 | 2077 | - | 217 | 1121 | 162.1 |
| | | 2 | 1332 | - | 381 | 1962 | |

Table 7.13.9: Results of Simulation (Reservoirs-2 & 1)

| Reservoir Under Consideration | Other possible Alternative Reservoir Configurations | Res. No. | Design Variable | | | | | Ave. Ann. Ener. Def. | No.of Ann. Ener. Def. | Ave. Ann. Spill | $PW_{nb}$ Rials $10^9$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | $\bar{E}$ | | | | |
| Res.-2<br>(K-3) | 2,1<br>(K-3,4) | 1 | 2050 | - | 350 | 1343 | 573 | 9.5 | 4 | 2341 | 15746 |
| | | 2 | 2200 | - | 650 | 2154 | 963 | 45.6 | 4 | 3590 | |

### 7.4.3.3 Computation For Reservoir-3

For reservoir-3 also, all possible alternative configutations of reservoirs which it can form with U/S reservoirs 2 and 1are tested, the similar types of computations were carried out as done for reservoir-2 earlier, in the following steps:

### 1. Computation for reservoir-3 as an individual project

Since, both the U/S reservoirs 2 and 1 are only hydropower projects, it can be initially designed assuming that U/S reservoirs 2 and 1 do not exist. The results of the computations are given in Tables from 7.14.1 to 7.14.6.

Table 7.14.1: Results of LP Model for Individual Project (Reservoir-3)

| Reservoir Under Consideration | Inflow | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|
| | | Y | Ir | H | E | |
| Res.-3 (K-2) | Average | 4784 | - | 589 | 3034 | 172.9 |
| | 90% | 4214 | - | 369 | 1903 | 12.8 |

Table 7.14.2: Results of LP Model for Individual Project (Reservoir-3) (With Intermediate Catchment Flows)

| Reservoir Under Consideration | Inflow | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|
| | | Y | Ir | H | E | |
| Res.-3 (K-2) | Average | 2436 | - | 21 | 106 | 0.6 |
| | 90% | 2412 | - | 9 | 46 | 0.2 |

Table 7.14.3 : First Set of Upper & Lower Bounds on Design Variables for Individual Project (Reservoir-3)

| Reservoir Under Consideration | Design Variable | | |
|---|---|---|---|
| | Y | Ir | H |
| Res.-3 (K-2) | 4800 | – | 600 |
| | 4200 | – | 350 |

**Table 7.14.4: A Few Selected Alternatives from Simulation from First Sample for Individual Project (Reservoir-3)**

| Reservoir Under Consideration | Design Variables for better Selected Alternatives | | | | Total present value of net benefits in Rials $10^9$ ($PW_{nb}$) |
|---|---|---|---|---|---|
| | Y | Ir | H | E | |
| Res.-3 (K-2) | 4800 | - | 600 | 2003 | 8527.1 |
| | 4700 | - | 600 | 1966 | 8427.0 |
| | 4600 | - | 600 | 1928 | 9415.0 |
| | 4500 | - | 600 | 1898 | 8326.6 |
| | 4400 | - | 600 | 1851 | 8216.7 |
| | 4300 | - | 600 | 1816 | 8125.0 |
| | 4200 | - | 600 | 1767 | 8014.8 |

**Table 7.14.5: Second Set of Upper & Lower Bounds on Design Variables for Individual Project (Reservoir-3)**

| Reservoir Under Consideration | Design Variable | | |
|---|---|---|---|
| | Y | Ir | H |
| Res.-3 (K-2) | 4800 | - | 650 |
| | 4400 | - | 650 |

**Table 7.14.6: Results of Simulation from Second Sample for Individual Project (Reservoir-3)**

| Reservoir Under Consideration | Design Variable | | | | | Ave. Ann. Ener. Def. | No.of ann. Ener. Def. | Ave. Ann. Spill | $PW_{nb}$ Rials $10^9$ |
|---|---|---|---|---|---|---|---|---|---|
| | Y | Ir | H | E | $\bar{E}$ | | | | |
| Res.-3 (K-2) | 4600 | - | 600 | 1938 | 881 | 40.3 | 4 | 3783 | 8424 |

## 2. Study of integration of reservoir-3 with U/S reservoirs 2 and 1

### 2(a) Computation for integrated reservoirs 3 and 2

The reservoir-3 is integrated with U/S reservoir-2 assuming that the next U/S reservoir-1 does not exist. In LP model computations no bounds were kept on design variables. Where as in simulation computations, the project features (design variables) of U/S reservoir-2 were kept same as obtained earlier in Table 7.13.6. The results of computations are given in Tables from 7.14.7 to 7.14.9. It is seen that the size of reservoir-3 has reduced to 4500 m.c.m. from 4600 m.c.m. of Table 7.14.6.

**Table 7.14.7: Results of LP Model for Integrated Reservoirs for Average Inflows (Reservoirs-3 and 2)**

| Reservoir Under Consideration | Other possible Alternative Reservoir Configurations | Res. No. | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | |
| Res.-3<br>(K-2) | 3,2<br>(K-2,3) | 2 | 3281 | - | 642 | 3308 | 608.9 |
| | | 3 | 2436 | - | 583 | 3003 | |

**Table 7.14.8: Results of LP Model for Integrated Reservoirs for 90% Dependable Inflows (Reservoirs-3 and 2)**

| Reservoir Under Consideration | Other possible Alternative Reservoir Configurations | Res. No. | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | |
| Res.-3<br>(K-2) | 3,2<br>(K-2,3) | 2 | 2578 | - | 384 | 1980 | 167.3 |
| | | 3 | 2412 | - | 345 | 1778 | |

Table 7.14.9: Results of Simulation (Reservoirs-3 and 2)

| Reservoir Under Consideration | Other possible Alternative Reservoir Configurations | Res. No. | Design Variable | | | | | Ave. Ann. Ener. Def. | No.of Ann. Ener. Def. | Ave. Ann. Spill | $PW_{nb}$ Rials $10^9$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | $\bar{E}$ | | | | |
| Res.-3<br>(K-2) | 3,2<br>(K-2,3) | 2 | 2250 | - | 650 | 1916 | 1172 | 24.0 | 4 | 4223 | 17911 |
| | | 3 | 4500 | - | 600 | 2042 | 874 | 18.4 | 4 | 3737 | |

**2(b) Computation for integrated reservoirs 3, 2 and 1**

For this integrated study no bounds were kept on design variables in LP model as done earlier. For simulation the features (design variables) of reservoirs 2 and 1 were kept same as obtained earlier in Table 7.13.9. The results are given in Tables from 7.14.10 to 7.14.12. It is seen that the size of reservoir-3 has again increased to 4600 m.c.m.

Table 7.14.10: Results of LP Model for Integrated Reservoirs for Average Inflows (Reservoirs-3, 2 and 1)

| Reservoir Under Consideration | Other possible Alternative Reservoir Configurations | Res. No. | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | |
| Res.-3<br>(K-2) | 3,2,1<br>(K-2,3,4) | 1 | 2633 | - | 356 | 1832 | 985.0 |
| | | 2 | 1831 | - | 639 | 3294 | |
| | | 3 | 2436 | - | 580 | 2989 | |

**Table 7.14.11: Results of LP Model for Integrated Reseroirs for 90% Dependable Inflows (Reservoirs-3, 2 and 1)**

| Reservoir Under Consideration | Other possible Alternative Reservoir Configurations | Res. No. | Design Variable |  |  |  | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|---|
|  |  |  | Y | Ir | H | E |  |
| Res.-3<br>(K-2) | 3,2,1<br>(K-2,3,4) | 1 | 2077 | - | 217 | 1121 | 264.9 |
|  |  | 2 | 1332 | - | 381 | 1962 |  |
|  |  | 3 | 2412 | - | 342 | 1778 |  |

**Table 7.14.12: Results of Simulation (Reservoirs-3, 2 and 1)**

| Reservoir Under Consideration | Other possible Alternative Reservoir Configurations | Res. No. | Design Variable |  |  |  |  | Ave. Ann. Ener. Def. | No.of Ann. Ener. Def. | Ave. Ann. Spill | $PW_{nb}$ Rials $10^9$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Y | Ir | H | E | $\bar{E}$ |  |  |  |  |
| Res.-3<br>(K-2) | 3,2,1<br>(K-2,3,4) | 1 | 2050 | - | 350 | 1343 | 573 | 9.5 | 4 | 2341 | 24480 |
|  |  | 2 | 2200 | - | 650 | 2154 | 963 | 45.6 | 4 | 3590 |  |
|  |  | 3 | 4600 | - | 600 | 1951 | 1007 | 43.8 | 4 | 4011 |  |

### 2(c) Computation for integrated reservoir 3 and 1

The LP model calculations were done as earlier. For simulation the design variables were fixed as given in Table 7.12.5. The results are given in Tables from 7.14.13 to 7.14.15. It is found that the size of reservoir-3 could be reduced to 4550 m.c.m.

Table 7.14.13: Results of LP Model for Integrated Reservoirs for Average Flows (Reservoirs-3 and 1)

| Reservoir Under Consideration | Other possible Alternative Reservoir Configurations | Res. No. | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | |
| Res.-3<br>(K-2) | 3,1<br>(K-2,4) | 1 | 2633 | - | 356 | 1832 | 444.6 |
| | | 3 | 3228 | - | 586 | 3019 | |

Table 7.14.14: Results of LP Model for Integrated Reservoirs for 90% Dependable Inflows (Reservoirs-3 and 1)

| Reservoir Under Consideration | Other possible Alternative Reservoir Configurations | Res. No. | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | |
| Res.-3<br>(K-2) | 3,1<br>(K-2,4) | 1 | 2077 | - | 217 | 1120 | 52.7 |
| | | 3 | 3518 | - | 348 | 1973 | |

Table 7.14.15: Results of Simulation (Reservoirs 3 and 1)

| Reservoir Under Consideration | Other possible Alternative Reservoir Configurations | Res. No. | Design Variable | | | | | Ave. Ann. Ener. Def. | No. of ann. Ener. Def. | Ave. Ann. Spill | $PW_{nb}$ Rials $10^9$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | $\bar{E}$ | | | | |
| Res.-3<br>(K-2) | 3,1<br>(K-2,4) | 1 | 2050 | - | 350 | 1343 | 573 | 9.5 | 4 | 2341 | 15061 |
| | | 3 | 4550 | - | 600 | 1942 | 976 | 58.3 | 4 | 4003 | |

### 7.4.3.4 Computation For Reservoir-4

### 1. Computation for reservoir-4 as an individual project

Since all the reservoirs U/S ofreservoir-4 (Karun-1) are hydropower projects, it can also be initially designed assuming that the U/S reservoirs are not present. For this multi-purpose reservoir LP model was run for average and 70% dependable year's flows. For reservoir capacity and hydropower capacity the earlier criteria was used for fixing ranges for simulation, However, for annual irrigation target wider range was selected. For irrigation a success of 70% project dependability (11 years out of 38 years) and for hydropower as high as 85% project dependability were achieved. The results of the models are given in Tables 7.15.1 and 7.15.2.

**Table 7.15.1: Results of LP Model for Individual Project (Reservoir-4)**

| Reservoir Under Consideration | Inflow | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|
| | | Y | Ir | H | E | |
| Res.-4 (K-1) | Average | 4012 | 6668 | 787 | 4055 | 540.3 |
| | 70% | 3516 | 5223 | 624 | 3218 | 419.0 |

**Table 7.15.2: Results of Simulation for Individual Project (Reservoirs-4)**

| Reservoir Under Consideration | DesignVariale | | | | | Ave. Ann. Ener. Def. | No.of Ann. Ener. Def. | Ave. Ann. Irr. Def. | No.of Ann. Irr. Def. | Ave. Ann. Spill | $PW_{nb}$ Rials $10^9$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Y | Ir | H | E | $\bar{E}$ | | | | | | |
| Res.-4 (K-1) | 3050 | 6400 | 800 | 1838 | 195 | 31.8 | 4 | 118 | 10 | 3904 | 7394 |

### 2. Computation for integration of reservoir-4 with U/S eservoirs

For LP model 3 sets of runs were made. In Table 7.15.3 average flows were considered and in Table 7.15.4 the 90% dependable year's flows were taken. In another case, Table 7.15.5, 90% dependable year's flows for hydropower projects and 70% dependable year's flows for multipurpose project were taken. The results of integrated reservoirs studies are given in Tables 7.15.3 to 7.15.6.

**Table 7.15.3: Results of LP Model for Integrated Reservoirs for Average Inflows (Various Combinations of Reservoirs 4, 3, 2 and 1)**

| Reservoir Under Consideration | Other possible Alternative Reservoir Configurations | Res No | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | |
| Res.-4<br>(K-1) | 4,3<br>(K-1,2) | 3 | 4784 | - | 589 | 3034 | 718.0 |
| | | 4 | 1680 | 6551 | 776 | 4001 | |
| Res.-4<br>(K-1) | 4,3,2<br>(K-1,2,3) | 2 | 3281 | - | 642 | 3308 | 1149.0 |
| | | 3 | 2436 | | 583 | 3003 | |
| | | 4 | 1680 | 6494 | 769 | 3966 | |
| Res.-4<br>(K-1) | 4,3,2,1<br>(K-1,2,3,4) | 1 | 2633 | - | 356 | 1832 | 1522.8 |
| | | 2 | 1831 | - | 639 | 3294 | |
| | | 3 | 2436 | - | 580 | 2989 | |
| | | 4 | 1680 | 6466 | 766 | 3949 | |
| Res.-4<br>(K-1) | 4,3,1<br>(K-1,2,4) | 1 | 2633 | - | 356 | 1832 | 745.6 |
| | | 3 | 3228 | | 586 | 3019 | |
| | | 4 | 1680 | 4095 | 483 | 2488 | |
| Res.-4<br>(K-1) | 4,2<br>(K-1,3) | 2 | 3281 | - | 642 | 3308 | 831.0 |
| | | 4 | 1784 | 6585 | 780 | 4022 | |
| Res.-4<br>(k-1) | 4,2,1<br>(K-1,3,4) | 1 | 2633 | - | 356 | 1832 | 1207.4 |
| | | 2 | 1831 | - | 639 | 3294 | |
| | | 4 | 1784 | 6558 | 777 | 4006 | |
| Res.-4<br>(K-1) | 4,1<br>(K-1,4) | 1 | 2633 | - | 356 | 1832 | 721.0 |
| | | 4 | 2611 | 6623 | 785 | 4046 | |

Table 7.15.4: **Results of LP Model for Integrated Reservoirs for 90% Dependable Inflows (Various Combinations of Reservoirs-4, 3, 2 and 1)**

| Reservoir Under Consideration | Other possible Alternative Reservoir Configurations | Res. No. | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | |
| Res.-4 | 4,3 | 3 | 4047 | - | 351 | 1809 | 309.0 |
| (K-1) | (K-1,2) | 4 | 1488 | 4011 | 469 | 2417 | |
| Res.-4 | 4,3,2 | 2 | 2578 | - | 384 | 1980 | 482.6 |
| (K-1) | (K-1,2,3) | 3 | 2412 | - | 345 | 1778 | |
| | | 4 | 1488 | 3955 | 462 | 2364 | |
| Res.-4 | 4,3,2,1 | 1 | 2077 | - | 217 | 1121 | 577.6 |
| (K-1) | (K-1,2,3,4) | 2 | 1332 | - | 381 | 1962 | |
| | | 3 | 2412 | - | 342 | 1778 | |
| | | 4 | 1488 | 3925 | 459 | 2364 | |
| Res.-4 | 4,3,1 | 1 | 2077 | - | 217 | 1121 | 219.0 |
| (K-1) | (K-1,2,4) | 3 | 3519 | - | 348 | 1793 | |
| | | 4 | 1188 | 2595 | 300 | 1544 | |
| Res.-4 | 4,2 | 2 | 2578 | - | 384 | 1980 | 384.3 |
| (K-1) | (K-1,3) | 4 | 1558 | 4046 | 473 | 2438 | |
| Res.-4 | 4,2,1 | 1 | 2077 | - | 217 | 1121 | 482.2 |
| (K-1) | (K-1,3,4) | 2 | 1332 | - | 381 | 1962 | |
| | | 4 | 1558 | 4018 | 470 | 2921 | |
| Res.-4 | 4,1 | 1 | 2077 | - | 217 | 1121 | 344.9 |
| (K-1) | (K-1,4) | 4 | 2489 | 4082 | 477 | 2460 | |

**Table 7.15.5: Results of LP Model for Integrated Reservoirs for Dependable Inflows* (Various Combinations of Reservoirs- 4, 3, 2 and 1)**

| Reservoir Under Consideration | Other possible Alternative Reservoir Configurations | Res. No. | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | |
| Res.-4<br>(K-1) | 4,3<br>(K-1,2) | 3 | 4214 | - | 369 | 1903 | 321.0 |
| | | 4 | 1757 | 4174 | 488 | 2517 | |
| Res.-4<br>(K-1) | 4,3,2<br>(K-1,2,3) | 2 | 2578 | - | 384 | 1980 | 494.2 |
| | | 3 | 2412 | - | 345 | 1778 | |
| | | 4 | 1757 | 4117 | 482 | 2482 | |
| Res.-4<br>(K-1) | 4,3,2,1<br>(K-1,2,3,4) | 1 | 2077 | - | 217 | 1121 | 589.2 |
| | | 2 | 1332 | - | 381 | 1962 | |
| | | 3 | 2412 | - | 342 | 1778 | |
| | | 4 | 1757 | 4087 | 478 | 2464 | |
| Res.-4<br>(K-1) | 4,3,1<br>(K-1,2,4) | 1 | 2077 | - | 217 | 1121 | 231.0 |
| | | 3 | 3519 | - | 348 | 1793 | |
| | | 4 | 1757 | 2758 | 319 | 1645 | |
| Res.-4<br>(K-1) | 4,2<br>(K-1,3) | 2 | 2578 | - | 384 | 1980 | 400.0 |
| | | 4 | 1832 | 4249 | 497 | 2563 | |
| Res.-4<br>(K-1) | 4,2,1<br>(K-1,3,4) | 1 | 2077 | - | 217 | 1121 | 482.2 |
| | | 2 | 1332 | - | 381 | 1962 | |
| | | 4 | 1831 | 4221 | 494 | 2546 | |
| Res.-4<br>(K-1) | 4,1<br>(K-1,4) | 1 | 2077 | - | 217 | 1121 | 405.4 |
| | | 4 | 2520 | 4705 | 552 | 2844 | |

(*) 70% for Karun-1 and 90% for others.

Table 7.15.6: Results of Simulation for Integrated Reservoirs (Various Combinations of Reservoirs-4, 3, 2 and 1)

| Reservoir Under Consideration | Other possible Alternative Reservoir Configurations | Res. No. | Design Variable |  |  |  |  | Ave. Ann. Ener. Def. | No.of Ann. Ener. Def. | Ave. Ann. Irr. Def. | No.of Ann. Irr. Def. | Ave. Ann. Spill | $PW_{nb}$ Rials $10^9$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Y | Ir | H | E | $\bar{E}$ |  |  |  |  |  |  |
| Res.-4 (K-1) | 4,3 (K-1,2) | 3 | 4600 | - | 600 | 1937 | 880 | 40.0 | 4 | - | - | 3738 | 16029 |
|  |  | 4 | 2800 | 7200 | 800 | 2335 | 1534 | 15.3 | 4 | 340 | 11 | 2904 |  |
| Res.-4 (K-1) | 4,3,2 (K-1,2,3) | 2 | 2250 | - | 650 | 1916 | 1172 | 24.0 | 4 | - | - | 4223 | 25687 |
|  |  | 3 | 4500 | - | 600 | 2042 | 874 | 18.4 | 4 | - | - | 3737 |  |
|  |  | 4 | 3050 | 8000 | 800 | 2164 | 1684 | 15.8 | 8 | 525 | 11 | 2484 |  |
| Res.-4 (K-1) | 4,3,2,1 (K-1,2,3,4) | 1 | 2050 | - | 350 | 1343 | 573 | 9.5 | 4 | - | - | 2341 | 32471 |
|  |  | 2 | 2200 | - | 650 | 2154 | 963 | 45.6 | 4 | - | - | 3590 |  |
|  |  | 3 | 4600 | - | 600 | 1951 | 1007 | 43.8 | 4 | - | - | 4011 |  |
|  |  | 4 | 3050 | 8400 | 800 | 2273 | 1750 | 26.9 | 8 | 564 | 11 | 2420 |  |
| Res.-4 (K-1) | 4,3,1 (K-1,2,4) | 1 | 2050 | - | 350 | 1342 | 573 | 9.5 | 4 | - | - | 2341 | 23059 |
|  |  | 3 | 2000 | - | 650 | 2041 | 1046 | 33.5 | 4 | - | - | 3837 |  |
|  |  | 4 | 3050 | 8600 | 800 | 2147 | 1813 | 33.3 | 8 | 564 | 11 | 2280 |  |
| Res.-4 (K-1) | 4,2 (K-1,3) | 2 | 2250 | - | 650 | 1916 | 1172 | 24.0 | 4 | - | - | 4223 | 12934 |
|  |  | 4 | 3050 | 3200 | 800 | 677 | 1382 | 23.2 | 8 | 191 | 10 | 3080 |  |
| Res.-4 (K-1) | 4,2,1 (K-1,3,4) | 1 | 2050 | - | 350 | 1343 | 573 | 9.5 | 4 | - | - | 2341 | 23659 |
|  |  | 2 | 4550 | - | 600 | 1942 | 976 | 58.3 | 4 | - | - | 4003 |  |
|  |  | 4 | 3050 | 8580 | 800 | 2178 | 1812 | 22.0 | 8 | 561 | 11 | 2334 |  |
| Res.-4 (K-1) | 4,1 (K-1,4) | 1 | 2050 | - | 350 | 1343 | 573 | 9.5 | 4 | - | - | 2341 | 14176 |
|  |  | 4 | 3050 | 7500 | 800 | 1870 | 2013 | 19.3 | 8 | 332 | 11 | 2916 |  |

### 7.4.3.5 Computation For Site-5 (Run-of-River Hydro power Site)

In computation for LP model two sets of flows were taken. In Table 7.16.1 average flows were used. In Table 7.16.2, 90% dependable year's flows for hydropower and 70% dependable year's flows for multipurpose reservoir were used. The results of LP model and simulation model are given in Tables 7.16.1 to 7.16.3.

**Table 7.16.1: Results of LP Model for Integrated Reservoirs for Average Inflows (Site-5 and Reservoirs 4 ,3 ,2 and 1)**

| Reservoir Under Consideration | Reservoir Configurations | Res. No. | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | |
| Site-5<br>Run-of-River<br>Hydro-power<br>(G) | 5,4,3,2,1<br>(G,K-1,2,3,4) | 1 | 2633 | - | 356 | 1832 | 1927.0 |
| | | 2 | 1831 | - | 639 | 3294 | |
| | | 3 | 2436 | - | 580 | 2989 | |
| | | 4 | 1680 | 6466 | 766 | 3949 | |
| | | G | - | - | 637 | 3283 | |

(G)= Godar-e-Landar Run-of-River Hydro Power Site

**Table 7.16.2: Results of LP Model for Integrated Reservoirs for Dependable Inflows* (Site-5 and Reservoirs-4, 3, 2 and 1)**

| Reservoir Under Consideration | Reservoir Configurations | Res. No. | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | |
| Site-5<br>Run-of-River<br>Hydro-power<br>(G) | 5,4,3,2,1<br>(G,K-1,2,3,4) | 1 | 2077 | - | 217 | 1121 | 841.4 |
| | | 2 | 1332 | - | 381 | 1962 | |
| | | 3 | 2412 | - | 342 | 1778 | |
| | | 4 | 1757 | 4087 | 478 | 2464 | |
| | | G | - | - | 397 | 2048 | |

(* ) 90% for hydropower and 70% for multipurpose reservoir.

**Table 7.16.3: Results of Simulation (Site-5 and Reservoirs-4, 3, 2, 1)**

| Reservoir Under Consideration | Reservoir Configurations | Res. No. | Design Variable | | | | | Ave. Ann. Ener. Def. | No.of Ann. Ener. Def. | Ave. Ann. Irr. Def. | No.of Ann. Irr. Def. | Ave. Ann. Spill | $PW_{nb}$ Rials $10^9$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | $\bar{E}$ | | | | | | |
| Site-5 (G) | 5,4,3,2,1 (K-1,2,3,4,G) | 1 | 2050 | - | 350 | 1343 | 573 | 9.5 | 4 | – | – | 2341 | 32471 |
| | | 2 | 2200 | - | 650 | 2154 | 963 | 45.6 | 4 | – | – | 3590 | |
| | | 3 | 4600 | - | 600 | 1951 | 1007 | 43.8 | 4 | – | – | 4011 | |
| | | 4 | 3050 | 8400 | 800 | 2273 | 1750 | 26.9 | 8 | 564 | 11 | 2420 | |
| | | G | - | - | 650 | 1593 | 2345 | 7.5 | 4 | - | - | 9138 | |

### 7.4.3.6 Computation For Reservoir-6

### 1. Computation for reservoir-6 as an individual project

LP model and simulation models were applied to the reservoir-6 (Dez Dam) as an individual project. For LP model average monthly flows, and 70% dependable years flow (as it is a multi-purpose reservoir) were used. The results of LP model are given in Table 7.17.1. For simulation the ranges on design variables were fixed as given in Table 7.17.2. The results of simulation are given in Table 7.17.3. Based on these results a second set of ranges were selected as given in Table 7.17.4. The results of simulation are given in Table 7.17.5.

**Table 7.17.1: Results of LP Model for Individual Project (Reservoir-6)**

| Reservoir Under Consideration | Inflow | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|---|
| | | Y | Ir | H | E | |
| Res.-6 (Dez dam) | Average | 3170 | 4312 | 580 | 2989 | 344.2 |
| | 70% | 2716 | 3467 | 466 | 2403 | 273.3 |

Table 7.17.2: First Set of Upper & Lower Bounds on Design Variables for Individual Project (Reservoir-6)

| Reservoir Under Consideration | Design Variable | | |
|---|---|---|---|
| | Y | Ir | H |
| Res.-6 (Dez Dam) | 3400 | 5800 | 600 |
| | 2600 | 2600 | 450 |

Table 7.17.3: A Few Selected Alternatives from Simulation from First Sample for Individual Project (Reservoir-6)

| Reservoir Under Consideration | Design Variables For Better Selected Alternatives | | | | Total present value of net benefits in Rials $10^9$ ($PW_{nb}$) |
|---|---|---|---|---|---|
| | Y | Ir | H | E | |
| Res.-6 (Dez Dam) | 3400 | 5800 | 600 | 1076 | 5556 |
| | 3200 | 5600 | 600 | 1077 | 5474 |
| | 3000 | 5400 | 600 | 1037 | 5360 |
| | 2800 | 5200 | 600 | 984 | 5246 |
| | 2600 | 5000 | 600 | 936 | 5144 |

Table 7.17.4: Second Set of Upper & Lower Bounds on Design Variables for Individual Project (Reservoir-6)

| Reservoir Under Consideration | Design Variable | | |
|---|---|---|---|
| | Y | Ir | H |
| Res.-6 (Dez Dam) | 3400 | 5800 | 600 |
| | 3200 | 5000 | 600 |

**Table 7.17.5: Results of Simulation from Second Sample for Individual Project (Reservoir-6)**

| Reservoir Under Consideration | Design Vriabl | | | | | Ave. Ann. Ener. Def. | No.of Ann. Ener. Def. | Ave. Ann. Irr. Def. | No.of Ann. Irr. Def. | Ave. Ann. Spill | $PW_{nb}$ Rials $10^9$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Y | Ir | H | E | $\bar{E}$ | | | | | | |
| Res.-6 (Dez-Dam) | 3200 | 5300 | 600 | 1414 | 1641 | 35.7 | 8 | 152 | 8 | 2100 | 5971 |

## 7.5 SIZING OF IRRIGATION INCLUDING MULTI-IRRIGATION AREAS

From the above results it is found that the configuration of reservoirs consisting of all the five reservoirs and the run-of-river hydropower scheme is optimal. Hence, this configuration was chosen for further analysis. For sizing of irrigation including multi-irrigation areas the computations were done for the existing and the future development scenarios.

1. In LP model average flows were used. On multi-irrigation areas limits were put (refer Figures 5.12, 5.13 and Tables 5.23, 5.24). The results of existing and future developments are given in Tables 7.18.1 and 7.18.2 respectively.
2. Based on the results of LP model, simulation was applied to both the developmental cases. The results of simulation are given in Tables 7.18.3 and 7.18.4. The results show that there are no irrigation deficits and hopefully there may be surplus water available. Hence, the annual firm energy targets based on 90% project dependability were revised at Karun-1 and Dez.

**Table 7.18.1: Results of LP Model for Integrated Reservoirs for Average Inflows (Reservoirs 4 and 6 with Multi-irrigation areas) Existing Development**

| Res. No. | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|
| | Y | Ir | H | E | |
| 4 | 4012 | (SK*) 252 | 779 | 4017 | 821.3 |
| 6 | 3196 | (SD*)1802 | 598 | 3080 | |
| 1K | - | 1.5 | - | - | |
| 2k | - | 376 | - | - | |
| 3K | - | 124 | - | - | |
| 4K | - | 257 | - | - | |
| 5K | - | 32 | - | - | |
| 1D | - | 288 | - | - | |
| 2D | - | 292 | - | - | |
| 3D | - | 290 | - | - | |
| 4D | - | 32 | - | - | |
| 1KD | - | 786 | - | - | |
| 2KD | - | 1597 | - | - | |
| 3KD | - | 676 | - | - | |

**Note:** Refer Figure 5.12 and Table 5.23.
* (SK) & (SD) are self irrigation areas for Karun-1 and Dez respectively.

**Table 7.18.2: Results of LP Model for Integrated Reservoirs for Average Inflows (Reservoirs 1, 2, 3, 4, 5 and 6 With Multi-irrigation areas) Future Development**

| Res. No. | Design Variable | | | | Total annual net benefit in Rials $10^9$ |
|---|---|---|---|---|---|
| | Y | Ir | H | E | |
| 1 | 2633 | - | 356 | 1832 | 1888.4 |
| 2 | 1831 | - | 639 | 3294 | |
| 3 | 2436 | - | 580 | 2989 | |
| 4 | 1680 | (SK*) 720 | 766 | 3953 | |
| 5 | - | - | 637 | 3283 | |
| 6 | 3196 | (SD*) 1903 | 605 | 3116 | |
| 1K | - | 3 | | - | |
| 2k | - | 124 | | - | |
| 3K | - | 465 | | - | |
| 4K | - | 27 | | - | |
| 5K | - | 607 | | - | |
| 6K | - | 85 | | - | |
| 7K | - | 306 | | - | |
| 1D | - | 368 | | - | |
| 2D | - | 319 | | - | |
| 3D | - | 282 | | - | |
| 1KD | - | 673 | | - | |
| 2KD | - | 2398 | | - | |
| 3KD | - | 1079 | | - | |

Note: Refer Figure 5.13 and Table 5.24.

* (SK) & (SD) are self irrigation areas for Karun-1 and Dez respectively.

**Table 7.18.3: Results of Simulation (Reservoirs 4, and 6 With Multi-irrigation areas) Existing Development.**

| Res. No. | Design Variable | | | | | Ave. Ann. Ener. Def. | No.of Ann. Ener. Def. | Ave. Ann. Irr. Def. | No.of Ann. Irr. Def. | Ave. Ann. Spill | $PW_{nb}$ Rials $10^9$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Y | Ir | H | E | $\bar{E}$ | | | | | | |
| 4 | 3050 | (SK)* 252 | 800 | 2310 | 1304 | 32.1 | 4 | - | 0 | 3990 | 1 2 133 |
| 6 | 3200 | (SD)*1802 | 600 | 2117 | 711 | 33.3 | 4 | 3.3 | 1 | 2639 | |
| 1K | — | 1.5 | - | - | - | - | - | 0.0 | 0 | - | |
| 2K | - | 376 | - | - | - | - | - | 0.0 | 0 | - | |
| 3K | - | 124 | - | - | - | - | - | 0.0 | 0 | - | |
| 4K | - | 257 | - | - | - | - | - | 0.0 | 0 | - | |
| 5K | - | 32 | - | - | - | - | - | 0.0 | 0 | - | |
| 1D | - | 288 | - | - | - | - | - | 0.6 | 1 | - | |
| 2D | - | 292 | - | - | - | - | - | 1.0 | 1 | - | |
| 3D | - | 290 | - | - | - | - | - | 1.4 | 2 | - | |
| 4D | - | 32 | - | - | - | - | - | 0.1 | 2 | - | |
| 1KD | - | 786 | - | - | - | - | - | 0.0 | 0 | - | |
| 2KD | - | 1597 | - | - | - | - | - | 0.0 | 0 | - | |
| 3KD | - | 676 | - | - | - | - | - | 0.2 | 1 | - | |

* (SK) & (SD) are self irrigation areas for Karun-1 and Dez respectively.

Note : Diversion to the neighbouring basins from upstream of Karun-1 and downstream of Dez basin are equal to 792 m.c.m. and 260 m.c.m. respectively were considered in the model, refer Table 7.10.

Table 7.18.4: **Results of Simulation (Reservoirs 1, 2, 3, 4, 5, and 6with Multi-irrigation areas) Future Development.**

| Res. No. | Design Variable | | | | | Ave. Ann. Ener. Def. | No.of Ann. Ener. Def. | Ave. Ann. Ener. Def. | No.of Ann. Ener. Def. | Ave. Ann. Spill | $PW_{nb}$ Rials $10^9$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Y | Ir | H | E | $\bar{E}$ | | | | | | |
| 1 | 2050 | - | 350 | 1343 | 573 | 9.5 | 4 | - | - | 2341 | 5 1 137 |
| 2 | 2200 | - | 650 | 2154 | 963 | 45.6 | 4 | - | - | 3590 | |
| 3 | 4600 | - | 600 | 1951 | 1007 | 43.8 | 4 | - | - | 4011 | |
| 4 | 3050 | (SK)* 720 | 800 | 1826 | 2001 | 9.8 | 4 | 0 | 0 | 3239 | |
| 5 | - | - | 650 | 1593 | 2345 | 7.5 | 4 | - | - | 9136 | |
| 6 | 3200 | (SD)* 1903 | 600 | 2090 | 735 | 29.8 | 4 | 4.7 | 1 | 2655 | |
| 1K | - | 3 | - | - | - | - | - | 0 | 0 | - | |
| 2K | - | 124 | - | - | - | - | - | 1.2 | 2 | - | |
| 3K | - | 465 | - | - | - | - | - | 4.3 | 2 | - | |
| 4K | - | 27 | - | - | - | - | - | 0.2 | 2 | - | |
| 5K | - | 607 | - | - | - | - | - | 4.5 | 3 | - | |
| 6K | - | 85 | - | - | - | - | - | 1.0 | 3 | - | |
| 7K | - | 306 | - | - | - | - | - | 6.0 | 4 | - | |
| 1D | - | 368 | - | - | - | - | - | 1.6 | 2 | - | |
| 2D | - | 319 | - | - | - | - | - | 1.8 | 2 | - | |
| 3D | - | 282 | - | - | - | - | - | 1.7 | 2 | - | |
| 1KD | - | 673 | - | - | - | - | - | 15.5 | 4 | - | |
| 2KD | - | 2398 | - | - | - | - | - | 76.7 | 7 | - | |
| 3KD | - | 1079 | - | - | - | - | - | 73.0 | 8 | - | |

* (SK) & (SD) are self irrigation areas for Karun-1 and Dez respectively.

Note : Diversion to the neighbouring basins from upstream of Karun-1 and downstream of Dez basin are equal to 792 m.c.m. and 260 m.c.m. respectively were considered in the model, refer Table 7.10.

# CHAPTER-VIII

# ANALYSIS AND CONCLUSIONS

# Chapter-VIII

# ANALYSIS AND CONCLUSION

## 8.1 GENERAL

The analysis in this chapter is based on the models given in Chapters 3 and 4. These models were applied to the Karun River System in Iran described in Chapter 5. The Chapter 7 gives the computational procedure and the cost and benefit-loss functions needed. The computed values of cost and benefits are tabulated in Tables ~~Nos.~~ ~~from~~ 7.1 and 7.2.

The proposed and existing reservoirs were numbered sequentially from upstream to downstream. The computations were done basically in the following manner:

**Phase ~~-~~ I :** Project by project analysis ~~-~~ In the first step the deterministic linear programming optimization model was applied individually to one reservoir at a time, proceeding from upstream to downstream. In the second step a finer search by a detailed simulation model was carried out to study individual development alternatives.

**Phase ~~-~~ II :** Integrated developmental strategy analysis ~~-~~ Again the above models were used to study and analyze the integrated developmental strategies of the system consisting of five reservoirs and one run-of-river scheme in two steps as mentioned above.

The computer software (INDMAG PACKAGE) for generation of Input Data Matrix coupled with simplex package were used for linear programming preliminary screening. A flexible simulation package was used for finer screening. The average monthly flows and the monthly flows of a representative dependable flow year were used independently in LP preliminary screening model, where as 38 years monthly inflows were used in screening by simulation. For screening, the economic, and water use dependability criterias were used.

The sizing and selection of configuration of reservoirs started from the uppermost reservoir using linear programming and simulation models. In turn the next numbered down stream reservoir was added and all possible alternative configurations with these two reservoirs were analyzed. One by one each and every down stream reservoir was added and before adding a downstream reservoir, the reservoir just upstream was already earlier sized. For every set of reservoirs all the possible alternative configurations were analyzed by optimization-simulation screening models.

## 8.2 ANALYSIS OF LP SCREENING MODEL AND RESULTS

### 8.2.1 Important Features Different from Earlier Studies

The important features of LP screening model in this work which are different from earlier studies carried out by other workers are presented below:

(1) For preparation of Input Data Matrix for computation of linear programming by computer for all potentially feasible alternatives of a complex water resources system, are data intensive and Herculean task (Razavian et al. , 1990). Keeping this in mind a generalized computer algorithm has been prepared in this work to generate the Input Data Matrix of the non-zero elements for the set of constraint equations of the LP model presented in Chapter 3. This algorithm (computer programme INDMAG PACKAGE and its subroutine sub-programme MATRIX, see Appendix 6) is attached to the main computer programme on linear programming.

The main features of INDMAG PACKAGE are :

(i) It can be applied to any single/multipurpose reservoirs and single/multi-reservoirs consisting of any given configuration.

(ii) Any number of new system constraints and system variables can be added and the computer programme be suitably modified.

(iii) Individual input data files can be prepared for each reservoir and after testing, can be appended together easily for any reservoir system configurations.

(iv) The above package is feasible, efficient, flexible, convenient and fool proof as any omission /error can be easily rectified and correction incorporated as compared to other available packages like, MPS, LINGO etc. Also, it can be used repetitively without hesitation as input data is very small and its feeding is less time consuming.

(2) "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 INDMAG PACKAGE is one such step towards preparing a generalized algorithm (computer programme) very well fitting to the basic multi-reservoir multi-purpose design and planning problem in water resources.

doubt that
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ey wrote this

(3) Generally as found from earlier studies, the optimization screening model is applied directly only to a few selected integrated developmental strategies and then the optimal configuration is chosen among them.

Where as in this study project by project analysis is coupled with the integrated developmental strategy analysis. The first one to investigate and formulate the whole range of individual development alternatives, and to find the ranges of the design variables to size a reservoir. The latter approach to develop the design criteria~~s~~ for the whole system by which the best configuration of the system could be drawn.

(4) In the optimization screening models used by earlier workers, only average monthly river flows were regulated, where as in this study apart from average flows, monthly flows of various representative dependable year's flows were regulated. For example, 90% and 70% dependable year's flows for a hydroelectric project and multi-purpose project respectively as per the project dependabilities of each project.

Not really

### 8.2.2 Discussion on LP Model Results

The LP model was applied to various alternative configurations of Table 5.25. The results of LP model are given in Tables 7.12.1 and 7.12.2 for reservoir-1, in Tables 7.13.1, 7.13.2, 7.13.6 to 7.13.8 for reservoir-2, in Tables 7.14.1, 7.14.2, 7.14.7, 7.14.8, 7.14.10, 7.14.11, 7.14.13 to 7.14.14 for reservoir-3, in Tables 7.15.1 and 7.15.3 to 7.15.5 for reservoir-4, in Tables 7.16.1 and 7.16.2 for site-5, and in Table 7.17.1 for reservoir-6. For multi-irrigation areas the results were given in Tables 7.18.1 and 7.18.2 for existing and future development respectively.

The constraint Equation 3.23 was non linear and was linearized by assuming an effective head and comparing it with the head specified in the model solution. Fortunately, the solutions were relatively insensitive to changes in assumed heads.

The cost functions in the objective function were assumed to be linear in above model. These assumptions were fairly good because the values of design variables obtained were within the assumed linear segments.

The linear programming model was made more realistic and practicable by introducing some constraints depicting a few policy and practical aspects, as mentioned in section 7.4.1.

The hydroplant capacity H and the annual firm targets Ir and E for downstream reservoir were increased where as the reservoir capacity Y, of a downstream reservoir was not much affected while using the intermediate catchment inflows in the integrated reservoir study as compared to the values obtained for downstream reservoir using intermediate flows in project by project study as was expected. The variation in the values of Y, H and E with different flows are graphically shown in figure 8.1.

## 8.3 ANALYSIS OF SIMULATION RESULTS

The simulation was applied to all the alternative configurations for further exploring various design alternatives, using systematic sampling. The systematic sampling was done in two steps.

Based on the LP model results, it was possible to select the upper and lower bounds (ranges) of variables for further screening by simulation. The lower and upper ranges on the variables were fixed on the basis of 90% (or 70% as the case may be) annual dependable flows and average flows respectively. These were fixed using the following reasoning:

### (1) Ranges for reservoir capacity:

The quantity of regulated flows reaching a D/S reservoir will depend upon the type of water uses in the U/S reservoir/reservoirs, i.e.,

(i) In a set of series of reservoirs with only hydropower, say 3 in numbers, the last reservoir (reservoir-3) will receive natural flows from its own intermediate catchment plus the regulated flows of a quantity comparable to the combined natural flow contributions from the individual catchment of its U/S reservoirs-2 and 1, as there is no U/S consumptive water uses. Likewise reservoir-2 will receive natural flows from its own individual catchment

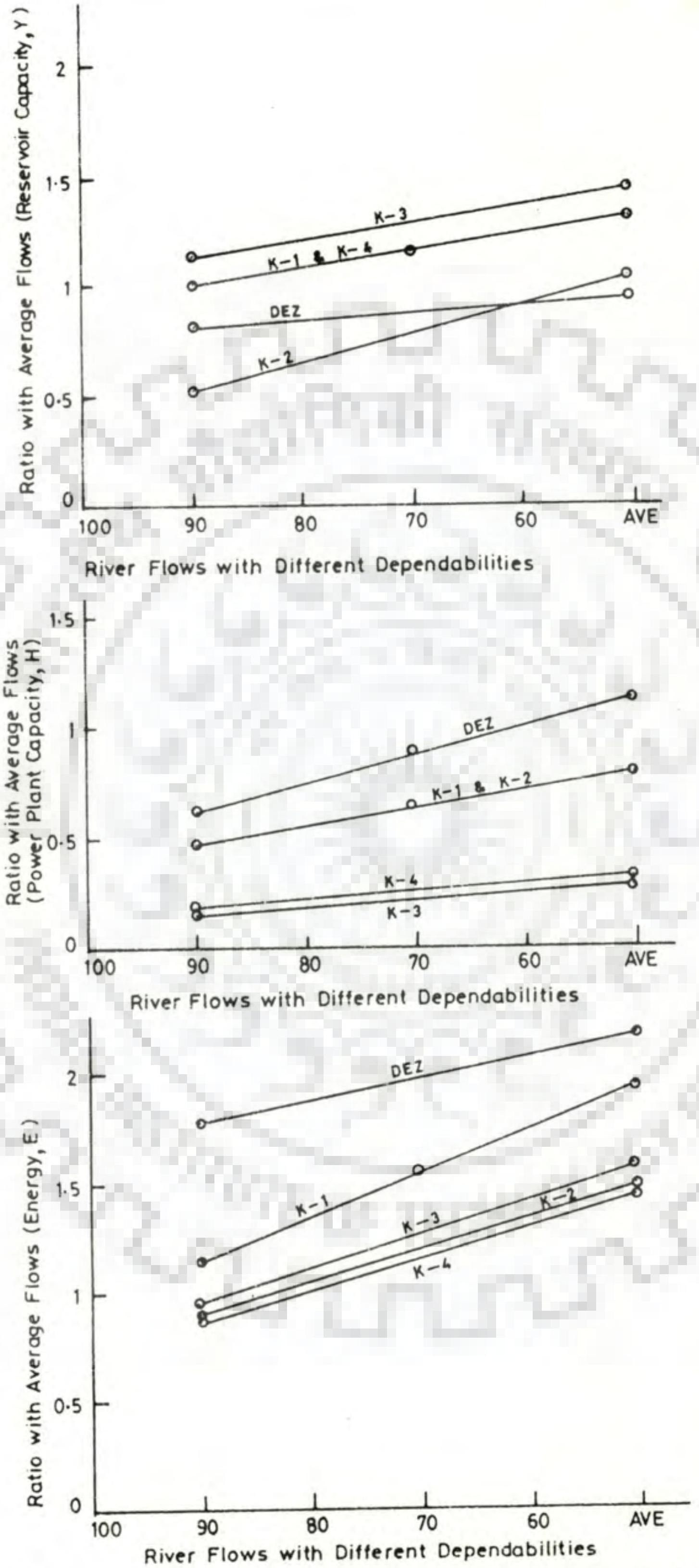

Fig. 8·1-Variations in Y, H and E Values in LP Model plus the regulated flows of a quantity comparable to the natural flows contribution from the individual catchment of its U/S reservoir-1.

In such cases each reservoir may be sized by an individual project analysis, considering that there are no U/S reservoirs and the natural flows from the whole U/S catchment is reaching to the reservoir under consideration. Hence,

(a) The upper bound on reservoir capacity for simulation may be fixed from the LP model results of individual project analysis using the above said average inflows, and

(b) However, the lower bound on reservoir capacity for simulation may be fixed from the LP results of individual project analysis using its only individual catchment average inflows.

(ii) In case if just immediate U/S reservoir in series has consumptive use the upper and lower bounds for simulation on reservoir capacity may be fixed from the LP model results of integrated reservoir analysis using average flows and 90% dependable year's inflows respectively.

### (2) Ranges for hydropower plant capacity:

The ranges on hydropower plant capacity may be fixed using the results of integrated reservoir studies. The upper bound from integrated study using average flows and lower bound from integrated study using 90% dependable year's flows.

### (3) Ranges for annual firm energy:

The ranges on annual firm energy target can be fixed on the basis of the results of integrated reservoir study using 90% dependable year's flows.

### (4) Ranges for annual firm irrigation:

In case of annual firm irrigation target, the upper bound may be fixed from integrated reservoir study using average flows and lower bound from integrated reservoir study using 70% dependable year's flows.

The values of variables selected from systematic sampling for various alternative designs for a reservoir were simulated to see if these were reasonable. Some of the alternative designs with higher reservoir capacities were inefficient, and some of them were inadmissible due to higher annual targets. Hence, for each design the annual targets were varied, keeping the reservoir and plant capacities fixed, and simulation was carried out till the desired project success was obtained. For a single purpose hydropower project the desired project success was 90%. For a multipurpose project this was 70%. The simulation results are given in Tables 7.12.2 to 7.12.5 for reservoir-1, in Tables 7.13.3 to 7.13.6 and 7.13.9 for reservoir-2, in Tables 7.14.3 to 7.14.6, 7.14.9, 7.14.12 and 7.14.15 for reservoir-3, in Tables 7.15.2 and 7.15.6 for reservoir-4, in Table 7.16.3 for site-5 and ultimately in Tables 7.17.2 and 7.17.5 for reservoir-6. For multi-irrigation areas the results were given in Tables 7.18.3 and 7.18.4 for existing and future development respectively

## 8.4 A PROPOSED SUITABLE SCHEME OF SCREENING

To explain the proposed scheme of screening all possible alternative configurations, which can be formed (15 in numbers)with 4 reservoirs are given along with the results of LP model without the sizing through simulation in Tables 8.1 and 8.2. Lastly, the simulated results of these combinations are given in Table 8.3.

Further, for simplicity only 3 reservoirs are considered for discussion. The calculations. started from the uppermost reservoir, i.e., reservoir number -1 (Karun-4) under consideration. With only one reservoir, there is only single alternative configuration, hence the single one will be the best configuration, as there is no other choice. Next is the case with 2 reservoirs, i.e., adding the next down-stream reservoir in turn for integrated study. Here, now the reservoir number-2 (Karun-3) is under consideration. With these two reservoirs there are only two possible alternative configurations, i.e., having solely reservoir 2 only, or having a combination of reservoirs 2 and 1. Here both the possibilities have to be tried for the selection of the best reservoir configuration and for their sizing.

With 3 reservoirs, i.e., reservoir number-3 under consideration, there are on the whole four possible alternative configurations. These are solely reservoir 3, various combinations of reservoir number-3 with all possible alternative configurations of reservoir number-2 (i.e., combination 3-2, and 3-2-1, totalling two in numbers), and various combinations of reservoir number-3 with all possible alternative configurations of reservoir number-1 (i.e., combination 3-1, totalling one in number). It is found from the computations that instead of analyzing all the four alternative configurations by linear programming-simulation models, it may be worthwhile to analyze only selected (reduced numbers)ones, i.e., only three in numbers in place of all possible ones (here four in numbers).

These three best trial alternative configurations are (i) reservoir number-3 solely (ii) combination of reservoir number-3 and the best configuration out of all possible cases of reservoir number-2, and (iii) combination of reservoir number-3 and the best configuration out of all possible cases of reservoir number-1.

Therefore, if we start from the uppermost reservoir, i.e., reservoir number-1 and add a downstream reservoir one by one and come to reservoir number-3, there are in all 1+2+4=7 possible configurations with three reservoirs. But with the scheme above mentioned there are only 1+2+3=6 best trial alternative configurations. This reduces the number of trial computations for 3 reservoirs from 100% to 86%, i.e., a reduction of 14%. The proposed screening scheme is given in Table 8.4. With 4 reservoirs this reduction is from 100% to 66%. With large number of reservoirs this reduction is considerable.

**The advantages of the above proposed scheme are:**

(i) None of the attractive alternative configurations may be left out without consideration and analysis, as it is ascertained by simulation here.

(ii) The best upstream configuration is made available before adding a downstream reservoir.

(iii) The sizing of reservoir capacity, hydroplant capacity and annual project targets are also done simultaneously by simulation.

(iv) In case, if firstly the optimal configuration is selected by LP model alone on the basis of maximizing the annual net benefits and then finally the simulation is applied to this optimal configuration only, as done earlier by other workers (Jacoby and Loucks, 1972 ;Chaturvedi and Srivastava, 1981;Karamouz et al., 1992), the selection of the ranges of variables would have been a difficult task due to a large number of variables involved in it. If proper selection of the ranges is not made, the final selection of the design will lead to exhaustive calculations and is likely to converge into a local optimum.

(v) The project by project analysis and the integrated reservoir analysis may guarantee a configuration of reservoirs and project sizes very near to a global optimum.

## 8.5 COMPARISON OF RESULTS WITH PROJECT PROVISIONS

The results of the optimal configuration consisting of all the five reservoirs and the run-of-river hydropower (Tables 7.16.3 and 7.17.5) are compared with the project provisions for reservoir capacities and hydropower, in Table 8.5. It is seen that both the values are very close to each other for reservoir capacities and for annual firm energy targets. In the current study it was assumed that each hydroplant would run for entire duration ($h_t$ = 720 hours in a month), whereas in project provisions they would run as peak load plants ($h_t$ varying from 180 hours to 720 hours in a month), hence the hydroplant capacities obtained have smaller values in the current study. Although, they are equivalent and would match with the project provisions for $h_t$ values similar to those as considered in the project provisions.

In case of irrigation the values of annual firm irrigation targets obtained for self and multi-irrigation areas were same as given in the project provisions (Tables 5.23 and 5.24 ) for present and future development cases. These values are again reproduced in Table 8.6 (also refer tables 7.18.3 and 7.18.4). The total annual firm irrigation water required for both the developments (i.e., 4101.5 m.c.m. and 6487 m.c.m. for Karun-1 and 2872 m.c.m and 2704 m.c.m. for Dez respectively) are smaller than those given in Tables 7.16.3 and 7.17.5 (i.e., 8400 m.c.m. and 5300 m.c.m. for Karun-1 and Dez respectively). It shows that surplus water is available at Karun-1 and Dez, which is true. This can be explained as there is a proposal by project authorities to utilize this excess water to protect the movement of salt water from the sea towards the land for present development. At least a net discharge of 81 $m^3$/sec (2554 m.c.m.)is considered in the lower Karun to prevent saltwater intrusion upstream of Mared as a minimum mandatory discharge from reservoirs for this purpose (Table 8.7). However, this excess water can be utilized for enhanced firm energy generation at Karun-1 and Dez for future development.

## 8.6 CONCLUSION

In this study an attempt was made to combine the major advances of systems analysis by optimization- simulation screening models, which are to be used for analyzing a complex water resources system.

The specific decision problem under consideration was screening of a multiple reservoir system (multi purpose, multi reservoir, and multi irrigation areas system) on the Karun river in Iran, to meet the current and forecast growth in demand of water, for irrigation, hydropower, flood control, and municipal and industrial water supply. The system consisted of 5 major dams, one run-of -river hydropower scheme and a number of multi-irrigation areas. The various alternative configurations of the above system were studied, based on various project proposals and engineering considerations for deciding the optimal configuration and the optimal project targets.

The approach was to develop a suitable methodology to identify the combination of multi-reservoir alternative to MAXIMIZE the economic benefits as well as to obtain desired project dependabilities, subjected to continuity constrains, technological constraints, and policy constraints.

In this context, it was profitable to investigate the value of mathematical programming in preliminary screening and how it should be coupled with a finer screening simulation study. In view of the large number of reservoirs being involved and the preliminary planning nature of the study a deterministic linear programming (LP) technique which is a suitable methodology for modeling in the initial phases of the investigation in such a large rive basin system development was adopted.

The computer software (INDMAG PACKAGE) developed for generation of Input Data Matrix coupled with simplex algorithm for linear programming, and a flexible simulation package were used for screenings in two phases. The Phase-I was project by project analysis, and the Phase-II was analysis of integrated developmental strategies. The average monthly flows and the monthly flows of a representative dependable flow year were used independently in preliminary screening optimization model, where as 38 years historical monthly flows were used in simulation model. For screening, the economic, and water use dependability criterias were used.

For the Karun River Basin development the final recommended optimal configuration of reservoirs and their sizes and project targets are given in Table 8.5 and the following conclusions are arrived at :

1. The existence of significant hydroelectric power and water storage potential on the Karun river system is confirmed and which can be developed on the Karun river above existing irrigation diversion dam at Gotvand up to the source of the river.As well as there is a promising potential for further development for irrigation .
2. Initial screening of various identified run-of-river sites below Karun-1 showed that Tunnel scheme proposal preferably is the best one considering the amount of energy generation, economic reasons, and longer useful life.
3. It was shown that sufficient water exist in the Karun basin to satisfy water supply needs for the existing development to a high degree of reliability.
4. For the full development case no irrigation failures were indicated. The average percentage draw downs were calculated as 36% and 33% of available live storage for the Karun-1 and Dez reservoirs respectively. This indicates that for the full development case, the ratio of separate demands on the two reservoirs to the available storage is close to being equal. This suggests that there is no strong preference in the use of the two reservoirs to meet common demands downstream of the confluence.
5. The waters of the Karun and Dez rivers are ultimately to be used for hydroelectric power generation in the mountains; for irrigation, industrial

and domestic water supply in the plains;and for salinity control and navigation at the tail end near the Persian Gulf.Any surplus water can be diverted to other river basins.

At last to summarize the outcomes of this study, the following conclusions may be drawn:

**(i)** The optimization-simulation screening models have been applied to a real life water resources system which is under development stages.

**(ii)** A large number of individual potential areas (multi-irrigation areas/under the command of project/projects were also considered, whereas in the mathematical screening models, used in earlier studies, the scope of irrigation was as single irrigation area (self irrigation) per project. This made the linear programming (LP) screening model more realistic.

**(iii)** The development of INDMAG software package to create the Input Data Matrix for LP model made the construction of the optimization model for all potential feasible alternatives a less data-intensive and non-Herculean task.

**(iv)** The approach used in INDMAG software algorithm is one such step towards preparing a generalized algorithm (computer programme)very well fitting to the basic multi reservoir design and planning problems.

**(v)** Due to the introduction of some design and practical aspects as constraints in the LP model, the results obtained were more realistic.

**(vi)** The results of linear programming model were helpful in simulation as they could select the upper and lower ranges of the design variables by regulating the average and the annual flow of a given dependability based on the desired project success respectively.

(vii) The combined use of linear programming and simulation screening models results were comparable in terms of reasonableness with values determined by conventional design methods, but were definite improvements on them.

(viii) The use of optimization-simulation models for screening and analysis by (a) project by project analysis and (b) integrated development strategy analysis, suggest a suitable scheme in the reduction in the number of alternatives of development to be examined and analyzed.

(ix) The project by project analysis and the integrated developmental strategy analysis is likely to guarantee a configuration of reservoirs and project sizes very near to a global optimum.

(x) Based on the above, it can be concluded that the approach used in this study is simple and can be easily used to analyze large and complex river basins planning problems.

(xi) In most cases of the conventional practice of planning, projects are planned on an individual basis. Even integrated planning of water resources by conventional methods, the choice is limited to a few alternatives which the planner could conceive from his experience and judgment. Since exhaustive analysis of all the possible configurations of reservoirs sites involves voluminous computations, such an analysis can seldom be attempted without the use of modern techniques.

## 8.7 RECOMMENDATION

It is to be impressed that the results of this study are not recommended in totality for direct implementation because of following reasons:

(i) The study is of conceptual nature,and

(ii) The study is to be further supported by a number of studies as detailed under suggestion for future work.

## 8.8 SUGGESTION FOR FUTURE WORK:

- A number of further studies should be commenced:
- The research report is conceptual in nature and may provide scope for verification by means of other techniques like dynamic programming.
- The operation models needs to be studied extensively with regard to data description and their proposed utility.
- The multi objective criteria of evaluation should be incorporated.
- These techniques should be applied for pending real life planning and design problems.
- Full feasibility studies on each project needs further detailed investigations.
- No further consideration should be given to the 300 m high dam at Karun-2 and the recommended two-dam development at Karun-2 and 3 should be confirmed.
- Construction of more diversion barrage is recommended because, Khuzestan plain area is very large (326000 and 450000 ha. for existing and future development) and till now there is only two diversion dams in this area. Therefore, for better distribution of water among the users (Multi Irrigation Areas), it is recommended that further investigations to be carried out to locate some additional numbers of diversion barrages.
- Effective reservoir operation at Dez and Karun-1 can significantly alleviate flooding on the plains. Provision of flood storages in reservoirs at Karun-2 and/or Karun-3 and also at Karun-4 may further decrease the frequency of flooding. This requires further investigations.

Table 8.1: **Results of LP Model for 15 possible Configurations, using Average Inflows**

| Reservoir Under Consideration | All possible Alternative Reservoir Configurations | Res. No. | Design Variable | | | | Total annual net benefits Rls $10^9$ |
|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | |
| Reservoir 1 | 1 (K-4) | 1 | 2633 | - | 356 | 1832 | 177.6 |
| Reservoir 2 | 2 (K-3) | 2 | 3281 | - | 642 | 3308 | 283.7 |
| | 2,1 (K-3,4) | 1 | 2633 | - | 356 | 1832 | 662.3 |
| | | 2 | 1831 | - | 639 | 3294 | |
| Reservoir 3 | 3 (K-2) | 3 | 4784 | - | 589 | 3034 | 172.9 |
| | 3,2 (K-2,3) | 2 | 3281 | - | 642 | 3306 | 608.9 |
| | | 3 | 2436 | - | 583 | 3003 | |
| | 3,2,1 (K-2,3,4) | 1 | 2633 | - | 356 | 1832 | 985.0 |
| | | 2 | 1831 | - | 639 | 3294 | |
| | | 3 | 2436 | - | 580 | 2989 | |
| | 3,1 (K-2,4) | 1 | 2633 | - | 356 | 1832 | 444.6 |
| | | 3 | 3228 | - | 586 | 3019 | |
| Reservoir 4 | 4 (K-1) | 4 | 4012 | 6638 | 787 | 4055 | 540.3 |
| | 4,3 (K-1,2) | 3 | 4784 | - | 589 | 3034 | 718.0 |
| | | 4 | 1680 | 6551 | 776 | 4001 | |

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**Table 8.1: continued**

| Reservoir Under Consideration | All possible Alternative Reservoir Configurations | Res. No. | Design Variable | | | | Total annual net benefits Rls $10^9$ |
|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | |
| Reservoir 4 | 4,3,2<br>(K-1,2,3) | 2 | 3281 | - | 642 | 3308 | 1149.0 |
| | | 3 | 2436 | - | 583 | 3003 | |
| | | 4 | 1680 | 6494 | 769 | 3966 | |
| | 4,3,2,1<br>(K-1,2,3,4) | 1 | 2633 | - | 356 | 1832 | 1522.8 |
| | | 2 | 1831 | - | 639 | 3294 | |
| | | 3 | 2436 | - | 580 | 2989 | |
| | | 4 | 1680 | 6466 | 766 | 3949 | |
| | 4,3,1<br>(K-1,2,4) | 1 | 2633 | - | 356 | 1832 | 745.6 |
| | | 3 | 3328 | - | 586 | 3019 | |
| | | 4 | 1680 | 4095 | 483 | 2488 | |
| | 4,2<br>(K-1,3) | 2 | 3281 | - | 642 | 3308 | 831.0 |
| | | 4 | 1784 | 6585 | 780 | 4022 | |
| | 4,2,1<br>(K-1,3,4) | 1 | 2633 | - | 356 | 1832 | 1207.4 |
| | | 2 | 1831 | - | 639 | 3294 | |
| | | 4 | 1784 | 6558 | 777 | 4006 | |
| | 4,1<br>(K-1,4) | 1 | 2633 | - | 356 | 1832 | 721.0 |
| | | 4 | 2611 | 6623 | 785 | 4046 | |

**Table 8.2: Results of LP Model for 15 possible configurations, using Dependable year's Inflows***

| Reservoirs Under Consideration | All possible Alternative Reservoir Configurations | Res No | Design Variable | | | | Total annual net benefits Rls $10^9$ |
|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | |
| Reservoir 1 | 1 (K-4) | 1 | 2077 | - | 217 | 1121 | 33.5 |
| Reservoir 2 | 2 (K-3) | 2 | 2578 | - | 384 | 1980 | 61.6 |
| | 2,1 (K-3,4) | 1 | 2077 | - | 217 | 1121 | 162.1 |
| | | 2 | 1332 | - | 381 | 1962 | |
| Reservoir 3 | 3 (K-2) | 3 | 4214 | - | 369 | 1903 | 12.8 |
| | 3,2 (K-2,3) | 2 | 2578 | - | 384 | 1980 | 167.3 |
| | | 3 | 2412 | - | 345 | 1778 | |
| | 3,2,1 (K-2,3,4) | 1 | 2077 | - | 217 | 1121 | 264.9 |
| | | 2 | 1332 | - | 381 | 1962 | |
| | | 3 | 2412 | - | 342 | 1778 | |
| | 3,1 (K-2,4) | 1 | 2077 | - | 217 | 1121 | 52.7 |
| | | 3 | 3518 | - | 348 | 1973 | |
| Reservoir 4 | 4 (K-1) | 4 | 3516 | 5223 | 624 | 3218 | 419.0 |
| | 4,3 (K-1,2) | 3 | 4214 | - | 369 | 1903 | 321.0 |
| | | 4 | 1757 | 4174 | 488 | 2517 | |

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**Table 8.2: continued**

| Reservoir Under Consideration | All possible Alternatives Configurations | Site No. | Design Variabl | | | | Total annual net benefits Rls $10^9$ |
|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | |
| Reservoir 4 | 4,3,2<br>(K-1,2,3) | 2 | 2578 | - | 384 | 1980 | 494.2 |
| | | 3 | 2412 | - | 345 | 1778 | |
| | | 4 | 1757 | 4117 | 482 | 2482 | |
| | 4,3,2,1<br>(K-1,2,3,4) | 1 | 2077 | - | 217 | 1121 | 589.2 |
| | | 2 | 1332 | - | 381 | 1962 | |
| | | 3 | 2412 | - | 342 | 1778 | |
| | | 4 | 1757 | 4087 | 478 | 2464 | |
| | 4,3,1<br>(K-1,2,4) | 1 | 2077 | - | 217 | 1121 | 231.0 |
| | | 3 | 3519 | - | 348 | 1793 | |
| | | 4 | 1757 | 2758 | 319 | 1645 | |
| | 4,2<br>(K-1,3) | 2 | 2578 | - | 384 | 1980 | 400.0 |
| | | 4 | 1832 | 4249 | 479 | 2563 | |
| | 4,2,1<br>(K-1,3,4) | 1 | 2077 | - | 217 | 1121 | 482.2 |
| | | 2 | 1332 | - | 381 | 1962 | |
| | | 4 | 1831 | 4221 | 494 | 2546 | |
| | 4,1<br>(K-1,4) | 1 | 2077 | - | 217 | 1121 | 405.4 |
| | | 4 | 2520 | 4705 | 552 | 2844 | |

(*) 90% for hydropower project and 70 % for multipurpose project

**Table 8.3 : Results of Simulation Model for 15 possible configurations**

| Reservoir Under Considera-tion | All possible Alternatives Reservoir configuration | Res. No. | Design Variable | | | | | Ave. Ann. Ener. Def. | No. of Ener. Def. | Ave. Ann. Irr. Def. | No. of Irr. Def. | Ave. Ann. Spill | $PW_{nb}$ Rials $10^9$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Y | Ir | H | E | $\bar{\bar{E}}$ | | | | | | |
| Reservoir-1 | 1<br>(K-4) | 1 | 2050 | - | 350 | 1343 | 573 | 9.5 | 4 | - | - | 2341 | 6449 |
| Reservoir-2 | 2<br>(K-3) | 2 | 2250 | - | 650 | 1916 | 1172 | 24.0 | 4 | - | - | 4223 | 9152 |
| | 2,1<br>(K-3,4) | 1 | 2050 | - | 350 | 1343 | 573 | 9.5 | 4 | - | - | 2341 | 15746 |
| | | 2 | 2200 | - | 650 | 2154 | 963 | 45.6 | 4 | - | - | 3590 | |
| Reservoir-3 | 3<br>(K-2) | 3 | 4600 | - | 600 | 1938 | 881 | 40.3 | 4 | - | - | 3783 | 8424 |
| | 3,2<br>(K-2,3) | 2 | 2250 | - | 650 | 1916 | 1172 | 24.0 | 4 | - | - | 4223 | 17911 |
| | | 3 | 4500 | - | 600 | 2042 | 874 | 18.4 | 4 | - | - | 3737 | |
| | 3,2,1<br>(K-2,3,4) | 1 | 2050 | - | 350 | 1343 | 573 | 9.5 | 4 | - | - | 2341 | 24480 |
| | | 2 | 2200 | - | 650 | 2154 | 693 | 45.6 | 4 | - | - | 3590 | |
| | | 3 | 4600 | - | 600 | 1951 | 1007 | 43.8 | 4 | - | - | 4011 | |
| | 3,1<br>(K-2 4) | 1 | 2050 | - | 350 | 1343 | 573 | 9.5 | 4 | - | - | 2341 | 15061 |
| | | 3 | 4550 | - | 600 | 1942 | 976 | 58.3 | 4 | - | - | 4003 | |
| Reservoir-4 | 4<br>(K-1) | 4 | 3050 | 6400 | 800 | 1838 | 1958 | 31.8 | 4 | 118 | 10 | 3904 | 7394 |
| | 4,3<br>(K-1,2) | 3 | 4600 | - | 600 | 1937 | 880 | 40.0 | 4 | - | - | 3738 | 16029 |
| | | 4 | 2800 | 7200 | 800 | 2335 | 1534 | 15.3 | 4 | 340 | 11 | 2904 | |
| | 4,3,2<br>(K-1,2,3) | 2 | 2250 | - | 650 | 1916 | 1172 | 24.0 | 4 | - | - | 4223 | 2568 |
| | | 3 | 4500 | - | 600 | 2042 | 874 | 18.4 | 4 | - | - | 3737 | |
| | | 4 | 3050 | 8000 | 800 | 2164 | 1684 | 15.8 | 8 | 525 | 11 | 2484 | |
| | 4,3,2,1<br>(K-1,2,3,4) | 1 | 2050 | - | 350 | 1343 | 573 | 9.6 | 4 | - | - | 2341 | 32471 |
| | | 2 | 2200 | - | 650 | 2154 | 963 | 45.6 | 4 | - | - | 3590 | |
| | | 3 | 4600 | - | 600 | 1951 | 1007 | 43.8 | 4 | - | - | 4011 | |
| | | 4 | 3050 | 8400 | 800 | 2273 | 1750 | 26.9 | 8 | 564 | 11 | 2420 | |
| | 4,3,1<br>(K-1,2,4) | 1 | 2050 | - | 350 | 1342 | 573 | 9.5 | 4 | - | - | 2341 | 23059 |
| | | 3 | 2000 | - | 650 | 2041 | 1046 | 33.5 | 4 | - | - | 3837 | |
| | | 4 | 3050 | 8600 | 800 | 2147 | 1813 | 33.3 | 8 | 564 | 11 | 2280 | |
| | 4,2<br>(K-1,3) | 2 | 2250 | - | 650 | 1916 | 1172 | 24.0 | 4 | - | - | 4223 | 12934 |
| | | 4 | 3050 | 3200 | 800 | 677 | 1382 | 23.2 | 8 | 191 | 10 | 3080 | |
| | 4,2,1<br>(K-1,3,4) | 1 | 2050 | - | 350 | 1343 | 573 | 9.5 | 4 | - | - | 2341 | 23659 |
| | | 2 | 4550 | - | 600 | 1942 | 976 | 58.3 | 4 | - | - | 4003 | |
| | | 4 | 3050 | 8580 | 800 | 2178 | 1812 | 22.0 | 8 | 561 | 11 | 2334 | |
| | 4,1<br>(K-1,4) | 1 | 2050 | - | 350 | 1343 | 573 | 9.5 | 4 | - | - | 2341 | 14176 |
| | | 4 | 3050 | 7500 | 800 | 1870 | 2013 | 19.3 | 8 | 332 | 11 | 2916 | |

Table 8.4 : A Proposed Scheme of Screening

| Reservoir Under Consideration | All possible Alternative Reservoir Configurations | | Possible best trial Alternative Reservoir Configurations | | ∑(3) | ∑(5) | Percent No. of best trial alternative Reservoir configurations to be analysed out of total all possible alternative configurations $\left[ \frac{(7)}{(6)} * 100 \right]$ |
|---|---|---|---|---|---|---|---|
| | Configurations | Total | Trials | Total | | | |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| **Reservoir 1** | 1 | 1 | Res.1 | 1 | 1 | 1 | 100 % |
| **Reservoir 2** | 2 | 2 | Res.2 | 2 | 3 | 3 | 100 % |
| | 2,1 | | Res.2 & best configuration out of all possible cases of res.1 | | | | |
| **Reservoir 3** | 3 | 4 | Res.3 | 3 | 7 | 6 | 86 % |
| | 3,2<br>3,2,1 | | Res.3 & best configuration out of all possible cases of res.2 | | | | |
| | 3,1 | | Res.3 & best configuration out of all possible cases of res.1 | | | | |
| **Reservoir 4** | 4 | 8 | Res.4 | 4 | 15 | 10 | 66 % |
| | 4,3<br>4,3,2<br>4,3,2,1<br>4,3,1 | | Res.4 & best configuration out of all possible cases of res.3 | | | | |
| | 4,2<br>4,2,1 | | Res.4 & best configuration out of all possible cases of res.2 | | | | |
| | 4,1 | | Res.4 & best configuration out of all possible cases of res.1 | | | | |
| **Reservoir 5** | 5 | 16 | Res.5 | 5 | 31 | 15 | 52% |
| | 5,4<br>5,4,3<br>5,4,3,2<br>5,4,3,2,1<br>5,4,3,1<br>5,4,2<br>5,4,2,1<br>5,4,1 | | Res.5 & best configuration out of all possible cases of res.4 | | | | |
| | 5,3<br>5,3,2<br>5,3,2,1<br>5,3,1 | | Res.5 & best configuration out of all possible cases of res.3 | | | | |
| | 5,2<br>5,2,1 | | Res.5 & best configuration out of all possible cases of res.2 | | | | |
| | 5,1 | | Res.5 & best configuration out of all possible cases of res.1 | | | | |

**Table 8.5: Comparision of Computed Reservoir Design Variables With Project Provisions**

| Site | | Resrvoir Capacity (m.c.m.) | Power plant capacity (MW) | Ann. firm energy (GWhr) | Ann. dump energy (GWhr) | Ave. ann. energy (GWhr) | Power Plant Factor |
|---|---|---|---|---|---|---|---|
| K-4 | Computed | 2050 | 350 *<br>(1150) | 1343 | 573 | 1916 | 1.00 |
| | Project Provision | 2036 | 1050 | 1280 | 867 | 2147 | 0.30 |
| K-3 | Computed | 2200 | 650 *<br>(2600) | 2154 | 963 | 3117 | 1.00 |
| | Project Provision | 2275 | 2000 - 3000 | 2068 | 2070 | 4138 | 0.25 |
| K-2 | Computed | 4600 | 600 *<br>(840) | 1951 | 1007 | 2958 | 1.00 |
| | Project Provision | 4673 | 760 | 2050 | 945 | 2995 | 0.70 |
| K-1 | Computed | 3050 | 800 *<br>(1200) | 2273 | 1750 | 4023 | 1.00 |
| | Project Provision | 3020 | 1000 | 2104 | 2021 | 4125 | 0.65 |
| G | Computed | - | 650 *<br>(1000) | 1593 | 2345 | 3938 | 1.00 |
| | Project Provision | - | 800 | 1390 | 1981 | 3371 | 0.65 |
| Dez | Computed | 3200 | 600 | 1414 | 1641 | 3052 | 1.00 |
| | Project Provision | 3340 | 520 | 1350 | 1622 | 2972 | 1.00 |

* The values in the bracket are computed equivalent power plant capacity with the power plant factor considered in project provisions.

**Table 8.6: Firm Irrigation Requirements for Self and Multi-irrigation Areas. Existing and Future Development Scenario.**

| Existing Development | | Future Development | |
|---|---|---|---|
| Irrigation area | (m.c.m.) | Irrigation area | (m.c.m.) |
| SK | 252.0 | SK | 720.0 |
| 1K | 1.5 | 1K | 3.0 |
| 2K | 376.0 | 2K | 124.0 |
| 3K | 124.0 | 3K | 465.0 |
| 4K | 257.0 | 4K | 27.0 |
| 5K | 32.0 | 5K | 607.0 |
| SD | 1802.0 | 6K | 85.0 |
| 1D | 288.0 | 7K | 306.0 |
| 2D | 292.0 | SD | 1903.0 |
| 3D | 290.0 | 1D | 368.0 |
| 4D | 32.0 | 2D | 319.0 |
| 1KD | 786.0 | 3D | 282.0 |
| 2KD | 1597.0 | 1KD | 673.0 |
| 3KD | 676.0 | 2KD | 2398.0 |
| | | 3KD | 1079.0 |

| | |
|---|---|
| Table 7.18.1 for Karun-1 =4101.5 | Table 7.18.2 for Karun-1 =6487 |
| Table 7.18.1 for Dez =2704.0 | Table 7.18.2 for Dez =2872 |

**Table 8.7: Salinity Control requirement for Existing and Full Development Cases**

| | |
|---|---|
| At Bahmanshir (through the Mared canal) | 35.3 $m^3$/sec |
| At the end of Karun river (Hafar river) downstream of Mared | 45.7 $m^3$/sec |
| Total | 81.0 |

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# APPENDICES

## Appendix 2.1

## Various Design Aspects, Techniques considered by Authors

| Ref. No | Design. | Operation | LP | DP | Simu-lation | Others | Deter-ministic | Stoch-astic | Single Purpose | Multi-Purpose | Single Res. | Multi Res. | Irri. | Hydro Power | Flood Control | M & I | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | + | + | + | + | - | - | + | - | - | + | - | + | + | + | + | + | - |
| 2 | + | - | + | - | + | - | + | - | - | + | - | + | + | + | + | + | + |
| 3 | + | + | + | - | + | - | + | + | - | + | - | + | + | + | - | - | - |
| 4 | + | + | + | + | + | - | + | + | - | + | - | + | + | - | - | + | - |
| 7 | + | - | + | - | + | - | + | - | - | + | - | + | + | + | - | + | - |
| 8 | - | + | - | - | + | - | + | - | + | - | - | - | + | - | - | - | - |
| 10 | + | + | - | - | + | - | + | - | - | + | - | + | + | + | + | + | - |
| 11 | + | + | - | - | + | - | + | - | - | + | - | + | + | + | + | + | - |
| 13 | + | - | + | - | + | - | + | - | - | + | - | + | + | + | + | + | - |
| 14 | - | + | - | - | + | - | + | - | + | - | + | - | + | - | - | - | - |
| 18 | + | + | - | - | + | - | + | + | - | + | + | + | + | + | + | + | - |
| 20 | + | - | + | + | + | - | + | - | - | + | - | + | + | + | + | + | - |
| 21 | + | - | - | - | + | - | + | - | - | + | - | + | + | + | - | - | - |
| 22 | - | + | - | - | + | - | + | - | - | + | - | + | + | + | - | + | - |
| 23 | - | + | - | - | + | - | + | - | - | + | - | + | - | + | - | - | - |
| 25 | - | + | - | - | + | - | + | + | - | + | + | - | - | + | + | + | - |
| 28 | + | - | + | + | + | - | + | - | - | + | - | + | + | + | + | + | - |
| 29 | - | + | - | - | + | - | + | - | - | + | - | + | + | + | + | - | - |
| 31 | - | + | - | + | + | - | + | + | - | + | - | + | + | + | + | + | - |
| 34 | + | - | - | - | + | - | + | - | - | + | - | + | - | + | + | - | - |
| 35 | - | + | - | - | + | - | + | - | - | + | - | + | + | + | + | + | + |
| 37 | - | + | + | + | + | + | + | - | - | + | - | + | + | + | + | - | - |
| 38 | + | - | - | + | - | - | - | + | - | + | - | + | + | + | + | - | + |
| 39 | + | - | + | + | + | + | + | + | + | + | + | - | + | + | + | - | - |
| 45 | - | + | - | - | + | - | + | - | - | + | - | + | + | + | + | - | - |
| 46 | - | + | - | - | + | - | + | - | - | + | - | + | + | + | - | - | - |
| 47 | - | + | - | - | + | - | + | - | - | + | - | + | + | + | + | + | + |
| 48 | + | + | - | - | + | - | + | - | - | + | - | + | + | + | + | + | + |
| 49 | - | + | - | - | + | - | + | - | + | + | - | + | + | + | - | - | - |
| 50 | - | + | - | - | + | - | + | - | - | + | + | - | + | + | - | - | + |
| 52 | + | + | + | - | - | - | - | + | - | + | - | + | + | + | - | - | - |
| 53 | + | - | + | - | - | - | - | - | - | + | - | + | - | - | + | + | - |
| 54 | + | - | + | - | - | - | + | - | - | + | + | - | + | + | + | - | - |
| 55 | + | - | - | - | - | + | + | + | + | - | + | - | - | - | - | + | - |
| 56 | + | - | - | - | - | + | - | + | + | - | + | - | - | + | - | - | + |

## Appendix 2.I

| Ref. No | Design. | Operation | LP | DP | Simu- lation | Others | Deter- ministic | Stoch- astic | Single Purpose | Multi- Purpose | Single Res. | Multi Res. | Irri. | Hydro Power | Flood Control | M & I | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 57 | + | - | + | - | + | - | + | - | - | + | + | - | + | + | - | - | - |
| 58 | + | + | - | - | + | + | + | - | - | + | - | + | + | - | - | - | + |
| 59 | + | - | - | - | - | + | + | + | + | - | + | + | - | - | - | + | - |
| 61 | - | + | - | - | + | - | + | - | - | + | - | + | - | + | + | - | - |
| 62 | + | - | + | + | + | - | + | - | - | + | - | + | + | + | + | - | - |
| 63 | + | - | + | + | + | - | + | + | - | + | + | - | + | + | - | - | - |
| 64 | + | - | + | - | + | - | + | - | - | + | + | - | + | + | - | + | - |
| 65 | - | + | - | - | + | - | + | - | - | + | - | + | + | + | + | - | - |
| 66 | + | + | + | + | + | + | - | - | - | + | + | - | + | + | - | - | - |
| 68 | + | - | + | - | + | - | + | - | - | + | - | + | + | + | - | + | - |
| 69 | + | - | + | - | + | - | + | - | - | + | - | + | + | + | + | - | - |
| 70 | + | - | + | - | - | - | + | - | + | - | + | - | + | - | - | - | - |
| 71 | - | + | - | - | + | - | + | - | - | + | - | + | + | + | + | + | - |
| 72 | - | + | + | + | - | - | + | + | - | + | - | + | + | + | + | + | - |
| 73 | + | - | + | - | - | - | + | - | + | - | + | - | + | - | + | - | - |
| 74 | - | + | - | - | + | - | + | - | - | + | + | - | + | + | + | - | - |
| 75 | + | - | + | + | + | - | + | - | - | + | + | - | + | + | - | - | - |
| 76 | + | - | + | + | + | - | + | - | - | + | - | + | + | + | - | - | - |
| 77 | + | - | + | - | - | - | + | - | - | + | - | + | + | + | - | - | - |
| 78 | - | + | - | - | + | - | + | - | - | + | - | + | + | + | - | - | - |
| 79 | + | + | - | - | + | - | + | - | - | + | - | + | + | + | + | + | + |
| 81 | + | - | + | + | + | - | + | - | - | + | - | + | + | + | + | - | - |
| 83 | - | + | - | - | + | - | + | - | - | + | - | + | - | + | - | - | + |
| 84 | + | + | - | - | + | - | + | - | - | + | - | + | + | + | + | - | - |
| 85 | - | + | - | - | + | - | + | - | - | + | + | - | + | + | - | - | - |
| 88 | - | + | - | - | + | - | + | + | + | - | - | + | - | + | - | - | - |
| 89 | - | + | - | - | + | - | + | - | - | + | + | - | - | + | - | + | + |
| 90 | - | + | - | - | + | - | + | + | - | + | + | - | - | - | + | - | + |
| 91 | - | + | - | - | + | - | + | + | + | - | - | + | - | - | + | - | - |
| 92 | - | + | - | - | + | - | + | - | - | + | + | - | - | - | - | - | + |
| 93 | - | + | - | - | + | - | + | - | - | + | - | + | + | + | + | - | - |
| 94 | - | + | - | - | + | - | + | - | - | + | - | + | + | + | + | - | - |
| 96 | + | - | + | - | - | - | + | + | - | + | - | + | + | + | + | - | - |
| 97 | + | - | + | + | - | - | + | + | - | + | - | + | + | + | + | - | - |
| 98 | + | + | + | + | + | + | + | + | + | + | + | - | + | + | + | + | + |

LP = Linear Programming
DP = Dynamic Programming
Irri. = Irrigation
M & I = Municipal & Industrial

# APPENDIX 4.I

```
C     ****************************************************************
C                ********************************************
C                           ************************
C
C                      RESERVOIR SIMULATION PROGRAMME
C
C                DEVELOPED BY: MOHAMMAD SADEGH SADEGHIAN
C
C                SUPERVISOR  : PROFESSOR D.K.SRIVASTAVA
C
C                           ************************
C                ********************************************
C     ****************************************************************
      DIMENSION S(20,12),FLOW(20,50,12),P(20,50,12)
      DIMENSION YMIN(20,12),YMAX(20,12)
      DIMENSION AREQ1(20,20),NTREQ(20,1)
      DIMENSION REQD1(20,12,20)
      DIMENSION PREQ1(20,12,20)
      DIMENSION AREU1(20,20),NTREU(20,1)
      DIMENSION PREU1(20,12,20)
      DIMENSION REQU1(20,12,20)
      DIMENSION SHARE(1,20,1),AVANS(1,20,1)
      DIMENSION DUDT1(20,12,20),RLDT1(20,12,20),DDDT1(20,12,20)
      DIMENSION SUPT1(20,12,20)
      DIMENSION AWACS(20),AWWCS(20)
      DIMENSION SPILL(20,12)
      DIMENSION NREMT(20,12),NRFUT(20,12),AVSPT(20,12)
      DIMENSION ANSPL(20,50),AASPL(20),TUSUT(20,12)
      DIMENSION AVDD1(20,12,20),AVUD1(20,12,20)
      DIMENSION CUSR1(20,50,20),CUUS1(20,50,20),AADD1(20,20)
      DIMENSION AAUD1(20,20),ANDD1(20,50,20),ANUD1(20,50,20)
      DIMENSION NADD1(20,20),NAUD1(20,20),NDDD1(20,12,20)
      DIMENSION NDUD1(20,12,20)
      DIMENSION O(20,12),CUMEL(20),CUMF(20),CUMP(20)
      DIMENSION NURCF(20),NTRCF(20,20),DSRFL(20,1,20),UPRFL(20,1,20)
      DIMENSION IUMRE(20),UPRFC(20),DSRFC(20),TFLOW(20,12)
      DIMENSION IWRT(6),EVAPO(20,12)
      DIMENSION NUSRE(20,1),ARU1(20,20),PRU1(20,12,20),REU1(20,12,20)
      DIMENSION DUD1(20,12,20),SUP1(20,12,20)
      DIMENSION NDSRE(20,1),ARD1(20,20),PRD1(20,12,20),RED1(20,12,20)
      DIMENSION DDD1(20,12,20),RLD1(20,12,20)
      DIMENSION AVD1(20,12,20),AVU1(20,12,20),CUR1(20,50,20)
      DIMENSION CUS1(20,50,20),AAD1(20,20),AAU1(20,20),AND1(20,50,20)
      DIMENSION ANU1(20,50,20),NAD1(20,20),NAU1(20,20),NDD1(20,12,20)
      DIMENSION NDU1(20,12,20),NSTAT(20)
      DIMENSION REQV1(20),QMAX(20),REQA1(20),ADNC1(20),REGE1(20)
      DIMENSION ENER1(20),ADNV1(20),ADND1(20),IREQ1(20,20)
      DIMENSION IENO1(20,20),ELE(20,12),PHMIN(20,12),ENERG(20,12)
      DIMENSION HE(20),PPEFF(20),TWL(20),PPC(20)
      DIMENSION FRATN(20,20),ISPPO(20),REQE1(20,12,20),DEFE1(20,12)
      DIMENSION DUME1(20,12),AMDE1(20,12),NMDE1(20,12),AADE1(20,50)
      DIMENSION AMDU1(20,12),NMDU1(20,12),AADU1(20,50)
```

```
      DIMENSION SUM4(20),SUM5(20),SUM6(20),ANLEN(20,50)
      DIMENSION SPILC(20),HOUR(20,12)
      DIMENSION SURF(20,1),SDRF(20,1)
      DIMENSION NRDIR(20),NTRDR(20,20),NTRTD(20),IDIV1(20,10,20),
     1 DIV(20,12)
      DIMENSION NYDE1(20),Y(20)
      DIMENSION PEALD(20,1,20),PEALU(20,1,20)
      DIMENSION PEAUU(20,1,20),PEAUD(20,1,20)
      DIMENSION ISITE(20),IUSE(20,20)
      COMMON/BLK1/FLOW,TFLOW
      COMMON/BLK2/NMONT
      COMMON/BLK3/SHARE
      COMMON/BLK5/NTREQ,NTREU
      COMMON/BLK6/AVANS
      COMMON/BLK8/NSTAT
      COMMON/BLK9/AWACS,AWWCS
      COMMON/BLK10/I,J,JJ,NSHRE,IT
      COMMON/BLK11/SUM1,SUM2,SUM3
      COMMON/BLK12/S,P,YMAX,YMIN
      COMMON/BLK13/NUSRE,NDSRE
      COMMON/BLK14/SURF,UPRFL,SDRF,DSRFL
      COMMON/BLK24/IPRTW
      COMMON/BLK27/PEALD,PEALU
      COMMON/BLK28/PEAUD,PEAUU
      COMMON/BLK29/ISITE,IUSE
      COMMON/B11/DUDT1,RLDT1,DDDT1,SUPT1
      COMMON/B12/AVDD1,AVUD1,CUSR1,CUUS1
      COMMON/B121/AADD1,AAUD1,ANDD1,ANUD1
      COMMON/B13/NDDD1,NDUD1,NADD1,NAUD1
      COMMON/B14/AVD1,AVU1,CUR1,CUS1
      COMMON/B141/AAD1,AAU1,ANU1
      COMMON/B1411/AND1
      COMMON/B15/NDD1,NDU1,NAD1,NAU1
      COMMON/B16/DUD1,RLD1,DDD1,SUP1
      COMMON/B17/RED1,REU1
      COMMON/B18/PRU1,PREU1
      COMMON/B19/PRD1,PREQ1
      COMMON/B191/AREU1,REQU1
      COMMON/B192/AREQ1,REQD1
      COMMON/B194/ARU1
      COMMON/B195/ARD1
      COMMON/B20/REQV1,QMAX,REQA1,ADNC1,REGE1,ENER1,ADNV1,ADND1,
     1 IENO1,ELE,PHMIN,FRATN
      COMMON/B201/IREQ1
      COMMON/B21/AADE1,AADU1,Y,PPC
      CHARACTER*50 FILE1,FILE2,FILE4
C     ,FILE4,FILE5,FILE6
      WRITE(*,*)'FILEINPUT='
      READ(*,'(A)')FILE1
      WRITE(*,*)'FILEOUTPUT='
      READ(*,'(A)')FILE2
C     WRITE(*,*)'FILEOUTPUT='
C     READ(*,'(A)')FILE3
      WRITE(*,*)'FILEOUTPUT='
      READ(*,'(A)')FILE4
```

```
C     WRITE(*,*)'FILEOUTPUT='
C     READ(*,'(A)')FILE5
C     WRITE(*,*)'FILEOUTPUT='
C     READ(*,'(A)')FILE6
      OPEN(UNIT=1,FILE=FILE1)
      OPEN(UNIT=2,FILE=FILE2)
C     OPEN(UNIT=3,FILE=FILE3)
      OPEN(UNIT=4,FILE=FILE4)
C     OPEN(UNIT=5,FILE=FILE5)
C     OPEN(UNIT=6,FILE=FILE6)
      READ(1,*)NSITE,NYEAR,KYEAR,NMONT
      READ(1,*)(NSTAT(I),I=1,NSITE)
      READ(1,*)CCF,RATE
      DO 1 I=1,NSITE
      READ(1,*)Y(I)
      READ(1,*)S(I,1)
200   FORMAT(//5X,'INITIAL STORAGE='F10.3)
      DO 2 JJ=1,NYEAR
      KK=JJ+KYEAR
      KKK=KK+1-1900
      READ(1,*)(FLOW(I,JJ,IT),IT=1,NMONT)
457   FORMAT(//5X,'MONTHLY FLOW DATA,YEAR:'I4,'-',I2,
     1 //3X,6F10.3/3X,6F10.3)
2     CONTINUE
      DO 3 JJ=1,NYEAR
      KK=JJ+KYEAR
      KKK=KK+1-1900
      READ(1,*)(P(I,JJ,IT),IT=1,NMONT)
40    FORMAT(//5X,'MONTHLY PRECIPITATION ,YEAR:',I4,'-',I2,
     1 //3X,6F10.3/,3X,6F10.3)
3     CONTINUE
      READ(1,*)(YMIN(I,IT),IT=1,NMONT)
50    FORMAT(//5X,'MINIMUM CAPACITY:',
     1 //,3X,6F10.3/3X,6F10.3)
      READ(1,*)(YMAX(I,IT),IT=1,NMONT)
60    FORMAT(//5X,'MAXIMUM CAPACITY:'
     1 //3X,6F10.3/3X,6F10.3)
      READ(1,*)(NTREQ(I,J),J=1,NSTAT(I))
      DO 17 J=1,NSTAT(I)
      IF (J.NE.1)GO TO 17
      READ(1,*)(AREQ1(I,II),II=1,NTREQ(I,1))
      DO 4 II=1,NTREQ(I,1)
      READ(1,*)(PREQ1(I,IT,II),IT=1,NMONT)
      DO 4 IT=1,NMONT
      REQD1(I,IT,II)=AREQ1(I,II)*PREQ1(I,IT,II)/100.0
4     CONTINUE
17    CONTINUE
      READ(1,*)(NTREU(I,J),J=1,NSTAT(I))
      DO 14 J=1,NSTAT(I)
      IF(J.NE.1) GO TO 14
      READ(1,*)(AREU1(I,II),II=1,NTREU(I,1))
      DO 8 II=1,NTREU(I,1)
      READ(1,*)(PREU1(I,IT,II),IT=1,NMONT)
      DO 8 IT=1,NMONT
      REQU1(I,IT,II)=AREU1(I,II)*PREU1(I,IT,II)/100.0
```

```
8       CONTINUE
14      CONTINUE
        READ(1,*)(NUSRE(I,J),J=1,NSTAT(I))
        DO 710 J=1,NSTAT(I)
        IF(J.NE.1)GO TO 710
        READ(1,*)(ARU1(I,II),II=1,NUSRE(I,1))
        DO 712 II=1,NUSRE(I,1)
        READ(1,*)(PRU1(I,IT,II),IT=1,NMONT)
        DO 712 IT=1,NMONT
        REU1(I,IT,II)=ARU1(I,II)*PRU1(I,IT,II)/100.0
712     CONTINUE
710     CONTINUE
        READ(1,*)(NDSRE(I,J),J=1,NSTAT(I))
        DO 810 J=1,NSTAT(I)
        IF(J.NE.1)GO TO 810
        READ(1,*)(ARD1(I,II),II=1,NDSRE(I,1))
        DO 812 II=1,NDSRE(I,1)
        READ(1,*)(PRD1(I,IT,II),IT=1,NMONT)
        DO 812 IT=1,NMONT
        RED1(I,IT,II)=ARD1(I,II)*PRD1(I,IT,II)/100.0
812     CONTINUE
810     CONTINUE
        READ(1,*)IUMRE(I)
        IF(IUMRE(I).EQ.1)GO TO 603
        READ(1,*)NURCF(I)
        READ(1,*)(NTRCF(I,LL),LL=1,NURCF(I))
603     DO 601 J=1,NSTAT(I)
        READ(1,*)(DSRFL(I,J,II),II=1,NTREQ(I,J))
601     CONTINUE
        DO 602 J=1,NSTAT(I)
        READ(1,*)(UPRFL(I,J,II),II=1,NTREU(I,J))
602     CONTINUE
        READ(1,*)(EVAPO(I,IT),IT=1,NMONT)
        READ(1,*)(IWRT(LL),LL=1,6)
        READ(1,*)IPRT,IPRTE,IPRTR,IPRTW,IPRTT
        READ(1,*)IWRT1,IBNFT,JBNFT,IPREE,IPRTS
        READ(1,*)PPEFF(I),PPC(I),TWL(I)
        READ(1,*)(PHMIN(I,IT),IT=1,NMONT)
        READ(1,*)(HOUR(I,IT),IT=1,NMONT)
        READ(1,*)ISPPO(I)
        READ(1,*)NRDIR(I)
        IF(NRDIR(I).NE.0)READ(1,*)(NTRDR(I,IU),IU=1,NRDIR(I))
        READ(1,*)NTRTD(I)
        IF(NTRTD(I).EQ.0)GO TO 9008
        DO 9004 II=1,NDSRE(I,1)
        READ(1,*)(IDIV1(I,II,IU),IU=1,NSITE)
9004    CONTINUE
9008    CONTINUE
        DO 3000 J=1,NSTAT(I)
        IF(J.NE.1)GO TO 3000
        READ(1,*)(IREQ1(I,II),II=1,NTREQ(I,J))
        READ(1,*)(IENO1(I,II),II=1,NTREQ(I,J))
        READ(1,*)(FRATN(I,II),II=1,NTREQ(I,J))
3000    CONTINUE
        READ(1,*)((PEALD(I,J,II),II=1,NTREQ(I,J)),J=1,NSTAT(I))
```

```
      READ(1,*)((PEALU(I,J,II),II=1,NTREU(I,J)),J=1,NSTAT(I))
      READ(1,*)((PEAUU(I,J,II),II=1,NUSRE(I,J)),J=1,NSTAT(I))
      READ(1,*)((PEAUD(I,J,II),II=1,NDSRE(I,J)),J=1,NSTAT(I))
      READ(1,*) ISITE(I)
      READ(1,*)(IUSE(I,II),II=1,NDSRE(I,1))
1     CONTINUE
C     **************************************************************
C                    INITIALIZATION OF VARIABLE TO ZERO
C     **************************************************************
      CALL INTI1(NSITE,NYEAR)
      CALL INIL1(NSITE,NYEAR)
      DO 401 I=1,NSITE
      AASPL(I)=0.0
      SUM4(I)=0.0
      SUM5(I)=0.0
      SUM6(I)=0.0
      NYDE1(I)=0
      DO 401 JJ=1,NYEAR
      ANSPL(I,JJ)=0.0
      AADE1(I,JJ)=0.0
      AADU1(I,JJ)=0.0
      ANLEN(I,JJ)=0.0
      DO 401 IT=1,NMONT
      NREMT(I,IT)=0
      NRFUT(I,IT)=0
      AVSPT(I,IT)=0
      AMDE1(I,IT)=0.0
      NMDE1(I,IT)=0.0
      AMDU1(I,IT)=0.0
      NMDU1(I,IT)=0.0
401   CONTINUE
      DO 7 JJ=1,NYEAR
      IF(IPRTS.EQ.1)WRITE(*,1500)JJ
1500  FORMAT(1X,'NYEAR='I5)
      DO 11 IT=1,NMONT
      IF(IPRTS.EQ.1)WRITE(*,1501)IT
1501  FORMAT(1X,'NMONT='I3)
      IJ=1
      DO 12 I=1,NSITE
      DO 701 J=1,NSTAT(I)
      SURF(I,J)=0.
      SDRF(I,J)=0.
701   CONTINUE
C     **************************************************************
C                          ENERGY COMPUTATION
C     **************************************************************
      REQE1(I,IT,II)=0.
      DEFE1(I,IT)=0.
      DUME1(I,IT)=0.
      REQV1(I)=0.
      REQA1(I)=0.
      ADNV1(I)=0.
      ADNC1(I)=0.
      ADND1(I)=0.
```

```
      REGE1(I)=0.
      ENER1(I)=0.
      ELE(I,IT)=ELEVAT(I,S(I,IT))
      HE(I)=ELE(I,IT)-TWL(I)
      CF=3600.*HOUR(I,IT)*365/(12.*CCF)
      FACTR=9.8*HE(I)*PPEFF(I)*HOUR(I,IT)*30.4
      IF(PPC(I).EQ.0)QMAX(I)=0.
      IF(PPC(I).NE.0)QMAX(I)=PPC(I)*1000.*CF/(9.8*HE(I)*PPEFF(I))
      LLLL=8000
      IF(IPRTE.EQ.1)WRITE(2,700)LLLL,ELE(I,IT),TWL(I),CF,FACTR,QMAX(I)
700   FORMAT(2X,'XXXX’ 5F12.2)
      IF(IPRTS.EQ.1)WRITE(*,1502)I
1502  FORMAT(1X,'NSITE='I3)
      SPILL(I,IT)=0.0
      DO 1001 NSHRE=1,4
      DO 1001 J=1,NSTAT(I)
1001  SHARE(NSHRE,I,J)=0
      DO 2000 J=1,NSTAT(I)
      DO 2001 II=1,NTREQ(I,J)
      IF(J.NE.1)GO TO 2001
C     ****************************************************************
C                                 OPTION FOR ENERGY
C     ****************************************************************
      IF(IREQ1(I,II).EQ.1)REQE1(I,IT,II)=CF*(REQD1(I,IT,II)*1000.)/
     1 FACTR
      IF(IREQ1(I,II).EQ.1)DDDT1(I,IT,II)=REQE1(I,IT,II)
      IF(IREQ1(I,II).NE.1)DDDT1(I,IT,II)=REQD1(I,IT,II)
      IF(IREQ1(I,II).EQ.1)REQV1(I)=REQE1(I,IT,II)
2001  CONTINUE
      DO 2002 II=1,NTREU(I,J)
      IF(J.EQ.1)DUDT1(I,IT,II)=REQU1(I,IT,II)
2002  CONTINUE
      DO 2003 II=1,NDSRE(I,J)
      IF(J.EQ.1)DDD1(I,IT,II)=0.
2003  CONTINUE
      DO 2004 II=1,NUSRE(I,J)
      IF(J.EQ.1) DUD1(I,IT,II)=0.
2004  CONTINUE
2000  CONTINUE
      IF(NRDIR(I).EQ.0)GO TO 9007
      DO 9000 IU=1,NRDIR(I)
      IUREN=NTRDR(I,IU)
      DO 9001 II=1,NDSRE(IUREN,1)
      IF(IDIV1(IUREN,II,I).EQ.1)DIV(I,IT)=DIV(I,IT)+
     1 RED1(IUREN,IT,II)-DDD1(IUREN,IT,II)
9001  CONTINUE
9000  CONTINUE
9007  TFLOW(I,IT)=FLOW(I,JJ,IT)+DIV(I,IT)
      IF(IUMRE(I).EQ.1)TFLOW(I,IT)=TFLOW(I,IT)+UPRFC(I)
      IF(IUMRE(I).NE.1)TFLOW(I,IT)=TFLOW(I,IT)+SPILC(I)+UPRFC(I)+
     1 DSRFC(I)
      NSHRE=1
      SHARE (1,I,1)=TFLOW(I,IT)
```

```
C     ****************************************************************
C                          USE WATER FROM SHARE1
C     ****************************************************************
      DO 5002 J=1,NSTAT(I)
      DO 5000 II=1,NTREU(I,J)
      IF (J.EQ.1)SUPT1(I,IT,II)=0.0
5000  CONTINUE
      DO 5001 II=1,NTREQ(I,J)
      IF (J.EQ.1)RLDT1(I,IT,II)=0.0
5001  CONTINUE
5002  CONTINUE
      DO 20 J=1,NSTAT(I)
      IF(IPRTS.EQ.1)WRITE(*,1503)
1503  FORMAT(1X,'CALL STAT1 *1* ')
      IF(J.EQ.1)CALL STAT1(I,JJ,IT,NSHRE)
      IF(IPRT.EQ.1)CALL WRTM(IJ)
20    CONTINUE
      SUMX=0
      DO 13 J=1,NSTAT(I)
      SUMX=SUMX+AVANS(NSHRE,I,J)
13    CONTINUE
      XXX=0
      YYY=0
      PPP=0
      QQQ=0
      ICAL=1
      IF(IPRTS.EQ.1)WRITE(*,1504)ICAL
1504  FORMAT(1X,'ICAL*2*='I3)
      J=1
      CALL CAL1(XXX,YYY,ICAL,NYEAR)
      IF(IPRTS.EQ.1)WRITE(*,1505)
1505  FORMAT('CALL CAL11 *3*')
      CALL CAL11(PPP,QQQ,ICAL,NYEAR)
      DO 5005 J=1,NSTAT(I)
      DO 5006 II=1,NTREQ(I,J)
      IF (J.EQ.1)RLDT1(I,IT,II)=0.0
5006  CONTINUE
5005  CONTINUE
      ZZZ=AREA(I,S(I,IT))
      EL=ZZZ*EVAPO(I,IT)
      P(I,JJ,IT)=ZZZ*P(I,JJ,IT)
      X=S(I,IT)+SUMX+P(I,JJ,IT)-EL-YMIN(I,IT)
      IF(X.LE.0.0)GO TO 1002
      YY=X-YMAX(I,IT)+YMIN(I,IT)
      IF(YY.LE.0.0)AWACS(I)=0.
      IF(YY.GT.0.0)AWACS(I)=YY
      IF(AWACS(I).GT.0.0)AWWCS(I)=YMAX(I,IT)-YMIN(I,IT)
      IF(X.LT.0.0)X=0.0
      IF(YY.LT.0.0)AWWCS(I)=X
      LLLL=9000
      IF(IPRTR.EQ.1)WRITE(2,*)LLLL,EL,S(I,IT),SUMX,X,YY,AWACS(I),
     1 AWWCS(I)
```

```
C       *****************************************************************
C                            USE WATER FROM SHARE 2
C       *****************************************************************
        NSHRE=2
        SHARE(2, I, 1)=AWWCS(I)
        DO 5003 J=1,NSTAT(I)
        DO 5004 II=1,NTREQ(I,J)
        IF (J.EQ.1)RLDT1(I,IT,II)=0.0
5004    CONTINUE
5003    CONTINUE
        DO 28 J=1,NSTAT(I)
        IF(IPRTS.EQ.1)WRITE(*,1506)
1506    FORMAT(1X,'CALL STAT1 *4*')
        IF(J.EQ.1)CALL STAT1(I,JJ,IT,NSHRE)
        IF(IPRT.EQ.1)CALL WRTM(IJ)
28      CONTINUE
        IF(AWACS(I).GT.0.0)SPILL(I,IT)=AWACS(I)
        IF(AWACS(I).LE.0)SPILL(I,IT)=0
        SUMX=0.
        DO 46 J=1,NSTAT(I)
        SUMX=SUMX+AVANS(NSHRE,I,J)
46      CONTINUE
        GO TO 405
1002    SPILL(I,IT)=0.0
        SUMX=X
C       *****************************************************************
C                   CALCULATION FOR FINAL RESERVOIR BEHAVIOUR
C       *****************************************************************
405     IF(I.EQ.1)CALL DIST1(I,IT)
        ICAL=2
        IF(IPRTS.EQ.1)WRITE(*,1507)
1507    FORMAT(1X,'ICAL=2*5* ')
        IF(IPRTS.EQ.1)WRITE(*,1508)
1508    FORMAT(1X,'CALL CAL1*6*')
        J=1
        CALL CAL1(XXX,YYY,ICAL,NYEAR)
        IF(IPRTS.EQ.1)WRITE(*,1509)
1509    FORMAT(1X,'CALL CAL11 *7*')
        CALL CAL11(PPP,QQQ,ICAL,NYEAR)
        UPRFC(I)=0.
        DO 7002 J=1,NSTAT(I)
        UPRFC(I)=UPRFC(I)+SURF(I,J)
7002    CONTINUE
        IF(IUMRE(I).EQ.1)GO TO 7001
        SPILC(I)=0.
        DSRFC(I)=0.
        DO 7000 IU=1,NURCF(I)
        IUREN=NTRCF(I,IU)
        SPILC(I)=SPILC(I)+SPILL(IUREN,IT)
        DO 7000 J=1,NSTAT(I)
        DSRFC(I)=DSRFC(I)+SDRF(IUREN,J)
7000    CONTINUE
7001    DO 5007 J=1,NSTAT(I)
        DO 5008 II=1,NTREQ(I,J)
```

```
      IF (J.EQ.1) RLDT1(I,IT,II)=0.0
5008  CONTINUE
5007  CONTINUE
      O(I,IT)=XXX
      TUSUT(I,IT)=YYY
C     ****************************************************************
C                    CALCULATE FINAL RESERVOIR CONTENT
C     ****************************************************************
      IF(SPILL(I,IT).NE.0.)S(I,IT+1)=YMAX(I,IT)
      IF(SPILL(I,IT).EQ.0.)S(I,IT+1)=YMIN(I,IT)+SUMX
C     ****************************************************************
C                            FOR ENERGY COMPUTATION
C     ****************************************************************
      IF(ISPPO(I).EQ.1.AND.SPILL(I,IT).LT.ADNC1(I))
     1 ADNC1(I)=SPILL(I,IT)
      IF(ISPPO(I).EQ.1)ENER1(I)=ENER1(I)+ADNC1(I)
      ENER1(I)=ENER1(I)/CF
      ENER1(I)=ENER1(I)*9.8*HE(I)*PPEFF(I)
      ENER1(I)=ENER1(I)*HOUR(I,IT)*365./12.0
      ENERG(I,IT)=ENER1(I)/1000.0
      IF(IPRTE.EQ.1)WRITE(2,1516)
1516  FORMAT(2X,'ENERGY')
      DO 9999 J=1,NSTAT(I)
      DO 9999 II=1,NTREQ(I,J)
      IF(IREQ1(I,II).NE.1)GO TO 9999
      LLLL=10000
      IF(IPRTE.EQ.1)WRITE(2,*)LLLL,ENER1(I),ENERG(I,IT),
     1 ADNC1(I),SPILL(I,IT),REGE1(I),REQE1(I,IT,II),ANLEN(I,JJ)
      REQE1(I,IT,II)=REQE1(I,IT,II)*FACTR/(1000.0*CF)
      Z=(ENERG(I,IT)/REQE1(I,IT,II))*100.0
      ZA=100.0-PEALD(I,1,II)
      IF(INT(Z).LT.INT(ZA))GO TO 6001
      IF(INT(Z).GT.INT(ZA))GO TO 6002
      IF(INT(Z).EQ.INT(ZA))GO TO 6005
C     IF(Z.LT.ZA)GO TO 6001
C     IF(Z.GT.ZA)GO TO 6002
C     IF(Z.EQ.ZA)GO TO 6005
6001  DEFE1(I,IT)=REQE1(I,IT,II)-ENERG(I,IT)
      AMDE1(I,IT)=AMDE1(I,IT)+DEFE1(I,IT)/FLOAT(NYEAR)
      NMDE1(I,IT)=NMDE1(I,IT)+1
      AADE1(I,JJ)=AADE1(I,JJ)+DEFE1(I,IT)
      ANLEN(I,JJ)=ANLEN(I,JJ)+ENERG(I,IT)
      GO TO 6003
6002  DUME1(I,IT)=ENERG(I,IT)-REQE1(I,IT,II)
      AMDU1(I,IT)=AMDU1(I,IT)+DUME1(I,IT)/FLOAT(NYEAR)
      NMDU1(I,IT)=NMDU1(I,IT)+1
      AADU1(I,JJ)=AADU1(I,JJ)+DUME1(I,IT)
      ANLEN(I,JJ)=ANLEN(I,JJ)+REQE1(I,IT,II)
      GO TO 6003
6005  ANLEN(I,JJ)=ANLEN(I,JJ)+REQE1(I,IT,II)
6003  IF(IPRTE.EQ.1)WRITE(2,*)LLLL,ENERG(I,IT),REQE1(I,IT,II),
     1 DEFE1(I,IT),DUME1(I,IT),AADE1(I,JJ),AADU1(I,JJ)
9999  CONTINUE
```

```
C       ****************************************************************
C                 CALCULATE STATISTICS FOR RESERVOIR BEHAVIOUR
C       ****************************************************************
        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
        AVSPT(I,IT)=AVSPT(I,IT)+SPILL(I,IT)/FLOAT(NYEAR)
        ANSPL(I,JJ)=ANSPL(I,JJ)+SPILL(I,IT)
        IF(IT.EQ.1)CUMF(I)=0
        IF(IT.EQ.1)CUMP(I)=0
        IF(IT.EQ.1)CUMEL(I)=0
        IF(IT.EQ.1.AND.JJ.EQ.1)AASPL(I)=0
C       ****************************************************************
C                        CALCULATE TOTAL EVAPORATION
C       ****************************************************************
        CUMEL(I)=CUMEL(I)+EL
C       CALCULATE TOTAL RESERVOIR INPUT
        CUMF(I)=CUMF(I)+TFLOW(I,IT)
        CUMP(I)=CUMP(I)+P(I,JJ,IT)
12      CONTINUE
11      CONTINUE
        DO 703 I=1,NSITE
        IF(IPRTE.EQ.1)WRITE(2,*)AADE1(I,JJ),AADU1(I,JJ)
        IF(IPRTT.NE.1)GO TO 1547
        WRITE(2,705)
        DO 704 IT=1,NMONT
        WRITE(2,706)I,JJ,IT,S(I,IT),FLOW(I,JJ,IT),TFLOW(I,IT),
     1  TUSUT(I,IT),O(I,IT),SPILL(I,IT),S(I,IT+1),ENERG(I,IT),
     1  ELE(I,IT)
705     FORMAT(/1X,'SITE',2X,'YEAR',2X,'TIME',2X,'INI. STORE',4X,
     1  'INFLOW',2X,'TOTAL FLOW',2X,'U/S SUB.',2X,'RES. REL.',5X,
     1  'SPILL',2X,'FINAL STORE',11X,'ENERGY',2X,'ELEVATION')
706
FORMAT(I5,I6,I6,F12.2,F10.2,F12.2,F10.2,F11.2,F10.2,F13.2,E17.5,F11.2/)
704     CONTINUE
1547    XX=CUMF(I)+CUMP(I)
        YY=XXX+YYY+CUMEL(I)+ANSPL(I,JJ)
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
        WRITE(2,96)
        WRITE(*,1510)
1510    FORMAT(1X,'WATER BALANCE FOUND INCORRECT *8*')
96      FORMAT(//5X,'WATER BALANCE FOUND INCORRECT')
        STOP
400     IF(IPRTT.EQ.1)WRITE(2,91)
        IF(IPRTS.EQ.1)WRITE(*,1511)
1511    FORMAT(1X,'WATER BALANCE FOUND OK *9*')
91      FORMAT(/5X,'WATER BALANCE FOUND OK')
        S(I,1)=S(I,NMONT+1)
        ICAL=3
        IF(IPRTS.EQ.1)WRITE(*,1512)
1512    FORMAT(1X,'ICAL=3 *10*')
        IF(IPRTS.EQ.1)WRITE(*,1513)
```

```
1513  FORMAT(1X,'CALL CAL1 *11* ')
      J=1
      CALL CAL1(XXX,YYY,ICAL,NYEAR)
      IF(IPRTS.EQ.1)WRITE(*,1514)
1514  FORMAT(1X,'CALL CAL11 *12*')
      CALL CAL11(PPP,QQQ,ICAL,NYEAR)
      AASPL(I)=AASPL(I)+ANSPL(I,JJ)/FLOAT(NYEAR)
      SUM4(I)=SUM4(I)+AADE1(I,JJ)/FLOAT(NYEAR)
      SUM5(I)=SUM5(I)+AADU1(I,JJ)/FLOAT(NYEAR)
      SUM6(I)=SUM6(I)+ANLEN(I,JJ)/FLOAT(NYEAR)
      DO 1548 II=1,NTREQ(I,1)
      IF(IREQ1(I,II).NE.1)GO TO 1548
      Z=(AADE1(I,JJ)/AREQ1(I,II))*100.0
      IF(INT(Z).GT.INT(PEALD (I,1,II)))NYDE1(I)=NYDE1(I)+1
C     IF(Z.GT.PEALD(I,1,II))NYDE1(I)=NYDE1(I)+1
1548  CONTINUE
      IF(IPRTE.EQ.1)WRITE(2,*)SUM4(I),SUM5(I),SUM6(I)
703   CONTINUE
7     CONTINUE
      DO 501 I=1,NSITE
      DO 500 J=1,NSTAT(I)
      IF(IPRTS.EQ.1)WRITE(*,1515)
1515  FORMAT(1X,'CALL WRT1 *13* ')
      IF(J.EQ.1.AND.IWRT1.EQ.1)CALL WRT1(NYEAR,NSITE,J,IWRT,NSHRE,I)
500   CONTINUE
501   CONTINUE
100   FORMAT(4F10.3)
      WRITE(2,902)
      DO 901 I=1,NSITE
      DO 901 IT=1,NMONT
      WRITE(2,903)I,IT,AVSPT(I,IT),NREMT(I,IT),NRFUT(I,IT)
902   FORMAT(1X,'SITE',2X,'TIME',2X,'AVE. SPILL',2X,
     1'NO. OF TIMES RES. EMPTY',2X,'NO. OF TIMES RES. FULL'/)
903   FORMAT(I5,I6,F12.3,I25,I24)
901   CONTINUE
      IF(IPRTS.EQ.0)GO TO 6008
      WRITE(2,904)
      DO 905 I=1,NSITE
      DO 905 JJ=1,NYEAR
      IF(IPRTE.EQ.1)WRITE(2,906)I,JJ,ANSPL(I,JJ)
904   FORMAT(1X,'SITE',2X,'YEAR',2X,'ANNUAL SPILL'/)
906   FORMAT(I5,I6,F14.3/)
905   CONTINUE
6008  WRITE(2,907)
      DO 908 I=1,NSITE
      WRITE(2,909)I,AASPL(I)
907   FORMAT(1X,'SITE',2X,'AVE. ANNUAL SPILL')
909   FORMAT(I5,F19.3)
908   CONTINUE
      WRITE(2,1543)
1543  FORMAT(2X,'SITE',2X,'MONTH',4X,'AVE.ENERGY',3X,'NO.OF',4X,
     1'AVE.ENERGY',3X,'NO.OF')
      WRITE(2,1544)
1544  FORMAT(21X,'DEFICIT',1X,'DEFICIT',11X,'DUMP',4X,'DUMP')
      DO 6004 I=1,NSITE
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      DO 6004 IT=1,NMONT
      WRITE(2,1545)I,IT,AMDE1(I,IT),NMDE1(I,IT),AMDU1(I,IT),NMDU1(I,IT)
1545  FORMAT(I6,I7,F15.3,I8,F15.3,I8)
6004  CONTINUE
      IF(IPREE.EQ.0)GO TO 6007
      DO 6006 I=1,NSITE
      WRITE(2,*)(AADE1(I,JJ),JJ=1,NYEAR)
      WRITE(2,*)(AADU1(I,JJ),JJ=1,NYEAR)
      WRITE(2,*)(ANLEN(I,JJ),JJ=1,NYEAR)
6006  CONTINUE
C     ****************************************************************
C               CALCULATE STATISTICS OF AVERAGE ANNUAL ENERGY
C     ****************************************************************
6007  DO 1541 I=1,NSITE
      WRITE(2,1542)I,SUM6(I),SUM5(I),SUM4(I)
1542  FORMAT(//1X,'SITE',I2,//2X,'AVERAGE ANNUAL GENERATED ENERGY=',
     1 F10.2,1X,'MW.HR',//2X,'AVERAGE ANNUAL DUMP ENERGY=',F14.2,
     2 'MW.HR',//2X,'AVERAGE ANNUAL ENERGY DEFICIT=',F10.2,'MW.HR')
C     FORMAT(1X,'SITE',2X,'SUM4=',F10.5,5X,'SUM5=',F10.5,5X,'SUM6='
C    1 ,F10.5)
      WRITE(2,1546)NYDE1(I)
1546  FORMAT(/2X,'NO. OF YEARLY DEFICITS IN ENERGY =',I4)
1541  CONTINUE
      IF(IBNFT.EQ.1)CALL BENFT(RATE,NSITE,NYEAR,JBNFT)
      STOP
      END
C     ****************************************************************
C    (1)                         STAT1
C     ****************************************************************
      SUBROUTINE STAT1(I,JJ,IT,NSHRE)
      DIMENSION DUDT1(20,12,20),DDDT1(20,12,20)
      DIMENSION NTREQ(20,1),NTREU(20,1),SHARE(1,20,1),AVANS(1,20,1)
      DIMENSION RLDT1(20,12,20),SUPT1(20,12,20)
      DIMENSION REQV1(20),QMAX(20),REQA1(20),ADNC1(20),REGE1(20)
      DIMENSION ENER1(20),ADNV1(20),ADND1(20),IREQ1(20,20)
      DIMENSION IENO1(20,20),ELE(20,12),PHMIN(20,12),ENERG(20,12)
      DIMENSION FRATN(20,20)
      COMMON/BLK3/SHARE
      COMMON/BLK5/NTREQ,NTREU
      COMMON/BLK6/AVANS
      COMMON/B11/DUDT1,RLDT1,DDDT1,SUPT1
      COMMON/B20/REQV1,QMAX,REQA1,ADNC1,REGE1,ENER1,ADNV1,ADND1,
     1 IENO1,ELE,PHMIN,FRATN
      COMMON/B201/IREQ1
      GO TO(10,20)NSHRE
C     ****************************************************************
C       U/S USE AND D/S RELEASES FROM SHARE1 AT SITE I IN TIME T FOR
C                                STATE 1
C     ****************************************************************
 10   AVANS(1,I,1)=SHARE(1,I,1)
      IF(IPRTS.EQ.1)WRITE(*,1516)
1516  FORMAT(1X,'STAT1*1.1*')
      CALL WATER(AVANS(1,I,1),DUDT1,RLDT1,DDDT1,SUPT1,NTREQ(I,1),
```

```
     1 NTREU(I,1),I,IT,NSHRE,REQV1,QMAX,REQA1,ADNC1,REGE1,ENER1,ADNV1,
     2 ADND1,IREQ1,IENO1,ELE,PHMIN,FRATN)
       IF(IPRTS.EQ.1)WRITE(*,1517)
1517   FORMAT(1X,'CALL WATER 1*1.2*')
       RETURN
C      ****************************************************************
C          D/S RELEASES FROM SHARE2 AT SITE I IN TIME T FOR STATE 1
C      ****************************************************************
20     AVANS(2,I,1)=SHARE(2,I,1)
       CALL WATER(AVANS(2,I,1),DUDT1,RLDT1,DDDT1,SUPT1,NTREQ(I,1),
     1 NTREU(I,1),I,IT,NSHRE,REQV1,QMAX,REQA1,ADNC1,REGE1,ENER1,ADNV1,
     2 ADND1,IREQ1,IENO1,ELE,PHMIN,FRATN)
       IF(IPRTS.EQ.1)WRITE(*,1518)
1518   FORMAT(1X,'CALL WATER 2 *1.3*')
       DO 50 II=1,NTREQ(I,1)
       IF(IREQ1(I,II).EQ.1.AND.ENER1(I).LT.DDDT1(I,IT,II))
     1 DDDT1(I,IT,II)=DDDT1(I,IT,II)-ENER1(I)
       IF(IREQ1(I,II).EQ.1.AND.ENER1(I).GE.DDDT1(I,IT,II))
     1 DDDT1(I,IT,II)=0.
50     CONTINUE
       RETURN
       END
C      ****************************************************************
C      (2)                         WATER
C      ****************************************************************
       SUBROUTINE WATER(AVANW,DUDT,RLDT,DDDT,SUPT,NTREQ,NTREU,I,IT,
     1 NSHRE,REQV,QMAX,REQA,ADNLC,REGEN,ENERG,ADNLV,ADNLD,
     2 IREQ,IENO,ELE,PHMIN,FRATN)
       DIMENSION DUDT(20,12,20),RLDT(20,12,20),DDDT(20,12,20),
     1 SUPT(20,12,20),REQV(20),QMAX(20),REQA(20),ADNLC(20),
     2 REGEN(20),ENERG(20),ADNLV(20),ADNLD(20),IENO(20,20),
     3 ELE(20,12),PHMIN(20,12),IREQ(20,20),FRATN(20,20)
       COMMON/BLK24/IPRTW
       IF(NSHRE.NE.1)GO TO 3
       DO 1 II=1,NTREU
       IF(IPRTS.EQ.1)WRITE(*,1520)
1520   FORMAT(1X,'WATER *1.5*')
       CALL RELES(AVANW,DUDT(I,IT,II),SUPT(I,IT,II))
       IF(IPRTS.EQ.1)WRITE(*,1521)
1521   FORMAT(1X,'CALL RELES1 *1.6*')
       LLLL=1111
       IF(IPRTW.EQ.1)
     1 WRITE(2,*)LLLL,AVANW,DUDT(I,IT,II),SUPT(I,IT,II),
     2 ELE(I,IT),PHMIN(I,IT)
1      CONTINUE
3      DO 2 II=1,NTREQ
       IF(IREQ(I,II).NE.1)CALL RELES(AVANW,DDDT(I,IT,II),RLDT(I,IT,II))
       IF(IPRTS.EQ.1)WRITE(*,1522)
1522   FORMAT(1X,'CALL RELES 2 *1.7*')
       LLLL=2222
       IF(IPRTW.EQ.1)
     1 WRITE(2,*)LLLL,AVANW,DDDT(I,IT,II),RLDT(I,IT,II),
     2 ELE(I,IT), PHMIN(I,II)
```

```
C     *****************************************************************
C              CALCULATE ENERGY GENERATED FROM OTHER RELEASES
C     *****************************************************************
      IF(IREQ(I,II).NE.1.AND.IENO(I,II).EQ.1)REGEN(I)=REGEN(I)+
     1 RLDT(I,IT,II)*FRATN(I,II)
      IF(IREQ(I,II).NE.1.AND.IENO(I,II).EQ.1)ENERG(I)=REGEN(I)
      IF((IREQ(I,II).NE.1.AND.IENO(I,II).EQ.1).AND.(ENERG(I).GT.
     1 QMAX(I)))ENERG(I)=QMAX(I)
      LLLL=4444
      IF(IPRTW.EQ.1)
     1 WRITE(2,*)LLLL,REGEN(I),RLDT(I,IT,II),
     2 FRATN(I,II),IREQ(I,II),IENO(I,II)
      IF(ELE(I,IT).LT.PHMIN(I,IT))GO TO 2
      IF(IREQ(I,II).NE.1)GO TO 2
C     *****************************************************************
C                  CALCULATE ADDITIONAL POWER RELEASES
C     *****************************************************************
      CALL POWER(AVANW,REQV(I),QMAX(I),REQA(I),ADNLC(I),REGEN(I),
     1 ENERG(I),ADNLV(I),ADNLD(I),RLDT(I,IT,II))
      IF(IPRTS.EQ.1)WRITE(*,1523)
1523  FORMAT(1X,'CALL POWER *1.8*')
      LLLL=3333
      IF(IPRTW.EQ.1)
     1 WRITE(2,*)LLLL,AVANW,REQV(I),QMAX(I),REQA(I),ADNLC(I),REGEN(I),
     2 ENERG(I),ADNLV(I),ADNLD(I),RLDT(I,IT,II),ELE(I,IT),
     3 PHMIN(I,IT)
2     CONTINUE
      RETURN
      END
C     *****************************************************************
C     (3)                        RELES
C     *****************************************************************
      SUBROUTINE RELES(AVANW,DEFCT,RLS)
      IF(AVANW.LT.DEFCT)RLS=AVANW
      IF(AVANW.GE.DEFCT)RLS=DEFCT
      AVANW=AVANW-RLS
      IF(RLS.LT.DEFCT)DEFCT=DEFCT-RLS
      IF(RLS.EQ.DEFCT)DEFCT=0
      RETURN
      END
C     *****************************************************************
C     (4)                        POWER
C     *****************************************************************
      SUBROUTINE POWER(AVANW,REQV,QMAX,REQA,ADNLC,REGEN,ENERG,
     1 ADNLV,ADNLD,RLDT)
      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
```

```
      IF(ADNLV.NE.0)GO TO 9007
      IF(ADNLV.EQ.0.AND.ADNLC.NE.0.AND.(REGEN-REQA).LE.ADNLC)
     1 GO TO 9001
      ENERG=REQA+ADNLC
      ADNLC=0
      REGEN=ENERG
      GO TO 2
9001  ENERG=REGEN
      ADNLC=QMAX-REGEN
      GO TO 2
9007  IF(AVANW.EQ.0)GO TO 2
      IF(AVANW.LT.ADNLV)ADNLD=AVANW
      IF(AVANW.GE.ADNLV)ADNLD=ADNLV
      ADNLV=ADNLV-ADNLD
      AVANW=AVANW-ADNLD
      ENERG=ENERG+ADNLD
      REGEN=ENERG
      IF(ADNLV.NE.0.)ADNLC=0.0
      RLDT=ADNLD
2     RETURN
      END
C     ****************************************************************
C     (5)                             CAL1
C     ****************************************************************
      SUBROUTINE CAL1(XXX,YYY,ICAL,NYEAR)
      DIMENSION NTREQ(20,1),NTREU(20,1)
      DIMENSION DUDT1(20,12,20),RLDT1(20,12,20),DDDT1(20,12,20)
      DIMENSION SUPT1(20,12,20),AVDD1(20,12,20),AVUD1(20,12,20)
      DIMENSION CUSR1(20,50,20),CUUS1(20,50,20),AADD1(20,20)
      DIMENSION AAUD1(20,20),ANDD1(20,50,20),ANUD1(20,50,20)
      DIMENSION NADD1(20,20),NAUD1(20,20),NDDD1(20,12,20)
      DIMENSION NDUD1(20,12,20)
      DIMENSION SURF(20,1),UPRFL(20,1,20),SDRF(20,1),DSRFL(20,1,20)
      DIMENSION PEALD(20,1,20),PEALU(20,1,20)
      DIMENSION AREQ1(20,20),AREU1(20,20)
      DIMENSION REQD1(20,12,20),REQU1(20,12,20)
      COMMON/BLK5/NTREQ,NTREU
      COMMON/BLK10/I,J,JJ,NSHRE,IT
      COMMON/ BLK14/SURF,UPRFL,SDRF,DSRFL
      COMMON/BLK27/PEALD,PEALU
      COMMON/B11/DUDT1,RLDT1,DDDT1,SUPT1
      COMMON/B12/AVDD1,AVUD1,CUSR1,CUUS1
      COMMON/B121/AADD1,AAUD1,ANDD1,ANUD1
      COMMON/B13/NDDD1,NDUD1,NADD1,NAUD1
      COMMON/B191/AREU1,REQU1
      COMMON/B192/AREQ1,REQD1
      GO TO(10,20,30)ICAL
      DO 100 II=1,NTREQ(I,1)
      IF(IPRTS.EQ.1)WRITE(2,*)I,ICAL,II,IT,RLDT1(I,IT,II)
100   CONTINUE
C     CALCULATE TOTAL D/S RELEASES DEMANDWISE
10    DO 3 II=1,NTREQ(I,1)
      CUSR1(I,JJ,II)=CUSR1(I,JJ,II)+RLDT1(I,IT,II)
```

```
      SDRF(I,J)=SDRF(I,J)+DSRFL(I,J,II)*RLDT1(I,IT,II)
      XXX=XXX+RLDT1(I,IT,II)
3     CONTINUE
      RETURN
C     CALCULATE STATISTICS FOR D/S DEMAND
20    DO 1 II=1,NTREQ(I,1)
      Z=(DDDT1(I,IT,II)/REQD1(I,IT,II))*100.0
      IF(Z.GT.PEALD(I,J,II))NDDD1(I,IT,II)=NDDD1(I,IT,II)+1
      AVDD1(I,IT,II)=AVDD1(I,IT,II)+DDDT1(I,IT,II)/FLOAT(NYEAR)
      ANDD1(I,JJ,II)=ANDD1(I,JJ,II)+DDDT1(I,IT,II)
1     CONTINUE
C     CALCULATE STATISTICS FOR U/S DEMAND
      DO 2 II=1,NTREU(I,1)
      Z=(DUDT1(I,IT,II)/REQU1(I,IT,II))*100.0
      IF(Z.GT.PEALU(I,J,II))NDUD1(I,IT,II)=NDUD1(I,IT,II)+1
      AVUD1(I,IT,II)=AVUD1(I,IT,II)+DUDT1(I,IT,II)/FLOAT(NYEAR)
      ANUD1(I,JJ,II)=ANUD1(I,JJ,II)+DUDT1(I,IT,II)
2     CONTINUE
C     CALCULATE TOTAL D/S RELEASES DEMANDWISE
      DO 7 II=1,NTREQ(I,1)
      CUSR1(I,JJ,II)=CUSR1(I,JJ,II)+RLDT1(I,IT,II)
      SDRF(I,J)=SDRF(I,J)+DSRFL(I,J,II)*RLDT1(I,IT,II)
      XXX=XXX+RLDT1(I,IT,II)
7     CONTINUE
C     CALCULATE TOTAL U/S SUBTRATION  DEMANDWISE
      DO 4 II=1,NTREU(I,1)
      CUUS1(I,JJ,II)=CUUS1(I,JJ,II)+SUPT1(I,IT,II)
      SURF(I,J)=SURF(I,J)+UPRFL(I,J,II)*SUPT1(I,IT,II)
      YYY=YYY+SUPT1(I,IT,II)
4     CONTINUE
      RETURN
30    DO 5 II=1,NTREQ(I,1)
      Z=(ANDD1(I,JJ,II)/AREQ1(I,II))*100.0
      IF(Z.GT.PEALD(I,J,II))NADD1(I,II)=NADD1(I,II)+1
      AADD1(I,II)=AADD1(I,II)+ANDD1(I,JJ,II)/FLOAT(NYEAR)
5     CONTINUE
      DO 6 II=1,NTREU(I,1)
      Z=(ANUD1(I,JJ,II)/AREU1(I,II))*100.0
      IF(Z.GT.PEALU(I,J,II))NAUD1(I,II)=NAUD1(I,II)+1
      AAUD1(I,II)=AAUD1(I,II)+ANUD1(I,JJ,II)/FLOAT(NYEAR)
6     CONTINUE
      RETURN
      END
C     ***************************************************************
C     (6)                            INTI1
C     ***************************************************************
      SUBROUTINE INTI1(NSITE,NYEAR)
      DIMENSION AVDD1(20,12,20),AVUD1(20,12,20)
      DIMENSION CUSR1(20,50,20),CUUS1(20,50,20),AADD1(20,20)
      DIMENSION AAUD1(20,20),ANDD1(20,50,20),ANUD1(20,50,20)
      DIMENSION NADD1(20,20),NAUD1(20,20),NDDD1(20,12,20)
      DIMENSION NDUD1(20,12,20)
      DIMENSION NTREQ(20,1),NTREU(20,1)
```

```
      COMMON/BLK2/NMONT
      COMMON/BLK5/NTREQ,NTREU
      COMMON/B12/AVDD1,AVUD1,CUSR1,CUUS1
      COMMON/B121/AADD1,AAUD1,ANDD1,ANUD1
      COMMON/B13/NDDD1,NDUD1,NADD1,NAUD1
      DO 1 I=1,NSITE
      DO 2 JJ=1,NYEAR
      DO 3 IT=1,NMONT
      DO 4 II=1,NTREQ(I,1)
      NDDD1(I,IT,II)=0
      AVDD1(I,IT,II)=0.
      ANDD1(I,JJ,II)=0.
      CUSR1(I,JJ,II)=0.
      NADD1(I,II)=0
      AADD1(I,II)=0.
4     CONTINUE
      DO 5 II=1,NTREU(I,1)
      NDUD1(I,IT,II)=0
      AVUD1(I,IT,II)=0.
      ANUD1(I,JJ,II)=0.
      CUUS1(I,JJ,II)=0.
      NAUD1(I,II)=0
      AAUD1(I,II)=0.
5     CONTINUE
3     CONTINUE
2     CONTINUE
1     CONTINUE
      RETURN
      END
C     ****************************************************************
C     (7)                            WRT1
C     ****************************************************************
      SUBROUTINE WRT1(NYEAR,NSITE,J,IWRT,NSHRE,I)
      DIMENSION S(20,12),FLOW(20,50,12),P(20,50,12)
      DIMENSION YMIN(20,12),YMAX(20,12)
      DIMENSION AREQ1(20,20),NTREQ(20,1),REQ1(20,12,20)
      DIMENSION PREQ1(20,12,20)
      DIMENSION AREU1(20,20),NTREU(20,1)
      DIMENSION PREU1(20,12,20),REQU1(20,12,20)
      DIMENSION SHARE(1,20,1),AVANS(1,20,1)
      DIMENSION DUDT1(20,12,20),RLDT1(20,12,20),DDDT1(20,12,20)
      DIMENSION AWACS(20),AWWCS(20)
      DIMENSION NSTAT(20),SUPT1(20,12,20)
      DIMENSION AVDD1(20,12,20),AVUD1(20,12,20)
      DIMENSION CUSR1(20,50,20),CUUS1(20,50,20),AADD1(20,20)
      DIMENSION AAUD1(20,20),ANDD1(20,50,20),ANUD1(20,50,20)
      DIMENSION NADD1(20,20),NAUD1(20,20),NDDD1(20,12,20)
      DIMENSION NDUD1(20,12,20),TFLOW(20,12),IWRT(6),SUM4(20),SUM5(20)
      COMMON/BLK1/FLOW,TFLOW
      COMMON/BLK2/NMONT
      COMMON/BLK3/SHARE
      COMMON/BLK5/NTREQ,NTREU
      COMMON/BLK6/AVANS
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```
      COMMON/BLK8/NSTAT
      COMMON/BLK9/AWACS,AWWCS
      COMMON/BLK11/SUM1,SUM2,SUM3
      COMMON/B11/DUDT1,RLDT1,DDDT1,SUPT1
      COMMON/B12/AVDD1,AVUD1,CUSR1,CUUS1
      COMMON/B121/AADD1,AAUD1,ANDD1,ANUD1
      COMMON/B13/NDDD1,NDUD1,NADD1,NAUD1
100   FORMAT(1X,30('*'),/)
101   FORMAT(/,10('-'))
210   FORMAT(1X,'SHARE NO.=',I4,4X,'WATER SHARE =',F10.3/)
50    IF(IWRT(1).NE.1)GO TO 51
      IF(IPRTS.EQ.1)WRITE(4,213)
      DO 28 II=1,NTREU(I,1)
      DO 29 IT=1,NMONT
      WRITE(4,214)I,J,II,IT,AVUD1(I,IT,II),NDUD1(I,IT,II)
213   FORMAT(1X,'SITE',2X,'STATE',2X,'U/S DEMAND',3X,'TIME',2X,
     1 'AVE. DEFICIT IN TIME',2X,'NO. OF DEFICITS'/)
214   FORMAT(I5,I7,I12,I7,F22.3,I17)
29    CONTINUE
28    CONTINUE
      WRITE(4,101)
      WRITE(4,100)
51    IF(IWRT(2).NE.1)GO TO 52
      WRITE(4,215)
      DO 31 II=1,NTREU(I,1)
      DO 32 JJ=1,NYEAR
      WRITE(4,216)I,J,II,JJ,ANUD1(I,JJ,II)
215   FORMAT(1X,'SITE',2X,'STATE',2X,'U/S DEMAND',2X,'YEAR',2X,
     1 'ANNUAL DEFICIT')
216   FORMAT(I5,I7,I12,I6,F16.3)
32    CONTINUE
31    CONTINUE
      WRITE(4,101)
      WRITE(4,100)
52    IF(IWRT(3).NE.1)GO TO 53
      WRITE(4,217)
      DO 34 II=1,NTREU(I,1)
      WRITE(4,218)I,II,AAUD1(I,II),NAUD1(I,II)
217   FORMAT(1X,'SITE',2X,'U/S DEMAND',2X,'AVE.ANNUAL DEFICIT',
     1 2X,'NO.OF ANNUAL DEFICIT'/)
218   FORMAT(I5,I12,F20.3,I22)
34    CONTINUE
      WRITE(4,101)
      WRITE(4,100)
53    IF(IWRT(4).NE.1)GO TO 55
      WRITE(4,201)
      DO 14 II=1,NTREQ(I,1)
      DO 15 IT=1,NMONT
      WRITE(4,202)I,J,II,IT,AVDD1(I,IT,II),NDDD1(I,IT,II)
201   FORMAT(1X,'SITE',2X,'STATE',2X,'D/S DEMAND',3X,'TIME',2X,
     1 'AVE. DEFICIT IN TIME',2X,'NO. OF DEFICITS'/)
202   FORMAT(I5,I7,I12,I7,F22.3,I17)
15    CONTINUE
14    CONTINUE
```

```
      COMMON/BLK8/NSTAT
      COMMON/BLK9/AWACS,AWWCS
      COMMON/BLK11/SUM1,SUM2,SUM3
      COMMON/B11/DUDT1,RLDT1,DDDT1,SUPT1
      COMMON/B12/AVDD1,AVUD1,CUSR1,CUUS1
      COMMON/B121/AADD1,AAUD1,ANDD1,ANUD1
      COMMON/B13/NDDD1,NDUD1,NADD1,NAUD1
100   FORMAT(1X,30('*'),/)
101   FORMAT(/,10('-'))
210   FORMAT(1X,'SHARE NO.=',I4,4X,'WATER SHARE =',F10.3/)
50    IF(IWRT(1).NE.1)GO TO 51
      IF(IPRTS.EQ.1)WRITE(4,213)
      DO 28 II=1,NTREU(I,1)
      DO 29 IT=1,NMONT
      WRITE(4,214)I,J,II,IT,AVUD1(I,IT,II),NDUD1(I,IT,II)
213   FORMAT(1X,'SITE',2X,'STATE',2X,'U/S DEMAND',3X,'TIME',2X,
     1 'AVE. DEFICIT IN TIME',2X,'NO. OF DEFICITS'/)
214   FORMAT(I5,I7,I12,I7,F22.3,I17)
29    CONTINUE
28    CONTINUE
      WRITE(4,101)
      WRITE(4,100)
51    IF(IWRT(2).NE.1)GO TO 52
      WRITE(4,215)
      DO 31 II=1,NTREU(I,1)
      DO 32 JJ=1,NYEAR
      WRITE(4,216)I,J,II,JJ,ANUD1(I,JJ,II)
215   FORMAT(1X,'SITE',2X,'STATE',2X,'U/S DEMAND',2X,'YEAR',2X,
     1 'ANNUAL DEFICIT')
216   FORMAT(I5,I7,I12,I6,F16.3)
32    CONTINUE
31    CONTINUE
      WRITE(4,101)
      WRITE(4,100)
52    IF(IWRT(3).NE.1)GO TO 53
      WRITE(4,217)
      DO 34 II=1,NTREU(I,1)
      WRITE(4,218)I,II,AAUD1(I,II),NAUD1(I,II)
217   FORMAT(1X,'SITE',2X,'U/S DEMAND',2X,'AVE.ANNUAL DEFICIT',
     1 2X,'NO.OF ANNUAL DEFICIT'/)
218   FORMAT(I5,I12,F20.3,I22)
34    CONTINUE
      WRITE(4,101)
      WRITE(4,100)
53    IF(IWRT(4).NE.1)GO TO 55
      WRITE(4,201)
      DO 14 II=1,NTREQ(I,1)
      DO 15 IT=1,NMONT
      WRITE(4,202)I,J,II,IT,AVDD1(I,IT,II),NDDD1(I,IT,II)
201   FORMAT(1X,'SITE',2X,'STATE',2X,'D/S DEMAND',3X,'TIME',2X,
     1 'AVE. DEFICIT IN TIME',2X,'NO. OF DEFICITS'/)
202   FORMAT(I5,I7,I12,I7,F22.3,I17)
15    CONTINUE
14    CONTINUE
```

```
      WRITE(4,101)
      WRITE(4,100)
55    IF(IWRT(5).NE.1)GO TO 56
      WRITE(4,203)
      DO 17 II=1,NTREQ(I,1)
      DO 18 JJ=1,NYEAR
      WRITE(4,204)I,J,II,JJ,ANDD1(I,JJ,II)
203   FORMAT(1X,'SITE',2X,'STATE',2X,'D/S DEMAND',2X,'YEAR',2X,
     1 'ANNUAL DEFICIT')
204   FORMAT(I5,I7,I12,I6,F16.3)
18    CONTINUE
17    CONTINUE
      WRITE(4,101)
      WRITE(4,100)
56    IF(IWRT(6).NE.1)GO TO 57
      WRITE(4,207)
      DO 20 II=1,NTREQ(I,1)
      WRITE(4,208)I,II,AADD1(I,II),NADD1(I,II)
207   FORMAT(1X,'SITE',2X,'D/S DEMAND',2X,'AVE.ANNUAL DEFICIT',
     1 2X,'NO.OF ANNUAL DEFICIT'/)
208   FORMAT(I5,I12,F20.3,I22)
20    CONTINUE
      WRITE(4,101)
57    RETURN
      END
C     ****************************************************************
C     (8)                             WRTM
C     ****************************************************************
      SUBROUTINE WRTM(IJ)
      DIMENSION S(20,12),FLOW(20,50,12),P(20,50,12)
      DIMENSION YMIN(20,12),YMAX(20,12)
      DIMENSION AREQ1(20,20),NTREQ(20,1)
      DIMENSION REQD1(20,12,20)
      DIMENSION PREQ1(20,12,20)
      DIMENSION AREU1(20,20),NTREU(20,1)
      DIMENSION PREU1(20,12,20)
      DIMENSION REQU1(20,12,20)
      DIMENSION SHARE(1,20,1),AVANS(1,20,1)
      DIMENSION DUDT1(20,12,20),RLDT1(20,12,20),DDDT1(20,12,20)
      DIMENSION SUPT1(20,12,20)
      DIMENSION ANNLF(20,3),DFM75(20,12),AWACS(20),AWWCS(20)
      DIMENSION NSTAT(20),TFLOW(20,12),IWRT(6),SUM4(20),SUM5(20)
      COMMON/BLK1/FLOW,TFLOW
      COMMON/BLK2/NMONT
      COMMON/BLK3/SHARE
      COMMON/BLK5/NTREQ,NTREU
      COMMON/BLK6/AVANS
      COMMON/BLK8/NSTAT
      COMMON/BLK9/AWACS,AWWCS
      COMMON/BLK10/I,J,JJ,NSHRE,IT
      COMMON/BLK11/SUM1,SUM2,SUM3
      COMMON/B11/DUDT1,RLDT1,DDDT1,SUPT1
      IF(J.NE.1)GO TO 1
```

```
      IF(NSHRE.NE.1)GO TO 10
      DO 4 II=1,NTREU(I,1)
      I1=1
      CALL WRT(SHARE(NSHRE,I,1),DUDT1(I,IT,II),SUPT1(I,IT,II),
     1 II,I1,IJ)
4     CONTINUE
10    DO 5 II=1,NTREQ(I,1)
      I1=2
      CALL WRT(SHARE(NSHRE,I,1),DDDT1(I,IT,II),RLDT1(I,IT,II),II,
     1 I1,IJ)
5     CONTINUE
1     RETURN
      END
C     ***************************************************************
C     (9)                          WRT
C     ***************************************************************
      SUBROUTINE WRT(SHARE,X1,X2,II,I1,IJ)
      COMMON/BLK10/I,J,JJ,NSHRE,IT
      IF(IJ.EQ.1)WRITE(3,100)
      IJ=IJ+1
100   FORMAT(1X,'SITE',2X,'YEAR',2X,'TIME',2X,'SHARE NO.',2X,
     1 'STATE',4X,'SHARE',2X,'USE NO.',5X,'DUDT',5X,'SUPT',5X,'DDDT',
     1 5X,'RLDT'/)
101   FORMAT(I5,I6,I6,I11,I7,F9.2,I9,2F9.2)
102   FORMAT(I5,I6,I6,I11,I7,F9.2,I9,18X,2F9.2)
      IF(I1.EQ.1)WRITE(3,101)I,JJ,IT,NSHRE,J,SHARE,II,X1,X2
      IF(I1.EQ.2)WRITE(3,102)I,JJ,IT,NSHRE,J,SHARE,II,X1,X2
      RETURN
      END
C     ***************************************************************
C     (10)                    FUNCTION AREA
C     ***************************************************************
      FUNCTION AREA(I,X)
      DIMENSION ISITE (20),IUSE(20,20)
      COMMON/BLK29/ISITE,IUSE
      GO TO(10,20,30,40,50,60)ISITE(I)
10    AREA=(2.085449)+(.02111959*(X))-(0.5795620*10.**(-5)*(X**2))
     1 +(.1116177*10.**(-8)*(X**3))-(0.7725764*10.**(-13)*(X**4))
      RETURN
20    AREA=(1.007202)+(0.03124523*(X))-(0.9516254*10.**(-5)*(X**2))+
     1 (0.1811031*10.**(-8)*(X**3))-(0.1214723*10.**(-12)*(X**4))
      RETURN
30    AREA=(3.111938)+(0.05115986*(X))-(0.2834853*10.**(-4)*(X**2))+
     1 (0.7146809*10.**(-8)*(X**3))-(0.6021572*10.**(-12)*(X**4))
      RETURN
40    AREA=(1.5744341)+(0.03354454*(X))-(0.1277495*10.**(-4)*(X**2))+
     1 (0.3388323*10.**(-8)*(X**3))-(0.3120559*10.**(-12)*(X**4))
      RETURN
50    AREA=1
      RETURN
60    AREA=(1.189636)+(0.03252220*(X))-(0.8011586*10.**(-5)*(X**2))+
     1 (0.1158014*10.**(-8)*(X**3))
      RETURN
      END
```

```
C     ******************************************************************
C     (11)                      FUNCTION ELEVATION
C     ******************************************************************
      FUNCTION ELEVAT(I,X)
      DIMENSION ISITE(20),IUSE(20,20)
      COMMON/BLK29/ISITE,IUSE
      GO TO(10,20,30,40,50,60)ISITE(I)
10    ELEVAT=(861.4277)+(0.1761322*(X))-(0.7791817*10.**(-4)*(X**2))+
     1(0.1678200*10.**(-7)*(X**3))-(0.1273204*10.**(-11)*(X**4))
      RETURN
20    ELEVAT=(685.6182)+(0.1804962*(X))-(0.8368492*10.**(-4)*(X**2))+
     1(0.1710941*10.**(-7)*(X**3))-(0.11897115*10.**(-11)*(X**4))
      RETURN
30    ELEVAT=(529.2402)+(0.09342957*(X))-(0.4109740*10.**(-4)*(X**2))+
     1(0.9647920*10.**(-8)*(X**3))-(0.7922552*10.**(-12)*(X**4))
      RETURN
40    ELEVAT=(387.0791)+(0.1695938*(X))-(0.9513646*10.**(-4)*(X**2))
     1+(0.2450179*10.**(-7)*(X**3))-(.2180034*10.**(-11)*(X**4))
      RETURN
50    ELEVAT=368
      RETURN
60    ELEVAT=(199.4976)+(.1985207*(X))-(.1305118*10.**(-3)*(X**2))
     1+(.3885361*10.**(-7)*(X**3))-(0.4029221*10.**(-11)*(X**4))
      RETURN
      END
C     ******************************************************************
C     (12)                              CALL11
C     ******************************************************************
      SUBROUTINE CAL11(PPP,QQQ,ICAL,NYEAR)
      DIMENSION NDSRE(20,1),NUSRE(20,1)
      DIMENSION DUD1(20,12,20),RLD1(20,12,20),DDD1(20,12,20)
      DIMENSION SUP1(20,12,20),AVD1(20,12,20),AVU1(20,12,20)
      DIMENSION CUR1(20,50,20),CUS1(20,50,20),AAD1(20,20)
      DIMENSION AAU1(20,20),AND1(20,50,20),ANU1(20,50,20)
      DIMENSION NAD1(20,20),NAU1(20,20),NDD1(20,12,20),NDU1(20,12,20)
      DIMENSION PEAUD(20,1,20),PEAUU(20,1,20)
      DIMENSION ARD1(20,20),ARU1(20,20)
      DIMENSION RED1(20,12,20),REU1(20,12,20)
      COMMON/BLK10/I,J,JJ,NSHRE,IT
      COMMON/BLK13/NUSRE,NDSRE
      COMMON/BLK28/PEAUD,PEAUU
      COMMON/B14/AVD1,AVU1,CUR1,CUS1
      COMMON/B141/AAD1,AAU1,ANU1
      COMMON/B1411/AND1
      COMMON/B15/NDD1,NDU1,NAD1,NAU1
      COMMON/B16/DUD1,RLD1,DDD1,SUP1
      COMMON/B17/RED1,REU1
      COMMON/V194/ARU1
      COMMON/B195/ARD1
      GO TO(10,20,30)ICAL
C     CALCULATE TOTAL D/S RELEASES DEMANDWISE
10    DO 3 II=1,NDSRE(I,1)
      CUR1(I,JJ,II)=CUR1(I,JJ,II)+RLD1(I,IT,II)
      PPP=PPP+RLD1(I,IT,II)
```

```
3       CONTINUE
        RETURN
C       CALCULATE STATISTICS FOR U/S DEMAND
20      DO 1 II=1,NDSRE(I,1)
        Z=(DDD1(I,IT,II)/RED1(I,IT,II))*100.0
        IF(Z.GT.PEAUD(I,J,II))NDD1(I,IT,II)=NDD1(I,IT,II)+1
        AVD1(I,IT,II)=AVD1(I,IT,II)+DDD1(I,IT,II)/FLOAT(NYEAR)
        AND1(I,JJ,II)=AND1(I,JJ,II)+DDD1(I,IT,II)
1       CONTINUE
C       CALCULATE STATISTICS FOR U/S DEMAND
        DO 2 II=1,NUSRE(I,1)
        Z=(DUD1(I,IT,II)/REU1(I,IT,II))*100.0
        IF(Z.GT.PEAUU(I,J,II))NDU1(I,IT,II)=NDU1(I,IT,II)+1
        AVU1(I,IT,II)=AVU1(I,IT,II)+DUD1(I,IT,II)/FLOAT(NYEAR)
        ANU1(I,JJ,II)=ANU1(I,JJ,II)+DUD1(I,IT,II)
2       CONTINUE
C       CALCULATE TOTAL D/S RELEASES DEMANDWISE
        DO 7 II=1,NDSRE(I,1)
        CUR1(I,JJ,II)=CUR1(I,JJ,II)+RLD1(I,IT,II)
        PPP=PPP+RLD1(I,IT,II)
7       CONTINUE
C       CALCULATE TOTAL U/S SUBTRATION  DEMANDWISE
        DO 4 II=1,NUSRE(I,1)
        CUS1(I,JJ,II)=CUS1(I,JJ,II)+SUP1(I,IT,II)
        QQQ=QQQ+SUP1(I,IT,II)
4       CONTINUE
        RETURN
30      DO 5 II=1,NDSRE(I,1)
        Z=(AND1(I,JJ,II)/ARD1(I,II))*100.0
        IF(Z.GT.PEAUD(I,J,II))NAD1(I,II)=NAD1(I,II)+1
        AAD1(I,II)=AAD1(I,II)+AND1(I,JJ,II)/FLOAT(NYEAR)
5       CONTINUE
        DO 6 II=1,NUSRE(I,1)
        Z=(ANU1(I,JJ,II)/ARU1(I,II))*100.0
        IF(Z.GT.PEAUU(I,J,II))NAU1(I,II)=NAU1(I,II)+1
        AAU1(I,II)=AAU1(I,II)+ANU1(I,JJ,II)/FLOAT(NYEAR)
6       CONTINUE
        RETURN
        END
C       *******************************************************************
C       (13)                          INIL1
C       *******************************************************************
        SUBROUTINE INIL1(NSITE,NYEAR)
        DIMENSION AVD1(20,12,20),AVU1(20,12,20)
        DIMENSION CUR1(20,50,20),CUS1(20,50,20),AAD1(20,20)
        DIMENSION AAU1(20,20),AND1(20,50,20),ANU1(20,50,20)
        DIMENSION NAD1(20,20),NAU1(20,20),NDD1(20,12,20)
        DIMENSION NDU1(20,12,20)
        DIMENSION NUSRE(20,1),NDSRE(20,1)
        COMMON/BLK2/NMONT
        COMMON/BLK13/NUSRE,NDSRE
        COMMON/B14/AVD1,AVU1,CUR1,CUS1
        COMMON/B141/AAD1,AAU1,ANU1
        COMMON/B1411/AND1
        COMMON/B15/NDD1,NDU1,NAD1,NAU1
```

```
      DO 1 I=1,NSITE
      DO 2 JJ=1,NYEAR
      DO 3 IT=1,NMONT
      DO 4 II=1,NDSRE(I,1)
      NDD1(I,IT,II)=0
      AVD1(I,IT,II)=0.
      AND1(I,JJ,II)=0.
      CUR1(I,JJ,II)=0.
      NAD1(I,II)=0
      AAD1(I,II)=0.
4     CONTINUE
      DO 5 II=1,NUSRE(I,1)
      NDU1(I,IT,II)=0
      AVU1(I,IT,II)=0.
      ANU1(I,JJ,II)=0.
      CUS1(I,JJ,II)=0.
      NAU1(I,II)=0
      AAU1(I,II)=0.
5     CONTINUE
3     CONTINUE
2     CONTINUE
1     CONTINUE
      RETURN
      END
C     *******************************************************************
C     (14)                           WRT11
C     *******************************************************************
      SUBROUTINE WRT11(NYEAR,NSITE,J,IWRT,NSHRE,I)
      DIMENSION S(20,12),FLOW(20,50,12),P(20,50,12)
      DIMENSION YMIN(20,12),YMAX(20,12)
      DIMENSION ARD1(20,20),NDSRE(20,1),RED1(20,12,20)
      DIMENSION PRD1(20,12,20)
      DIMENSION ARU1(20,20),NUSRE(20,1)
      DIMENSION PRU1(20,12,20),REU1(20,12,20)
      DIMENSION SHARE(1,20,1),AVANS(1,20,1)
      DIMENSION DUD1(20,12,20),RLD1(20,12,20),DDD1(20,12,20)
      DIMENSION AWACS(20),AWWCS(20)
      DIMENSION NSTAT(20),SUP1(20,12,20)
      DIMENSION AVD1(20,12,20),AVU1(20,12,20)
      DIMENSION CUR1(20,50,20),CUS1(20,50,20),AAD1(20,20)
      DIMENSION AAU1(20,20),AND1(20,50,20),ANU1(20,50,20)
      DIMENSION NAD1(20,20),NAU1(20,20),NDD1(20,12,20)
      DIMENSION NDU1(20,12,20),TFLOW(20,12),IWRT(6),SUM4(20),SUM5(20)
      COMMON/BLK1/FLOW,TFLOW
      COMMON/BLK2/NMONT
      COMMON/BLK3/SHARE
      COMMON/BLK6/AVANS
      COMMON/BLK8/NSTAT
      COMMON/BLK9/AWACS,AWWCS
      COMMON/BLK11/SUM1,SUM2,SUM3
      COMMON/BLK12/S,P,YMAX,YMIN
      COMMON/BLK13/NUSRE,NDSRE
      COMMON/B14/AVD1,AVU1,CUR1,CUS1
      COMMON/B141/AAD1,AAU1,ANU1
      COMMON/B1411/AND1
```

```
      COMMON/B15/NDD1,NDU1,NAD1,NAU1
      COMMON/B16/DUD1,RLD1,DDD1,SUP1
100   FORMAT(1X,30('*'),/)
101   FORMAT(/,10('-'))
210   FORMAT(1X,'SHARE NO.=',I4,4X,'WATER SHARE =',F10.3/)
50    IF(IWRT(1).NE.1)GO TO 51
      WRITE(5,213)
      DO 28 II=1,NUSRE(I,1)
      DO 29 IT=1,NMONT
      WRITE(5,214)I,J,II,IT,AVU1(I,IT,II),NDU1(I,IT,II)
213   FORMAT(1X,'SITE',2X,'STATE',2X,'U/S REQUIR',3X,'TIME',2X,
     1 'AVE. DEFICIT IN TIME',2X,'NO. OF DEFICITS'/)
214   FORMAT(I5,I7,I12,I7,F22.3,I17)
29    CONTINUE
28    CONTINUE
      WRITE(5,101)
      WRITE(5,100)
51    IF(IWRT(2).NE.1)GO TO 52
      WRITE(5,215)
      DO 31 II=1,NUSRE(I,1)
      DO 32 JJ=1,NYEAR
      WRITE(5,216)I,J,II,JJ,ANU1(I,JJ,II)
215   FORMAT(1X,'SITE',2X,'STATE',2X,'U/S REQUIR',2X,'YEAR',2X,
     1 'ANNUAL DEFICIT')
216   FORMAT(I5,I7,I12,I6,F16.3)
32    CONTINUE
31    CONTINUE
      WRITE(5,101)
      WRITE(5,100)
52    IF(IWRT(3).NE.1)GO TO 53
      WRITE(5,217)
      DO 34 II=1,NUSRE(I,1)
      WRITE(5,218)I,II,AAU1(I,II),NAU1(I,II)
217   FORMAT(1X,'SITE',2X,'U/S REQUIR',2X,'AVE.ANNUAL DEFICIT',
     1 2X,'NO.OF ANNUAL DEFICIT'/)
218   FORMAT(I5,I12,F20.3,I22)
34    CONTINUE
      WRITE(5,101)
      WRITE(5,100)
53    IF(IWRT(4).NE.1)GO TO 55
      WRITE(5,201)
      DO 14 II=1,NDSRE(I,1)
      DO 15 IT=1,NMONT
      WRITE(5,202)I,J,II,IT,AVD1(I,IT,II),NDD1(I,IT,II)
201   FORMAT(1X,'SITE',2X,'STATE',2X,'D/S REQUIR',3X,'TIME',2X,
     1 'AVE. DEFICIT IN TIME',2X,'NO. OF DEFICITS'/)
202   FORMAT(I5,I7,I12,I7,F22.3,I17)
15    CONTINUE
14    CONTINUE
      WRITE(5,101)
      WRITE(5,100)
55    IF(IWRT(5).NE.1)GO TO 56
      WRITE(5,203)
      DO 17 II=1,NDSRE(I,1)
      DO 18 JJ=1,NYEAR
```

```
      WRITE(5,204)I,J,II,JJ,AND1(I,JJ,II)
203   FORMAT(1X,'SITE',2X,'STATE',2X,'D/S REQUIR',2X,'YEAR',2X,
     1 'ANNUAL DEFICIT')
204   FORMAT(I5,I7,I12,I6,F16.3)
18    CONTINUE
17    CONTINUE
      WRITE(5,101)
      WRITE(5,100)
56    IF(IWRT(6).NE.1)GO TO 57
      WRITE(5,207)
      DO 20 II=1,NDSRE(I,1)
      WRITE(5,208)I,II,AAD1(I,II),NAD1(I,II)
207   FORMAT(1X,'SITE',2X,'D/S REQUIR',2X,'AVE.ANNUAL DEFICIT',
     1 2X,'NO.OF ANNUAL DEFICIT'/)
208   FORMAT(I5,I12,F20.3,I22)
20    CONTINUE
      WRITE(5,101)
57    RETURN
      END
C     ****************************************************************
C     (15)                          DIST1
C     ****************************************************************
      SUBROUTINE DIST1(I,IT)
      DIMENSION RED1(20,12,20)
      DIMENSION DDD1(20,12,20)
      DIMENSION REU1(20,12,20)
      DIMENSION DUD1(20,12,20)
      DIMENSION DDDT1(20,12,20)
      DIMENSION DUDT1(20,12,20)
      DIMENSION SUPT1(20,12,20)
      DIMENSION RLDT1(20,12,20)
      DIMENSION RLD1(20,12,20)
      DIMENSION SUP1(20,12,20)
      COMMON/B11/DUDT1,RLDT1,DDDT1,SUPT1
      COMMON/B16/DUD1,RLD1,DDD1,SUP1
      COMMON/B17/RED1,REU1
      DDD1(I,IT,1)=DDDT1(I,IT,1)
      DDD1(I,IT,2)=DDDT1(I,IT,2)
      DDD1(I,IT,3)=DDDT1(I,IT,3)
      DDD1(I,IT,4)=DDDT1(I,IT,4)
      DDD1(I,IT,5)=DDDT1(I,IT,5)
      DDD1(I,IT,6)=DDDT1(I,IT,6)
      DDD1(I,IT,7)=DDDT1(I,IT,7)
      DUD1(I,IT,1)=DUDT1(I,IT,1)
      DUD1(I,IT,2)=DUDT1(I,IT,2)
      RETURN
      END
C     ****************************************************************
C     (16)                        WRT12
C     ****************************************************************
      SUBROUTINE WRT12(I,J)
      DIMENSION NUSRE(20,1),NTREU(20,1),ARU1(20,20),PRU1(20,12,20)
      DIMENSION REU1(20,12,20),PREU1(20,12,20),REQU1(20,12,20)
      DIMENSION AREU1(20,20)
      DIMENSION NDSRE(20,1),NTREQ(20,1),ARD1(20,20),PRD1(20,12,20)
```

```
      DIMENSION RED1(20,12,20),PREQ1(20,12,20),REQD1(20,12,20)
      DIMENSION AREQ1(20,20)
      COMMON/BLK2/NMONT
      COMMON/BLK5/NTREQ,NTREU
      COMMON/BLK13/NUSRE,NDSRE
      COMMON/B17/RED1,REU1
      COMMON/B18/PRU1,PREU1
      COMMON/B19/PRD1,PREQ1
      COMMON/B191/AREU1,REQU1
      COMMON/B192/AREQ1,REQD1
      COMMON/B194/ARU1
      COMMON/B195/ARD1
C     COMMON/B191/ARD1
      WRITE(6,1008)
      DO 1005 II=1,NUSRE(I,1)
      WRITE(6,1009)I,J,II,ARU1(I,II)
1005  CONTINUE
1008  FORMAT(1X,'SITE',2X,'STATE',2X,'U/S REQUIR ACTUAL',2X
     1 ,'ANNUAL VALUE'/)
1009  FORMAT(I5,I7,I19,F14.3)
      WRITE(6,1002)
      DO 1000 II=1,NTREU(I,1)
      WRITE(6,1001)I,J,II,AREU1(I,II)
1000  CONTINUE
1002  FORMAT(//,1X,'SITE',2X,'STATE',2X,'U/S DEMAND CLUBED',2X
     1 ,'ANNUAL VALUE'/)
1001  FORMAT(I5,I7,I19,F14.3)
      DO 1017 II=1,NUSRE(I,1)
      WRITE(6,1015)
      DO 1018 IT=1,NMONT
      WRITE(6,1016)I,J,II,IT,PRU1(I,IT,II),REU1(I,IT,II)
1018  CONTINUE
1017  CONTINUE
1015  FORMAT(//,1X,'SITE',2X,'STATE',2X,'U/S REQUIR ACTUAL',2X,'TIME',
     1 2X,'PERCENT REQUIR',6X,'REQUIR'/)
1016  FORMAT(I5,I7,I19,I6,F16.3,F12.3)
      DO 1021 II=1,NTREU(I,1)
      WRITE(6,1020)
      DO 1022 IT=1,NMONT
      WRITE(6,1023)I,J,II,IT,PREU1(I,IT,II),REQU1(I,IT,II)
1022  CONTINUE
1021  CONTINUE
1020  FORMAT(//,1X,'SITE',2X,'STATE',2X,'U/S DEMAND CLUBED',2X,
     1 'TIME',2X,,'PERCENT DEMAND',6X,'DEMAND'/)
1023  FORMAT(I5,I7,I19,I6,F16.3,F12.3)
      WRITE(6,2008)
      DO 2005 II=1,NDSRE(I,1)
      WRITE(6,2009)I,J,II,ARD1(I,II)
2005  CONTINUE
2008  FORMAT(1X,'SITE',2X,'STATE',2X,'D/S REQUIR ACTUAL',2X
     1 ,'ANNUAL VALUE'/)
2009  FORMAT(I5,I7,I19,F14.3)
      WRITE(6,2002)
      DO 2000 II=1,NTREQ(I,1)
      WRITE(6,2001)I,J,II,AREQ1(I,II)
```

```
2000      CONTINUE
2002      FORMAT(//,1X,'SITE',2X,'STATE',2X,'D/S DEMAND CLUBED',2X
     1    ,'ANNUAL VALUE'/)
2001      FORMAT(I5,I7,I19,F14.3)
          DO 2017 II=1,NDSRE(I,1)
          WRITE(6,2015)
          DO 2018 IT=1,NMONT
          WRITE(6,2016)I,J,II,IT,PRD1(I,IT,II),RED1(I,IT,II)
2018      CONTINUE
2017      CONTINUE
2015      FORMAT(//,1X,'SITE',2X,'STATE',2X,'D/S REQUIR ACTUAL',2X,
     1    'TIME',2X,'PERCENT REQUIR',6X,'REQUIR'/)
2016      FORMAT(I5,I7,I19,I6,F16.3,F12.3)
          DO 2021 II=1,NTREQ(I,1)
          WRITE(6,2020)
          DO 2022 IT=1,NMONT
          WRITE(6,2023)I,J,II,IT,PREQ1(I,IT,II),REQD1(I,IT,II)
2022      CONTINUE
2021      CONTINUE
2020      FORMAT(//,1X,'SITE',2X,'STATE',2X,'D/S DEMAND CLUBED',2X,
     1    'TIME',2X,'PERCENT DEMAND',6X,'DEMAND'/)
2023      FORMAT(I5,I7,I19,I6,F16.3,F12.3)
          RETURN
          END
C         ****************************************************************
C                                  (17) BENFT
C         ****************************************************************
          SUBROUTINE BENFT(RATE,NSITE,NYEAR,JBNFT)
          DIMENSION NUSRE(20,1),NDSRE(20,1),ARD1(20,20),IREQ1(20,20),
     1    AADE1(20,50),AND1(20,50,20),AADU1(20,50),Y(20),PPC(20)
          DIMENSION  CCRE1(20),CCPP1(20),AORE1(20),AOPP1(20),VORE1(20),
     1    VOPP1(20),TVCC1(20),TVBD1(20),TVOD1(20),AFBD1(20,20),
     1    AOWD1(20,20),CCWD1(20,20),VPBD1(20,20),
     1    VDBD1(20,20),VOWD1(20,20),APBD1(20,20,50),ALBD1(20,20,50),
     1    ADBD1(12,20,50),ISITE(20),IUSE(20,20)
          COMMON/BLK13/NUSRE,NDSRE
          COMMON/BLK29/ISITE,IUSE
          COMMON/B1411/AND1
          COMMON/B195/ARD1
          COMMON/B201/IREQ1
          COMMON/B21/AADE1,AADU1,Y,PPC
          TVC1=0
          TVB1=0
          TVO1=0
          PVNB1=0
          DO 16 I=1,NSITE
          CCRE1(I)=0
          CCPP1(I)=0
          AORE1(I)=0
          AOPP1(I)=0
          VORE1(I)=0
          VOPP1(I)=0
          TVCC1(I)=0
          TVBD1(I)=0
          TVOD1(I)=0
```

```
      DO 16 II=1,NDSRE(I,1)
      AFBD1(I,II)=0
      AOWD1(I,II)=0
      CCWD1(I,II)=0
      AOWD1(I,II)=0
      VPBD1(I,II)=0
      VDBD1(I,II)=0
      VOWD1(I,II)=0
      DO 16 JJ=1,NYEAR
      APBD1(I,II,JJ)=0
      ALBD1(I,II,JJ)=0
      ADBD1(I,II,JJ)=0
16    CONTINUE
      DO 1 I=1,NSITE
      DO 2 II=1,NDSRE(I,1)
      AFBD1(I,II)=ABFD1(ARD1(I,II),I,II)
      IF(JBNFT.EQ.1)WRITE(2,100)AFBD1(I,II)
100   FORMAT(1X,'AFBD1',F12.3)
2     CONTINUE
      DO 3 JJ=1,NYEAR
      DO 4 II=1,NDSRE(I,1)
      IF(IREQ1(I,II).EQ.1)ALBD1(I,II,JJ)=ALFD1(AADE1(I,JJ),I,II)
      IF(IREQ1(I,II).EQ.0)ALBD1(I,II,JJ)=ALFD1(AND1(I,JJ,II),I,II)
      IF(JBNFT.EQ.1)WRITE(2,99)ALBD1(I,II,JJ)
99    FORMAT(1X,'ALBD1',F12.3)
4     CONTINUE
3     CONTINUE
      DO 5 JJ=1,NYEAR
      DO 6 II=1,NDSRE(I,1)
      APBD1(I,II,JJ)=AFBD1(I,II)-ALBD1(I,II,JJ)
      IF(JBNFT.EQ.1)WRITE(2,101)APBD1(I,II,JJ)
101   FORMAT(1X,'APBD1',F12.3)
      IF(IREQ1(I,II).EQ.1)ADBD1(I,II,JJ)=ADFD1(AADU1(I,JJ),I,II)
      IF(JBNFT.EQ.1)WRITE(2,130)ADBD1(I,II,JJ)
130   FORMAT(1X,'ADBD1',F12.3)
6     CONTINUE
5     CONTINUE
      CCRE1(I)=CFRE1(Y(I),I)
      IF(JBNFT.EQ.1)WRITE(2,102)CCRE1(I)
102   FORMAT(1X,'CCRE1',F12.3)
      CCPP1(I)=CFPP1(PPC(I),I)
      IF(JBNFT.EQ.1)WRITE(2,103)CCPP1(I)
103   FORMAT(1X,'CCPP1',F12.3)
      DO 7 II=1,NDSRE(I,1)
      CCWD1(I,II)=CFWD1(ARD1(I,II),I,II)
      IF(JBNFT.EQ.1)WRITE(2,104)CCWD1(I,II)
104   FORMAT(1X,'CCWD1',F12.3)
7     CONTINUE
      AORE1(I)=AOFR1(Y(I),I)
      IF(JBNFT.EQ.1)WRITE(2,105)AORE1(I)
105   FORMAT(1X,'AORE1',F12.3)
      AOPP1(I)=AOFP1(PPC(I),I)
      IF(JBNFT.EQ.1)WRITE(2,106)AOPP1(I)
106   FORMAT(1X,'AOPP1',F12.3)
      DO 8 II=1,NDSRE(I,1)
```

```
        AOWD1(I,II)=AOFD1(ARD1(I,II),I,II)
        IF(JBNFT.EQ.1)WRITE(2,107)AOWD1(I,II)
107     FORMAT(1X,'AOWD1',F12.3)
8       CONTINUE
        DO 9 JJ=1,NYEAR
        DO 10 II=1,NDSRE(I,1)
        PWF=1.0/((1.0+RATE)**JJ)
        IF(JBNFT.EQ.1)WRITE(2,108)PWF
108     FORMAT(1X,'PWF',F12.3)
        VPBD1(I,II)=VPBD1(I,II)+PWF*APBD1(I,II,JJ)
        IF(JBNFT.EQ.1)WRITE(2,109)VPBD1(I,II)
109     FORMAT(1X,'VPBD1',F12.3)
        IF(IREQ1(I,II).EQ.1)VDBD1(I,II)=VDBD1(I,II)+PWF*ADBD1(I,II,JJ)
        IF(JBNFT.EQ.1)WRITE(2,98)VDBD1(I,II)
98      FORMAT(1X,'VDBD1',F12.3)
10      CONTINUE
9       CONTINUE
        PWFA=((((1.0+RATE)**NYEAR)-1.0)/RATE)/((1.0+RATE)**NYEAR)
        IF(JBNFT.EQ.1)WRITE(2,110)PWFA
110     FORMAT(1X,'PWFA',E15.5)
        VORE1(I)=PWFA*AORE1(I)
        IF(JBNFT.EQ.1)WRITE(2,111)VORE1(I)
111     FORMAT(1X,'VORE1',E15.5)
        VOPP1(I)=PWFA*AOPP1(I)
        IF(JBNFT.EQ.1)WRITE(2,112)VOPP1(I)
112     FORMAT(1X,'VOPP1',E15.5)
        DO 11 II=1,NDSRE(I,1)
        VOWD1(I,II)=PWFA*AOWD1(I,II)
        IF(JBNFT.EQ.1)WRITE(2,113)VOWD1(I,II)
113     FORMAT(1X,'VOWD1',F12.3)
11      CONTINUE
        TVCC1(I)=CCRE1(I)+CCPP1(I)
        IF(JBNFT.EQ.1)WRITE(2,114)TVCC1(I)
114     FORMAT(1X,'TVCC1',F12.3)
        DO 12 II=1,NDSRE(I,1)
        TVCC1(I)=TVCC1(I)+CCWD1(I,II)
        IF(JBNFT.EQ.1)WRITE(2,115)TVCC1(I)
115     FORMAT(1X,'TVCC1',F12.3)
12      CONTINUE
        DO 13 II=1,NDSRE(I,1)
        TVBD1(I)=TVBD1(I)+VPBD1(I,II)
        IF(JBNFT.EQ.1)WRITE(2,116)TVBD1(I)
116     FORMAT(1X,'TVBD1',F12.3)
        IF(IREQ1(I,II).EQ.1)TVBD1(I)=TVBD1(I)+VDBD1(I,II)
        IF(JBNFT.EQ.1)WRITE(2,97)TVBD1(I)
97      FORMAT(1X,'TVBD1',F12.3)
13      CONTINUE
        TVOD1(I)=VORE1(I)+VOPP1(I)
        IF(JBNFT.EQ.1)WRITE(2,117)TVOD1(I)
117     FORMAT(1X,'TVOD1',E17.5)
        DO 14 II=1,NDSRE(I,1)
        TVOD1(I)=TVOD1(I)+VOWD1(I,II)
        IF(JBNFT.EQ.1)WRITE(2,118)TVOD1(I)
118     FORMAT(1X,'TVOD1',E15.5)
14      CONTINUE
```

```
1       CONTINUE
        DO 15 I=1,NSITE
        TVC1=TVC1+TVCC1(I)
        IF(JBNFT.EQ.1)WRITE(2,119)TVC1
119     FORMAT(1X,'TVC1',F12.3)
        TVB1=TVB1+TVBD1(I)
        IF(JBNFT.EQ.1)WRITE(2,120)TVB1
120     FORMAT(1X,'TVB1',F12.3)
        TVO1=TVO1+TVOD1(I)
        IF(JBNFT.EQ.1)WRITE(2,121)TVO1
121     FORMAT(1X,'TVO1',E15.5)
15      CONTINUE
        PVNB1=-TVC1+TVB1-TVO1
        WRITE(2,122)PVNB1
122     FORMAT(1X,'PVNB1',F16.3)
        RETURN
        END
C**********************************************************************
C                               FUNCTION
C**********************************************************************
C ABFD1:ANNUAL BENEFIT FUNCTION (D/S USES) FOR USE II AT SITE I (A3)
        FUNCTION ABFD1(X,I,II)
        DIMENSION ISITE (20),IUSE(20,20)
        COMMON/BLK29/ISITE,IUSE
        GO TO (1,2,3,4,5,6) ISITE (I)
1       GO TO (11) IUSE(I,II)
11      ABFD1=.35*X
        RETURN
2       GO TO (21) IUSE(I,II)
21      ABFD1=.25*X
        RETURN
3       GO TO (31)IUSE(I,II)
31      ABFD1=.25*X
        RETURN
4       GO TO (70,71,72,73,74,75,76,77,78,79.80,81,82)IUSE (I,II)
70      ABFD1=0
        RETURN
71      ABFD1=5*X
        RETURN
72      ABFD1=5*X
        RETURN
73      ABFD1=5*X
        RETURN
74      ABFD1=5*X
        RETURN
75      ABFD1=5*X
        RETURN
76      ABFD1=5*X
        RETURN
77      ABFD1=5*X
        RETURN
78      ABFD1=5*X
        RETURN
79      ABFD1=5*X
        RETURN
```

```
80        ABFD1=5*X
          RETURN
81        ABFD1=5*X
          RETURN
82        ABFD1=. 15*X
          RETURN
5         GO TO (51)IUSE(I,II)
51        ABFD1=. 3*X
          RETURN
6         GO TO (83,84,85,86,87,88)IUSE (I,II)
83        ABFD1=0
          RETURN
84        ABFD1=5*X
          RETURN
85        ABFD1=5*X
          RETURN
86        ABFD1=5*X
          RETURN
87        ABFD1=5*X
          RETURN
88        ABFD1=. 15*X
          RETURN
          END
C         ***************************************************************
C AOFP1:ANNUAL OM COST FUNCTION OF HYDROPOWER AT SITE I- (OM 31)
          FUNCTION AOFP1(X,I)
          DIMENSION ISITE (20),IUSE(20,20)
          COMMON/BLK 29 /ISITE,IUSE
          GO TO(1,2,3,4,5,6)ISITE(I)
C
1         AOFP1=(15. 1867)+(0. 0727399*(X))-(1. 66151*10. **(-5)*(X**2))
     2    +(3. 86844*10. **(-9)*(X**3))
          RETURN
C
2         AOFP1=(27. 055)+(0. 0834022*(X))+(9. 94212*10. **(-6)*(X**2))
     1    -(1. 159*10. **(-9)*(X**3))
          RETURN
C
3         AOFP1=(5. 26863)+(0. 146865*(X))-(2. 31093*10. **(-5)*(X**2))
     1    -(1. 86108*10. **(-9)*(X**3))
          RETURN
C
4         AOFP1=(1. 74987)+(0. 0363192*(X))-(2. 21688*10. **(-5)*(X**2))
     1    +(9. 34995*10. **(-9)*(X**3))
          RETURN
C
5         AOFP1=(34. 6491)+(0. 165153*(X))+(5. 76373*10. **(-5)*(X**2))
     1    -(2. 5827*10. **(-8)*(X**3))
          RETURN
C
6         AOFP1=(1. 21212)+(0. 0443957*(X))-(1. 52875*10. **(-5)*(X**2))
     1    +(2. 16895*10. **(-9)*(X**3))
          RETURN
          END
```

```
C        ****************************************************************
C        MORE THAN A3
         FUNCTION ALFD1(X,I,II)
         DIMENSION ISITE (20),IUSE(20,20)
         COMMON/BLK 29 /ISITE,IUSE
         GO TO (1,2,3,4,5,6) ISITE (I)
1        GO TO (11)IUSE(I,II)
11       ALFD1=.42*X
         RETURN
2        GO TO (21) IUSE(I,II)
21       ALFD1=.30*X
         RETURN
3        GO TO (31)IUSE(I,II)
31       ALFD1=.30*X
         RETURN
4        GO TO (70,71,72,73,74,75,76,77,78,79,80,81,82)IUSE (I,II)
70       ALFD1=0
         RETURN
71       ALFD1=6*X
         RETURN
72       ALFD1=6*X
         RETURN
73       ALFD1=6*X
         RETURN
74       ALFD1=6*X
         RETURN
75       ALFD1=6*X
         RETURN
76       ALFD1=6*X
         RETURN
77       ALFD1=6*X
         RETURN
78       ALFD1=6*X
         RETURN
79       ALFD1=6*X
         RETURN
80       ALFD1=6*X
         RETURN
81       ALFD1=6*X
         RETURN
82       ALFD1=.18*X
         RETURN
5        GO TO (51)IUSE(I,II)
51       ALFD1=.36*X
         RETURN
6        GO TO (83,84,85,86,87,88)IUSE (I,II)
83       ALFD1=0
         RETURN
84       ALFD1=6*X
         RETURN
85       ALFD1=6*X
         RETURN
86       ALFD1=6*X
         RETURN
```

```
87      ALFD1=6*X
        RETURN
88      ALFD1=.18*X
        RETURN
        END
C       ***************************************************************
C AOFR1:ANNUAL OM COST FUNCTION OF RESERVOIR AT SITE I- (OM 11)
        FUNCTION AOFR1(X,I)
        DIMENSION ISITE (20),IUSE(20,20)
        COMMON/BLK 29 /ISITE,IUSE
        GO TO(1,2,3,4,5,6)ISITE(I)
1       AOFR1=(5.20432)+(0.0197592*(X))-(3.355671*10.**(-6)*(X**2))
     1  +(2.76598*10.**(-10)*(X**3))
        RETURN
2       AOFR1=(7.47569)+(0.0143747*(X))-(8.0495*10.**(-7)*(X**2))
     1  +(3.2714*10.**(-11)*(X**3))
        RETURN
C
3       AOFR1=(4.03859)+(0.0148571*(X))-(2.73661*10.**(-6)*(X**2))
     1  +(2.68544*10.**(-10)*(X**3))
        RETURN
C
4       AOFR1=(0.0336752)+(0.000212637*(X))-(2.77013*10.**(-8)*(X**2))
     1  +(1.66186*10.**(-12)*(X**3))
        RETURN
C
5       AOFR1=0
        RETURN
C
6       AOFR1=(0.19404)+(0.00263214*(X))-(3.6957*10.**(-7)*(X**2))
     1  +(3.41304*10.**(-11)*(X**3))
        RETURN
       END
C       ***************************************************************
C       LESSER THAN A3
        FUNCTION ADFD1(X,I,II)
        DIMENSION ISITE (20),IUSE(20,20)
        COMMON/BLK 29 /ISITE,IUSE
        GO TO (1,2,3,4,5,6) ISITE (I)
1       GO TO (11)IUSE(I,II)
11      ADFD1=.28*X
        RETURN
2       GO TO (21) IUSE(I,II)
21      ADFD1=.20*X
        RETURN
3       GO TO (31)IUSE(I,II)
31      ADFD1=.20*X
        RETURN
4       GO TO (70,71,72,73,74,75,76,77,78,79,80,81,82)IUSE (I,II)
70      ADFD1=0
        RETURN
71      ADFD1=4*X
        RETURN
72      ADFD1=4*X
        RETURN
```

```
73      ADFD1=4*X
        RETURN
74      ADFD1=4*X
        RETURN
75      ADFD1=4*X
        RETURN
76      ADFD1=4*X
        RETURN
77      ADFD1=4*X
        RETURN
78      ADFD1=4*X
        RETURN
79      ADFD1=4*X
        RETURN
80      ADFD1=4*X
        RETURN
81      ADFD1=4*X
        RETURN
82      ADFD1=.12*X
        RETURN
5       GO TO (51)IUSE(I,II)
51      ADFD1=.24*X
        RETURN
6       GO TO (83,84,85,86,87,88)IUSE (I,II)
83      ADFD1=0
        RETURN
84      ADFD1=4*X
        RETURN
85      ADFD1=4*X
        RETURN
86      ADFD1=4*X
        RETURN
87      ADFD1=4*X
        RETURN
88      ADFD1=.12*X
        RETURN
        END
C       ****************************************************************
```

# APPENDIX 6.I

```
C     ****************************************************************
C               ******************************************
C                         ************************
C
C                  (LINEAR PROGRAMMING SCREENING MODEL)
C
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
      IMPLICIT REAL*8 (A-H,O-Z)
      INTEGER CODE,XB,BASICS,OPTSOL
      COMMON KP1,MP1,N,K,M,NGET,NLET,NET,NTYPE,NP1,
     1 NC,NC1,INDEXG,INDEXL,INDEXE,NFLAG,BASICS,OPTSOL
      COMMON SUM
      COMMON NOPT
      CHARACTER*12 FILI,FILO
C     DIMENSION A(500,950),B(500),C(950),XB(500),CODE(500),ARTV(950)
      DIMENSION A(1000,2000),B(1000),C(2000),XB(1000),CODE(1000),
     1 ARTV(2000)
      COMMON/BLK1/A
      COMMON/BLK2/B
      COMMON/BLK3/C
      COMMON/BLK4/CODE
      WRITE(*,*)'ENTER INPUT FILENAME>>'
      READ(*,'(A)')FILI
      WRITE(*,*)'ENTER OUTPUT FILENAME>>'
      READ(*,'(A)')FILO
      OPEN(UNIT=1,FILE=FILI,STATUS='OLD')
      OPEN(UNIT=2,FILE=FILO,STATUS='UNKNOWN')
      READ(1,*)IGEN
      WRITE(2,700)IGEN
      READ(1,*)IPRNT1
      WRITE (2,*)IPRNT1
 700  FORMAT(5I5)
 50   READ(1,*)NTYPE,NOPT
      WRITE(2,700)NTYPE,NOPT
      WRITE(*,1000)
1000  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   WRITE(2,700)M,K,NLET,NGET,NET
      WRITE(2,40)
 40   FORMAT(1X,'THE ORIGINAL COEFFICIENTS OF THE CONSTRAINTS',//
     1 15X,'CODE=0 LT OR= CONSTRAINTS',/15X,'CODE1=GT OR= CONSTRAINTS',
     2 /15X,'CODE 2=CONSTRAINTS',//)
      WRITE(2,55)
 55   FORMAT('I CODE CONSTANT A(I,1) A(I,2) A(I,3) A(I,4) A(I,5),A(I,6)
     1 A(I,7)',//16X,'A(I,8) A(I,9) A(I,10) A(I,11) A(I,12) A(I,13)',//
     2 16X,'A(I,14)', //)
      DO 45 I=1,M
      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
      WRITE(2,36)
 36   FORMAT(//5X,'THE COEFFICIENT IN THE ORIGINAL OBJECTIVE FUNCTION
     1 TO BE MINIMIZED',/5X,'ARE:',/)
      GO TO 37
 35   WRITE(2,38)
 38   FORMAT(//5X,'THE COEFFICIENTS IN THE ORIGINAL OBJECTIVE'
     1 , 'FUNCTIONS ARE TO BE MINIMIZED',/5X,'ARE:',/)
 37   WRITE(2,39)(C(J),J=1,K)
 39   FORMAT(1X,7F10.2/1X,7F10.2)
C     READ(1,*)NOPT
150   WRITE(*,1001)
1001  FORMAT(2X,'CALL SSARTV')
      CALL SSARTV(XB)
      WRITE(*,1003)
1003  FORMAT(2X,'RETURN')
C     IF(IFLAG.EQ.1) GO TO 50
      BASICS=0.0
      OPTSOL=0.0
      WRITE(2,160)
 160  FORMAT(//)
      WRITE(*,1002)
1002  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 OBJECTIVE FUNCTION IS',
     1F12.2/)
C     CLOSE(UNIT=1)
 333  STOP
      END
```

```
C     ******************************************************************
      SUBROUTINE  SSARTV(XB)
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON KP1,MP1,N,K,M,NGET,NLET,NET,NTYPE,NP1,
     1 NC,NC1,INDEXG,INDEXL,INDEXE,NFLAG,BASICS,OPTSOL
      COMMON SUM
      COMMON NOPT
      INTEGER CODE,XB,BASICS,OPTSOL
C     DIMENSION A(500,950),B(500),C(950),XB(500),CODE(500),ARTV(950)
      DIMENSION A(1000,2000),B(1000),C(2000),XB(1000),CODE(1000),
     1 ARTV(2000)
      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)
          IMPLICIT REAL*8 (A-H,O-Z)
          COMMON KP1,MP1,N,K,M,NGET,NLET,NET,NTYPE,NP1,
     1    NC,NC1,INDEXG,INDEXL,INDEXE,NFLAG,BASICS,OPTSOL
          COMMON SUM
          COMMON NOPT
          INTEGER CODE,XB,BASICS,OPTSOL
C         DIMENSION A(500,950),B(500),C(950),XB(500),CODE(500),ARTV(950)
          DIMENSION A(1000,2000),B(1000),C(2000),XB(1000),CODE(1000),
     1    ARTV(2000)
          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,/)
          MR=(M+3)/4
          DO 110 I=1,MR
110       WRITE(2,106)I,XB(I),A(I,NP1),I+MR,XB(I+MR),A(I+MR,NP1),I+2*MR,
```

```
     1  XB(I+2*MR),A(I+2*MR,NP1),I+3*MR,XB(I+3*MR),A(I+3*MR,NP1)
106     FORMAT(2X,4(' |  XB(',I3,')=X(',I3,')=',F12.1))
        WRITE(2,'(//)')
        DO 1011 I=1,M-1
        DO 1011 J=I,M
        IF(XB(I).GT.XB(J))THEN
        IPI=XB(I)
        XB(I)=XB(J)
        XB(J)=IPI
        APOP=A(I,NP1)
        A(I,NP1)=A(J,NP1)
        A(J,NP1)=APOP
        ENDIF
1011    CONTINUE
        DO 1012 I=1,MR
1012    WRITE(2,1106)XB(I),A(I,NP1),XB(I+MR),A(I+MR,NP1),
     1  XB(I+2*MR),A(I+2*MR,NP1),XB(I+3*MR),A(I+3*MR,NP1)
1106    FORMAT(2X,4(' | XB(',I3,')=',F12.1))
        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 FUNCTION IS', E 14.8/)
        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..00001)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 SOLUTION IS OPTIMAL')
      RETURN
      END
```

# APPENDIX 6.I.A

```
C     ************************************************************
C             ********************************************
C                     ************************
C
C     GENERATION OF INPUT DATA MATRIX FOR LINEAR PROGRAMMING MODEL FOR
C
C     MULTIPLE  RESERVOIR , MULTI PURPOSE AND MULTI-IRRIGATION SYSTEMS
C
C                         (INDMAG PACKAGE)
C
C              DEVELOPED BY: MOHAMMAD SADEGH SADEGHIAN
C
C              SUPERVISOR  : PROFESSOR D.K. SRIVASTAVA
C
C                     ************************
C             ********************************************
C     ************************************************************
      SUBROUTINE MATRIX
      IMPLICIT REAL * 8 (A-H,O-Z)
      INTEGER Q,QSFMI,PTH,G,W
      REAL LM
      CHARACTER * 80 TITLE
      DIMENSION A(1000,2000),B(1000),C(2000),XB(1000),CODE(1000),
     1 ARTV(2000),
     1 WS(20,12),FLOW(20,12),FLOW1(20,12),FLOW2(20,12),ET(20,12),
     1 A1(20),C11(20),ITHMI(20)
      DIMENSION ICOLR(20,20),ICOLI(20,20),ICOLP(20,20),NCOLR(20),
     1 NCOLI(20)
      DIMENSION XK1(20,12),YD(20),MMFS(20),NCOLP(20),P(20,12),
     1 MMFL(20)
      DIMENSION XNETA(20,12),ALPHA(20,12),HEAD(20,12),TIME(12),
     1 OM11(20)
      DIMENSION IAL(20,2000),IUP(20,2000),ILO(20,2000),
     1 UL(20,2000),IEQ(20,2000),ISAL(20),NVAAL(20,2000)
      DIMENSION EQU(20,2000),A2(20),C21(20),OM21(20),C31(20),
     1 OM31(20),A3(20),A0(20),AA(20),NVAR(20),LM(20,2000),
     1 EQ(20,7),NFLM(20),IFLM(20,12),F(20,12)
      DIMENSION NSURC(20,20),NOS(20),XK3(20,12)
      DIMENSION IRFMI(20),LRFMI(20),QSFMI(20),
     1  IRP(20),IRJP(20,20),IQ2(20),IQ3(20),G(20),IBAR(20),A4(20)
      COMMON KP1,MP1,N,K,M,NGET,NLET,NET,NTYPE,NP1,
     1 NC,NC1,INDEXG,INDEXL,INDEXE,NFLAG,BASICS,OPTSOL
      COMMON SUM
      COMMON NOPT
      INTEGER CODE,XB,BASICS,OPTSOL
      COMMON/BLK1/A
      COMMON/BLK2/B
      COMMON/BLK3/C
      COMMON/BLK4/CODE
      COMMON/BLK5/ICOLI,ICOLP,NCOLP,NVAR
      COMMON IPRNT1
      READ(1,*)NRE
```

```
      IF(IPRNT1.NE.0.) WRITE(2,*)NRE
      READ(1,*)MM
      IF(IPRNT1.NE.0.) WRITE(2,*)MM
      DO 700 ITH=1,NRE
      READ (1,91)TITLE
      WRITE (2,91)TITLE
91    FORMAT(1A)
      READ(1,*)IRENO
      READ(1,*)NOS(IRENO)
      IF(NOS(IRENO).NE.0)READ(1,*)(NSURC(IRENO,K1),K1=1,NOS(IRENO))
      READ(1,*)NFLM(ITH)
      IF(NFLM(ITH).EQ.0.)GOTO 112
      READ(1,*)(IFLM(ITH,I),I=1,MM)
      READ(1,*)MMFS(ITH),MMFL(ITH)
112   READ(1,*)(FLOW(ITH,I),I=1,MM)
      READ(1,*)(FLOW1(ITH,I),I=1,MM)
      READ(1,*)(FLOW2(ITH,I),I=1,MM)
      READ(1,*)(P(ITH,I),I=1,MM)
      READ(1,*)(WS(ITH,I),I=1,MM)
      READ(1,*)NVAR(ITH)
      READ(1,*) ITHMI(ITH)
      READ(1,*)NCOLR(ITH),NCOLI(ITH),NCOLP(ITH)
      IF(NCOLR(ITH).NE.0)READ(1,*)(ICOLR(ITH,I),I=1,NCOLR(ITH))
      IF(NCOLI(ITH).NE.0)READ(1,*)(ICOLI(ITH,I),I=1,NCOLI(ITH))
      IF(NCOLP(ITH).NE.0)READ(1,*)(ICOLP(ITH,I),I=1,NCOLP(ITH))
      IF(NCOLI(ITH).NE.0)READ(1,*)(XK1(ITH,I),I=1,MM)
      IF(NCOLI(ITH).NE.0)READ(1,*)(XK3(ITH,I),I=1,MM)
      READ(1,*)IRP(ITH)
      READ(1,*)IRFMI(ITH)
      READ(1,*)LRFMI(ITH)
      READ(1,*)QSFMI(ITH)
      READ(1,*)(IRJP(PTH,JTH),JTH=ITH+L+1,ITH+L+Q)
      READ(1,*)YD(ITH)
      IF(NCOLP(ITH).EQ.0)GOTO 100
      READ(1,*)(XNETA(ITH,I),I=1,MM)
      READ(1,*)COEFF,EFFCI
      READ(1,*)(ALPHA(ITH,I),I=1,MM)
      READ(1,*)(HEAD(ITH,I),I=1,MM)
      READ(1,*)(TIME(I),I=1,MM)
100   IF(NCOLR(ITH).NE.0)READ(1,*)C11(ITH),OM11(ITH)
      IF(NCOLI(ITH).NE.0)READ(1,*)A2(ITH),C21(ITH),OM21(ITH)
      IF(NCOLP(ITH).NE.0)READ(1,*)A3(ITH),C31(ITH),OM31(ITH)
      IF(NFLM(ITH).NE.0)READ(1,*)A4(ITH)
      READ(1,*)A0(ITH),AA(ITH)
      READ(1,*)(ET(ITH,I),I=1,MM)
      READ(1,*)ISAL(ITH)
      READ(1,*)(NVAAL(ITH,J1),J1=1,ISAL(ITH))
      IF(ITH.EQ.1) IST=1
      IF(ITH.NE.1)IST=NVAR(ITH-1)+1
      DO 13 J1=IST,NVAR(ITH)
      IF(IAL(ITH,J1).EQ.0) GO TO 13
      READ(1,*)IUP(ITH,J1),ILO(ITH,J1),IEQ(ITH,J1)
      READ(1,*)UL(ITH,J1),LM(ITH,J1),EQU(ITH,J1)
13    CONTINUE
      READ(1,*)G(ITH)
```

```
      READ(1,*)IBAR(ITH)
      IF(IPRNT1.NE.0.) WRITE(2,*)IRENO
      IF(IPRNT1.NE.0.) WRITE(2,*)NOS(IRENO)
      IF(NOS(IRENO).NE.0.AND.IPRNT1.NE.0.) WRITE(2,*)(NSURC(IRENO,K1),
     1 K1=1,NOS(IRENO))
      IF(IPRNT1.NE.0.AND.IPRNT1.NE.0.) WRITE(2,*)NFLM(ITH)
      IF(NFLM(ITH).EQ.0)GO TO 113
      IF(IPRNT1.NE.0.) WRITE(2,*)(IFLM(ITH,I),I=1,MM)
      IF(IPRNT1.NE.0.) WRITE(2,*)MMFS(ITH),MMFL(ITH)
113   IF(IPRNT1.NE.0.) WRITE(2,*)(FLOW(ITH,I),I=1,MM)
      IF(IPRNT1.NE.0.) WRITE(2,*)(FLOW1(ITH,I),I=1,MM)
      IF(IPRNT1.NE.0.) WRITE(2,*)(FLOW2(ITH,I),I=1,MM)
      IF(IPRNT1.NE.0.) WRITE(2,*)(P(ITH,I),I=1,MM)
      IF(IPRNT1.NE.0.) WRITE(2,*)(WS(ITH,I),I=1,MM)
      IF(IPRNT1.NE.0.) WRITE(2,*)NVAR(ITH)
      IF(NCOLR(ITH).NE.0.AND.IPRNT1.NE.0.)WRITE(2,*)NCOLR(ITH),
     1 NCOLI(ITH),NCOLP(ITH)
      IF(NCOLI(ITH).NE.0.AND.IPRNT1.NE.0.)WRITE(2,*)(ICOLR(ITH,I),
     1 I=1,NCOLR(ITH))
      IF(NCOLP(ITH).NE.0.AND.IPRNT1.NE.0.)WRITE(2,*)(ICOLI(ITH,I),
     1 I=1,NCOLI(ITH))
      IF(IPRNT1.NE.0.AND.IPRNT1.NE.0.) WRITE(2,*)(ICOLP(ITH,I),
     1 I=1,NCOLP(ITH))
      IF(NCOLI(ITH).NE.0.AND.IPRNT1.NE.0.)WRITE(2,*)(XK1(ITH,I),
     1 I=1,MM)
      IF(NCOLI(ITH).NE.0.AND.IPRNT1.NE.0.)WRITE(2,*)(XK3(ITH,I),
     1 I=1,MM)
      IF(IPRNT1.NE.0.) WRITE(2,*)YD(ITH)
      IF(NCOLP(ITH).EQ.0)GO TO 101
      IF(IPRNT1.NE.0.) WRITE(2,*)(XNETA(ITH,I),I=1,MM)
      IF(IPRNT1.NE.0.) WRITE(2,*)COEFF,EFFCI
      IF(IPRNT1.NE.0.) WRITE(2,*)(ALPHA(ITH,I),I=1,MM)
      IF(IPRNT1.NE.0.) WRITE(2,*)(HEAD(ITH,I),I=1,MM)
      IF(IPRNT1.NE.0.) WRITE(2,*)(TIME(I),I=1,MM)
101   IF(NCOLR(ITH).NE.0.AND.IPRNT1.NE.0.)WRITE(2,*)C11(ITH),OM11(ITH)
      IF(NCOLI(ITH).NE.0.AND.IPRNT1.NE.0.)WRITE(2,*)A2(ITH),
     1 C21(ITH),OM21(ITH)
      IF(NCOLP(ITH).NE.0.AND.IPRNT1.NE.0.)WRITE(2,*)A3(ITH),
     1 C31(ITH),OM31(ITH)
      IF(NFLM(ITH).NE.0.AND.IPRNT1.NE.0.)WRITE(2,*)A4(ITH)
      IF(IPRNT1.NE.0.) WRITE(2,*)A0(ITH),AA(ITH)
      IF(IPRNT1.NE.0.) WRITE(2,*)(ET(ITH,I),I=1,MM)
      IF(ITH.EQ.1)IST=1
      IF(ITH.NE.1)IST=NVAR(ITH-1)+1
      DO 20 J1=IST,NVAR(ITH)
      IF(IAL(ITH,J1).EQ.0) GO TO 20
      IF(IPRNT1.NE.0.)WRITE(2,*)IUP(ITH,J1),ILO(ITH,J1),IEQ(ITH,J1)
      IF(IPRNT1.NE.0.) WRITE(2,*)UL(ITH,J1),LM(ITH,J1),EQU(ITH,J1)
20    CONTINUE
      IF(IPRNT1.NE.0.) WRITE(2,*)G(ITH)
      IF(IPRNT1.NE.0.) WRITE(2,*)IBAR(ITH)
700   CONTINUE
      READ(1,*)IPRNT
      READ(1,*)IDSCO
      IF(IPRNT1.NE.0.) WRITE(2,*)IPRNT
```

```
      IF(IPRNT1.NE.0.) WRITE(2,*)IDSCO
      DO 79 ITH=1,NRE
      KL=0
      IF(ITH.EQ.1)IROW=0
      IF(ITHMI(ITH).EQ.1)GO TO 57
      IF(IRFMI(ITH).EQ.-1)GO TO 3014
C     ****************************************************************
C     IRRIGATION CONSTRAINT FOR PTH RESERVOIR FOR ITS OWN COMMAND AREA
C     ****************************************************************
      JCOL=0
      JROW=0
3004  JROW=JROW+1
      DO 3003 PTH=ITH,ITH+L
      IF(IRP(ITH).NE.1)GO TO 3003
      IROW=IROW+1
      B(IROW)=FLOW1(PTH,JCOL+1)+FLOW2(PTH,JCOL+1)
      CODE(IROW)=0
      A(IROW,ICOLR(PTH,6)+JCOL)=-1
      A(IROW,ICOLI(PTH,1))=XK1(PTH,JCOL+1)
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR(ITH+L+Q)),
     1 CODE(IROW), B(IROW)
3003  CONTINUE
      JCOL=JCOL+1
      IF(JROW.LT.MM)GO TO 3004
C     ****************************************************************
C          IRRIGATION CONSTRAINTS FOR JTH MULTI-IRRIGATION AREA
C     ****************************************************************
      IF(QSFMI(ITH).EQ.0)GO TO 6001
      JCOL=0
      JROW=0
3007  JROW=JROW+1
      DO 3017 PTH=ITH,ITH+L
      IQ2(PTH)=7
      IQ3(PTH)=2
3017  CONTINUE
      DO 3005 JTH=ITH+L+1,ITH+L+Q
      IROW=IROW+1
      B(IROW)=FLOW(JTH,JCOL+1)+FLOW2(JTH,JCOL+1)
      CODE(IROW)=0
      DO 3006 PTH=ITH,ITH+L
      IF(IRJP(PTH,JTH).EQ.-1)GO TO 3006
      IF(IRJP(PTH,JTH).EQ.1)A(IROW,ICOLR(PTH,IQ2(PTH))+JCOL)=-1
      IF(IRJP(PTH,JTH).EQ.1)A(IROW,ICOLI(PTH,IQ3(PTH)))=
     1 XK1(JTH,JCOL+1)
      IQ2(PTH)=IQ2(PTH)+1
      IQ3(PTH)=IQ3(PTH)+1
3006  CONTINUE
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR(ITH+L+Q)),
     1 CODE(IROW),B(IROW)
3005  CONTINUE
      JCOL=JCOL+1
      IF(JROW.LT.MM)GO TO 3007
```

```
C       ******************************************************************
C                  TOTAL RELEASE CONSTRAINT FOR PTH RESERVOIR
C       ******************************************************************
6001    JCOL=0
        JROW=0
3008    JROW=JROW+1
        DO 3009 PTH=ITH,ITH+L
        IF(QSFMI(ITH).EQ.0.AND.IRP(ITH).NE.1)GO TO 3009
        IROW=IROW+1
        IQ=7
        B(IROW)=0
        CODE(IROW)=2
        A(IROW,ICOLR(PTH,1)+JCOL)=1
        A(IROW,ICOLR(PTH,4)+JCOL)=-1
        IF(IRP(PTH).EQ.1)A(IROW,ICOLR(PTH,6)+JCOL)=-1
        IF(QSFMI(ITH).EQ.0)GO TO 6002
        DO 3010 JTH=ITH+L+1,ITH+L+Q
        IF(IRJP(PTH,JTH).EQ.-1)GO TO 3010
        IF(IRJP(PTH,JTH).EQ.1)A(IROW,ICOLR(PTH,IQ)+JCOL)=-1
        IQ=IQ+1
3010    CONTINUE
6002    IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR(ITH+L+Q)),
     1  CODE(IROW),B(IROW)
3009    CONTINUE
        JCOL=JCOL+1
        IF(JROW.LT.MM)GO TO 3008
C       ******************************************************************
C           ANNUAL IRRIGATION TARGET AT JTH MULTI - IRRIGATION AREA
C       ******************************************************************
        IF(QSFMI(ITH).EQ.0)GO TO 3014
        DO 3018 PTH=ITH,ITH+L
        IQ3(PTH)=2
3018    CONTINUE
        DO 3015 JTH=ITH+L+1,ITH+L+Q
        IROW=IROW+1
        B(IROW)=0
        CODE(IROW)=2
        A(IROW,ICOLI(JTH,1))=1
        DO 3016 PTH= ITH,ITH+L
        IF(IRJP(PTH,JTH).EQ.-1) GO TO 3016
        IF(IRJP(PTH,JTH).EQ.1)A(IROW,ICOLI(PTH,IQ3(PTH)))=-1
        IQ3(PTH)=IQ3(PTH)+1
3016    CONTINUE
        IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR(ITH+L+Q)),
     1  CODE(IROW),B(IROW)
3015    CONTINUE
3014    IF(EQ(ITH,1).EQ.0.)GO TO 51
C       ******************************************************************
C                             CONTINUITY EQUATION
C       ******************************************************************
        JCOL=0
        JROW=0
4003    IROW=IROW+1
        JROW=JROW+1
        AT=0.5*AA(ITH)*ET(ITH,JCOL+1)
```

```
      B(IROW)=FLOW(ITH,JCOL+1)+P(ITH,JCOL+1)-
     1 (WS(ITH,JCOL+1))-AO(ITH)*(ET(ITH,JCOL+1))
      IF(IBAR(ITH).EQ.1)CODE(IROW)=0
      IF(IBAR(ITH).EQ.0) CODE(IROW)=2
      XMULT=1.0
      IF(B(IROW).LT.0.0)XMULT=-1.0
      B(IROW)=B(IROW)*XMULT
      IF(IBAR(ITH).EQ.1)A(IROW,ICOLR(ITH,1)+JCOL)=1.*XMULT
      IF(IBAR(ITH).EQ.1)GO TO 5000
      A(IROW,ICOLR(ITH,2)+JCOL)=-(1-AT)*XMULT
      A(IROW,ICOLR(ITH,1)+JCOL)=1.0*XMULT
5000  IF(NOS(ITH).EQ.0)GO TO 4002
      DO 4000 IW=1,G(ITH)
      W=NSURC(ITH,IW)
      IF(NCOLI(W).EQ.0.OR.ITHMI(W).EQ.-1) GO TO 4001
      A(IROW,ICOLR(W,1)+JCOL)=-1*XMULT
      A(IROW,ICOLI(W,1))=(XK1(W,JCOL+1)-XK3(W,JCOL+1))*XMULT
      GO TO 4000
4001  A(IROW,ICOLR(W,1)+JCOL)=-1*XMULT
4000  CONTINUE
4002  IF(IBAR(ITH).EQ.1)GO TO 5001
      IF(JCOL.LT.(MM-1))A(IROW,ICOLR(ITH,2)+JCOL+1)=(1+AT)*XMULT
      IF(JCOL.EQ.(MM-1))A(IROW,ICOLR(ITH,2))=(1+AT)*XMULT
5001  IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR(ITH)),CODE(IROW),
     1 B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM)GO TO 4003
 51   IF(EQ(ITH,2).EQ.0.) GO TO 52
C     ****************************************************************
C     CONTENTS OF RESERVOIR CAN NOT EXCEED CAPACITY OF THE RESERVOIR
C     ****************************************************************
      JCOL=0
      JROW=0
  3   IROW=IROW+1
      JROW=JROW+1
      B(IROW)=0
      CODE(IROW)=0
      A(IROW,ICOLR(ITH,2)+JCOL)=1
      A(IROW,ICOLR(ITH,3))=-1
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR(ITH)),CODE(IROW),
     1 B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM) GO TO 3
 52   IF(EQ(ITH,3).EQ.0.) GO TO 53
C     ****************************************************************
C         STORAGE AT ANY TIME MUST EXCEED OR EQUAL TO DEAD STORAGE
C     ****************************************************************
      JCOL=0
      JROW=0
  4   IROW=IROW+1
      JROW=JROW+1
      B(IROW)=YD(ITH)
      CODE(IROW)=1
      A(IROW,ICOLR(ITH,2)+JCOL)=1.
```

```
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR(ITH)),CODE(IROW),
     1 B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM)GO TO 4
 53   IF(EQ(ITH,4).EQ.0.) GO TO 54
C     *****************************************************************
C             STORAGE CAPACITY FOR FLOOD-CONSERVATION PURPOSE
C     *****************************************************************
      JCOL=0
      JROW=MMFS(ITH)-1
  5   JROW=JROW+1
      IF(IFLM(ITH,JROW).EQ.-1)GO TO 111
      IROW=IROW+1
      B(IROW)=0
      CODE(IROW)=0
      A(IROW,ICOLR(ITH,2)+JROW-1)=1
      A(IROW,ICOLR(ITH,5)+JCOL)=-1
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR(ITH)),CODE(IROW),
     1 B(IROW)
      JCOL=JCOL+1
111   IF(JROW.LT.MMFL(ITH))GO TO 5
 54   IF(EQ(ITH,5).EQ.0.) GO TO 55
C     *****************************************************************
C             ENERGY GENERATION LIMITED TO TURBINE DISCHARGE
C     *****************************************************************
      JCOL=0
      JROW=0
  6   IROW=IROW+1
      JROW=JROW+1
      B(IROW)=0
      CODE(IROW)=2
      A(IROW,ICOLR(ITH,1)+JCOL)=-COEFF*HEAD(ITH,JCOL+1)*EFFCI
      A(IROW,ICOLP(ITH,3)+JCOL)=1
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR(ITH)),CODE(IROW),
     1 B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM)GO TO 6
 55   IF(EQ(ITH,6).EQ.0.) GO TO 56
C     *****************************************************************
C                ENERGY GENERATION LIMITED TO LOAD FACTOR
C     *****************************************************************
      JCOL=0
      JROW=0
  7   IROW=IROW+1
      JROW=JROW+1
      B(IROW)=0
      CODE(IROW)=2
      A(IROW,ICOLP(ITH,1))=-ALPHA(ITH,JCOL+1)*TIME(JCOL+1)
      A(IROW,ICOLP(ITH,3)+JCOL)=1
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR(ITH)),CODE(IROW),
     1 B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM)GO TO 7
 56   IF(EQ(ITH,7).EQ.0.) GO TO 57
```

```
C     ****************************************************************
C                           ADDITIONAL ENERGY
C     ****************************************************************
      JCOL=0
      JROW=0
 8    IROW=IROW+1
      JROW=JROW+1
      B(IROW)=0
      CODE(IROW)=2
      A(IROW,ICOLP(ITH,2))=-XNETA(ITH,JCOL+1)
      A(IROW,ICOLP(ITH,3)+JCOL)=1
      A(IROW,ICOLP(ITH,4)+JCOL)=-1
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR(ITH)),CODE(IROW),
     1 B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM)GO TO 8
C     ****************************************************************
C                 LIMIT ON Q(T),S(T),A(J),Y,DS,I,ETC.
C     ****************************************************************
57    I3=IROW+1
      IF(ITH.EQ.1)IST=1
      IF(ITH.NE.1)IST=NVAR(ITH-1)+1
      DO 10 J1=IST,NVAR(ITH)
      IF (IAL(ITH,J1).EQ.0) GO TO 10
      IF(IUP(ITH,J1).NE.0) GO TO 14
      IROW=IROW+1
      A(IROW,J1)=1
      B(IROW)=UL(ITH,J1)
      CODE(IROW)=IUP(ITH,J1)
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR(ITH)),CODE(IROW),
     1 B(IROW)
 14   IF(ILO(ITH,J1).NE.1) GO TO 15
      IROW=IROW+1
      A(IROW,J1)=1
      B(IROW)=LM(ITH,J1)
      CODE(IROW)=ILO(ITH,J1)
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR(ITH)),CODE(IROW),
     1 B(IROW)
 15   IF(IEQ(ITH,J1).NE.2) GO TO 10
      IROW=IROW+1
      A(IROW,J1)=1
      B(IROW)=EQU(ITH,J1)
      CODE(IROW)=IEQ(ITH,J1)
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR(ITH)),CODE(IROW),
     1 B(IROW)
 10   CONTINUE
      M=IROW
C     ****************************************************************
C                 DEVELOPMENT OF OBJECTIVE FUNCTION
C     ****************************************************************
80    IF(ICOLR(ITH,3).NE.0)C(ICOLR(ITH,3))=-(C11(ITH)+OM11(ITH))
      IF(ICOLI(ITH,1).NE.0)C(ICOLI(ITH,1))=A2(ITH)-(C21(ITH)+
     1 OM21(ITH))
      IF(NCOLP(ITH).NE.0)C(ICOLP(ITH,1))=-(C31(ITH)+OM31(ITH))
```

```
      IF(NCOLP(ITH).NE.0)C(ICOLP(ITH,2))=A3(ITH)
      IF(NFLM(ITH).NE.0)C(ICOLR(ITH,3))=C(ICOLR(ITH,3))+(NFLM(ITH)*
     1 A4(ITH))
      IF(MMFS(ITH).EQ.0)GO TO 102
      JCOL=0
      DO 21 I=MMFS(ITH),MMFL(ITH)
      IF(IFLM(ITH,I).EQ.-1)GO TO 21
      C(ICOLR(ITH,5)+JCOL)=-A4(ITH)
      JCOL=JCOL+1
21    CONTINUE
102   IF(IPRNT.NE.0)WRITE(2,*)(C(K),K=1,NVAR(ITH))
79    CONTINUE
C     *****************************************************************
C                         DEFINING M,K,NLET,NGET,NET
C     *****************************************************************
      K=NVAR(NRE)
      IF(IDSCO.EQ.1)CALL DGNCO(IROW,NRE,IPRNT)
      M=IROW
      NLET=0
      NGET=0
      NET=0
      DO 40 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
40    CONTINUE
      RETURN
      END
C     *****************************************************************
C                     SUBROUTINE DGNCO(IROW,NRE,IPRNT)
C     *****************************************************************
      SUBROUTINE DGNCO(IROW,NRE,IPRNT)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A(1000,2000),B(1000),C(2000),CODE(1000),
     1 ICOLI(20,20),ICOLP(20,20),NVAR(20),NCOLP(20)
      INTEGER CODE
      COMMON/BLK1/A
      COMMON/BLK2/B
      COMMON/BLK3/C
      COMMON/BLK4/CODE
      COMMON/BLK5/ICOLI,ICOLP,NCOLP,NVAR
      READ(1,*)IRDC,IPDC
      IF(IPRNT1.NE.0.) WRITE(2,*)IRDC,IPDC
      IF(IRDC.EQ.1)READ(1,*)TIRRI
      IF(IRDC.EQ.1.AND.IPRNT.NE.0.)WRITE(2,*)TIRRI
      IF(IPDC.EQ.1)READ(1,*)THPRE
      IF(IPDC.EQ.1.AND.IPRNT.NE.0.)WRITE(2,*)THPRE
      IF(IRDC.NE.1)GO TO 3
      IROW=IROW+1
      CODE(IROW)=1
      B(IROW)=TIRRI
      DO 1 ITH=1,NRE
      IF(ICOLI(ITH,1).EQ.0)GO TO 1
      A(IROW,ICOLI(ITH,1))=1
1     CONTINUE
```

```
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR(NRE)),CODE(IROW),
     1 B(IROW)
3     IF(IPDC.NE.1)GO TO 4
      IROW=IROW+1
      CODE(IROW)=1
      B(IROW)=THPRE
      DO 2 ITH=1,NRE
      IF(NCOLP(ITH).EQ.0)GO TO 2
      A(IROW,ICOLP(ITH,1))=1
2     CONTINUE
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR(NRE)),CODE(IROW),
     1 B(IROW)
4     RETURN
      END
C     ****************************************************************
```

## APPENDIX 6.II

### Sample Input Data for INDMAG Package for Single Purpose Irrigation Reservoir

In order to explain the flexibility in the input data for **INDMAG** computer package on linear programming, a sample input data for single purpose irrigation reservoir is given below.

**6.II.1** Matrices [A], [B], and [C] in Detached coefficient Form:

The coefficients of the matrices [A], [B], and [C] for a single purpose irrigation reservoir are given in Table 6.II.1

**6.II.2** A Sample Input Data for INDMAG PACKAGE:

The sample input data for the computer package, INDMAG, on linear programming for the problem in para 6.II.1 are given in Annexure 6.II.A.

**Table 6.II.1 Coefficient of the Matrices [A], [B], and [C] for Irrigation Reservoir With two Time Periods.**

| COL. NO. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VAR. | $O_{1,1}$ | $O_{1,2}$ | $S_{1,0}$ | $S_{1,1}$ | $Y_1$ | $Sp_{1,1}$ | $Sp_{1,2}$ | $O^0_{1,1}$ | $O^0_{1,2}$ | $Ir_1$ | SIGN [CODE] | RHS [B] |
| CIN | $C^R_{1,1}$ | | $C^R_{1,2}$ | | $C^R_{1,3}$ | $C^R_{1,4}$ | | $C^R_{1,6}$ | | $C^I_{1,1}$ | | |
| VCIN | 1 | | 3 | | 5 | 6 | | 8 | | 10 | | |
| Equations | | | | | Coefficient Matrix [A] | | | | | | | |
| 6-4-1-1 | 1 | 0 | $-b_{1,1}$ | $d_{1,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | = | $X_{1,1}$ |
| 6-4-1-2 | 0 | 1 | $d_{1,2}$ | $-b_{1,2}$ | 0 | 0 | 0 | 0 | 0 | 0 | = | $X_{1,2}$ |
| 6-7-1-1 | 0 | 0 | 1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | $\leq$ | 0 |
| 6-7-1-2 | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | $\leq$ | 0 |
| 6-8-1-1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $\geq$ | $Yd_1$ |
| 6-8-1-2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | $\geq$ | $Yd_1$ |
| 6-19-1-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | $K_{1,1}$ | $\leq$ | $I''_{1,1}$ |
| 6-19-1-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | $K_{1,2}$ | $\leq$ | $I''_{1,2}$ |
| 6-21-1-1 | 1 | 0 | 0 | 0 | 0 | -1 | 0 | -1 | 0 | 0 | = | 0 |
| 6-21-1-2 | 0 | 1 | 0 | 0 | 0 | 0 | -1 | 0 | -1 | 0 | = | 0 |
| | | | | | Coefficient Matrix [C] | | | | | | | |
| 6-26 | 0 | 0 | 0 | 0 | $M_1$ | 0 | 0 | 0 | 0 | $V_1$ | | |

CIN = Column Index Number, VCIN = Value of CIN, SIGN represents CODE, M = Number of constraint equations in Matrix [A], and K = Total of Variables. Here, M = 10 and K = 10.

**Note :** All the parameters, $b_{1,t}$, $d_{1,t}$, $X_{1,t}$, $M_1$ and $V_1$ in the Matrices [A], [B] and [C] are known quantities and are computed from the Basic Input Data by the Computer Program, INDMAG PACKAGE.

## ANNEXURE 6.II.A

## Sample Input Data File for Single Purpose Irrigation Reservoir for INDMAG PACKAGE.

| Input Parameter/Variable Read Statment | Input Parameter/Variable Data to be Given |
|---|---|
| IGEN | 1 |
| IPRNT1 | 0 |
| NTYPE NOPT | 1 0 |
| NRE | 1 |
| MM | 2 |
| SITNA | KARUN-1 |
| SITNO | SITE-4 |
| IRENO | 1 |
| NOS | 0 |
| NSURC | - |
| NFLM | 0 |
| IFLM | - |
| MMFS | - |
| FLOW | 1530 533 |
| FLOW1 | 2*0 |
| FLOW2 | 2*0 |
| P | 2*0 |
| WS | 2*0 |
| NVAR | 10 |
| ITHMI | 1 |
| NCOLR NCOLI NCOLP | 6 1 0 |
| ICOLR | 1 3 5 6 0 8 |
| ICOLI | 10 |
| ICOLP | - |
| XK1 | 0.78 0.22 |
| XK3 | .156 .044 |
| IRP | 1 |
| IRFMI | 1 |
| LRFMI | 0 |
| QSFMI | 0 |
| IRJP | - |
| YD | 1280 |
| XNETA | - |
| COEFF EFFCI | - |
| ALPHA | - |
| HEAD | - |
| TIME | - |
| C11 OM11 | 17.85 1.95 |
| A2 C21 OM21 | 10 4.31 0.93 |
| A3 C31 OM31 | - |
| A4 | - |
| A0 AA | 30 0.01 |
| ET | 0.3 .013 |
| ISAL | -1 |
| NVAAL | - |
| IUP ILO IEQ | - |
| UL LM EQU | - |
| EQ | 1 1 1 0 0 0 0 |
| G | 0 |
| IBAR | 0 |
| IPRNT | 0 |
| IDSCO | - |
| RDC IPDC | - |
| TIRRI | - |
| THRRE | - |

# APPENDIX 6. III

## Sample Input Data for (INDMAG, MPS, and LINGO) Packages for Single Purpose Hydropower Reservoir

In order to explain the flexibility in the input data for INDMAG computer package and its comparison with other standard computer packages on linear programming, i.e., MPS, LINGO a sample input data for each of the above techniques for a single purpose hydropower reservoir are given below.

**6.III.1** Matrices [A], [B], and [C] in Detached Coefficient Form :

The coefficients of the matrices [A], [B], and [C] for a single purpose hydropowr reservoir are given in Table 6.III.1.

**6.III.2** A Sample Input Data for INDMAG PACKAGE :

The sample input data for the computer package, INDMAG, on linear programming for the problem in para 6.III.1 are given in Annexure 6.III.A.

**6.III.3** A Sample Input Data for MPS :

The sample input data for the computer package, MPS, on linear programming for the problem in para 6.III.1 are given in Annexure 6.III.B.

**6.III.4** A Sample Input Data for LINGO :

The sample input data for the computer package, LINGO, on linear programming for the problem in para 6.III.1 are given in Annexure 6.III.C.

Table 6.III.1 Coefficients of the Matrices [A],[B],and [C] for Hydropower Reservoir With Two Time Periods

| ROWS | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | COL. NO. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | | |
| | VAR. | $O_{1,1}$ | $O_{1,2}$ | $S_{1,0}$ | $S_{1,1}$ | $Y_1$ | $H_1$ | $E_1$ | $E^T_{1,1}$ | $E^T_{1,2}$ | $\bar{E}_{1,1}$ | $\bar{E}_{1,2}$ | SIGN | RHS [B] |
| | COLUMNS | O11 | O12 | S10 | S11 | Y1 | H1 | E1 | ET11 | ET12 | EB11 | EB12 | | |
| | CIN | $C^R_{1,1}$ | | $C^R_{1,2}$ | | $C^R_{1,3}$ | $C^P_{1,1}$ | $C^P_{1,2}$ | $C^P_{1,3}$ | | $C^P_{1,4}$ | | | |
| | VCIN | 1 | | 3 | | 5 | 6 | 7 | 8 | | 10 | | | |
| ROWS | Equations | Coefficient Matrix [A] | | | | | | | | | | | | |
| RC6411 | 6-4-1-1 | 1 | 0 | $-b_{1,1}$ | $d_{1,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | $X_{1,1}$ |
| RC6412 | 6-4-1-2 | 0 | 1 | $d_{1,2}$ | $b_{1,2}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | $X_{1,2}$ |
| RC7111 | 6-7-1-1 | 0 | 0 | 1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | $\leq$ | 0 |
| RC6712 | 6-7-1-2 | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | $\leq$ | 0 |
| RC6811 | 6-8-1-1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $\geq$ | $Yd_1$ |
| RC6812 | 6-8-1-2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $\geq$ | $Yd_1$ |
| HC62311 | 6-23-1-1 | $-R_{1,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | = | 0 |
| HC62312 | 6-23-1-2 | 0 | $-R_{1,2}$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | = | 0 |
| HC62411 | 6-24-1-1 | 0 | 0 | 0 | 0 | 0 | $-T_{1,1}$ | 0 | 1 | 0 | 0 | 0 | = | 0 |
| HC62412 | 6-24-1-2 | 0 | 0 | 0 | 0 | 0 | $-T_{1,2}$ | 0 | 0 | 1 | 0 | 0 | = | 0 |
| HC62511 | 6-25-1-1 | 0 | 0 | 0 | 0 | 0 | 0 | $-n_{1,1}$ | 1 | 0 | -1 | 0 | = | 0 |
| HC62512 | 6-25-1-2 | 0 | 0 | 0 | 0 | 0 | 0 | $-n_{1,2}$ | 0 | 1 | 0 | -1 | = | 0 |
| | | Coefficient Matrix [C] | | | | | | | | | | | | |
| OBJ626 | 6-26 | 0 | 0 | 0 | 0 | $M_1$ | $-Z_1$ | $a_{3,1}$ | 0 | 0 | 0 | 0 | | |

CIN = Column Index Number , VCIN = Value of CIN.RHS represents CODE,

M=Number of constraint equations in Matrix[A],and K=total Number of Variables.

Here ,M =12 , & K =11

Note : All the parameters $,b_{1,t}$ $,d_{1,t}$ $,X_{1,t}$, $R_{1,t}$, $T_{1,t}$ $,M_1$ ,and $Z_1$ in the Matrices [A],[B],and [C] are known quantities and are computed from the Basic Input Data by the computer programme, INDMAG.

[Also put, $R11=R_{1,1}$ $,R12 =R_{1,2}$ $,b11 =b_{1,1}$ ,b12 =,$d11=d_{1,1}$ $,d12 = d_{1,2}$ $,T11=T_{1,1}$ $,T12 =T_{1,2}$ , $n11 = n_{1,1}$ , $n12 = n_{1,2}$ , $X11 = X_{1,1}$ $,X12=X_{1,2}$ $,Yd1=Yd_1$ $,M1=M_1$ $,Z1=Z_1$ ,and $,A31=A_{3,1}$]

## ANNEXURE 6.III.A

**Sample Input Data File for Single Purpose Hydropower Reservoir for INDMAG PACKAGE.**

| Input Parameter/Variable Read Statement | Input Parameter/Variable Data to be Given |
|---|---|
| IGEN | 1 |
| IPRNT1 | 0 |
| NTYPE NOPT | 1 0 |
| NRE | 1 |
| MM | 2 |
| SITNA | KARUN-3 |
| SITNO | SITE-2 |
| IRENO | 1 |
| NOS | 0 |
| NSURC | - |
| NFLM | 0 |
| IFLM | - |
| MMFS | - |
| FLOW1 | 1152.2 393.4 |
| FLOW1 | 2*0 |
| FLOW2 | 2*0 |
| P | 2*0 |
| WS | 2*0 |
| NVAR | 11 |
| ITHMI | -1 |
| NCOLR NCOLI NCOLP | 3 0 4 |
| ICOLR | 1 3 5 |
| ICOLI | - |
| ICOLP | 6 7 8 10 |
| XK1 | - |
| XK3 | - |
| IRP | -1 |
| IRFMI | -1 |
| LRFMI | - |
| QSFMI | - |
| IRJP | - |
| YD | 1280 |
| XNETA | 0.506 0.494 |
| COEFF EFFCI | 2.6 0.885 |
| ALPHA | 0.64 0.61 |
| HEAD | 2*160 |
| TIME | 2*720 |
| C11 OM11 | 148 16.1 |
| A2 C21 OM21 | - |
| A3 C31 OM31 | 0.25 57.3 31.5 |
| A4 | - |
| A0 AA | 30 0.01 |
| ET | 0.21 0.09 |
| ISAL | -1 |
| NVAAL | - |
| IUP ILO IEQ | - |
| UL LM EQU | - |
| EQ | 1 1 1 0 1 1 1 |
| G | 0 |
| IBAR | 0 |
| IPRNT | 0 |
| IDSCO | - |
| IRDC IPDC | - |
| TIRRI | - |
| THRRE | - |

## ANNEXURE 6.III.B

### Sample Input Data File for MPS computer Package on Linear Programming

The input data feeding for the linear programming model for a single purpose hydropower reservoir, using standard programme called MPS (Mathematical Programming System) available with IBM 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.

### 6.III.B.1 Input Data for Rows (Constraint Equation Row Name)

```
1-2  5-14

ROWS

N    OBJ626
E    RC6411
E    RC6412
L    RC6711
L    RC6712
G    RC6811
G    RC6812
L    RC61811
L    RC61812
E    HC62311
E    HC62312
E    HC62411
E    HC62412
E    HC62511
E    HC62512
```

Note:

N is for objective function

G is for ≥ sign constraint equation

L is for ≤ sign constraint equation

E is for = sign constraint equation

### 6.III.B.2 Input Data for COLUMNS-Only Nonzero Coefficients of Matrices [A] & [C] are to be Given as Data

```
1-2 5-14       15-24     25-39              40-49      50-64

COLUMNS

    O11        RC6411    1.0                HC62311    -R11
    O12        RC6412    1.0                HC62312    -R12
    S10        RC6411    -b11               RC6412     d11
    S10        RC6711    1.0                RC6811     1.0
    S10        RC61812   1.0
    S11        RC6411    d11                RC6412     -b12
    S11        RC6712    1.0                RC6812     1.0
    Y1         RC6711    -1.0               OBJ626     M1
    YMAX11     RC61811   -1.0               OBJ626     -A41
    H1         HC62411   -T11               HC62412    -T12
    H1         OBJ626    -Z1
    E1         HC62511   -η11               HC62512    -η12
    E1         OBJ626    A31
    ET11       HC62311   1.0                HC62411    1.0
    ET11       HC62511   1.0
    ET12       HC62312   1.0                HC62412    1.0
    ET12       HC62512   1.0
    EB11       HC62511   -1.0
    EB12       HC62512   -1.0
```

### 6.III.B.3 Input Data for RHS -Only Nonzero Coefficients of Matrix [B] are to be Given as Data

```
1-2 5-14       15-24     25-39

RHS
    RHS1       RC6411    X11
    RHS1       RC6412    X12
    RHS1       RC6811    Yd1
    RHS1       RC6812    Yd1

ENDATA
```

## ANNEXURE 6.III.C

## Sample Input Data File for LINGO Computer Package on Linear Programming

```
MODEL :
1] MAX=M1*Y1-A41*YMAX11-Z*H1+A31*E1
2]O11 - b11 * S10 + d11 * S11 = X11;
3]O12 + d12 * S10 - b12 * S11 = X12;
4]S10 - Y1 < 0. ;
5]S11 - Y1 < 0. ;
6]S10 > Yd1 ;
7]S11 > Yd1 ;
8]-R11 * O11 + ET11 =0. ;
9]-R12 * O12 + ET12 =0. ;
10]-T11 * H1 + ET11 =0. ;
11]-T12 * H1 + ET12 =0. ;
12]-η11 * E1 + ET11 -EB11 =0. ;
13]-η12 * E1 + ET12 -EB12 =0. ;
END
```

# APPENDIX 6.IV

## Sample Input Data for INDMAG PACKAGE for Two Hydropower Reservoirs in Series

In order to explain the flexibility in the input data for **INDMAG** computer package on linear programming, a sample input data for two reservoirs in series is given below.

**6.IV.1** Matrices [A], [B], and [C] in Detached Coefficient Form:

The coefficients of the matrices [A], [B], and [C] for two hydropower reservoirs in series is given in Table 6.IV.1.

**6.II.2** A Sample Input Data for INDMAG PACKAGE:

The sample input data for the computer package, INDMAG, on linear programming for the problem in para 6.IV.1 are given in Annexure 6.IV.A.

Table 6.IV.1: Coefficients of the Matrices [A], [B], and [C] for Two Hydropower Reservoirs In Series With Two Time Periods

| CO NO. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VAR. | $O_{1,1}$ | $O_{1,2}$ | $S_{1,0}$ | $S_{1,1}$ | $Y_1$ | $H_1$ | $E_1$ | $E^T_{1,1}$ | $E^T_{1,2}$ | $E_{1,1}$ | $E_{1,2}$ | $O_{2,1}$ | $O_{2,2}$ | $S_{2,0}$ | $S_{2,1}$ | $Y_2$ | $H_2$ | $E_2$ | $E^T_{2,1}$ | $E^T_{2,2}$ | $E_{2,1}$ | $E_{2,2}$ | SIGN | RHS [B] |
| CIN | $C^R_{1,1}$ | | $C^R_{1,2}$ | | $C^R_{1,3}$ | $C^P_{1,1}$ | $C^P_{1,2}$ | $C^P_{1,3}$ | | $C^P_{1,4}$ | | $C^R_{2,1}$ | | $C^R_{2,2}$ | | $C^R_{2,3}$ | $C^P_{2,1}$ | $C^P_{2,2}$ | $C^P_{2,3}$ | | $C^P_{2,4}$ | | | |
| VCIN | 1 | | 3 | | 5 | 6 | 7 | 8 | | 10 | | 12 | | 14 | | 16 | 17 | 18 | 19 | | 21 | | | |
| Eq. | | | | | | | | | | | Coefficient Matrix [A] | | | | | | | | | | | | | |
| 6-4-1-1 | 1 | 0 | $-b_{1,1}$ | $d_{1,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | $X_{1,1}$ |
| 6-4-1-2 | 0 | 1 | $d_{1,2}$ | $b_{1,2}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | $X_{1,2}$ |
| 6-7-1-1 | 0 | 0 | 1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | 0 |
| 6-7-1-2 | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | 0 |
| 6-8-1-1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≥ | $Yd_1$ |
| 6-8-1-2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≥ | $Yd_1$ |
| 6-23-1-1 | $-R_{1,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-23-1-2 | 0 | $-R_{1,2}$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-24-1-1 | 0 | 0 | 0 | 0 | 0 | $-T_{1,1}$ | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-24-1-2 | 0 | 0 | 0 | 0 | 0 | $-T_{1,2}$ | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-25-1-1 | 0 | 0 | 0 | 0 | 0 | 0 | $-n_{1,1}$ | 1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-25-1-2 | 0 | 0 | 0 | 0 | 0 | 0 | $-n_{1,2}$ | 0 | 1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| 6-4-2-1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | $-b_{2,1}$ | $d_{2,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | $X_{2,1}$ |
| 6-4-2-2 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | $d_{2,2}$ | $b_{2,2}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | $X_{2,2}$ |
| 6-7-2-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | 0 |
| 6-7-2-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | ≤ | 0 |
| 6-8-2-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≥ | $Yd_2$ |
| 6-8-2-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≥ | $Yd_2$ |
| 6-23-2-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $-R_{2,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | = | 0 |
| 6-23-2-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $-R_{2,2}$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | = | 0 |
| 6-24-2-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $-T_{2,1}$ | 0 | 1 | 0 | 0 | 0 | = | 0 |
| 6-24-2-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $-T_{2,2}$ | 0 | 0 | 1 | 0 | 0 | = | 0 |
| 6-25-2-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $-n_{2,1}$ | 1 | 0 | -1 | 0 | = | 0 |
| 6-25-2-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $-n_{2,2}$ | 0 | 1 | 0 | -1 | = | 0 |
| | | | | | | | | | | | Coefficient Matrix [C] | | | | | | | | | | | | | |
| 6-26 | 0 | 0 | 0 | 0 | $M_1$ | $-Z_1$ | $a_{3,1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $M_2$ | $-Z_2$ | $a_{3,2}$ | 0 | 0 | 0 | 0 | | |

CIN = Column Index Number , VCIN = Value of CIN, RHS represents CODE, M=Number of constraint equations in Matrix[A],and K=total Number of Variables. Here, M =24, & K =22

Note: All the parameters, $b_{1,t}, b_{2,t}, d_{1,t}, d_{2,t}, X_{1,t}, X_{2,t}, T_{1,t}, T_{2,t}, M_1, M_2, Z_1$, and $Z_2$ in the Matrices [A], [B], and [C] are known quantities and are computed from the Basic Input Data by the computer programme, **INDMAG PACKAGE.**

## ANNEXURE 6.IV.A

**Sample Input Data File for Two Hydropower Reservoirs in Series for INDMAG PACKAGE.**

| Input Parameter/Variable Read Statement | Input Parameter/Variable Data to be Given |
|---|---|
| IGEN | 1 |
| IPRNT1 | 0 |
| NTYPE NOPT | 1 0 |
| NRE | 1 |
| MM | 2 |
| SITNA | KARUN-4 |
| SITNO | SITE-1 |
| IRENO | 1 |
| NOS | 0 |
| NSURC | - |
| NFLM | 0 |
| IFLM | - |
| MMFS | - |
| FLOW | 571 342 |
| FLOW1 | 2*0 |
| FLOW2 | 2*0 |
| P | 2*0 |
| WS | 2*0 |
| NVAR | 11 |
| ITHMI | -1 |
| NCOLR NCOLI NCOLP | 3 0 4 |
| ICOLR | 1 3 5 |
| ICOLI | - |
| ICOLP | 6 7 8 10 |
| XK1 | - |
| XK3 | - |
| IRP | -1 |
| IRFMI | -1 |
| LRFMI | - |
| QSFMI | - |
| IRJP | - |
| YD | 1176 |
| XNETA | 0.506 0.494 |
| COEFF EFFCI | 2.6 0.885 |
| ALPHA | 0.64 0.61 |
| HEAD | 2*150 |
| TIME | 2*720 |
| C11 OM11 | 147.4 16 |
| A2 C21 OM21 | - |
| A3 C31 OM31 | .55 122.5 66.7 |
| A4 | - |
| A0 AA | 10 0.009 |
| ET | 0.30 0.09 |
| ISAL | -1 |
| NVAAL | - |
| IUP ILO IEQ | - |
| UL LM EQU | - |
| EQ | 1 1 1 0 1 1 1 |
| G | 0 |
| IBAR | 0 |
| SITNA | KARUN-3 |
| SITNO | SITE-2 |

| | |
|---|---|
| IRENO | 2 |
| NOS | 1 |
| NSURC | 1 |
| NFLM | 0 |
| IFLM | - |
| MMFS | - |
| FLOW | 366 270 |
| FLOW1 | 2*0 |
| FLOW2 | 2*0 |
| P | 2*0 |
| WS | 2*0 |
| NVAR | 22 |
| ITHMI | -1 |
| NCOLR NCOLI NCOLP | 3 0 4 |
| ICOLR | 12 14 16 |
| ICOLI | - |
| ICOLP | 17 18 19 21 |
| XK1 | - |
| XK3 | - |
| IRP | -1 |
| IRFMI | -1 |
| LRFMI | - |
| QSFMI | - |
| IRJP | - |
| YD | 930 |
| XNETA | .506 .494 |
| COEFF EFFCI | 2.6 0.885 |
| ALPHA | 0.64 0.61 |
| HEAD | 2*160 |
| TIME | 2*720 |
| C11 OM11 | 148 16.1 |
| A2 C21 OM21 | - |
| A3 C31 OM31 | .45 57.8 31.5 |
| A4 | - |
| A0 AA | 30 0.103 |
| ET | 0.25 0.07 |
| ISAL | -1 |
| NVAAL | - |
| IUP ILO IEQ | - |
| UL LM EQU | - |
| EQ | 1 1 1 0 1 1 1 |
| G | 0 |
| IBAR | 0 |
| IPRNT | 0 |
| IDSCO | - |
| IRDC IPDC | - |
| TIRRI | - |
| THRRE | - |