TECHNO ECONOMIC AND MANAGEMENT (TEAM) APPROACH TO RIVER BASIN PLANNING

A THESIS

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of

DOCTOR OF PHILOSOPHY

in

WATER RESOURCES DEVELOPMENT

By

MARYONO BONY

WATER RESOURCES DEVELOPMENT TRAINING CENTRE
UNIVERSITY OF ROORKEE
ROORKEE-247 667 (INDIA)

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **TECHNO ECONOMIC AND MANAGEMENT (TEAM) APPROACH TO RIVER BASIN PLANNING** in fulfilment of the requirement for the award of the Degree of Doctor of Philosophy, submitted in the department of Water Resources Development Training Centre of the University of Roorkee, is an authentic record of my own work carried out during the period from April 1989 to September 1993 under the supervision of Prof. (Dr.) G.N Yoganarasimhan and Prof. (Dr.) Bharat Singh.

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

(MARYONO BONY)

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

Bharat Singh
(BHARAT SINGH)
Prof.(Emeritus) Water Resources
Training Centre Development
University of Roorkee
Roorkee - 247 667 India

G.N. Yog
(G N YOGANARASIMHAN) 16 Sep 93
Prof. Water Res. Development
Training Centre Development
University of Roorkee
Roorkee - 247 667 India

Roorkee, Dated : 16 Sep 93

The Ph.D. Viva-Voce examination of Mr. Maryono Bony, Research Scholar has been held on 14 Feb. '94

Bharat Singh
Signature of Supervisor(s)

Signature of Director
WRDTC

T. Prasad
Signature of
External Examiner

S Y N O P S I S

Multiple reservoir planning and management related to water resources mobilization within a river basin involves numerous rather complex physical, technological, economic and social aspects. Often, the most difficult engineering aspect of such a management planning effort is the development of a near optimal combination of reservoirs and water use facilities, their sizing, and sequencing. For large water resources system, the difficulty of the task is primarily due to the large number of possible alternative development and management strategies added with uncertainty of water inflow into the supply system. Any methodological approach to analyze the system should provide a rational guideline to decision making concerning interdependent water supply projects, and the elaboration of equipment programs, ensuring coherence and efficiency of various projects taking into account, the economic, social and environmental aspects and provide an objective information of the related organisms.

For a large and complex system, a major challenge is to reduce the set of alternatives 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 alternatives with a mathematical programming technique to determine the most attractive alternative, then build a detailed simulation model of the most attractive alternatives. The simulation brings in the operation of various physical facilities, especially reservoirs which significantly influence the alternatives. Therefore a combination of screening, reservoir operations study and

simulation form an integrated approach to River Basin Planning and Management Study.

The development of quick screening and rough simulation model supported by stochastic reservoir operation models, one used for sizing of the individual reservoir and the other used for development of rule curve for use in the simulation is the subject matter of this study.

The specific problem is the screening of multiple reservoirs which is a subset of the river basin planning and is approached by a set of Techno - Economic and Management procedures called the TEAM-approach. The screening and sequencing of projects has been carried out by a two stage - two level - hierarchical analysis. In the first stage, development of discrete economically viable projects, satisfying regional aspiration and environmental and social constraints is carried out. In the second stage, sequencing of projects is formulated as a integer 0-1 programming problem and is solved by a two level hierarchical heuristic procedure.

A rough hydraulic simulation model is developed to examine the interaction of reservoirs. The distinguishing feature of this River Basin Simulation (RIBS) is its simplicity, the principles of allocation of water using a double sweep, once from upstream to downstream and then from downstream to upstream to meet all demands according to priorities and the reservoir management rules. Actual releases are affected from upper most reservoir downstream to account for return flows. The reservoir is zoned into components and each zone is assigned with release priorities. The double sweep concept is used to take maximum advantage of uncontrolled flows and allocation of reservoir waters under shortage conditions.

The operation of reservoir is studied both for fixing of storage for flood control in developing discrete project levels and also to evolve an optimal operation policy which can be incorporated into the simulation. Both these models are formulated as stochastic dynamic programming models and are solved by policy iteration and successive approximation.

A river basin LUSI - SERANG which is the eastern part of JRATUNSELUNA basin in Central Java Indonesia is analyzed to demonstrate the concept, efficiency and the appropriateness of the approach. The monthly critical flow sequence is used in initial screening and the historical inflow of 20 years is used in simulation and in deriving data for reservoir operation studies.

Based on the results, it can be concluded that the approach is simple and can easily be used to analyze River Basins with personal computers.

Several computer programs have been developed for supporting the screening, sequencing, reservoir operation and simulation studies. These programs shall be helpful in making task of analyzing river basin planning more realistic.

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(Maryono Bony)

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CHAPTER 1

MULTIPLE RESERVOIR SYSTEM PLANNING AND MANAGEMENT

1.0 INTRODUCTION

Basin resources planning has become an increasingly important concept in comprehensive planning of water resources in water deficient areas. 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, 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 program that will determine such an optimal development strategy.

Knowledge of the magnitude of physical phenomena relating to water resources and water uses, economic evaluation of different possible programs of development and the selection procedure of development program providing the best choice among different alternatives is the key issue in water resources planning. Within this frame work, multiple reservoir planning and management is a subset of the activities of river basin planning. The tools of calculation that can contribute to analyze such a system are the multi-reservoir screening and sequencing, detailed evaluation through simulation and setting up the operation plan consistent with planning. The context of the problem is shown in figure:1.1 within the over all river basin water plan activities. Various factors along with the system constraints and the mechanisms which link up data variables of planning and management are somewhat difficult to handle within a unique decision optimization tool. It is rather better to make use of composite mathematical instrument within the frame work of progressive approach of "Planning Project" that may enable the decision maker participate in the optimization orientation program.

1.1 APPROACH FOR MULTIPLE RESERVOIR PLANNING AND OPERATION.

The problem of multireservoir planning and operation consists of three separate but interrelated problems; screening of multi reservoir combinations, the timing and the system operation. An integrated, comprehensive model incorporating all the three aspects leads to an intractable large scale programming problem. The simplifying assumptions to make it tractable make the model detached from the realities of the world and the results are not adaptable to real world situation. Each of these problems being complex in itself is dealt separately, and various methods to integrate them have been reported in the literature.

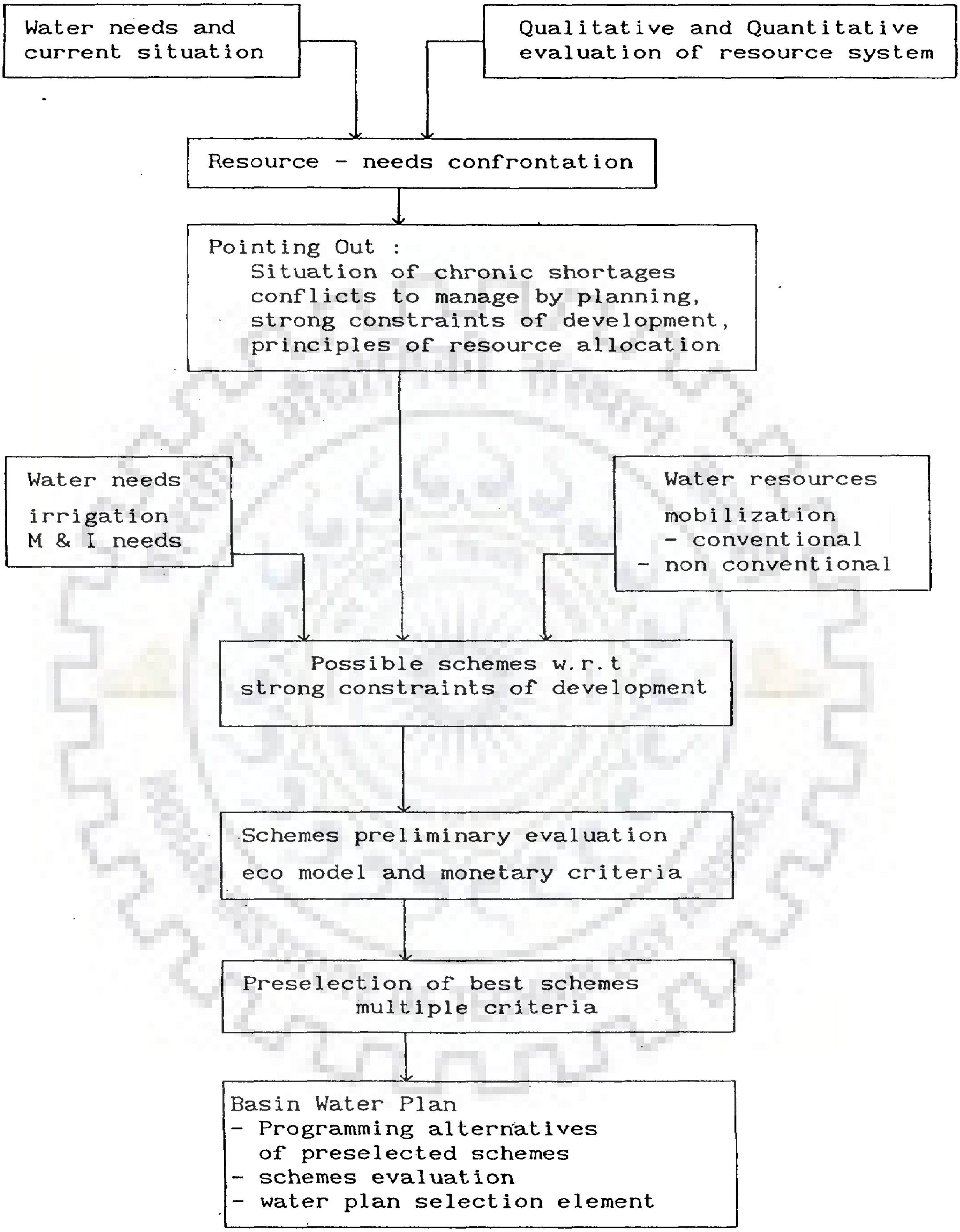


Fig 1.1 Overall River Basin Water Plan Activities.

Analysis of a multi reservoir system has evolved from consideration of a single engineering oriented one-by-one project to total system analysis with multiple objectives involving technical, economic, environmental and social considerations. For large and complex systems a major challenge is to reduce the set of alternatives 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 alternatives with mathematical programming techniques to determine the most attractive alternative. The concept of screening is used to identify economical variable and potentially efficient system configuration and component capacities. This is followed by detailed simulation has been widely accepted, but it is not without problems.

Several families of multi - reservoir screening models have been developed since 1962. These include the explicitly stochastic reservoir models, explicitly stochastic models based on linear decision rules and chance constraints on release and storage volumes. A different strategy for river basin screening model design is to incorporate implicitly in a model the probability distribution of natural unregulated flows by having the model's representation of system performance depend on either a historical or an average stream flow sequence. The simplest example of this approach is the use of average seasonal flows in a linear programming model of system operation. Deterministic stream flow sequences have also been combined with iterative use of dynamic programming models of reservoir operation to optimize size of reservoir and to set hydro power target, although this type ofmodel of system operation makes inefficient screening models because they do not identify optimal system component capacities and targets directly. Use of critical period hydrology, concept of single equivalent reservoir in certain specific configurations and the use of yield models are the simplified versions of the screening models. Large scale linear programming has been the favourate model for use in the screening process, although non linear models have also been attempted.

On the computation methods of solving such large scale mathematical programming problems, one comes across, column generation method, generalized upper bounding techniques, hierarchical or multistage computations including net work techniques, decomposition, aggregation and Lagrange function methods leading to dual based solution strategy.

Construction of an optimization model for all potentially feasible alternatives can be data intensive and an uphill task. Furthermore, the more complex the optimization model, the more difficult, it is to ensure that a global optimum has been found. On the other hand, simplifying the algorithm to avoid those problems can lead to planning errors. One solution to this dilemma is to use "rough simulation" for preliminary screening and to take care of the risk of overlooking attractive alternatives.

Various river basin models vary in their contents (incorporations of technical details, water use, and economic evaluation and appraisal criteria among others) and the rules of allocation of water and the model representation.

The timing or sequencing of multireservoir has been approached mainly through net work modeling and dynamic programming approaches. Most of these models are designed to identify a set of cost effective combinations and sequence of models to meet a specific demand with or without interaction of projects and budget constraints. Dynamic programming has been the most often used optimization technique for water resources optimal capacity expansion planning. The integer programming technique of branch and bound, non linear programming, search procedures and heuristic methods are also used.

The water supply of a particular reservoir system is assumed in most of these studies to be the sum of the firm supplies of individual storage facilities. This type of assumption may be approximately correct if the water use is for M & I water supply. It is well known, however, that by operating a group of storage facilities as an integrated system, the firm yields of the entire system can greatly be increased over the summation of individual reservoir yield and the reliability of supplies can also be improved. To more accurately estimate the firm yield of various reservoir systems, reservoir operational analysis has been incorporated directly into capacity expansion model based on rational operating rules which may not be optimal ones. Further the time aggregation to reduce computational effort make the operation policies unfit for adoption for long term operation strategy.

Reservoir operation is the integral part of reservoir planning. Operation studies are incorporated directly into the planning model with simplifying assumptions or indirectly through an iterative process. Further the operation policy is refined by trial and error through simulation. A reservoir operation policy specifies the amount of water to be released from storage at any time depending on the state of the reservoir, level of demands for conservation purposes, empty storage space to be allocated for flood control purposes, environmental requirement and any other information about the likely inflow into the reservoir in the finite future horizon. The conventional methods of the operation of reservoir are based on rule curves and reservoir zoning concept. In the deterministic optimal operation, the emphasis is on application of a methodology rather than on management of real systems. The important requirement in a multireservoir context is the determination of long term operation policies exploiting complementary operations taking into consideration the uncertainties of the inflow.

Monte Carlo method, explicit stochastic dynamic programming and the Markov models and a host of solution techniques to reduce the memory and computation efforts of dynamic programming have been the subject of research reported in the literature.

1.2 OBJECTIVE OF THE PRESENT STUDY

Recognizing the need of a simple, quick technique to evaluate the alternatives in an integrated fashion, this study is directed to develop a decentralized methodology to screen the multiple reservoir alternatives and sequence them and to test the functioning of the selected system by a rough simulation. Advantage is taken of the basic structure of the problem to decompose the problem into subsystems and their integration.

The scope of the work is :

(i) To develop a two stage two level analytical methodology to screen and sequence a set of multiple reservoir in a river basin.

(ii) To develop a rough hydraulic simulation which is essentially an allocation model.

(iii) To develop operation policy for the reservoir taking into consideration the uncertainty of inflows, which can be used for determining the flood storage and for specifying target storage levels for the simulation program.

(iv) Application of the methodology to analyze a multiple reservoir problem to demonstrate the concept of decentralized planning advanced in this study.

1.3 ORGANIZATION OF THE PRESENT THESIS

Consistent with the said objectives, this research work is reported in six chapters. The second chapter is devoted to a critical review related to the problems of screening, sequencing, simulation and reservoir operation within the frame work of multiple reservoirs planning and management.

A two stage - two level methodology to screen and sequence a set of multiple reservoirs is presented in chapter - 3 along with the details of the results of case study. Chapter - 4 presents a simulation model developed for rough hydraulic simulation of the behavior of the multiple reservoirs. The distinguishing features of the model are brought out and the operation studies of the set of projects screened in chapter - 3 are presented. Chapter - 5 is the development of stochastic dynamic programming model for the operation of a single reservoir. The operation of a single reservoir is relevant in a particular context of multiple reservoirs wherein the operation of the system is influenced in a significnt manner by a dominant reservoir of the system. The results of a case study are presented. The conclusions of the present study and suggestions for future work are presented in chapter - 6.

CHAPTER 2

SCREENING AND MANAGEMENT OF MULTI RESERVOIRS

2.0 INTRODUCTION

In many parts of the world good quality water is severely limited and is beginning to restrain economic devélopment. To provide for full water resources utilization, good comprehensive planning and total water management is needed. The planning considerations which are important are :

(i) To identify potential conflicts early in the planning stage and establish a method to resolve these conflicts.

(ii) Define the limits of money, time and human resources available and recognize that everything desired cannot be accomplished. Improve analysis to place projects in a priority listing for implementation. Top projects should give high economic return, produce environmental enhancement, and key social betterment.

(iii) More fully develop a long range planning approach that includes the selection of short term solutions. River valley projects in developing countries generaly have a long gestation period of the order of 12 to 18 years from the time the project is conceived to the time it is implemented. Scheduling for water resources planning studies, advance engineering, and design implementation must be such that a final product periodically solves a key problem in a reasonable time frame. Periodic updating of planning is necessary and this needs comprehensive quick analytic methods to screen the projects.

(iv) The current objectives must be fully recognized through out the planning process.

(v) Innovative planning is required to develop methods that give results in a shorter time and at lesser cost. It is necessary to ensure that the answers are within expected reliability.

Special emphasis is needed to define the limits of water and land resources so that they are not lost to the future by being stressed beyond the ability to recover from short term overuse. The planning should consider physical, environmental, financial and social impacts of the alternatives to arrive at a group of high quality plans from which the recommended solution can be selected.

2.1 MULTI RESERVOIRS SCREENING APPROACH

The concept of screening was introduced for analyzing large river basins with multiple resources and water uses to identify potentially better alternative, so that money, time and effort could be diverted to examine in detail the alternatives. This process is believed to identify cost effective and potentially efficient system configurations and component capacities which can be refined with marginal adjustments where necessary through detailed simulation models. Many screening models have been developed, majority of them being linear programming type for very obvious reasons of large number of variables involved in such problems and the availability of LP codes.

These screening models are static in construct and incorporate implicitly the probability distribution of natural unregulated flows in a model by having the representation of system performance of the model 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's (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 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. Major and Lenton (1979) 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 Major and

Lenton, the total reservoir capacity was increased to average 5.5 times that recommended by their screening model to obtain satisfactory performence. 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 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 flow 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. To model annual system operation, one can employ continuity constraints on annual storage volumes S_y^s and annual release targets Y^s.

$$S^{s}_{y+1} = S^{s}_{y} + Q^{s}_{y} + \alpha_{y}\, Y^{s} \; \ldots\ldots > y = 1,\ 2,\ \ldots,50,\ldots$$
$$s = 1,\ 2,\ 3,\ \ldots\ldots$$

where, Q^{s}_{y} are the 'historical' annual inflows at each site and α_{y} is discussed below. also :

$$12\, D \le \Sigma_{s}\, Y^{s} \; \ldots\ldots\ldots\ldots > \forall\, y$$

where, D is the monthly demand. Finally one defines required "over year" storage capacity requirements K^{s}_{over} by constraints

$$0 \le S^{s}_{y} \le K^{s}_{over} \ldots\ldots\ldots\ldots\ldots \forall\, y, s$$

often many of the constraints expressing continuity, can be combined without affecting the model solution.

Here the α^{1}_{y}s are 1 for all years y, except those in which failures are allowed. The number of years m in which the target release should be provided to achieve a specified annual reliability can be estimated using a probability distribution; α^{1}s can be set to indicate a specified release failure. Once a design is obtained and its operation is simulated, a more appropriate value could be selected. The failure years are selected by trial and error so as to minimize the sum of the required over year storage capacities K^{s}_{over}.

Within - year system operation is modeled as follows. Continuity of within - year storage volumes that are needed in addition to stored water described by the over-year storage variables satisfy.

$$S_{t+1}^{s} = S_t^s + \beta_t^s \quad Y^s - Y_t^s \; \ldots\ldots\ldots\ldots \; \forall \; t,s$$

where, β_t^s and Y^s represents critical within-year inflows discussed below and Y_t^s are within-year releases.

Subject to :

$$D \le \Sigma_s \; Y_t^s \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \forall \; t$$

The necessary storage capacity K^s at each site is constrained so that :

$$S_t^s + K_{over}^s \le K^s \; \ldots\ldots\ldots\ldots\ldots\ldots \; \forall \; t,s$$

thus making the upper bound on S_y^s redundant.

The critical within-year inflow in period t is approximated as $\beta_t^s Y^s$.

For high levels of development the final year in draw down sequence need not have abnormally low flows. In this formulation of the model the critical within year flows may be assumed to be Y^s with $\beta_t^s Y^s$ arriving in each month t. Two reasonable values of β are;

(i) The β_t^s can be the ratio of the inflow in period t of the driest year of record to the total inflow in that year, or

(ii) β_t^s can be the ratio of the mean monthly flow $\bar{Q}_t^s$ to the mean annual flow at each site; of these two, the earlier one appears to be better in terms of satisfying the specified reliabilities.

Another family of models which can also be used for screening are those based on Linear Decision rules and chance constraints on release and storage volumes.

Since their introduction by Revelle et al(1969), a combination of chance constraints and linear decision rules has held promise of producing relatively small, explicitly stochastic, reservoir system screening models.

Revelle et al suggested that reservoir screening models can be constructed by using a linear release rule of the form :

$$R_t^s = S_t^s - b_t^s$$

where, b_t^s is a decision parameter and S_t^s is the initial storage volume at site s. This is usually referred to as S type policy. The functional form and the implicit objectives that form reflects are not well suited to many water supply problems, still this did not prevent many to consider and extend the concept (Nayak and Arora-1971, Leclerk and Marks, 1973, Loucks and Dorfman 1975, Houck - 1979, Houck et al 1980, Houck and Datta 1981)

Continuity combined with Linear decision rule leads to

$$R_t^s = Q_{t-1}^s + b_{t-1}^s - b_t^s$$

so that $$S_t^s = Q_{t-1}^s + b_{t-1}^s$$

The physical requirement that $0 \leq S_y^s \leq K_s$ is replaced by two approximation chance constraints

$$P\,[0 \leq S_t^s\,] \geq r \ldots\ldots\ldots\ldots\ldots\ldots\ldots \forall\ t,s$$

$$P\,[S_t^s \leq K^s\,] \geq r \ldots\ldots\ldots\ldots\ldots\ldots\ldots \forall\ t,s$$

If minimum storage recreation targets or reserved flood control storage targets are appropriate, they too can be incorporated in the model by replacing zero and K^s by the appropriate values. The last three equations are equivalent to

$$-b^s_{t-1} \leq Q^{s,1-r}_{t-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \forall\ t,s$$

$$-b^s_{t-1} + K^s \geq Q^{s,r}_{t-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots \forall\ t,s$$

Here $Q^{s,1-r}_{t-1}$ and $Q^{s,r}_{t-1}$ are the 100(1-r) and 100r percentile of the inflow distribution in period t at site S. Like wise, the releases R^s_t must be non negative, so it was mandated that :

$$P\ (0 \leq R^s_t\ ) \geq r$$

or equivalent by $b^s_t - b^s_{t-1} \leq Q^{s,1-r}_{t-1} \ldots\ldots\ldots \forall\ t,s$

Finally, the total release in each period was considered to exceed the target with a (monthly) reliability of at least :

$$P\ \left[\sum_s R^s_t \geq D\right] \geq \delta \ldots\ldots\ldots\ldots\ldots\ldots\ldots \forall\ t$$

$$\text{or} \quad D + \sum_s (b^s_t - b^s_{t-1}) \leq \left[\sum_s Q^s_{t-1}\right]^{(1-\delta)}$$

where, $\sum_s Q^{(1-\delta)}_{t-1}$ is the 100 $(1-\delta)$ percentile ofthe combined inflow distribution.

Loucks (1970) suggested a linear decision rule of the form :

$$R^s_t = S^s_t - Q^s_t - b^s_t$$

Which referred to as SQ type, with this rule, releases in each period t at site S depend on the immediate inflow Q_t^s as well as the initial storage level S_t^s , with this

$$S_t^s = b_{t-1}^s$$

So that storage variables are no longer random variables and the physical operating constraint

$$O \le S_t^s \le K^s$$

can be enforced with a cent percent reliability and the other equations corresponding that in S type model are :

$$b_t^s - b_{t-1}^s \le Q_t^{s,1-\delta} \quad \ldots\ldots\ldots\ldots\ldots \forall\ t,s$$

$$D + \sum_s (b_t^s - b_{t-1}^s) \le [\sum_s Q_t^s]^{1-\delta} \ldots\ldots\ldots \forall\ t,s$$

The overall Linear Decision rule-model performance is reported to be disappointing. The storage requirements are always over estimated.

It is also reported by Stedinger (1983) that the LDR policies on which chance constrained screening models are based are very inefficient operating polices for water supply problems, perhaps with reserved flood control storage and minimum recreation targets. They are poor in the sense that for given reservoir capacities, the reliability with which they can provide the minimum release target is less than that which can be obtained by Space Rule and the total short fall incurred by the policies is substantially greater than that incurred by the Space Rule. Given the unrealistic operation policy upon which the screening models are based, one seems to have little assurance that the identified reservoir capacities will be cost efficient.

2.2 DECOMPOSITION AND MULTILEVEL OPTIMIZATION

There is substantial interest among the researchers to analyze large system such as a river basin by decomposition techniques based on multilevel optimization. The several advantages of such a technique have been neatly summarized by Haims. The theory of decomposition and multilevel optimization was developed by Messorovic, Wismer, Lasdon and others. The important advantages of the technique are;

(i) Conceptual simplification of complex systems.

(ii) Reduction in dimension.

(iii) None of the system model functions need to be Linear

(iv) Simple programming and computational procedure.

(v) Each subsystem can be handled with suitable optimization technique.

(vi) Central to the computational procedure is the duality theory of non-linear programming, in particular the economic interpretation of Lagrange multipliers.

(vii) Appropriate for the regional planning.

(viii) Handle multi-objective functions.

The summary of the decomposition theory and multilevel optimization follow Wismer. A large system is decomposed into two or more subsystems and arranged in hierarchy at different levels. These subsystems are analysed independently and coordinated at higher level through analysis of compiling variables and additional variables. Although there are many different ways of transforming a given constrained problem into multilevel subproblems, they are all essentially combinations of two approaches;

(i) Model coordination method (or feasible method)and

(ii) Goal co-ordination method (or dual-feasible method).

The main difference between goal and model co-ordination methods is that in goal co-ordination method dual feasibility is maintained, while in model co-ordination method, solution remains primal feasible all through the iterative process. For either approach, the overall system optimum is reached by;

(i) Adopting a two level structure with different problems solved in each level and results transferred from one to another,

(ii) Decomposing the system into subsystems by identifying interacting and non interacting variables, with the set of non interacting variables (and relationships) , subproblems related to each subsystems are created, and solved independently at the lower levels (first level), with input information about the interaction variables from the higher levels (second level). This information concerning interaction variables is either an estimate of their actual value (model co-ordination), or their price (goal co-ordination). Subproblem results for each subsystem are then used, at each iteration, by the second level to generate an improved and new estimation of interacting values, until no further improvement of the overall objective function is possible.

These two methods of co-ordination are explained below:

2.2.1 Model Co-ordination Method (M-CM)

Consider the system shown in Figure.2.1 below:

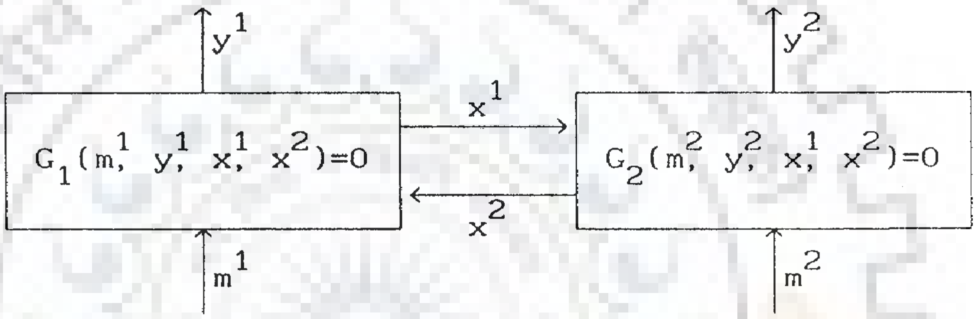


Figure: 2.1 Example of coupled system

where : m = vector of manipulated variables,

m^i = the vector of manipulated variables for subsystem i

y = Vector of output variables for the system,

y^i = Vector of output variables for system i,

x^1 = Vector of interaction variables from subsystem 1 to subsystem 2, and,

x^2 = vector of interaction variables from subsystem 2 to subsystem 1.

Let the static system of equations be :

$$G\ (m, y, x) = o, \text{ where } G \text{ contains } G_1, G_2$$

Let the objective function which is to be minimized be :

$$P(m,y,x) = P_1(m^1, y^1, x^1) + P_2(m^2, y^2, x^2)$$

It may be noticed that the overall system performance function is the sum of the two subsystem performance functions. So, the overall problem is :

$$\text{Min } P(m,y,x)$$

$$\text{S.T. } G(m,y,x) = 0$$

Even when the performance function may be separated into two non interacting functions, there is an interaction because of interaction variable x which affect and both subsystems. The model co-ordination method converts this integrated optimization problem into a two level problem by fixing the interaction variable ; that is :

$$\text{Constraint } x = z$$

Under these assumptions the problem may be split as follows :

First level problem :

$$\text{Determine } H(z) = \text{Min } P(m,y,z)$$

$$\text{S.t.} \qquad G(m,y,z) = 0$$

Second level problem :

$$\min_{z} H(z)$$

being x constant = z in the first level subproblem.

First level problem is solved by finding values of m and y, for a given z, that minimize P and satisfy G.

Define S_1 = (Z/H(z) exists), that is, the set of all z such that the system equations are satisfied and the minimum of the objective function is finite. If the original problem (integrated) has a solution, then S, is not empty and contains (at least) the point z = x optimum. The procedure works sequentially. It first estimates a value of z at the second level; that information is used then by the first level to determine the values of m and y for x = z. The first level transmits then to the second level those value of m and y and this level produces in turn a better estimation of the interaction variable, x, etc. Then the solution of the optimization problem proceeds in an interactive fashion between the two levels.

Figure.2.2 below shows the information flow between first and second level

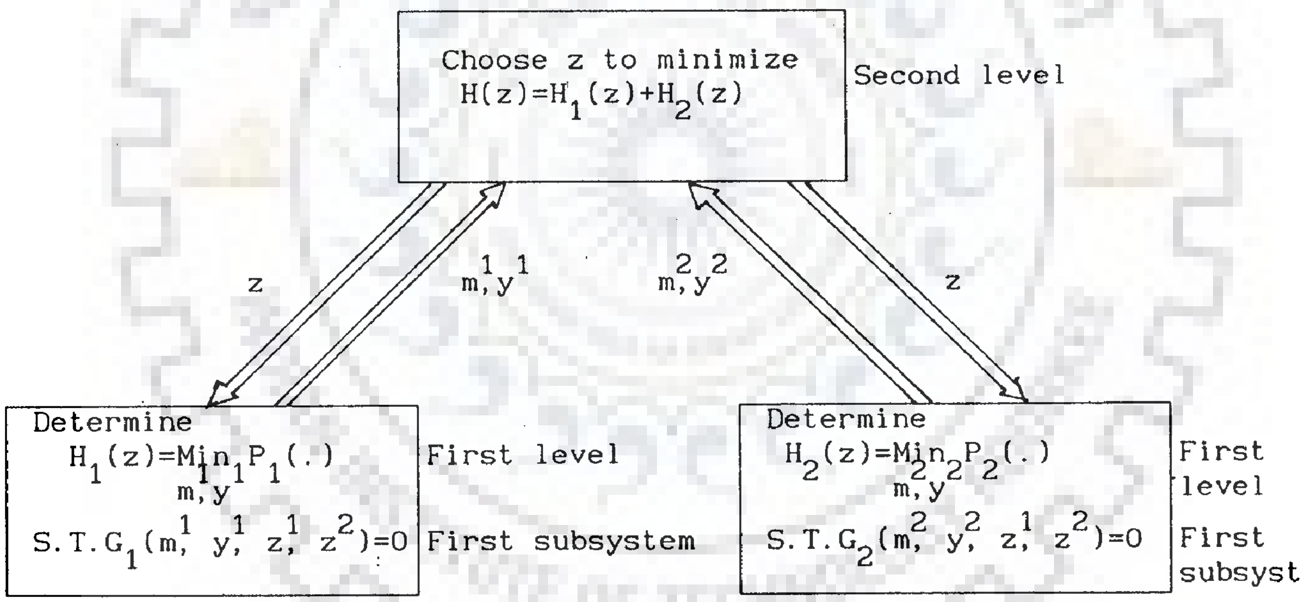


Figure: 2.2 Multilevel solution using model coordination

First level problem for sub system i :

$$H_i(z) = \underset{m^i y^i}{Min} \; P_i \; (m^i, \; y^i, \; z^i \;)$$

$$\text{S.T.} \qquad G \; (m^i, y^i, z^1, z^2 \;) = 0$$

The second level problem is to choose z as to minimize

$$H(z) = H_1(z) + H_2(z).$$

The various minimizations are to be done over the appropriate sets, so that the minimum exists. It is to be noticed that z = x is always feasible so that the system could actually be operated at those intermediate values.

2.2.2 The Goal Co-ordination Method (G-CM)

The goal co-ordination method removes the interactions by "cutting" all links between subsystems. This is shown in the figure.2.3 where the outputs of a Subsystem which are inputs to another are labeled x^i as before, but the corresponding inputs are labeled z^i; that is, z^i and x^i need not be equal. More over, z^i are now, variables and must be, like m, y, and x by optimizing the subsystem.

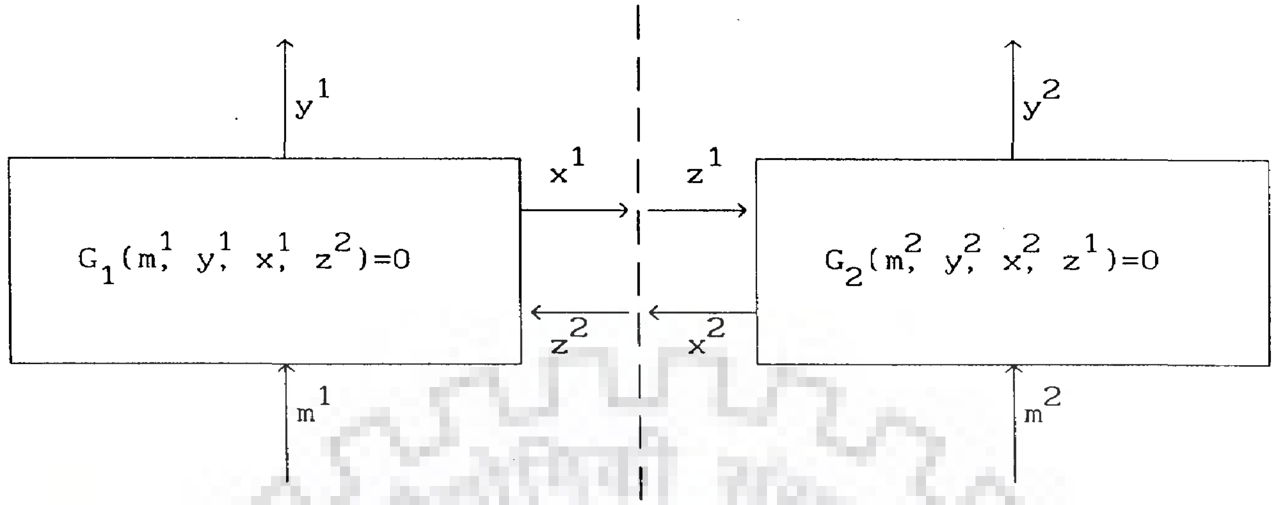


Figure: 2.3 Decoupled system

This decouples the two subsystem completely and since objective function was already decoupled, there is no interaction in the system at all. So in order to ensure that the independent subsystems yield the overall system optimality, it is necessary that the "interaction - balance principle" be satisfied, that is, the independently selected x^i and z^i must be equal.

The multi level formulation of this problem cuts the interacting tables to create a first- level problem which can be easily decomposed into independent Subproblems to arrive at a solution for which the interaction-balance principle holds.

Consider in addition a penalty term which penalizes the performance of the system if the interactions do not balance :

$$P(m,y,x,z,\lambda) = P_1(m^1,y^1,x^1) + P_2(m^2,y^2,x^2) + \lambda\ (x-z)$$

where, λ is a vector of weighting parameters. With the introduction of z, the system equations are now :

$$G_1\ (m^1, y^1, z^2, x^1) = 0$$

$$G_2\ (m^2, y^2, z^1, x^2) = 0$$

Minimizing the objective function (with penalty term) over the set of allowable system variables results in a function of λ :

$$H(\lambda) = \underset{(m,y,x,\lambda)\text{feasible}}{\text{Min}}\ P\ (m, y, x, z, \lambda)$$

Again $S_1 = \left[\ \lambda \mid H(\lambda) \text{ exists} \right]$. By expanding the penalty terms :

$$\lambda(x - z) = \lambda_1(x^1 - z^1) + \lambda_2\ (x^2 - z^2)$$

The first level Sub problems can be separated into

Subsystem 1 :

$$\underset{(m^1, y^1, x^1, z^2)}{\text{Min}}\ P_1\ (m^1,\ y^1, x^1) + \lambda_1 x^1 - \lambda_2 z^2$$

$$\text{S.T} \qquad G_1(m^1, y^1, x^1, z^2) = 0$$

Subsystem 2 :

$$\underset{(m^2, y^2, x^2, z^1)}{\text{Min}}\ P_2\ (m^2,\ y^2, x^2) + \lambda_2 x^2 - \lambda_1 z^1$$

$$\text{S.T.} \qquad G_2(m^2, y^2, x^2, z^1) = 0$$

Where the Goals of the individual subsystems have been modified in that co-ordinating variables λ enter into each subsystem goal. Just as before, the task of the second level is to determine the values for these fixed or coordinating variables. Again, the numerical solution is iterative with the two levels altering solutions of their associated problems. Figure. 2.4 shows the Subproblem definitions and the interaction between levels.

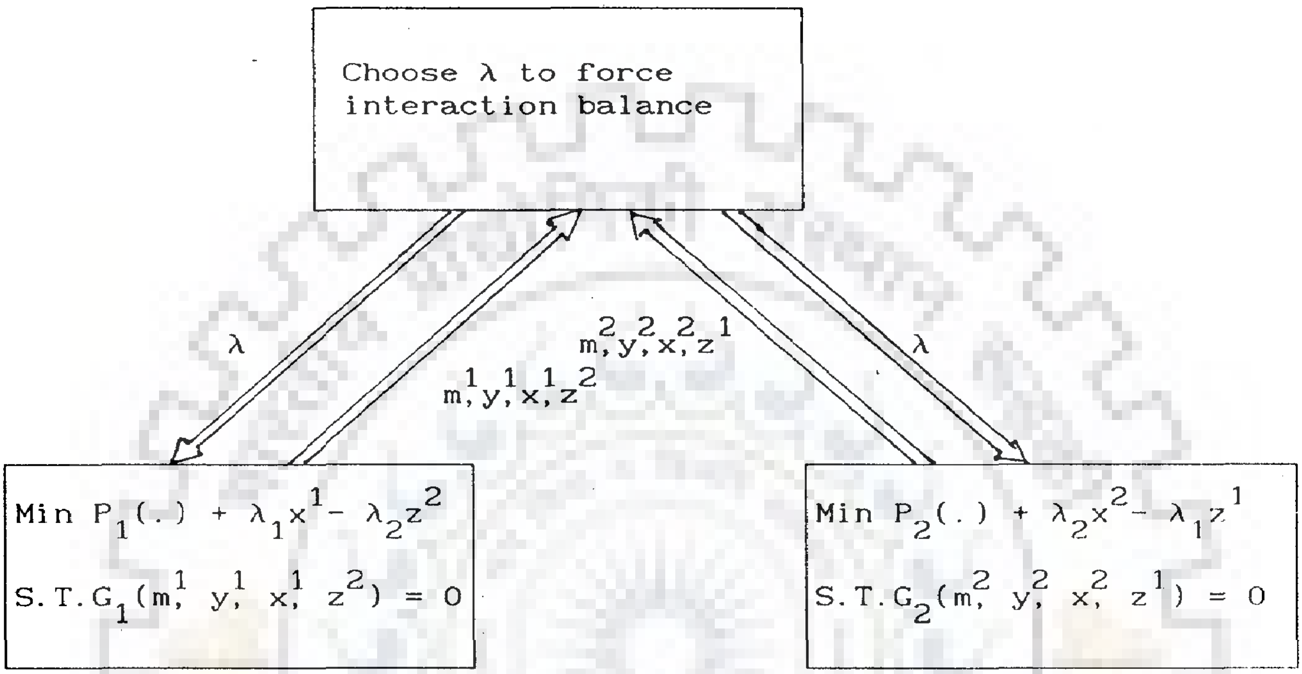


Figure: 2.4 Multilevel solution via goal coordination

First level problem :

Determine H (λ) by minimizing

P (m,y,x,z)

Second level problem :

Choose λ such that solution to the first problem results in satisfaction of the interaction - balance principle ; x = z How to choose the interaction variable.

Goal co-ordination - λ^* - Assume $P = \sum_{i=1}^{N} P_i \, (m^i, y^i, x^i, z^i)$ is to be minimized, where N = number of subsystems. The integrated problem may be written :

$$\text{Min} \quad P$$

$$\text{S.T.} \quad G(m, y, x, z) = 0$$

$$x^i = z^i \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \forall i$$

Assuming the existence of feasible solutions and a minimum for the overall system, the objective is to find that optimum by searching for a saddle point of the constrained problem. Therefore, form the Lagrange function ;

$$L = \sum_{i=1}^{N} \left[P_i + \lambda_i \, (z^i - x^i) \right]$$

The goal - coordination fixes the Lagrange multipliers and form the first - level Subproblem as :

i^{th} Subproblem :

$$\text{Min} \left[P\,(m^i, y^i, x^i, z^i) + \lambda_i \, (z^i - x^i) \right]$$

$$\text{S.T} \; G(m^i, y^i, x^i, z^i) = 0$$ Constraints set associated with i^{th} - subsystem.

Since each of these subproblems after minimization, is a dual function depending only on λ, the resulting function can be written as $h_i\,(\lambda)$ and the dual function for the integrated problem as :

$$H\,(\lambda) = \sum_{i=1}^{N} h_i\,(\lambda)$$

Second level problem :

Maximization of dual function $H(\lambda)$ over its domain :

$$\text{Max}_{\lambda} \; H(\lambda)$$

If the functions P_i are continuous, then directional derivatives of H (λ) exist and may be calculated. That is,

$$\nabla_{\lambda_i} H(\lambda) = (z^i - x^i)$$

Where notice that the gradient for the Second Level Co-ordinator is simply the "Unbalance of the interaction variables". From an economic point of view, Z^i are the demand by the i^{th} Subsystem and X^i are the Supply from the i^{th} Subsystem and Second-level unit attempts to match Supply and demand. The Lagrange multipliers enter each individual fist-level Subproblem linearly and act like prices adding or subtracting from performance function. The Second-level goal Co-ordination modifies prices of the interacting variables in order to obtain the overall System optimum.

At interaction K+1, the new λ_i is obtained by putting

$$\lambda_i^{k+1} = \lambda_i^k - \text{step} * \nabla_{\lambda i} H(\lambda) \text{ or}$$

$$\lambda_i^{k+1} = \lambda_i^k - \text{step} * (x^i - z^i)$$

Model Co-ordination $\rightarrow x^* (= z^*)$

Here the integrated problem is converted to a multilevel problem by fixing the interacting variables at prescribed values, say Z^i.

i^{th} Subproblem :

Determine $h_i\ (z^i) = \text{Min}\ P_i\ (m^i, y^i, z^i)$

S.T. $\quad G_i\ (m^i, y^i) = \text{feasible} \ldots\ldots\ \forall\ i$

Second level problem :

$$\mathrm{Min}_z\ H\ (Z)$$

Since the second level minimizes its objective function, gradients of H(z) can be used.

Write $P_i = P_i\ (m^i,\ y^i,\ z^i)$, and if P_i and its partial derivative with respect to Z^i exists

$$\nabla_{z^i} [\ h_i(Z)\ ] = \nabla_{z^i}[\ P_i(m_o^i,\ y_o^i,\ z_o^i\ )\ ]$$

Which is simply the gradient of P with respect to z^i evaluated at the optimum $(m_o^i,\ y_o^i\ )$ at iteration k+1 ;

$$z_i^{k+1} = z_i^k + \text{step} * \nabla_{z^i}\ [\ h_i\ (Z)\ ]\ ,\quad \text{or}$$

$$z_i^{k+1} = z_i^k + \text{step} * \left[\sum_{i=1}^{N} \frac{\partial p_i}{\partial z_j} \right] \ldots\ldots\ldots\ldots \forall j$$

where, j goes from 1 to the number of elements in vector z and $\dfrac{\partial p_i}{\partial z_j}$ is the dual variable associated with the constraint $x = z_j^k$ at iteration k.

2.3 APPROACHES TO CAPACITY EXPANSION PLANNING :

Planning system expansion involves decision of which project type to build, what project capacity to build, and when to build it - i.e. sizing, timing, and sequencing alternative projects. The purpose of model is to select and schedule construction of the set of reservoirs that expand a water supply system efficiently. Its value is an aid to planners and decision makers in comparing the economic consequences of alternative strategies.

Several mathematical programming techniques have been used to solve the water supply expansion problem. For example. Butcher et al (1969) presented a minimum present cost sequencing strategy for known project capacities and costs, then used dynamic programming and assumed each project was independent from the others.The system was designed in such a way that all projects were needed to meet demand requirements within the planning horizon. Morin and Esogbue (1971) modified the work of Butcher, et al (1969) to solve a much more general class of problems, i.e. the scheduling problem. In addition, they developed a more efficient algorithm for alleviating the "curse of dimensionality" inherent with the traditional dynamic programming approach. Morin and Esogbue (1972) introduced the multipurpose aspects of river basin planning into capacity expansion scheduling models.

Young, Mosely, and Evenson (1970) used simulation to time and squence elements of construction in a multi reservoir system. Alternatively, Riordan (1971) developed a general multi-stage capacity expansion model using dynamic programming to solve the dynamic investment - pricing problem of a publicly owned or regulated monopolistic enterprise. He also applied his general model to urban water supply system, Riordan (1971), Gysi and Loucks (1971) extended the works of Riordan with a study of the effects of water - pricing policies on consumer benefits and system costs. Later, Jacoby and Loucks (1972) used combined optimization and simulation models in river basin planning.

Erlenkotter (1973) developed a dynamic programming model for the study of hydro electric potential of a river basin, with the objective of meeting given projected power demand requirements at minimum discounted cost. His model considered the interdependent nature of the projects which implies system capacity is not necessarily sum of component capacities.

Tsou, Mitten and Russel (1973) developed a heuristic searching method for finding the sequence of projects that cater to a projected growing demand at minimum or near minimum discounted cost. They developed a ranking index which depends only upon the total output of the project under consideration, but not on the other candidate projects. Morin (1974) developed guide lines for the optimality for Tsou, Mitten and Russels (1973) search method and suggested extension to a more general scheduling problem.

Trott and Yeh (1973) developed an incremental dynamic programming-successive approximations method that calculates optimal operations for a reservoir system in conjunction with optimal capacities of reservoir, while optimal capacities of reservoir under consideration were determined by a gradient search procedure. Becker and Yeh (1974) in recognizing the facts that; (1) Firm water, not the storage capacity, is the product demanded as system out put; and (2) firm water output depends strongly on hydrology, optimal operation and system configuration, developed an efficient algorithm for sequencing and timing. A similar algorithm to that developed by Becker and Yeh (1974) was presented by Jacobsen (1974) for the solution to the small scale dynamic plant location problem. The forward dynamic programming algorithm developed by Becker and Yeh (1974) and later independently, by Jacobsen (1974) is now recognized as OSDP (One Shot Dynamic Programming) in the field of capacity expansion. Jacobsen (1974) has demonstrated that the OSDP algorithm is superior and flexible when compared to other available methods. ErlenKotter (1975) presented an interesting comment on this particular algorithm. Becker and Yeh (1974) later extended the algorithm to a multiple objective model.

Roger and Lee (1975) attempted to solve the water resources investment problem with an adaptive strategy dynamic programming model. They maximized the net social (economic efficiency) benefits where benefits were estimated by the 'willingness to pay' criterion and projects were assumed to be independent and project output were additive.

Morin and Marsten (1975) reported a hybrid dynamic programming/branch and bound approach for solving a class of sequencing problems. Their approach improves computation efficiency by reducing the computer storage and time requirements. Erlenkotter and Rogers (1977) developed a project sequencing model that allows operating costs to influence the timing decisions for project establishment and suggested a dynamic programming solution procedure. Mathematical models also have been reported by Martin (1975), and O'Laoghaire and Himmelblau (1974) for complex water resources Planning.

Most planning models use a demand requirement that is fixed and known throughout the planning horizon in their optimizations. These models do not consider the price at which the product will be sold. In fact, such models inherently assume that demand is independent of project cost and related product prices. Those models that did consider price variability assumed that they could add to the system optimality or that system capacity is the sum of individual plant capacities. The model presented by Nancy Young, Moore and William Yeh (1980) modifies Becker and Yeh's algorithm by incorporating a price - sensitive demand curve that changes with time.

2.4 HISTORICAL PERSPECTIVE OF SIMULATION IN WATER RESOURCES :

As early as the 19^{th} 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.

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 investigating at most one reservoir and one irrigated area or one hydropower station. 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.

Simulation of large river basins began in 1953 with the study of hydropower on the main stream of the Missouri river by the U.S. Corps of Engineers (1957). The first full river basin simulation was performed in the Nile basin in 1955 by Morrice and Allen [Morrice - 1958, Morris and Allan, 1959]. 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 program took place, as described by Mass et al (1962). This program 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 multiproject system.

The simulation modeling work of the Harvard water program 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. Fiering (1967) later presented some further discussion of simulation technique on the Lehigh Basin. The Lehigh Basin simulation model and its extensions, the Delaware Basin simulation model (1961 - 1965) are two examples that show the influence of the earlier Harvard studies. In the years intervening, many surface water models for river systems analysis have been developed, HEC-4 and HEC-5, developed by the US, Army Corps of Engineers, are two examples of the more widely known models developed by the Army Corps of Engineers.

A series of river basin simulation models have been developed by the water resources division of the Department of Civil Engineering at MIT. The model described in detail by MC Bean et al

(1972) was the first model and was developed for use as part of the MIT Argentina project on the river Colorado (Major and Lenton - 1978). An improved version was developed by Schaake (1974). The Final version which provided the basis for MITSIM is a further improvement on Schaake's model including multi purposes, multi objective, ground water as a source of water supply, and detail information on both physical and economic system performance.

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. SIMYLD-1, SIMYLD-II, SIM-III, SIM-IV, AL-2, AL-3, and AL-4 are the models developed as a part of this study. These are documented in a series of reports released by Texas water development Board, (1974). These models differ from the models mentioned earlier in two respects. In the first the irrigation, its production function and distribution of water under scarcity condition was highlighted. The second is a sort of optimization concept introduced by presenting the river basin to conform to a network and thereby adapting the algorithms that were available for network analysis such as the Out of Kilter Algorithm. The Out of Kilter Algorithm (OKA) developed by Fulkerson (1961) is a primal-dual linear programming procedure that can be applied to a capacitated network flow problem. In an OKA simulation of a water resource system, water allocations within a system are represented by allocation "arcs". Each of these arcs is defined by three parameters ; (1) lower bound of flow; (2) upper bound of flow; and (3) Cost per unit of flow. Since OKA is minimal cost network flow algorithm, water will be allowed to those arcs with lowest cost parameters. In other words, those arcs with the lowest cost parameters have the highest priority of allocation. Therefore, the cost parameter is usually the "priority factor" with the high priority meaning low unitcost and this will be used as a driving tool to specify priorities of allocation within the system. SIM-V and Al-V are the latest version of these models (Martin (1981) and (1982))

2.5 RESERVOIR OPERATION :

The development of methods to define reservoir operating rules has been the focus of research for many years. Many of these methods are covered in the text books like that ofLoucks et al (1981). These methods can be classified by such characteristics as the type of optimization solution procedure used (e.g. linear programming and dynamic programming), the characterization of stream flows, (e.g. an explicitly stochastic model like Markov lag one, or a single deterministic sequence), and the form of operating rule (e,g a look up table or an equation). Yakowitz (1982) discussed in detail the role and suitability of dynamic programming in reservoir operations. Yeh (1985) reviewed the state of the art of reservoir management models. Since then, there have been other advances in this area including the work of Stedinger et al, (1985), Wang and Adams (1986), Karamouz and Houk, (1987) and others. This work focuses on the class of methods that has been called explicitly stochastic incooperating a conditional probability function and stochastic dynamic programming. Some of the published work on the application of stochastic optimization models to reservoir scheduling are reviewed. This review does not include many notable deterministic models, such as those developed by Becker and Yeh (1974).

For the purposes of the analysis, the models are classified according to their assumptions concerning the amount of information available to the decision maker at the time decisions are made.

In general, the planning horizon is divided into discrete events ($t = 1,2, \ldots, tt$), during which decisions are made. The models are used to derive decision rules for each period which gives an optimal decision based on the information available at that time.

The formulations differ in their assumption as to which past, present, or future flows are known to the decision maker at the time he specifies releases (or storage levels). At the time the releases for a given time period, t, are determined, it may be assumed that the flows for certain periods are known with certainty having been either observed or accurately forecast. For flows beyond these initial periods, it is assumed that only the probability distribution (possibly conditioned on observable parameters) is known.

2.5.1 The different formulations are the following :

1. Perfect information - The decision maker has foresight of the flows over the entire planning horizon (past, present and future flows are known). The optimal release, r_t, for each period t, is a function of the flows in all periods; $r_t = r_t(f_1, f_2, \ldots f_{tt})$. The policy produced is anticipative.

2. Accurate short - term forcast - At the beginning of each time period, the decision maker determines the course of action with exact knowledge of the flow for a specified number of time periods into the future (past,

present and limited future flows known). The optimal release for each time period, t is a function of the flows in the first (t+s) time periods, in which s is the length of the fore cast : $r_t = r_t\ (f_1, f_2, \ldots, f_{t+s})$

3. Observe flow then determine release - The decision maker observes the flow for a given time period and all preceding periods before he determines the releases and ending storage for those periods. None of the future flows are known (past and present flows known). The optimal release is a function of only the past flows and the flows for the current time period : $r_t = r_t(f_1, f_2, \ldots, f_t)$

4. Determine release then observe flow - The decision maker specifies the releases for each time period before the flow for that time period is observed. He has exact knowledge of only the flow in preceding time periods. The end of the period storage level depends on the yet to be observed flow. The decision maker could alternately specify the end of period storage with the release being determined by the random flow (past flows known). The optimal release depends on only past flows $r_t = r_t\ (f_1, f_2, \ldots, f_{t-i}\ )$

5. Full commitment - The decision maker specifies a deterministic sequence of releases or storage for the entire planning horizon before any of the flows are observed (no flows known) the optimal release or storage level is invariant with respect to flows.

The results obtained from a stochastic optimization can be very sensitive to the formulation used. Loucks and Dorfman (1975) compared two linear decision rules in a chance constrained model. The first specified the release as a linear function of the initial storage; $r_t = S_t - b_t$, in which b_t is the decision parameter (a "make decision then observe flow formulation"). The second formulation expressed the release as a linear function of the storage and the current inflow; $r_t = S_t + f_t - b_t$ (an "observe flow then make decision "formulation).

These rules were compared in problems of determining the minimum storage capacity required to meet a specified release target.The first model yielded a required storage capacity of up to five times that yielded by the second.

For a given optimization problem, the five previously given formulations give successively less optimistic expected benefits.The underlying reason for the differences in expected benefits is the successive decrease in the information available to the decision maker.

The difference between the expected value of the objective function with the formulation 1 (perfect information), and its expected value with the formulation which most accurately reflects the uncertainty of the real world problem is the value of a perfect forecast of the future. This difference is often referred to as the value of perfect information, the economic impact of uncertainty or the loss from uncertainty perfect foresight - This formulation has been used by many authors. The decisions produced are anticipated and therefore, in the strict sense, foresight would be required to implement them. The objective function value produced by this formulation has an optimistic bias equal to the value of perfect information.

The users of perfect foresight models derive an approximation to the optimal non anticipative decision rules from the anticipative decision produced by the model. Two problems may be encountered :

1. The anticipative decision may show weak correlation with parameters known in the real world environment.
2. The optimal anticipative decision and the optimal non anticipative decision may not be similar.

Many examples of the perfect information formulation have been developed. Early examples are the single reservoir models of Hall and Howell (1963) and Young (1967). Hall and Howell applied dynamic programming optimal deterministic policies for a sample of flow sequences drawn from a synthetically generated hydrograph record. From the samples, the average draft for a given value of current storage and expected inflow was assumed to be optimal. Young used a similar approach but used least square regression to estimate the optimal policy from the optimal deterministic policies. In addition to the historical parameters of the system, he also used to forecast inflow as a variable in the regression.

Roefs and Bodin (1970) developed a multireservoir approach consisting of stream flow synthesis, deterministic optimization and multivariate analysis of the deterministic results.This model used Dantzig - Wolfe decomposition to solve the deterministic optimization problems. Croley (1974). Croley and Rao (1979) have developed single reservoir models which use the project information formulation. The classical mass curve technique analyzed by Klemes (1974) also is based on this formulation.

Accurate short term forecast - Models which explicitly use the "accurate short term forecast" are uncommon in the literature. Houck (1978) developed a chance constrained linear programming model in which the optimal policy is approximated by multiple linear decision rules. The linear decision rules express the optimal release for each period as a linear function of the storage at the beginning of the period. The rules can be conditioned on the flows of any of the time periods, including future time periods.Thus this model can be applied to an "accurate short term forecast" formulation.

2.5.2 Observe flow then determine Release :

An "observe inflow then determine release" formulation was proposed by Loucks (1975). He observed that knowledge of the current inflow is available at the end of each period and thus should be used in determining the current reservoir release. He proposed a linear decision rule in which the optimal release is approximated as a linear function of the initial storage and inflow for each period. Eisel (1972) also developed a chance constrained model in which the optimal release was a function of the initial storage and inflow for the period.

Takeuchi and Moreau (1969) developed a multireservoir model using this formulation. A dynamic programming model was employed with linear separable programming being used to solve the deterministic subproblems. In this approach they assumed that for any time period both the current loss function and the expected future loss functions, could be approximated as a separable piece wise linear function. Revelle Gundelach (1969) proposed a generalized linear decision rule in which the current release was a function of past and present inflows, as well as current storage.

The Acres multireservoir model developed by Sigvaldanson (1976) used an observed flow then determined release formulation. It uses the Out-of-Kilter optimization for optimizing the operation of the system during each time period by minimizing a collective sum of penalized deviations from ideal operating conditions.

2.5.3 Determine release then observe inflow :

This formulation is "Under anticipative" since it does not take into account all the information available to the decision maker. It assumes that a commitment must be made at the beginning of each period before flows are observed or a good forecast becomes available. There are numerous models based on this formulation. Many are application of stochastic programming methods such as Howard's (1960) policy iteration, Bellman's (1957) stochastic dynamic programming and Charne's and Cooper's (1959) chance constrained linear programming In this standard form, these methods use a "make decisions then observe stochastic variables" approach.They traditionally have been applied in areas such as inventory and production management where decisions often are made at the beginning of each period with no recourse (i.e., orders cannot be canceled) later in the period.

Buras (1965) developed a two reservoir stochastic dynamic programming model in which the optimal decision was a function of the storage at an upstream reservoir, a downstream reservoir, and the water in transit. Sweig and Cole (1968) developed a multireservoir stochastic programming model in which the optimal release depended on storage at the start of the period and whether or not the flow of the previous period was above or below average. Butcher (1971) developed a single reservoir stochastic dynamic programming model in which the optimal release was a function of the storage at the start of the period and the inflow of the preceding period.

In the linear decision rule approach of Revelle, Joeres, and Kirby (1969), Linear programming was used to develop rule which specified the release during any period as difference between the storage at the beginning of the period and a decision parameter for the period. Revelle and Kirby (1970) subsequently extended this approach to a formulation which based release commitments on storage and forecasted evaporation loss. The forecasted evaporation loss for the period was given as a separable function of beginning storage.

Joeres, Liebman, and Revelle (1971) and also Nayak and Arora (1971) extended the linear decision rule model to a multireservoir system. Eastman and Revelle (1973) presented a direct solution technique for the linear decision rule and a method of constraining reservoir storage within a season. Houck, Cohon and Revelle (1979) developed a multireservoir model which incorporated economic objectives and hydropower generation. This model also used a linear decision rule in which release is a function of current storage.

Askew (1974) developed a stochastic dynamic programming model in which reliability constraints limiting the probability of failure were heuristically imposed by adding a penalty for failure to the objective function. Rossman (1977) presented an exact algorithm based on a stochastic dynamic programming model with randomized release rules which maximized expected benefits subject to reliability constraints.

Both Askew's and Rossman's models expressed the optimal release as a function of the storage level at beginning of period.

CHAPTER 3

SCREENING AND SEQUENCING OF MULTI RESERVOIRS

3.0 STATEMENT OF THE PROBLEM :

Water resources development logistics is concerned with the effective management of the river waters, from upgrading to delivery of water to consumer at the right time and place. The acquisition of physical facilities such as dams, diversions, conveyance structures etc, is associated with what is referred to as strategic planning effort. The specific decision problem under consideration is a multi-reservoir system, where in an optimal combination of reservoirs and their sequencing is to be determined to meet the current and forecast growth in demand for water for irrigation, hydropower and municipal and industrial water supply. It is imperative to organize this effort in a well balanced form, allocating resources to those projects and level that offer the highest potential pay off.

An effective strategic model should be able to support the development of logistic policies to provide the top managers with a better understanding of decisions on design of new facilities and the capacity expansion of the existing water supply.

Specifically the strategic planning model should provide information on ;

(i) Evaluating different options for capacity expansion, and

(ii) Measuring economic consequences of capacity expansion.

The iterative planning effort in the multi-reservoir planning context is shown in the flow diagram Figure. 3.1, where in the specific component under consideration is also indicated.

The problem now is to develop methodology to identify the combination of socially acceptable multiple reservoir alternative to maximize the economic benefit, satisfying the system constraints and to sequence them to meet the resource constraint.

3.1 PROBLEM FORMULATION :

The problem formulation exploit the special structure of the multi - reservoir planning problem. The specific requirements are that although the live storage of any reservoir is a continuous variable, it is possible to identify discrete live storage requirements and the corresponding total storage including the dead storage, flood storage, surcharge storage and the free board to meet a specified demand which is economically viable. Further large scale transfers of water, although highly profitable and optimal from economic point of view, such transfers are not socially acceptable unless the proposed new reservoirs also meet the local requirements.

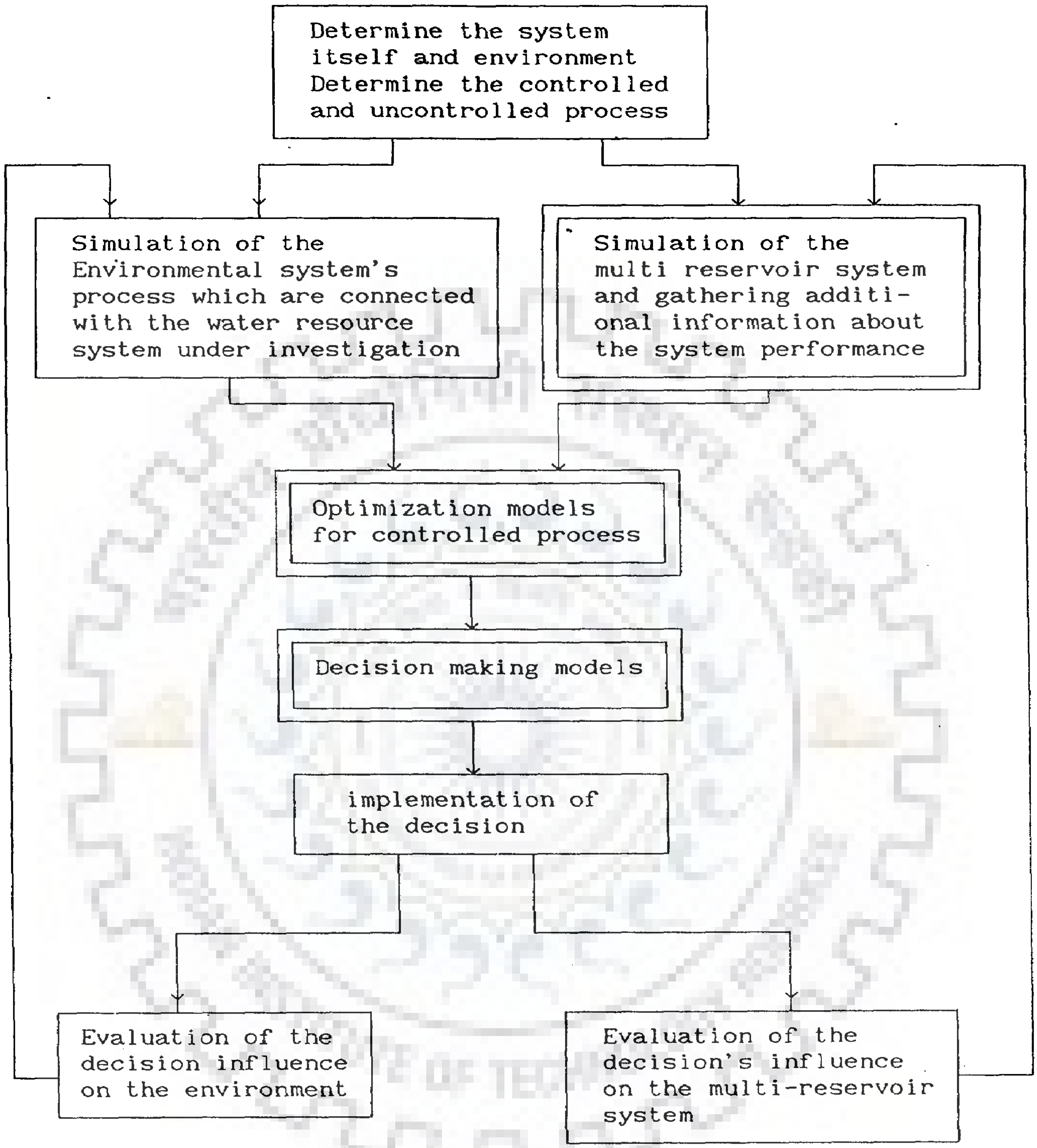


FIGURE 3.1 ITERATIVE PROCESS OF OPTIMAL CONTROL

With this specific requirements, the project selection and sequencing problem can be cast as a resource allocation decision problem as :

$$\text{Maximize} \sum_{I} \sum_{J} V(I,J) * X(I,J) \qquad (3.1)$$

Subject to:

$$\sum_{I} \sum_{J} A(I,J,K,L) * X(I,J) \leq B(K,L) \qquad (3.2)$$

For K = 1,2,3,....AR resource types and

L = 1,2,3,....,NP time periods

$$\sum_{I} \sum_{J} S\left[X(I,J),M\right] \leq Q(M) \qquad (3.3)$$

Fo M = 1,2,3.......NR organization constraints

$$\sum_{J} X(I,J) \leq 1 \qquad (3.4)$$

For I = 1,2,3,.........,N projects,

For J = 1,2,3,.........,NI

Where, NI is the number of versions of Project I, and

$X(I,J) = 0$ or 1. (3.5)

Here, V(I,J) represents the values or reward for under taking and successfully completing version J of the I^{th} project, and X(I,J) represents a decision to either select or reject version J of the I^{th} project.

When X(I,J) = 0, the version is rejected; otherwise it is selected. Here A(I,J,K,L) represent the amount of resource K required by version J of project I during time period L, the number of resources being considered is AR and the number of time periods being considered is NP. The number of organizational constraints is NR and the projects competing for the available resources is N. S is the function that relates the version to an organizational variable M, and Q is a dimensional equivalent of S in terms of M.

To avoid the problem of limiting each project to a single level of feasible funding, this model calls for differentiated exclusive versions of each project. A version of a project is an alternative manner in which the project can be undertaken during any one time period i,e a technical alternative route, an alternative schedule of resources versus accomplishment. Three types of constraints are defined, budgetary constraints, organizational constraints and exclusivity of versions. The first type represented by inequality (3.2), is the resource scarcity or budget constraint. The second type, represented by inequality (3.3), are organizational constraints involving dependence on projects, environmental restraints etc. The third type represented by inequality (3.4) and the integer constraint (3.5) together takes care of infeasibility of having two versions of the same project in the solution set.

This model is to be supported by another model which can generate economically viable discrete project versions or a combination of them. The variables related to a reservoir in formulating this problem are in Figure:3.2. These and other relevant variables are defined below :

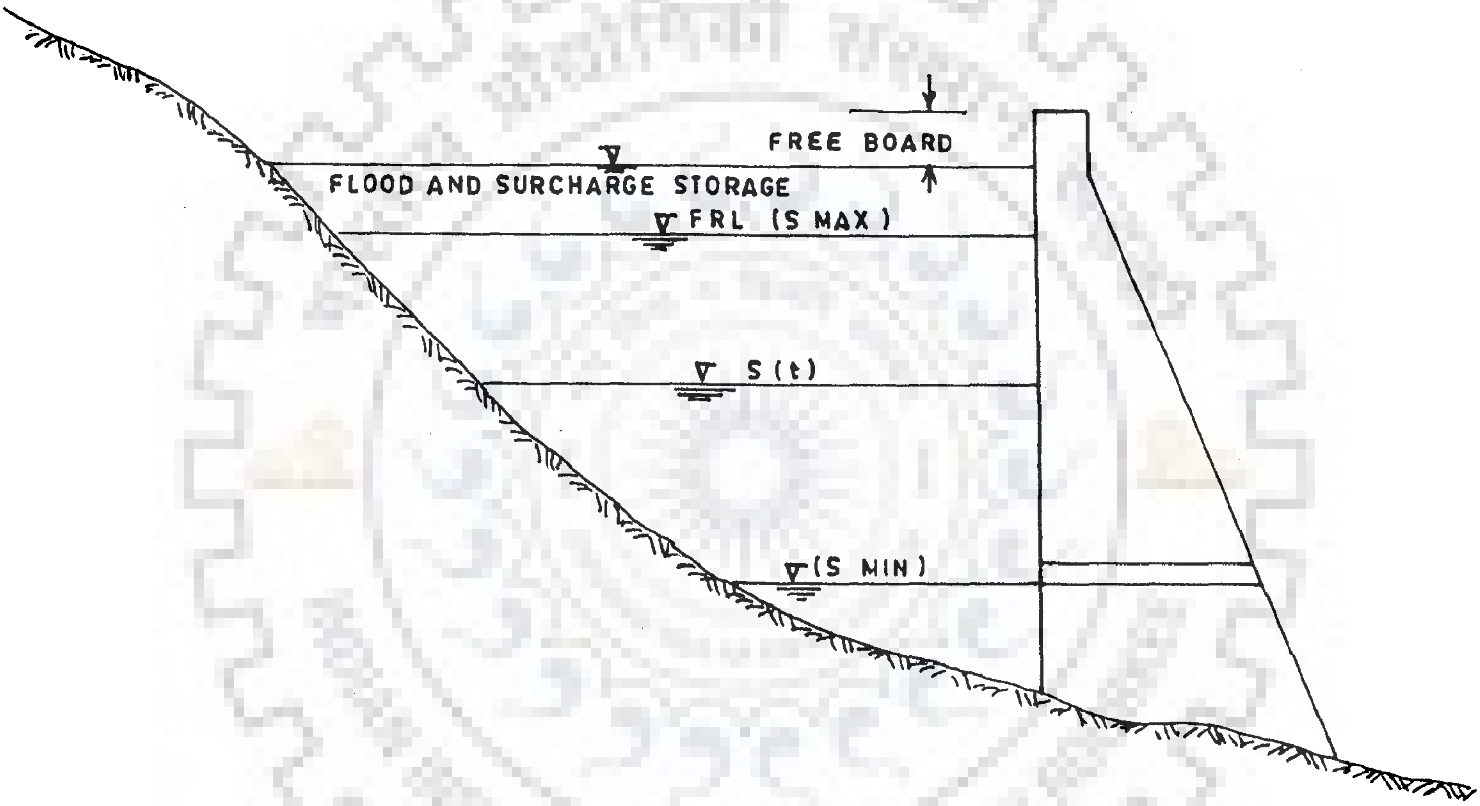


FIGURE 3·2

VARIABLES RELATED TO A RESERVOIR

1. **Reservoir related variables.**

S_j^{max} = The maximum storage capacity of the reservoir j

S_j^{min} = The capacity of the reservoir j corresponding to the dead storage level or minimum draw down level.

$S_{j,t}$ = Storage of reservoir j at the end of time period t.

$I_{j,t}$ = Random inflow into reservoir j during period t.

$R_{j,t}$ = Release through the power plant (or normal release from a non power reservoir) from reservoir j during period t.

$W_{j,t}$ = Release for M & I water supply from reservoir j during time period t.

$G_{j,t}$ = Release through the Spill / River outlets / by pass to maintain a maximum allowable storage in reservoir j during period t.

$EV_{j,t}$ = Evaporation from reservoir j during time period t.

$\lambda_{j,k}$ = a 0 - 1 variable equal to 1 if reservoir k release flows to reservoir j during the period t, equal to zero other wise.

m = Total number of reservoirs.

α_{ji} = a 0 - 1 variable equal to 1 if irrigation area i discharge return flow to reservoir j during the period t, equal to zero otherwise.

β_{ji} = a 0 - 1 variable equal to 1 if return flow from i^{th} M & I consumption centre discharge return flow to j^{th} reservoir.

2. **Irrigation related variables:**

L_i = Area irrigated under i^{th} irrigation district or region through out the period.

RF_{it} = Return flow from i^{th} irrigation district in the t^{th} period.

$\gamma_{i,j}$ = a 0-1 variable and is equal to 1 if i^{th} irrigation area is linked to j^{th} reservoir directly or equal to zero otherwise.

δ_{it} = Irrigation water requirement of the i^{th} irrigation region in t^{th} period net of effective precipitation.

$U_{j,t}$ = Volume of water diverted for irrigation from the j^{th} reservoir in duration t.

$A_{i,t}$ = Area irrigated under i^{th} district in t^{th} period.

$UCF_{i,t}$ = uncontrolled flow available for irrigation for i^{th} district and t^{th} time other than that available from releases from reservoirs including Spill.

$RFC_{i,t}$ = Return flow from the i^{th} irrigation district in the t^{th} period. per unit irrigation releases

Λ_i = Total cultivable command area under the i^{th} district.

$IR_{i,t}$ = Irrigation release for i^{th} district in the t^{th} period.

3. **Hydropower related variables:**

$P_{j,t}$ = Rate of energy generated (power) at the j^{th} reservoir in t^{th} period.

K_t = Unit conversion constant.

$H_{j,t}$ = effective head available for power generation.

$e_{j,t}$ = Combined overall energy conversion efficiency.

a_j, b_j = are constants of regression equation relating power generation during period t at reservoir j to the storage $S_{j,t-1}$

Fp = Firm power generated from the total system.

4. Flood control related variables:

$P\alpha_{j,t}$ = Probability level to be satisfied for the reservoir j, in period t.

$FC_{j,t}$ = the maximum $S_{j,t}$ in the reservoir j during time period t for absorbing flood.

5. M & I related variables

WD_j = M & I water supply to be met by the reservoir j.

3.1.1 CONSTRAINTS :

1. Reservoir constrains :

(i) Mass balance

$$S_{j,t} = S_{j,t-1} + I_{j,t} - R_{j,t} - W_{j,t} - G_{j,t} - EV_{j,t} - U_{j,t} + \sum_k \lambda_{jk} D_{kt} + \sum_i \alpha_{ji} R\,F_i + \sum_l \beta_{jl} R\,M_l \qquad (3.6)$$

Which states that the storage at the end of any time period is equal to storage at the end of previous period plus all possible inflows such as random natural inflow, sum of all the down stream releases from the upstream reservoirs linked to the particular reservoir including Spills and the return flows from all the irrigated areas and the M & I uses upstream of the reservoir.

Similar mass balance equations can be written without storage terms at all the junction points where in sum of all inflows is equal to release down stream and at diversion points sum of all inflows is equal to sum of all outflows including diversions to all uses.

(ii) Bounds on Storage :

For all reservoirs the storage has to satisfy specific upper and lower bounds i.e.,

$$0 \leq S_j^{min} \leq S_{j,t} \leq S_j^{max} \qquad (3.7)$$

Which specifies the non negativity of storage content at the time periods and also 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 S_j^{min} 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 time of the reservoir. These relationships are only empirical and are difficult to incorporate into mathematical model, if not impossible. S_j^{min} is also sometime 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 c and the corresponding storage as S_j^c and the sediment storage by S_j^s we can write:

$$S_j^{min} = \max \{S_j^c, S_j^s\} \qquad (3.8)$$

S_j^{max} is also governed by various factors. It is bound on the lower side by the compromized or uncompromized flood storage requirement and on the upper side by the topographic conditions of the site and the limits on land submergence and the social considerations.

(iii) Definition of Total Storage

Further the total storage is determined as the sum of S_j^{max}, the flood storage determined by routing of flood hydrograph of specified return period, the Surcharge storage and the free board.

$$V = \max\{ S_j^{max} + S_{j,t}^f + FB \} \qquad (3.9)$$

where, S_{jt}^f is the flood and surcharge storage and FB is the free board. FB is a function of the type of dam, Location of reservoir, its orientation and the lake size and its configuration.

2. Irrigation Constraints.

(i) For any i^{th} irrigation area, the amount of water supplied must supplement the uncontrolled flow if any to fully meet the water requirements of crops, for any area A_i directly linked to a reservoir.

$$U_{j,t} \geq \gamma_{ij} \; A_{i,t} \; \delta_{i,t} - UCF_{i,t} \qquad (3.10)$$

For an irrigation district supplied from multiple reservoirs directly.

$$\sum_j U_{j,t} \geq \sum_j \gamma_{ij} \; A_{i,t} \; \delta_{i,t} - UCF_{i,t} \qquad (3.11)$$

For an irrigtion district, the irrigation water requirements is to be met by down stream releases from a number of reservoirs.

The constraint takes the form.

$$\sum_j \gamma_{i,j} \; D_{j,t} \geq \sum_j \gamma_{i,j} \; (A_{i,t} \; \delta_{i,t} - UCF_{i,t}) +$$

$$\sum_l \gamma_{lj} \; (W_{l,t} - UCF_{l,t}) \; \ldots\ldots \; \forall i,l \text{ and } \forall i+1 \qquad (3.12)$$

(ii) Definition of return flow

$$IR_{i,t} = \sum_j U_{j,t} \qquad (3.13)$$

$$RF_{i,t} = RFC_{i,t} * IR_{i,t} \qquad (3.14)$$

(iii) Area irrigated through out the season

$$L_i \leq A_{i,t} \tag{3.15}$$

(iv) Land Constraint

$$L_i \leq \Lambda_i \tag{3.16}$$

In writing the above constraints some simplifying assumptions are made. With regard to water supply to crops there are two different concepts. One is the hydrologic point of view specifying evapotranspiration needs corrected for all types of losses such as conveyance application and non beneficial evapotranspiration, and the other one is the one dimensional production function concept which relates the total seasonal quantity of water to yield per unit area of crop. It is assumed here that these two approaches are consistent with each other, and the amount of evapotranspiration requirement is computed by one of the acceptable equations (in this case Modified Penman's).

3. Constraints Related to Hydropower:

(i) Basic Hydropower equation :

$$P_{j,t} = K_t \; R_{j,t} \; H_{j,t} \tag{3.17}$$

here, $H_{j,t}$ is to be computed as gross head which is a function of storage $S_{j,t}$ which is varying continuously with time and the tail water elevation which is a function of release minus the loss of head in conveyance system and the penstocks. At the planning stage a rough estimation of this loss is necesary. For some of the reservoirs where the water spread is large, it is possible to approximate the rate of power generation as linear function of storage as :

$$RP_{j,t} = a_j + b_j \, S_{j,t-1} \tag{3.18}$$

The non liniearity can be taken care of iteratively by assuming head and correcting it successively. Alternatively one can adopt the linear approximation suggested by Loucks et al (1981). In order to aproximate the product of storage and release in each period, the estimated values of these parameters in each period are provided as the starting point. The product $R_{j,t}$ $S_{j,t-1}$ can be expresed as :

$$R_{j,t} S_{j,t-1} = R^o_{j,t} \; S_{j,t-1} + R_{j,t} S^o_{j,t-1} - R^o_{j,t} S^o_{j,t-1} \tag{3.19}$$

where, $R^o_{j,t}$ = estimated release through the power plant from reservoir j during period t; and $S^o_{j,t-1}$ = estimated storage level of reservoir j at the end of period t-1.

Power generated as available is not quite valuable. It is necessary to define the firm power.

$$FP_j = \underset{t}{\text{Min}} \{ P_{j,t} \} \tag{3.20}$$

Alternatively FP_j can be defined as the specified fraction of the total power generated in different period as

$$FP_j = F_t \{ \sum_t \sum_j P_{jt} \} \tag{3.21}$$

where, F_t is a fraction. It may need a trial and error to arrive at a proper F_t. From this as available energy in excess of firm energy can be calculated.

4. Flood Control Constraints :

The probabilistic statement of flood control storage requirement can be stated as :

$$\text{Prob} \{ S_{j,t} \le FC_{j,t} \} \ge P\, \alpha_{j,t} \qquad (3.22)$$

This probabilistic statement can be converted to its deterministic equivalent as and the continuity equation can be written as :

$$FC_{j,t} - S_{j,t-1} + R_{j,t} + W_{j,t} + U_{j,t} + G_{j,t} + EV_{j,t} -$$

$$\sum_k \lambda_{jk} D_{kt} - \sum_i \alpha_{ji} RF_i - \sum_l \beta_{jl} RM_l \ge F^{-1}(P\, \alpha_{j,t}) \qquad (3.23)$$

where, F^{-1} (.) is the inverse CDF of $I_{j,t}$.

This necessitates the assumption of the independent or conditional probability distribution of the inflow.

5. M & I constraints :

The M & I demand must be fully met.

$$W_{j,t} \ge WD_{j,t} \qquad (3.24)$$

where, $WD_{j,t}$ is the specified M&I demand from reservoir j in time period t. When M & I demand is to be met by joint releases from reservoirs constraints similar to that of irrigation constraints needs to be specified.

6. Other Constraints :

These could be :

i) Minimum area to be irrigated in each district.

ii) Non negativity constraints.

The Objective is to :

$$\text{Max } Z : \sum(A_i P_i - A_i^o \hat{P}_i^o) - (A_i - A_i^o)\,\hat{P} + FP.B_p + B_f(FS) +$$

$$B_w(WM) - \sum C_j(V_j) - \sum C_i(A_i) - \sum C_p(H_p) \qquad (3.25)$$

The benefit of surface water irrigation is computed as the difference in annual net income with and without the project water. This involve calculating field level net return per hectare of land served with irrigation water. Benefits per hectare of land served were then defined as the difference in net returns between surface water irrigation and expected land use if no project were built.

The benefit of flood control is to be computed as the expected annual loss saved. The benefit of M & I water supply is very difficult to compute as the monetary benefit for unit of water supply is difficult to assign. It should be at least equal to the cost of alternative supply.

The cost coefficients are equivalent annual unit costs of storage, similar cost of water distribution and land development and the annualized unit cost of power house.

The unique formulation is intractable even for this supply sub system inspite of the simplifying assumption of standard water use policy for irrigation (i.e. set cropping pattern). The complication is not only of non linearities, but is also of their exact functional relationships and the iterative nature of the solution strategy. Further the uncertainty of the inflow adds to the complexity. This is usually taken care of either by Monte Carlo simulation, or use of critical hydrologic sequence followed by detailed simulation, or by chance constrained formulation setting reliabiity constraints or by stochastic programming.

3.2 SOLUTION METHODOLOGY :

The screening and sequencing problem is proposed to be solved by the following methodology.

1. In working the requirement that each reservoir or a group of reservoirs has to satisfy its regional requirements, each reservoir is approximately dimensioned by Lp iterations or incremental method using critical sequence of inflow.

2. The rough design of step 1 is refined by rough simulation and adjusted for flood control storage, sediment storage, surcharge storage and free board. This provides a set of discrete alternatives for each of the reservoirs.

3. If necessary where ever hydropower stations are there further adjustments are made for drawdown level corresponding to minimum cost per unit of energy.

4. A second stage two level heuristic procedure is now used to sequence the projects.

This heuristic procedure follows Toyoda's Algorithm (1975). Toyoda's Algorithm is designed to solve the problem; find the set of X(I), in order to :

$$\text{Max } Z = \sum_{i} V(I) * X(I) \qquad (3.26)$$

$$\text{Subject to } \sum_{i} A(I,K) * X(I) \leq B(K) \qquad (3.27)$$

for K = 1,2...... AR and

$$X(I) = 0 \text{ or } 1 \qquad (3.28)$$

For I = 1, 2, ...N. Where V(I) and B(K) must be positive A(I,K) is restricted to non negative values, the constraint (3.27) are then transformed to:

$$\sum F(I,K) * X(I) \leq 1 \qquad (3.29)$$

to achieve commonality of measurement among resources. F(I,K) is the proportion of the total resources K availability by project I.

Solutions are arrived at by the gradient method, which consist of the iterative movement toward the optimum through the choice of the most effective direction at each iteration. This effective direction is determined by the use of a penalty vector and a measure of each project's relative value.

If a project selection problem is modeled by letting X(I) represent the acceptance or rejection of project I in equation (3.26) through (3.28), the algorithm proceed as follows. Make T(U) empty, where T(U) is the set of accepted projects. Assign all projects to T(D), where T(D) is the set of all projects not in T(U). Let P(U) be a penalty vector with one dimension per resource. Each dimension keeps track of the cumulative usage of the resource. Then, to begin P(U) is a zero penalty vector : Let z = O where z is the objective function ; let every X(I) be zero, let T(C) be the set of all feasible project versions, where a feasible version will not use more resources than are available, and such that no other version of the same project is in T(U). IF T(C) is empty, the procedure terminates here : there are no candidate projects. The effective gradient for each project version is the basis for starting the algorithm. But since P(U) is set to zero, it cannot be computed, Instead the effective gradient G(I) of project I is computed as :

$$G(I) = \left[V(I) * (N^{0.5}) \right] \Big/ \sum_{k} F(I,K) \qquad (3.30)$$

This corresponds to temporarily substituting P(U) = (1,1,...,1), so that all the resources are given equal penalty. This procedure is used only for the first iteration of the procedure.

If P(U) is not set to zero, we may compute:

$$\text{Abs} [P(U)] = \text{Abs} \left[c(1), c(2), \ldots, c(N) \right] \qquad (3.31)$$

where, Abs[P] represents the absolute value of P, and c(K) the component K of vector P specifically :

$$\text{Abs}\left[P(U) \right] = \left[\sum [C(K)]^2 \right]^{0.5} \qquad (3.32)$$

$$U(I) = \left[\sum_k F(I,K) * C(K) \right] \Big/ \text{Abs} \left[P(U)\right] \tag{3.33}$$

$$G(I) = V(I) \;/\; U(I) \tag{3.34}$$

Some times :

$$\sum_k F(I,K) * C(K) = 0 \tag{3.35}$$

In such case, a large number is assigned to G(I) thus find that project q with the largest effective gradient G(q). Accept q ; that is, add it to T(U). Add P(q) to P(U), where P(q) is the proportional resource usage of each resource by project q. Add V(q) to z. Remove q from T(D), let X(q)=1 and continue to recycle through the above described operation until T(C) is empty. Once the top valued project is selected, an additional constraint must be added to eliminate the alternative version of this project from being selected at some other iteration.

3.3 CASE STUDY :

3.3.1 Project Area :

The methodology is applied to a river basin LUSI-SERANG - JRAGUNG-TUNTANG in Central Java and is shown in Figure. 3.3 Although integration of these river system may offer some benefit interms of irrigation there appears to be no interaction between LUSI - SERANG system, the JRAGUNG - TUNTANG, and the others. In view of this it is proposed to analyze LUSI-SERANG.

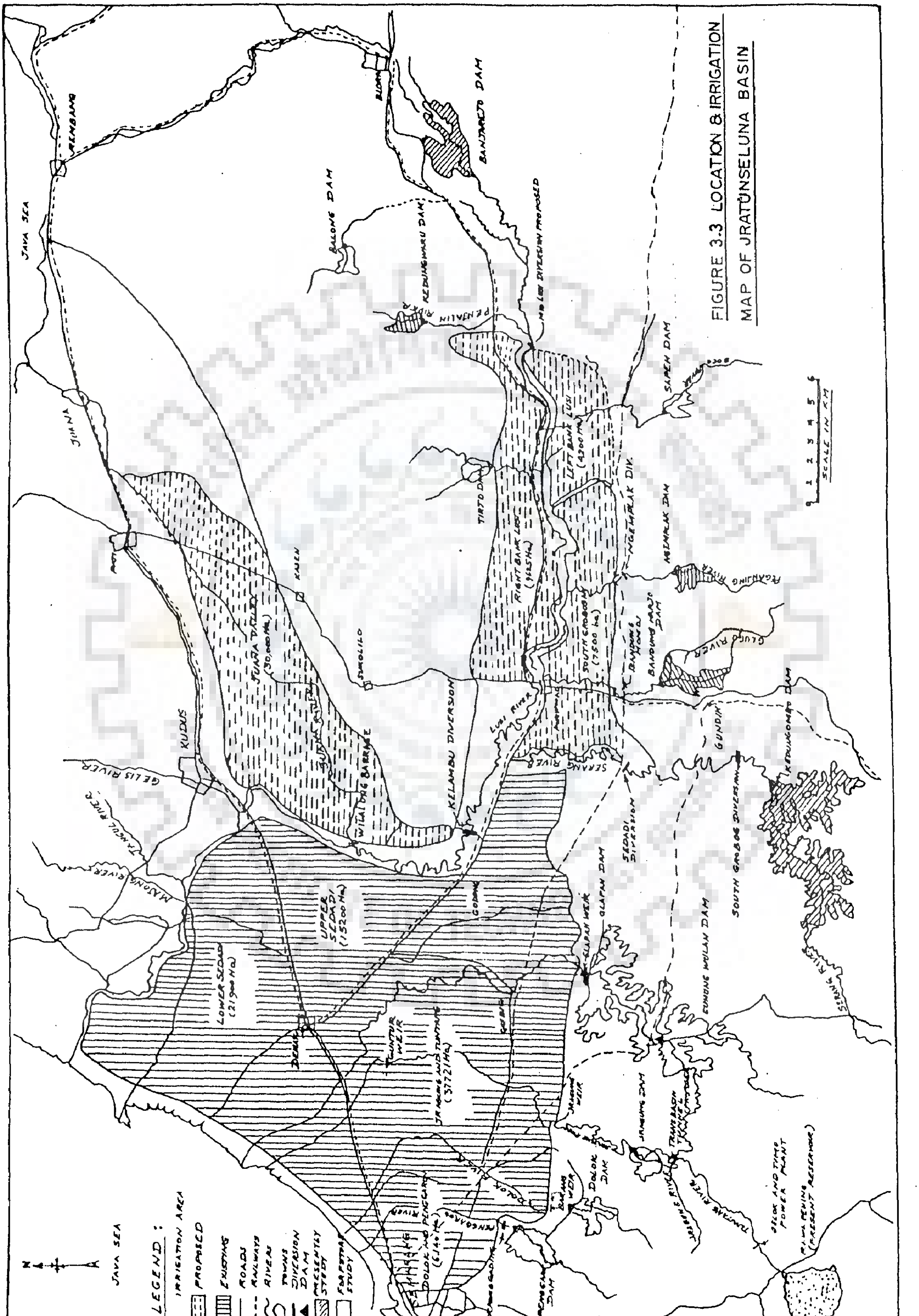


FIGURE 3.3 LOCATION & IRRIGATION MAP OF JRATUNSELUNA BASIN

The schematics of the river system is shown in Figure. 3.4. There are 8 reservoir possibilities in LUSI - SERANG basin. Out of these, 5 potential reservoirs are to be developed and the system is shown in Figure. 3.5. Table. 3.1 gives the details of these dam sites.

Potential irrigation area of the total system is 88,425 ha . All the diversions in this system are more or less complete. It is required to examine the technical feasibility, economical viability and sequencing of this basin development. The details of irrigation potential is given in Table. 3.2.

It is estimated that a total discharge of 5.5 m^3/sec is necessary to M & I supply in and around Semarang city. Out of this 3.5 m^3/sec will be drawn from LUSI-SERANG system. For the purpose of analysis, it is assumed that no reservoir has been constructed. In the actuality the Kedung Ombo dam and the power house at the foot of the dam is already completed.

3.3.2 Hydrology :

(i) Climate and Rainfall :

The climate of the area is consistently warm and humid but it is affected by the monsoon which produces annual wet (high rainfall) and dry (low rainfall) seasons. Monthly mean temperatures range from 26^{0}C to 28^{0}C and humidity ranges from an average of 70 % in dry season to an average of 85% during wet season. The wet season usually commences in late October or early November and lasts until May while the dry season is from June to September with May and October as transitional months.

FIGURE NO. 3·4
JRATUNSELUNA RIVER BASIN DEVELOPMENT
SCHEMATIC DIAGRAM

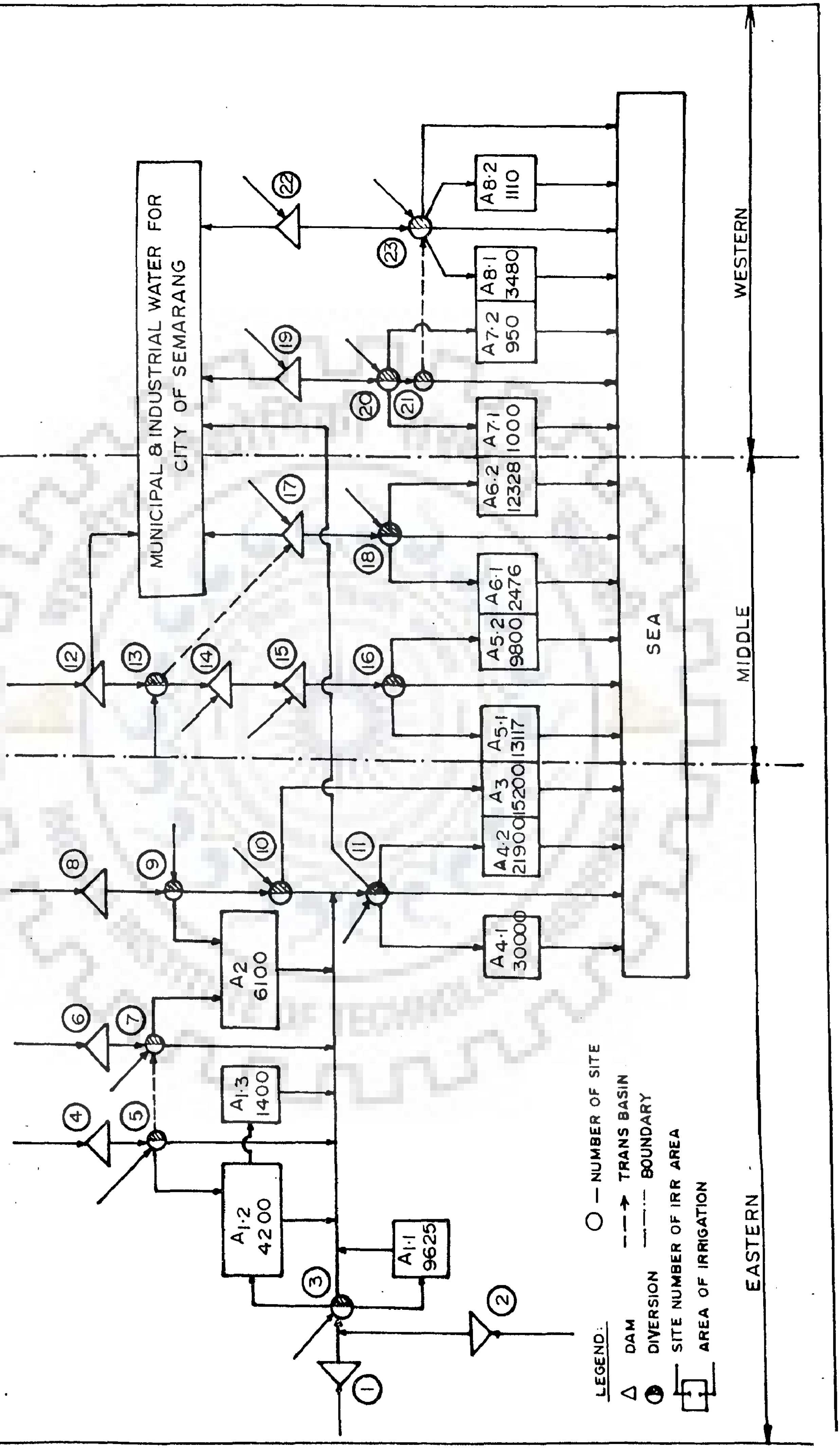


FIGURE 3·5

LUSI-SERANG

SCHEMATIC DIAGRAM

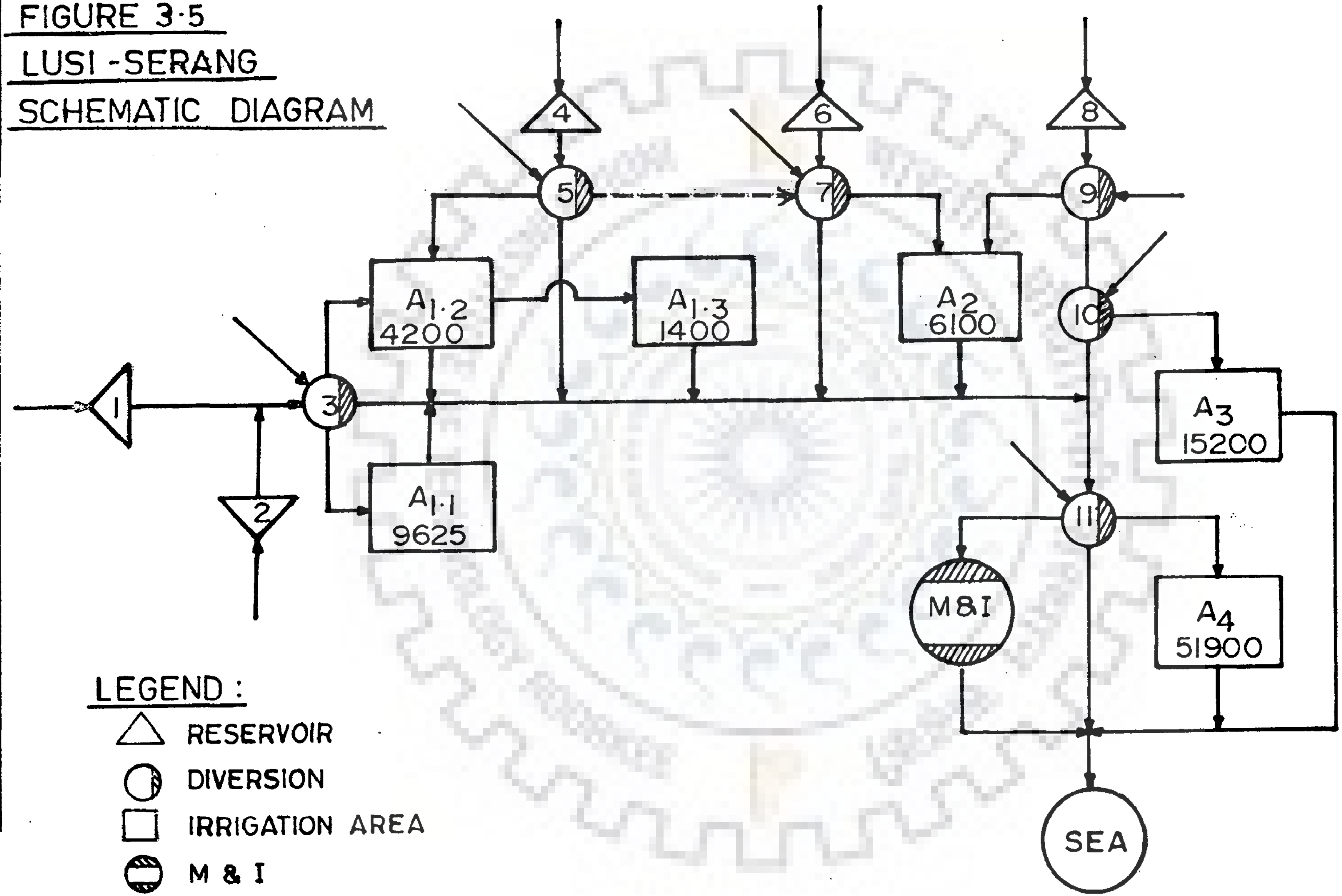


TABLE : 3.1. PERTINENT DATA & DAM SITES OF LUSI-SERANG RIVER BASIN

No. Description	CA Km2	Annual Yield (MCM)	Type of Reser.	Storage (M C M) Live	Dead	Gross
1.Banjarejo	506	411	II	77	23	100
2.Kedungwaru	88	79	IV,III	19	05	24
3.Ngemplak	73	71	III	68	22	90
4.Bandungharjo	41	40	IV,III	22	13	35
5.Kedung Ombo	614	728	IV,III	634.5	88.5	723

TBLE : 3.2. POTENTIAL IRRIGATION AREAS OF LUSI-SERANG RIVER BASIN

(UNIT :IN HA)

NO	AREA	NOTATION	LEFT	RIGHT	TOTAL	REMARKS
1	Lusi	A1.1	4200	9625	13825	
2	Ngemplak	A1.2	-	1400	1400	
3	Sidorejo	A2	-	6100	6100	
4	Upper Sedadi	A3	15200	-	15200	
5	lower Sedadi	A4.1	21900	-	21900	
6	Juana	A4.2	3700	26300	30000	
	Total		45000	43425	88425	

Annual rainfall varies from 1900 mm to 2450 mm in the service area, and from 2200 mm in dam site area to almost 3500 mm in the extreme south-west of the catchment area. The variation of rainfall from year to year is not large but there is a large variation between the wet and dry season rainfall. Data of 90% dependable rainfall for each service area are shown in Table 3.3. Data of climatological and meteorological observations from Gubuk station for the period 1968 to 1988 are given in Table. 3.4.

The calculation of crop water requirement has been made using Gubuk station data for the LUSI-SERANG irrigation area and the results are shown in Table. 3.5.

(ii) Stream flow :

The surface drainage of each proposed dam sites and diversions in the basin can be seen through Table. 3.6-1 to 3.6-11. Water level recorded data are observed and recorded daily at the existing diversion weir namely Sedadi weir (Site No.10) on Serang river.For the present study stream flow data has been taken for 20 years. The long term average monthly discharge at every proposed and existing dam and diversion structures are given.

3.3.3 Crop Water Requirement:

The water requirement of each crop has been calculated on the basis of evaporative demand of crop. It is mainly influenced by the climate, growing season, crop development, and agricultural and irrigation practices followed by the farmers in the project area.

TABLE: 3.3 MONTHLY RAINFALL OF SERVICE AREA

(90% DEPENDABLE OF RAIN FALL)

UNIT: MM

NO	SERVICE AREA	LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOT
1	LUSI	A1	183	164	164	77	26	15	0	0	1	43	142	202	1017
2	SIDOREJO/ SOUTH GROBOGAN	A2	162	166	166	102	22	13	0	0	4	36	153	232	1087
3	UPPER SEDADI	A3	230	129	129	68	2	9	0	0	1	7	110	214	1028
4	LOWER SEDADI & JUANA	A4	280	136	136	57	2	5	0	0	0	11	105	154	1052

TABLE: 3.4 METEROLOGICAL AND CLIMATOLOGICAL DATA

STATION: GUBUK (KAPUNG) LAT: 7 D.S ALT: 24 M

NO	MONTH	TEMPERATURE DEGREE C MAX	MIN	AVG	RELATIVE HUMIDITY MAX	MIN	AVG	RELATIVE SUNSHINE DURATION (%)	WIND SPEED AT 2.0 M (M/SEC)	PAN EVAPORATION (MM)
	JAN	29.2	23.9	26.6	97.0	65.0	81.0	55.0	5.83	90.00
	FEB	30.1	23.8	27.0	97.0	62.0	79.5	60.0	4.58	94.00
3	MAR	31.1	24.3	27.7	96.0	55.0	75.5	64.0	3.96	110.00
4	APR	32.3	24.8	28.6	95.0	50.0	72.5	76.0	3.13	113.00
5	MAY	32.8	24.5	28.7	95.0	47.0	71.0	81.0	3.13	121.00
6	JUN	32.4	23.9	28.2	94.0	41.0	67.5	84.0	3.54	97.00
7	JUL	32.6	23.2	27.9	94.0	40.0	67.0	90.0	4.79	109.00
8	AUG	33.0	22.7	27.9	93.0	34.0	63.5	89.0	5.00	151.00
9	SEP	33.7	23.5	28.0	91.0	33.0	62.0	88.0	5.00	170.00
10	OCT	33.4	24.0	28.7	92.0	37.0	64.5	83.0	4.17	159.00
11	NOV	31.9	24.1	28.0	95.0	45.0	70.0	71.0	3.13	112.00
12	DEC	30.9	23.8	27.4	96.0	57.0	71.5	58.0	3.54	100.00
	AVERAGE	32.0	23.9	28.0	94.6	47.2	70.5	75.0	4.15	119.00

TABLE: 3.5 CROP WATER REQUIREMENT

(UNIT : MM)

NO.	CROPS	CONTIND RICE-1	RICE-2				UPLAND CROPS *)				RICE-1		
	MONTH IRRIGATION AREA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1.	LUSI - A1	40	0	470	180	150	110	180	290	60	150	420	60
2.	SOUTH GROBOGAN/ SIDOREJO - A2	40	0	460	140	150	110	180	290	60	170	400	60
3.	UPPER SEDADI-A3	30	0	490	190	180	110	180	290	60	220	470	50
4.	LOWER SEDADI & JUANA - A4	40	0	480	210	180	110	180	280	60	220	480	60

NOTE : *) Upland Crops = Mixed crops betweeen maize and soybean

TABLE: 3.6-1 MONTHLY YIELD OF LUSI RIVER AT BANJAREJO DAMSITE

SITE NO. 1 UNIT: IN MCM

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1	87.6	55.4	59.2	72.8	40.7	1.6	10.1	1.0	0.1	1.3	32.9	79.8	442.5
2	88.9	108.4	49.6	44.8	35.2	10.9	15.2	8.2	4.9	13.9	37.1	38.3	455.4
3	80.4	92.4	66.7	73.1	45.8	24.1	8.1	8.7	3.2	11.5	59.9	61.9	535.8
4	72.0	52.7	47.1	38.4	34.2	33.2	10.3	23.6	5.2	13.1	17.4	44.2	391.4
5	44.2	46.0	110.9	31.9	16.4	11.4	26.5	5.9	0.1	2.6	16.8	85.7	398.4
6	65.1	117.3	89.5	38.6	7.6	15.3	13.7	11.0	4.6	12.6	19.4	85.2	479.9
7	34.0	76.4	72.0	34.0	62.5	13.2	8.3	0.9	1.8	2.1	20.7	90.8	416.7
8	77.7	63.4	56.5	46.7	36.4	9.8	2.6	2.2	2.8	3.5	45.6	64.8	412.0
9	70.4	83.2	46.9	48.0	18.7	7.8	0.9	0.0	0.6	1.6	16.1	68.6	362.8
10	72.3	92.9	43.4	81.1	6.6	10.1	9.8	6.9	1.5	21.4	34.0	45.8	425.8
11	80.4	106.0	50.4	24.1	8.9	2.6	0.0	0.0	1.4	3.2	8.8	74.2	360.0
12	32.1	41.1	50.6	46.4	35.7	7.3	12.2	4.6	19.0	7.5	46.1	50.1	352.7
13	81.2	49.8	67.0	41.2	19.7	1.8	5.1	0.6	0.0	1.6	12.7	90.5	371.2
14	46.9	33.9	79.8	18.1	31.1	12.7	0.9	0.4	5.7	6.4	23.8	80.4	340.1
15	72.9	33.6	44.5	44.1	6.3	0.0	3.6	0.0	1.9	6.2	21.0	85.2	319.3
16	69.9	56.1	51.2	41.0	68.8	36.3	31.0	12.7	3.6	7.8	29.7	62.4	470.5
17	62.9	72.1	79.8	35.8	10.6	8.0	1.3	0.4	6.9	6.2	21.3	34.0	339.3
18	60.0	47.9	88.7	54.2	23.5	10.9	4.7	0.6	4.5	7.8	19.2	49.0	371.0
19	85.4	53.2	47.4	22.8	77.9	20.5	13.1	0.0	6.3	13.7	33.7	59.5	433.5
20	76.3	44.8	76.3	28.5	49.6	2.6	0.0	3.5	0.2	0.5	22.6	50.6	355.5
MEAN	68.0	66.3	63.9	43.3	31.8	12.0	8.9	4.6	3.7	7.2	26.9	65.1	401.7

TABLE: 3.6-2 MONTHLY YIELD OF PENJALIN RIVER AT KEDUNGWARU DAMSITE

SITE NO. 2

UNIT: IN MCM

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1	9.2	8.2	8.0	12.0	4.0	2.9	1.0	0.1	0.3	0.9	5.5	8.4	60.5
2	11.1	16.3	6.5	9.6	3.8	3.8	1.9	4.9	1.9	2.6	6.7	11.2	80.3
3	14.4	19.4	13.3	15.3	9.2	4.8	5.3	1.5	0.2	2.5	8.0	11.6	105.5
4	10.7	10.4	10.5	4.5	4.4	11.4	1.1	3.9	2.1	3.4	5.0	7.6	75.0
5	6.0	8.1	15.4	7.0	3.7	3.1	9.6	0.9	0.1	1.5	4.0	13.0	72.4
6	8.5	13.9	25.2	8.9	2.9	1.7	5.5	4.1	0.7	3.0	2.3	17.4	94.1
7	11.8	18.7	25.4	4.0	14.3	2.2	3.6	0.5	0.5	1.1	3.3	10.0	95.4
8	18.4	12.8	5.4	10.6	3.7	0.3	0.6	1.2	0.7	0.8	9.3	13.5	77.3
9	20.2	10.5	7.2	7.6	6.4	1.5	0.1	0.0	0.0	0.6	3.7	7.5	65.3
10	22.6	13.4	10.0	10.3	1.7	2.0	5.6	5.2	1.3	2.7	6.4	9.8	91.0
11	16.4	14.8	9.7	4.8	3.5	0.7	0.0	0.0	0.2	1.1	2.4	12.3	66.1
12	11.2	11.9	10.5	9.9	7.3	2.4	0.4	1.2	4.5	4.0	6.3	8.6	78.2
13	19.7	10.2	13.3	4.3	3.4	0.4	0.9	0.2	0.1	0.0	1.0	11.8	65.3
14	15.0	11.7	18.0	3.0	5.1	2.7	0.2	0.4	0.8	1.4	4.0	7.5	69.8
15	19.1	7.3	8.4	11.6	1.1	0.0	0.0	0.1	0.2	1.4	3.1	16.0	68.3
16	13.0	8.7	11.5	7.5	10.5	3.6	9.0	4.5	2.1	1.5	6.7	11.7	90.3
17	9.1	12.5	17.5	9.3	3.6	1.3	1.3	0.6	0.7	1.5	3.5	9.5	70.4
18	12.4	8.2	13.9	9.8	6.3	1.8	0.8	0.0	1.4	0.6	5.2	8.0	68.4
19	16.7	14.8	14.1	8.6	9.3	5.7	0.4	0.0	1.1	4.2	4.8	10.2	89.9
20	18.6	8.7	16.9	5.4	5.7	0.0	0.0	1.6	0.0	0.2	4.8	9.6	71.5
MEAN	14.2	12.0	13.0	8.2	5.5	2.6	2.4	1.6	1.0	1.8	4.8	10.8	77.9

TABLE: 3.6-3 MONTHLY YIELD OF INTERMEDIATE FLOW OF LUSI RIVER AT MID LUSI DIVERSION

SITE NO. 3 UNIT: IN MCM

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1	92.0	82.9	53.6	63.7	38.3	0.0	9.5	0.9	0.0	0.5	29.7	74.6	445.7
2	81.4	96.4	45.1	37.0	32.8	7.5	13.9	3.6	3.2	11.9	31.9	28.6	393.3
3	69.2	76.7	56.1	60.7	38.4	20.3	3.1	7.5	3.1	9.5	54.3	52.9	451.8
4	64.2	44.4	38.5	35.4	31.2	23.1	9.6	20.6	2.3	10.2	13.1	39.4	332.0
5	40.0	39.7	96.9	26.2	13.4	8.8	18.0	5.2	0.0	1.2	13.5	76.1	339.0
6	59.2	108.1	67.9	31.2	5.0	14.2	8.7	7.3	4.1	10.1	17.9	71.2	404.9
7	23.6	60.8	49.5	31.4	50.7	11.5	5.8	0.4	1.4	1.1	18.2	24.4	278.8
8	62.4	53.1	53.4	38.0	34.2	9.9	2.1	1.1	2.2	2.8	38.1	53.9	351.2
9	53.0	76.0	41.6	42.3	13.0	6.6	0.8	0.0	0.6	1.1	13.0	57.8	305.8
10	52.6	83.2	35.1	74.0	5.2	8.5	4.6	2.0	0.3	19.6	19.0	37.8	341.9
11	67.2	95.4	42.7	20.3	5.8	2.0	0.0	0.0	1.3	2.0	6.8	64.7	308.2
12	22.2	30.8	42.1	38.4	29.8	5.2	12.3	3.6	15.7	2.8	11.6	43.5	258.0
13	64.7	41.6	56.4	38.5	17.1	1.5	4.4	0.4	0.0	1.7	12.2	82.5	321.0
14	33.8	23.6	65.0	15.8	27.2	10.5	0.7	0.0	5.1	6.6	24.2	53.2	265.5
15	56.3	62.5	65.5	27.9	7.4	7.0	0.1	0.0	6.5	5.3	20.9	76.1	335.5
16	56.7	27.6	37.9	34.3	5.5	0.0	3.7	0.0	1.8	5.0	16.9	72.6	262.0
17	59.7	49.6	41.7	35.1	61.1	34.2	23.2	8.7	1.6	4.9	18.7	25.7	364.2
18	50.0	41.6	78.3	46.6	18.1	9.5	4.1	0.6	3.3	7.5	14.9	43.0	317.5
19	72.1	40.5	35.2	15.1	71.7	15.6	13.2	0.0	5.5	10.0	30.2	51.7	360.8
20	60.8	37.9	62.5	24.2	45.9	2.7	0.0	2.0	0.2	8.8	18.7	43.0	306.7
MEAN	57.1	58.6	53.3	36.8	27.6	9.9	6.9	3.2	2.9	5.9	21.2	53.6	337.2

TABLE: 3.6-4 MONTHLY YIELD OF PENGGANJING RIVER AT NGEMPLAK DAM SITE

SITE NO. 4 UNIT: IN MCM

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1	14.3	13.7	9.6	12.5	4.8	1.4	1.6	0.2	3.0	0.4	4.8	7.7	74.0
2	14.4	13.2	10.3	10.5	5.0	1.6	3.7	2.3	1.1	2.0	10.0	5.7	79.8
3	14.6	11.6	5.9	7.5	4.3	2.5	4.8	0.7	1.1	3.9	5.2	7.1	69.2
4	12.8	10.9	10.3	3.4	4.3	8.6	0.4	2.0	1.1	1.4	3.9	10.9	70.0
5	9.3	9.4	23.5	8.7	1.3	1.8	2.9	0.2	0.0	1.8	4.6	10.9	74.4
6	10.9	16.4	17.1	7.0	4.5	3.6	6.1	2.7	2.0	4.6	5.7	12.8	93.4
7	15.5	9.3	11.4	8.2	8.7	5.2	1.4	0.4	0.2	1.4	4.8	8.0	74.5
8	9.4	9.8	5.9	4.6	5.7	2.1	0.9	0.2	1.1	0.9	6.8	8.6	55.5
9	10.5	7.8	14.3	3.6	11.2	0.7	0.0	0.0	0.2	1.1	5.7	5.5	62.6
10	16.4	11.2	8.2	14.3	1.8	4.3	1.8	1.8	2.0	3.2	4.5	9.6	80.7
11	17.3	14.6	8.7	5.9	0.5	0.5	0.0	0.0	0.0	1.3	3.0	11.6	60.0
12	4.5	10.9	7.7	5.5	5.3	2.7	0.5	0.9	1.3	2.9	1.6	5.5	47.1
13	9.6	6.8	10.7	13.9	1.6	1.4	0.5	0.0	0.0	1.6	4.8	8.6	62.6
14	9.4	8.4	11.0	2.5	2.0	4.3	0.0	0.2	0.0	3.2	4.8	6.1	54.5
15	14.8	10.9	10.9	7.7	1.1	0.0	0.0	0.7	0.0	1.1	5.0	14.3	64.0
16	12.1	16.9	8.4	7.3	9.8	2.1	6.4	2.1	1.4	2.1	8.7	6.1	83.4
17	5.0	11.8	10.0	3.0	0.0	0.5	1.6	0.0	0.0	4.5	4.3	10.7	51.4
18	12.8	10.7	17.3	6.4	7.0	0.7	1.4	0.0	1.8	3.4	5.2	9.4	76.1
19	21.2	9.8	10.3	7.7	8.4	5.9	0.2	0.9	0.5	5.7	5.3	9.6	85.5
20	19.4	10.5	10.3	6.8	5.3	1.6	0.0	0.5	0.0	0.9	7.0	10.7	72.0
MEAN	12.7	11.2	11.1	7.4	4.6	2.6	1.7	0.8	0.8	2.4	5.3	9.0	69.6

TABLE: 3.6-5 MONTHLY YIELD OF INTERMEDIATE FLOW OF PENGGANJING RIVER AT NGEMPLAK DIVERSION

SITE NO. 5 UNIT: IN MCM

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1	3.6	3.4	2.4	3.1	1.2	0.4	0.4	0.1	0.8	0.1	1.2	1.9	18.6
2	3.6	3.3	2.6	2.6	1.3	0.4	0.9	0.6	0.3	0.5	2.5	1.4	20.0
3	3.7	2.9	1.5	1.9	1.1	0.6	1.2	0.2	0.3	1.0	1.3	1.8	17.5
4	3.2	2.7	2.6	0.9	1.1	2.2	0.1	0.5	0.3	0.4	1.0	2.7	17.7
5	2.3	2.4	5.9	2.2	0.3	0.5	0.7	0.1	0.0	0.5	1.2	2.7	18.8
6	2.7	4.1	4.3	1.8	1.1	0.9	1.5	0.7	0.5	1.2	1.4	3.2	23.4
7	3.9	2.3	2.9	2.1	2.2	1.3	0.4	0.1	0.1	0.4	1.2	2.0	18.9
8	2.4	2.3	1.5	1.2	1.4	0.5	0.2	0.1	0.3	0.2	1.7	2.2	14.0
9	2.6	2.5	3.6	0.9	2.8	0.2	0.0	0.0	0.1	0.3	1.4	1.4	15.8
10	4.1	2.0	2.1	3.6	0.5	1.1	0.5	0.2	0.5	0.8	1.1	2.4	18.9
11	4.3	2.8	2.2	1.5	0.1	0.1	0.0	0.0	0.0	0.3	0.8	2.9	15.0
12	1.1	3.7	1.9	1.4	1.3	0.7	0.1	0.2	0.3	0.7	0.4	1.4	12.9
13	2.4	2.7	2.7	3.5	0.4	0.4	0.1	0.0	0.0	0.4	1.2	2.2	16.0
14	2.4	2.8	2.8	0.6	0.5	1.1	0.0	0.1	0.0	0.8	1.2	1.5	13.8
15	3.7	2.1	2.7	1.9	0.3	0.0	0.0	0.2	0.0	0.3	1.3	3.6	16.1
16	3.0	4.2	2.1	1.8	2.5	0.5	1.6	0.5	0.4	0.5	2.2	1.5	20.8
17	1.3	3.0	2.5	0.8	0.0	0.1	0.4	0.0	0.0	1.1	1.1	2.7	13.0
18	3.2	2.7	4.3	1.6	1.8	0.2	0.4	0.0	0.5	0.9	1.3	2.4	19.3
19	5.3	2.5	2.6	1.8	2.1	1.5	0.1	0.2	0.1	1.4	1.3	2.4	21.4
20	4.9	2.6	2.6	1.7	1.3	0.4	0.0	0.1	0.0	0.2	1.8	2.7	18.3
MEAN	3.2	3.9	2.8	1.9	1.2	0.7	0.4	0.2	0.2	0.6	1.3	2.3	17.5

TABLE: 3.6-6 MONTHLY YIELD OF GLUGU RIVER AT BANDUNGHARJO DAMSITE

SITE NO. 6 UNIT: IN MCM

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1	8.0	7.7	5.4	7.0	2.7	0.8	0.9	0.1	1.7	0.2	2.7	4.3	41.5
2	8.1	7.4	5.8	5.9	2.8	0.9	2.0	1.3	0.6	1.1	5.6	3.2	44.6
3	8.2	6.5	3.3	4.2	2.4	1.4	2.7	0.4	0.6	2.2	2.9	4.0	38.6
4	7.2	6.1	5.8	1.9	2.4	4.8	0.2	1.1	0.6	0.8	2.2	6.1	39.2
5	5.2	5.3	13.2	4.9	0.7	1.0	1.6	0.1	0.0	1.0	2.6	6.1	41.7
6	6.1	9.2	9.6	3.9	2.5	2.0	3.4	1.5	1.1	2.6	3.2	7.2	46.2
7	8.7	5.2	6.4	4.6	4.9	2.9	0.8	0.2	0.1	0.8	2.7	4.5	41.8
8	5.3	5.2	3.3	2.6	3.2	1.2	0.5	0.1	0.6	0.5	3.8	4.8	30.8
9	5.9	5.5	8.0	2.0	6.3	0.4	0.0	0.0	0.1	0.6	3.2	3.1	34.9
10	9.2	4.4	4.6	8.0	1.0	2.4	1.0	1.0	1.1	1.8	2.5	5.4	39.8
11	9.7	6.3	4.9	3.3	0.3	0.3	0.0	0.0	0.0	0.7	1.7	6.5	33.8
12	2.5	8.2	4.3	3.1	3.0	1.5	0.3	0.5	0.7	1.6	0.9	3.1	29.7
13	5.4	6.1	6.0	7.8	0.9	0.8	0.3	0.0	0.0	0.9	2.7	4.8	36.8
14	5.3	3.8	6.2	1.4	1.1	2.4	0.0	0.1	0.0	1.8	2.7	3.4	28.2
15	8.3	4.7	6.1	4.3	0.6	0.0	0.0	0.4	0.0	0.6	2.8	8.0	36.1
16	6.8	9.5	4.7	4.1	5.5	1.2	3.6	1.2	0.8	1.2	4.9	3.4	49.6
17	2.8	6.8	5.6	1.7	0.0	0.3	0.9	0.0	0.0	2.5	2.4	6.0	29.0
18	7.2	6.1	9.7	3.6	3.9	0.4	0.8	0.0	1.0	1.9	2.9	5.3	42.9
19	11.9	5.5	5.8	4.3	4.7	3.3	0.1	0.5	0.3	3.2	3.0	5.4	42.2
20	10.9	5.9	5.8	3.8	3.0	0.9	0.0	0.3	0.0	0.5	3.9	6.0	42.4
MEAN	7.1	6.3	6.2	4.1	2.6	1.5	1.0	0.4	0.5	1.3	2.3	5.0	38.5

TABLE: 3.6-7 MONTHLY YIELD OF INTERMEDIATE FLOW OF GLUGU RIVER
AT BANDUNGHARJO DIVERSION

SITE NO. 7 UNIT: IN MCM

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1	1.6	1.5	1.1	1.4	0.5	0.2	0.2	0.0	0.3	0.1	0.5	0.9	8.3
2	1.6	1.5	1.2	1.2	0.6	0.2	0.4	0.3	0.1	0.2	1.1	0.6	9.0
3	1.6	1.3	0.7	0.8	0.5	0.3	0.5	0.1	0.1	0.4	0.6	0.8	7.7
4	1.4	1.2	1.2	0.4	0.5	1.0	0.1	0.2	0.1	0.2	0.4	1.2	7.9
5	1.0	1.2	2.6	1.0	0.1	0.2	0.3	0.0	0.0	0.2	0.5	1.2	8.3
6	1.2	1.8	1.9	0.8	0.5	0.4	0.7	0.3	0.2	0.5	0.6	1.4	10.3
7	1.7	1.0	1.3	0.9	1.0	0.6	0.2	0.0	0.0	0.2	0.5	0.9	8.3
8	1.1	1.0	0.7	0.5	0.6	0.2	0.1	0.0	0.1	0.1	0.8	1.0	6.2
9	1.2	1.1	1.6	0.4	1.3	0.1	0.0	0.0	0.0	0.1	0.6	0.6	7.0
10	1.8	0.9	0.9	1.6	0.2	0.5	0.2	0.2	0.2	0.4	0.5	1.1	8.5
11	1.9	1.3	1.0	0.7	0.1	0.1	0.0	0.0	0.0	0.1	0.3	1.3	6.8
12	0.5	1.6	0.9	0.6	0.6	0.3	0.1	0.1	0.1	0.3	0.2	0.6	5.9
13	1.1	1.2	1.2	1.6	0.2	0.2	0.1	0.0	0.0	0.2	0.5	1.0	7.3
14	1.1	0.4	1.2	0.3	0.2	0.5	0.0	0.0	0.0	0.4	0.5	0.7	5.3
15	1.7	0.9	1.2	0.9	0.1	0.0	0.0	0.1	0.0	0.1	0.5	1.6	7.1
16	1.4	2.0	0.9	0.8	1.1	0.2	0.7	0.2	0.2	0.2	1.0	0.7	9.4
17	0.3	1.4	1.1	0.3	0.0	0.1	0.2	0.0	0.0	0.5	0.5	1.2	5.6
18	1.4	1.2	1.9	0.7	0.8	0.1	0.2	0.0	0.2	0.2	0.6	1.1	8.4
19	2.4	1.1	1.2	0.9	0.9	0.7	0.0	0.1	0.1	0.6	0.6	1.1	9.7
20	2.2	1.2	1.2	0.8	0.6	0.2	0.0	0.1	0.0	0.1	0.8	1.2	8.4
MEAN	1.4	1.2	1.3	0.8	0.5	0.3	0.2	0.1	0.1	0.3	0.6	1.0	7.8

TABLE: 3.6-8 MONTHLY YIELD OF SERANG RIVER AT KEDUNGOMBO DAMSITE

SITE NO. 8 UNIT: IN MCM

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1	93.3	77.3	72.1	92.0	55.6	9.4	17.5	1.8	1.3	0.7	15.7	54.3	491.0
2	108.8	135.3	77.8	116.3	82.5	16.4	21.4	7.2	11.2	27.6	139.1	91.3	834.9
3	182.4	107.5	84.7	114.8	25.8	14.0	35.6	12.9	14.0	26.1	82.6	74.2	774.6
4	150.0	172.8	92.7	25.8	31.9	31.1	11.0	14.7	10.3	21.5	38.5	135.1	735.4
5	111.1	67.0	173.5	99.7	25.9	8.5	23.2	4.6	3.1	2.8	9.2	71.9	600.5
6	93.9	205.9	182.0	121.6	115.9	23.6	58.5	65.1	10.9	58.7	66.1	171.1	1173.3
7	187.9	143.0	139.7	105.3	102.2	28.5	40.3	4.2	2.6	6.6	49.0	161.8	971.1
8	71.8	145.6	78.4	77.8	87.6	18.4	14.4	2.8	1.5	6.1	59.1	52.3	615.8
9	88.2	86.5	102.9	46.6	108.4	13.0	3.5	0.7	0.4	0.5	44.9	52.8	548.4
10	121.5	106.4	75.6	122.2	34.1	16.7	13.8	10.7	1.1	6.2	58.9	105.4	672.6
11	151.6	109.3	146.3	89.4	11.0	3.0	1.8	0.6	0.2	1.2	15.3	49.9	579.6
12	43.1	116.5	104.5	126.8	55.0	25.4	16.2	9.9	0.7	42.1	44.2	37.5	621.9
13	127.2	135.5	143.5	78.2	18.0	6.1	4.2	0.5	0.4	4.4	29.4	53.0	600.4
14	109.3	148.0	214.6	63.9	28.0	48.8	13.4	10.7	2.8	37.5	45.3	83.9	806.2
15	173.2	176.9	87.8	73.4	14.0	2.0	0.2	0.2	0.2	0.2	21.9	95.9	645.9
16	120.2	179.4	126.6	105.4	103.4	26.1	45.5	31.1	7.9	25.2	91.8	108.9	971.5
17	102.2	130.5	94.6	73.8	16.4	15.1	6.6	1.8	0.9	20.1	18.9	96.1	577.0
18	57.0	64.6	97.2	40.8	65.5	18.8	13.6	9.2	19.8	14.5	35.7	90.7	527.4
19	154.0	105.8	108.6	75.6	83.9	49.9	1.1	0.2	0.2	9.7	25.8	82.8	697.6
20	131.8	81.5	63.1	41.0	30.4	10.5	9.9	1.8	0.2	0.2	24.9	67.2	462.5
MEAN	118.9	124.8	113.3	84.5	54.8	19.3	17.6	9.5	4.5	15.6	45.8	86.8	695.4

TABLE: 3.6-9 MONTHLY YIELD OF INTERMEDIATE FLOW OF SERANG RIVER AT SOUTH GROBOGAN DIVERSION

SITE NO. 9 UNIT: IN MCM

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1	14.0	11.6	10.8	13.8	8.3	1.4	2.6	0.3	0.2	0.1	2.4	8.2	73.7
2	16.3	23.3	11.7	17.5	12.4	2.5	3.2	1.0	1.7	4.1	20.9	13.7	128.3
3	27.4	16.2	12.7	17.2	3.9	2.1	5.3	1.9	2.1	3.9	12.4	11.1	116.2
4	22.5	25.9	13.9	3.9	4.8	4.7	1.7	2.2	1.6	3.2	5.8	20.3	110.5
5	16.7	10.1	26.0	15.0	3.9	1.3	3.5	0.7	0.5	0.4	1.4	12.3	91.8
6	14.1	30.9	27.3	18.2	17.4	3.5	8.8	9.8	1.6	8.8	9.9	25.7	176.0
7	28.2	21.5	21.0	15.8	15.3	4.3	6.0	0.6	0.4	1.0	7.4	24.3	145.8
8	10.8	21.8	11.8	11.7	13.1	2.8	2.2	0.4	0.2	0.9	9.9	7.9	93.5
9	13.2	13.0	15.4	7.0	16.3	2.0	0.5	0.1	0.1	0.1	6.7	7.9	82.3
10	19.2	16.0	11.3	18.3	5.1	2.5	2.1	1.6	0.2	0.9	8.8	15.8	101.8
11	22.7	16.4	22.0	13.4	1.7	0.5	0.3	0.1	0.0	0.2	2.3	7.5	87.1
12	6.5	17.5	15.7	19.0	8.3	3.8	2.4	1.5	0.1	6.3	6.6	5.6	93.3
13	19.1	20.3	21.5	11.7	2.7	0.9	0.6	0.1	0.1	0.7	4.4	6.0	88.1
14	16.4	22.2	32.2	9.6	4.3	7.3	2.0	1.6	0.4	5.6	6.8	12.6	121.0
15	26.0	26.5	13.2	11.0	2.1	0.3	0.0	0.0	0.0	0.0	3.3	14.4	96.8
16	18.0	26.9	19.0	15.8	15.5	3.9	6.9	4.7	1.2	3.9	13.8	16.3	145.9
17	15.3	19.6	14.2	11.1	2.5	2.3	1.0	0.3	0.1	3.0	2.8	14.4	86.6
18	8.6	9.7	14.6	6.1	9.8	2.8	2.0	1.4	4.5	2.2	5.4	13.6	80.7
19	23.1	15.9	16.3	11.3	12.6	7.5	0.2	0.0	0.0	1.5	3.9	12.4	104.7
20	19.8	12.2	10.2	6.2	4.6	1.6	1.5	0.3	0.0	0.0	3.7	10.1	70.2
MEAN	17.9	18.9	17.0	12.7	8.2	2.9	2.6	1.4	0.8	2.3	6.9	13.0	104.7

TABLE: 3.6-10 MONTHLY YIELD OF INTERMEDIATE FLOW OF SERANG RIVER AT SEDADI DIVERSION

SITE NO. 10 UNIT: IN MCM

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1	24.1	19.9	18.7	23.8	14.4	67.5	4.5	0.5	0.3	0.2	4.0	14.0	191.9
2	28.1	71.9	20.1	30.0	21.2	4.2	5.5	1.9	2.9	7.2	36.0	23.6	252.6
3	47.1	27.7	21.8	0.0	6.6	3.6	9.4	1.3	3.6	6.8	21.4	19.2	168.5
4	37.7	44.7	24.0	6.6	8.2	8.0	2.9	8.8	2.6	5.6	9.9	34.8	193.8
5	28.7	17.2	43.6	25.7	6.8	2.2	6.0	1.2	0.8	0.7	2.4	21.2	156.5
6	24.2	53.2	47.1	31.5	30.1	6.1	15.1	16.9	2.8	15.2	17.0	44.3	303.5
7	48.5	36.9	36.0	27.2	26.4	7.4	10.5	1.2	0.7	1.8	12.6	41.7	250.9
8	18.5	37.9	20.2	20.1	22.7	4.7	3.6	0.7	0.4	1.6	14.2	13.4	158.0
9	22.8	22.3	26.6	12.0	27.5	3.4	0.9	0.2	0.0	0.2	11.6	13.6	141.1
10	30.4	27.4	19.6	31.6	8.8	4.4	3.6	2.7	0.3	1.7	15.1	0.0	145.6
11	0.0	87.9	0.0	103.2	2.9	0.7	0.5	0.3	0.1	0.3	3.9	12.8	212.6
12	11.0	107.8	27.0	32.8	14.2	6.6	4.2	2.6	11.4	11.0	11.4	9.7	249.7
13	0.0	35.0	37.2	20.3	4.7	1.6	1.2	0.2	0.8	1.1	36.7	15.6	154.4
14	28.2	33.2	55.4	23.7	7.5	12.6	3.5	2.7	0.7	9.7	12.7	21.7	211.1
15	44.7	45.7	22.6	19.0	3.6	0.5	0.1	0.1	0.1	0.1	5.6	24.7	166.8
16	31.1	46.4	32.7	27.3	26.8	6.8	11.3	8.0	2.1	6.4	23.7	28.2	250.8
17	26.4	33.7	24.4	19.0	4.2	3.8	1.8	0.5	0.3	6.2	5.0	24.8	150.1
18	14.8	16.7	25.1	10.6	17.0	4.8	3.6	2.4	7.7	3.8	9.2	23.5	139.2
19	38.3	27.4	28.8	19.6	19.7	12.8	0.3	0.1	0.1	3.5	6.6	21.4	178.6
20	0.0	21.1	17.6	10.6	7.8	2.7	2.6	0.5	0.1	0.1	6.4	17.3	86.8
MEAN	25.2	40.7	27.4	24.7	14.1	8.2	4.6	2.4	1.9	4.2	13.3	21.3	188.1

TABLE: 3.6-11 MONTHLY YIELD OF INTERMEDIATE FLOW OF SERANG RIVER AT KELAMBU DIVERSION

SITE NO. 11

UNIT: IN MCM

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1	91.6	105.8	67.8	121.2	57.3	131.2	29.3	1.4	0.1	12.3	85.1	132.5	835.6
2	138.1	133.1	112.6	103.2	57.0	44.0	20.8	37.1	13.9	33.1	94.3	77.0	864.2
3	185.1	230.2	97.1	112.6	64.8	53.3	102.7	16.0	4.9	45.7	92.5	137.5	1142.4
4	138.7	120.5	87.1	24.5	20.9	97.3	8.7	21.5	17.0	31.9	42.5	84.7	695.3
5	45.4	105.0	172.4	113.9	26.2	97.6	87.3	8.7	0.8	22.6	65.8	147.4	893.1
6	100.8	228.7	231.6	121.7	45.0	46.6	79.5	39.3	17.4	56.5	82.0	195.4	1244.5
7	144.8	206.2	132.6	66.9	124.4	65.3	42.0	12.1	19.0	25.1	63.7	220.7	1122.8
8	147.5	176.4	100.8	105.4	34.7	15.9	6.1	7.8	9.7	14.4	114.8	101.3	834.8
9	182.7	156.4	115.1	81.8	108.3	10.0	6.3	0.1	1.7	20.9	60.9	88.8	833.0
10	219.4	216.1	111.0	142.2	12.7	40.3	36.3	27.6	12.3	41.4	87.6	102.3	1049.2
11	126.8	145.6	114.2	77.2	28.4	20.2	0.9	0.1	1.1	67.2	59.6	103.6	744.9
12	113.1	140.5	161.7	22.6	2.1	56.1	4.2	29.0	33.7	93.5	79.0	87.6	823.1
13	198.4	144.2	137.1	8.6	19.3	31.3	2.3	0.0	0.3	21.7	80.8	89.1	733.1
14	150.6	144.0	210.2	37.4	35.8	68.5	1.5	10.9	4.6	41.4	59.3	63.9	828.1
15	224.2	64.5	117.8	118.7	5.8	0.2	0.2	7.0	0.0	12.1	56.8	144.7	752.0
16	169.1	224.6	131.9	124.9	164.5	98.4	141.1	67.7	23.2	46.4	147.9	102.4	1442.1
17	150.4	217.5	200.6	130.9	1.3	1.2	0.5	0.1	37.6	39.8	80.0	125.7	985.6
18	179.3	138.8	207.6	105.9	107.8	37.3	11.7	3.0	34.3	36.3	104.8	85.0	1051.8
19	169.0	184.3	123.1	88.3	115.4	13.1	0.1	6.3	11.0	75.2	70.5	134.7	991.0
20	188.6	114.9	137.7	65.3	52.5	10.7	0.8	11.1	0.0	0.0	87.0	122.7	791.3
MEAN	153.2	159.9	138.5	88.7	54.2	46.9	29.1	15.3	12.1	36.9	80.8	117.4	932.9

The crop water requirement is a basis for calculating seasonal and peak project demand based on a given cropping pattern and intensity. The cropping pattern as "rice, rice and upland crops" (upland crops are mixed crops between maize and soybean) with a cropping intensity as 100, 98 and 26 percent respectively was considered to find out the total water requirement. Besides this the other water needs like water needed for leaching of salts, losses in the distribution system, and evaporation losses are accounted to find the gross water need. The gross water demand, thus determined is used to determine the project acreage.

The potential evapotranspiration (ETo), has been estimated by Modified Penman method (FAO.24 - Revised. 1977), which likely to give more dependable results compared to other methods. The equation is :

$$ETo = c\ [\ W.Rn + (1 - W).f(u).(ea - ed) \qquad (3.36)$$

where,

Eto = reference crop evapotranspiration in mm/day

W = temperature - related weighting factor

Rn = net radiation in equivalent evaporation in 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

ETcrop can be found by :

$$ETcrop = kc \ . \ ETo \qquad (3.37)$$

where , kc = crop coefficient

The values of coefficient,kc by Doorenbose and Pruit (1977) are used. The net irrigation requirement of the crop is calculated using the field water balance. The net irrigation requirement can be determined for seasonal, monthly or ten day periods. Here a monthly period is used as this is preliminary planning. The sum of net irrigation requirement for different crops over the irrigated area forms the basis for determining the irrigation demand.

To determine the total irrigation requirement, besides meeting the net irrigation requirement, water may also be required for leaching of accumulated salts from the root zone and for cultural practices. The leaching requirement (LR) is the portion of the irrigation water applied that must drain through the active root zone to remove accumulated salts. Since irrigation is never 100 percent efficient, allowance has to be made for conveyance losses and field application efficiency. In this study 80 % conveyance and 90 % for field application efficiency have been adopted. Project efficiency (EFp) is expressed in fraction of the net irrigation requirement (IRRN).

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

$$V_i = 10/EFp \left[\frac{A * IRRN}{1 - LR} \right]_i \qquad (3.38)$$

Where :

V_i = irrigation supply in month i (m3/month)

EFp = project irrigation efficiency (fraction)

A = acreage under a given crop (Ha)

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

LR = leaching requirements (fraction)

For the preliminary planning, the capacity of the engineering works can be determined from the peak supply needed during the month, (Vmax). Normally an allowance flexibility and safety is included.

3.3.4 Effective Rainfall :

3.3.4.1 Dependable Rainfall :

Crop water needs can be fully or partly met by rainfall. However only a part of the rainfall is effective in meeting water requirement. Some rainfall will be lost as direct runoff and part will percolate below root zone to groundwater.

Rainfall for each period varies from year to year and rather using mean rainfall, a dependable level of rainfall is used. In the present study 90 % dependable level of rainfall (available in 18 years out of 20 years data) is selected, so that crop production is affected by rainfall in 10 % of years only.

Twenty years rainfall data was arranged in descending order of magnitude and a year of 90 % dependable rainfall is chosen. Generaly the paddy bunds are 150 mm high which can store water not more than the height of bund. So 150 mm depth is the limit of ponding water in rice fields. Keeping in view this limit the months having a rainfall less than or equal to 150 mm are selected. The rainfall of these months is considered as effective rainfall.

3.3.4.2 Field Water Balance :

(i). Upland Crops (Polowijo Crops) :

Figure. 3.6 shows diagrammatically the daily water balance. Upland crops (Polowijo crops) use stored soil moisture from the maximum rooting depth of the crop. The maximum available soil moisture is its water holding capacity. The actual moisture on any day depends on the transfer of water into and out of the storage, which is represented by following water balance equation:

$$\Delta(SMC) = IRRG + R - RO2 - ET - RECH \qquad (3.39)$$

Where :

$\Delta(SMEC)$ = soil moisture content increase

IRRG = gross irrigation

R = rainfall

RO2 = runoff

ET = crop evapotranspiration

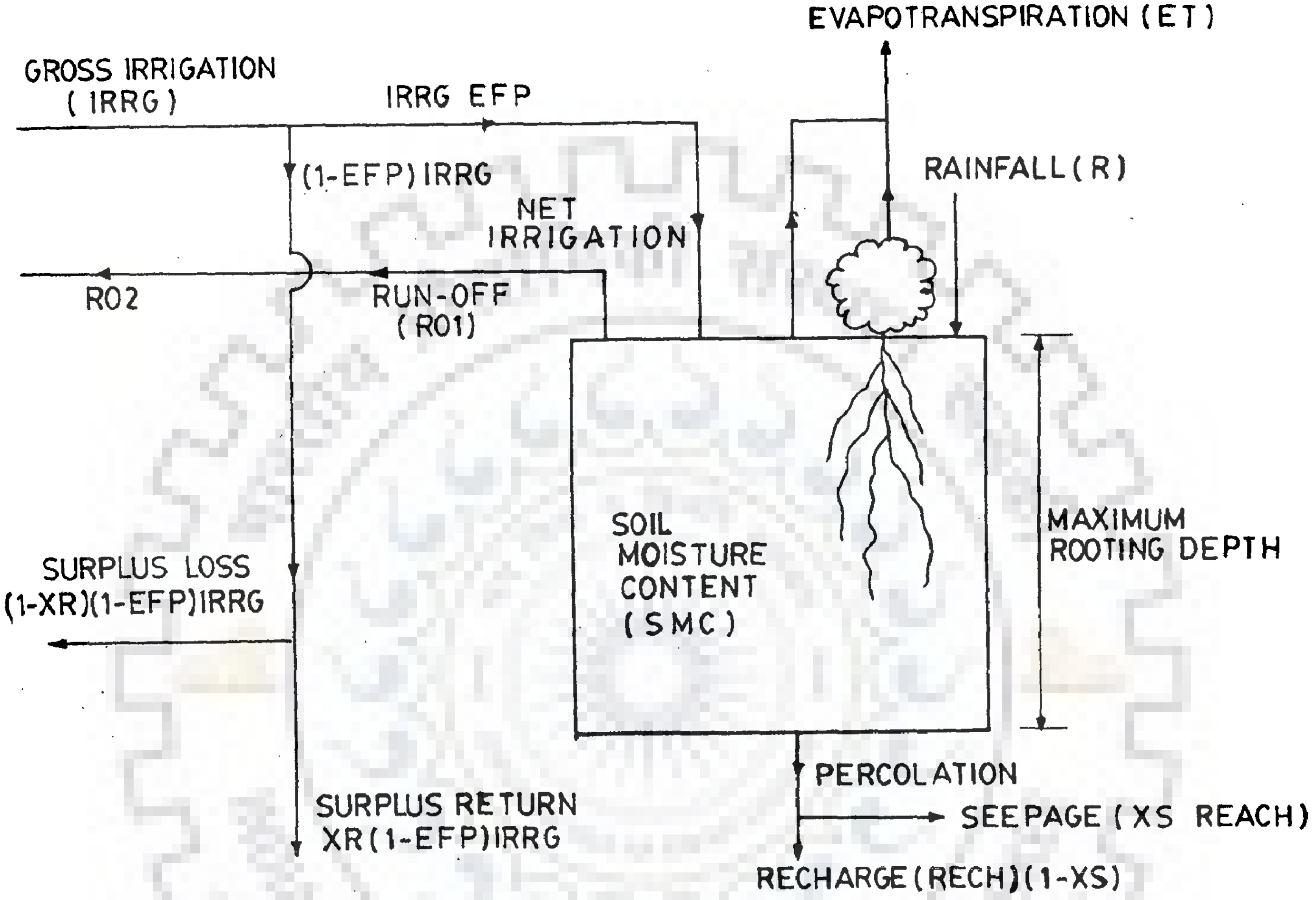
RECH = recharge to ground water

(ii). Rice (Paddy) :

Figure. 3.6 also shows the principle of the daily water balance for paddy. In this case the crop is grown in ponded condition which necessitates a different approach for computing

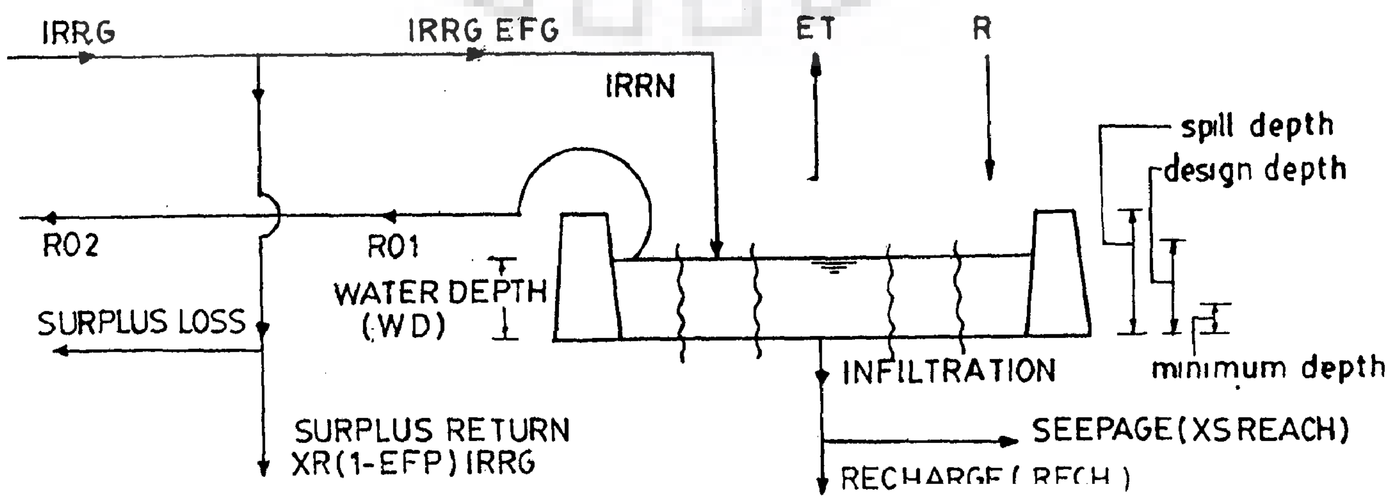
FIGURE 3.6 WATER BALANCE PROCEDURE FOR RICE AND NON-RICE CROPS

1. WATER BALANCE - NON-RICE



$$\Delta(SMC) = IRRG + R - RO2 - ET - RECH$$

2. WATER BALANCE - PADDY RICE



$$\Delta(WD) = IRRG + R - RO2 - ET - RECH$$

effective precipitation from that used for crops grown on soil moisture (upland crops or polowijo crops). For rice (paddy) the stored water is not soil moisture but simply a reservoir of water in the paddy field. The important consequence of this is that infiltration will occur continuously into the underlying soil, as long as there is ponded water in the field. The water balance equation for paddy field is :

$$\Delta(WD) = IRRG + R - RO2 - ET - RECH \tag{3.40}$$

Where :

$\Delta(WD)$ = water depth

IRRG = gross irrigation

R = rainfall

RO2 = runoff

ET = crop evapotranspiration

RECH = recharge to ground water

Reference crop evapotranspiration (ETo) is calculated as mentioned above, using Modified Penman method. This is then multiplied by appropriate crop coefficients (kc) to estimate the actual water requirement of each crop specified.

3.3.5 Municipal and Industrial Water (M & I):

Municipal and Industrial (M&I) demands in the Lusi-Serang basin is currently being met by wells, springs and rivers. The use of surface water from the river in the basin is needed for Municipal and Industrial (M & I) supply for the city of Semarang and is considered in the development plan. The main sources is Kedung Ombo reservoir on Serang river on Lusi-Serang system.

The estimated demand of M & I water for Semarang city in the year 1980 (PRC/ECI Consultant studies) is 1,215 liters per second whereas the supply available is only 734 liters per second. In 1990, the supply made available for Semarang city is 1,034 liters per second (SMEC/INDAH KARYA Consultant studies). The projected need by the year 2000, (PRC/ECI Consultant studies, in view of development taking place in this part of Java -Indonesia.) is 5,650 liters per second. The anticipated growth of demand with time is shown below :

Year	1980[1)]	1990[2)]	1995	2000
Total M&I water demand (l/sec)	1,215	2,660	3,870	5,650

Where :
1) - Available = 734 l/sec.
2) - Available = 1,034 l/sec.

The M & I requirement of Semarang city would be met partly from LUSI - SERANG system through Kelambu diversion (diversion site NO. 11) through a canal 40.0 km long with capacity of 3.50 m3/sec . The monthly water supply demand taken from study area is repeorted in Table. 3.7 below :

Table. 3.7 Monthly Demand for Municipal and Industrial Water Supply (M & I) for Study Area

(Unit in: MCM)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
M & I	9.37	8.47	9.38	9.08	9.37	9.07	9.38	9.37	9.07	9.38	9.07	9.37

3.3.6 Computation of Sediment :

Several methods are used for predicting sediment deposition and distribution in the reservoir for design purposes. The two methods which are universally accepted are:

1). Empirical area reduction method and
2).. Area increment method.

In this present study, the first i.e "Empirical area reduction method" has been used.

3.3.7 Development of Project Versions :

For development of the eastern part of Jratunseluna basin which is called LUSI - SERANG, the system is divided into three parts within the system itself, i.e. east, south and west parts. For each part, there are several alternative versions of project development, where in each version comprise of diversion with or without storage reservoirs on the upstream. For the project versions where there are reservoirs there are limitations on maximum dam height and storage capacity due to physical, social and environmental considerations. The particulars of the potential reservoirs within Lusi - Serang system are given in table. 3.1.

While making the project versions the use of return flow potential from upper irrigation to the lower part of irrigation area should also be considered. This has been taken into account in the present case study.

The various project versions are shown through Figure. 3.7-1 up to Figure. 3.7-11 as follows:

Project: 1, Version: 1 - diversion only (2 nos)

2 - diversion (2 nos) and one reservoir (site no.1)

3 - diversion (2 nos) and one reservoir (site no.2)

4 - diversion (2 nos) and two reservoirs (site no.1 & 2)

Project:2, Version: 1 - diversion only (2 nos)

2 - diversion (3 nos) and transbasin transfer of water.

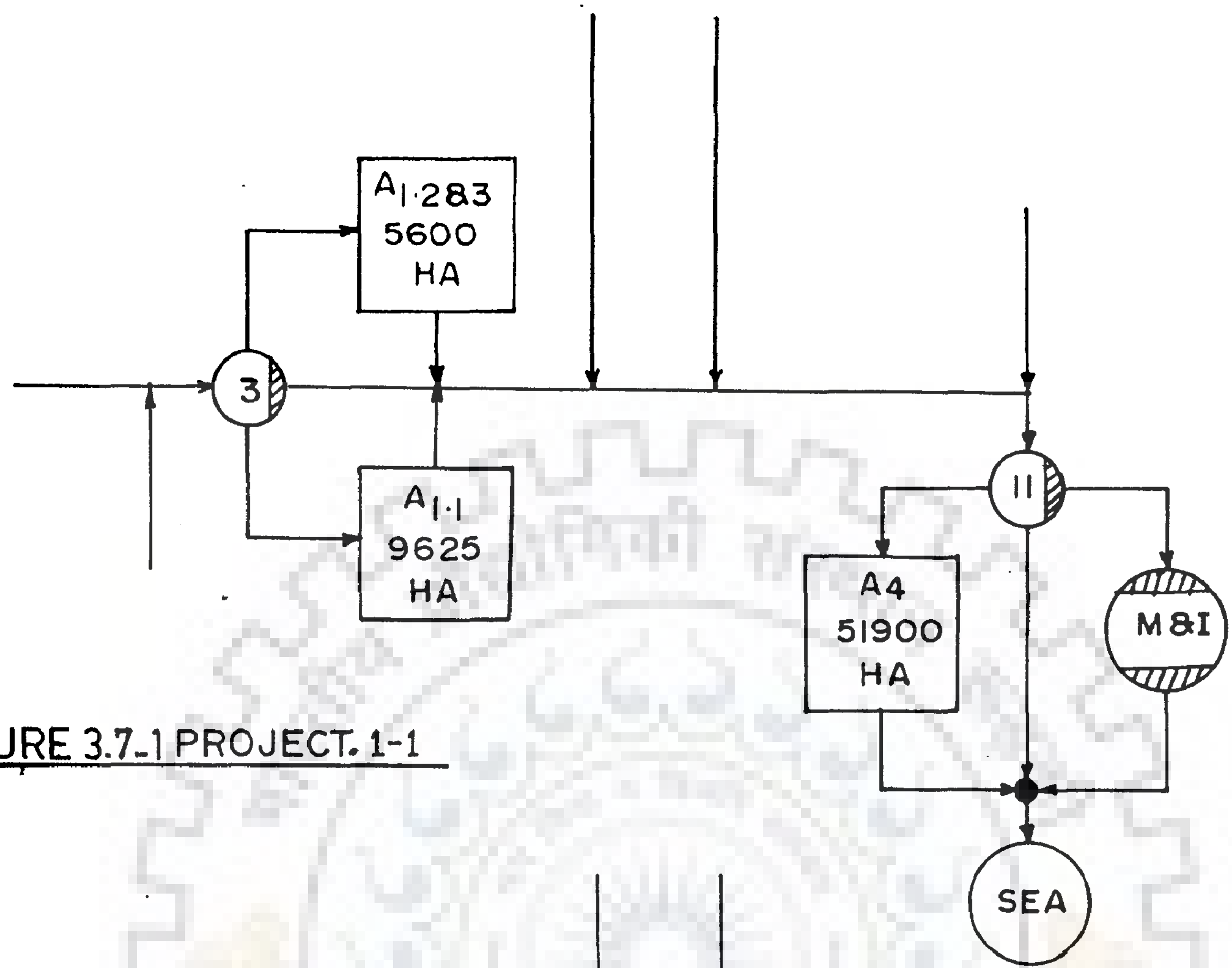
3 - diversion (2 nos) and one reservoir (site no.4)

4 - diversion (3 nos), transbasin transfer, one reservoir (site no.4).and with two area of irrigation.

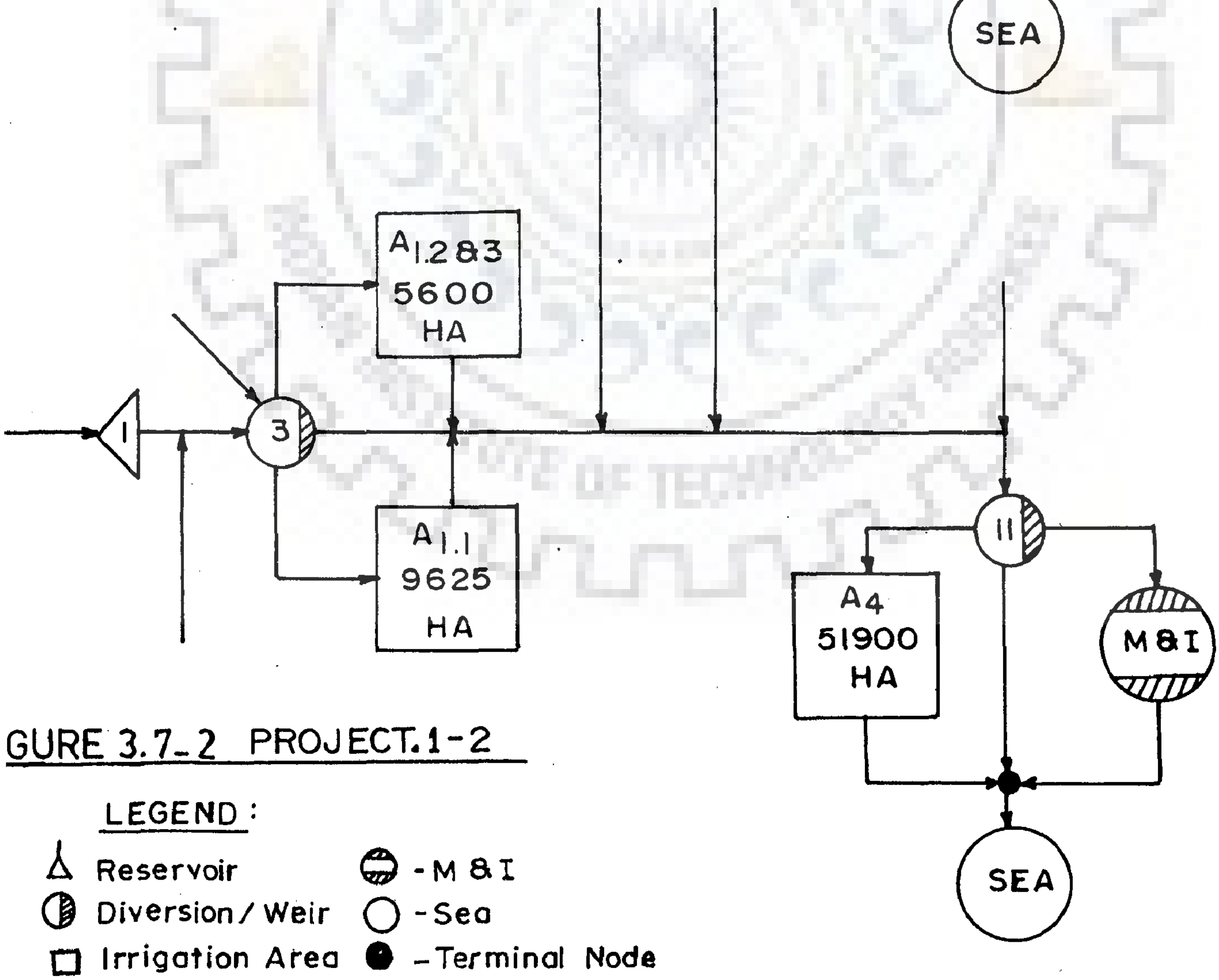
5 - diversion (3 nos), transbasin transfer, two reservoirs (site no.4 & 6), and with two area of irrigation.

6 - diversion (2 nos) and one reservoir (site no.6)

Project:3, Version: 1, 2 & 3 - diversion (3 nos) and one reservoir (site no. 8) with 3(three) different height of dam.



GURE 3.7-1 PROJECT. 1-1



GURE 3.7-2 PROJECT. 1-2

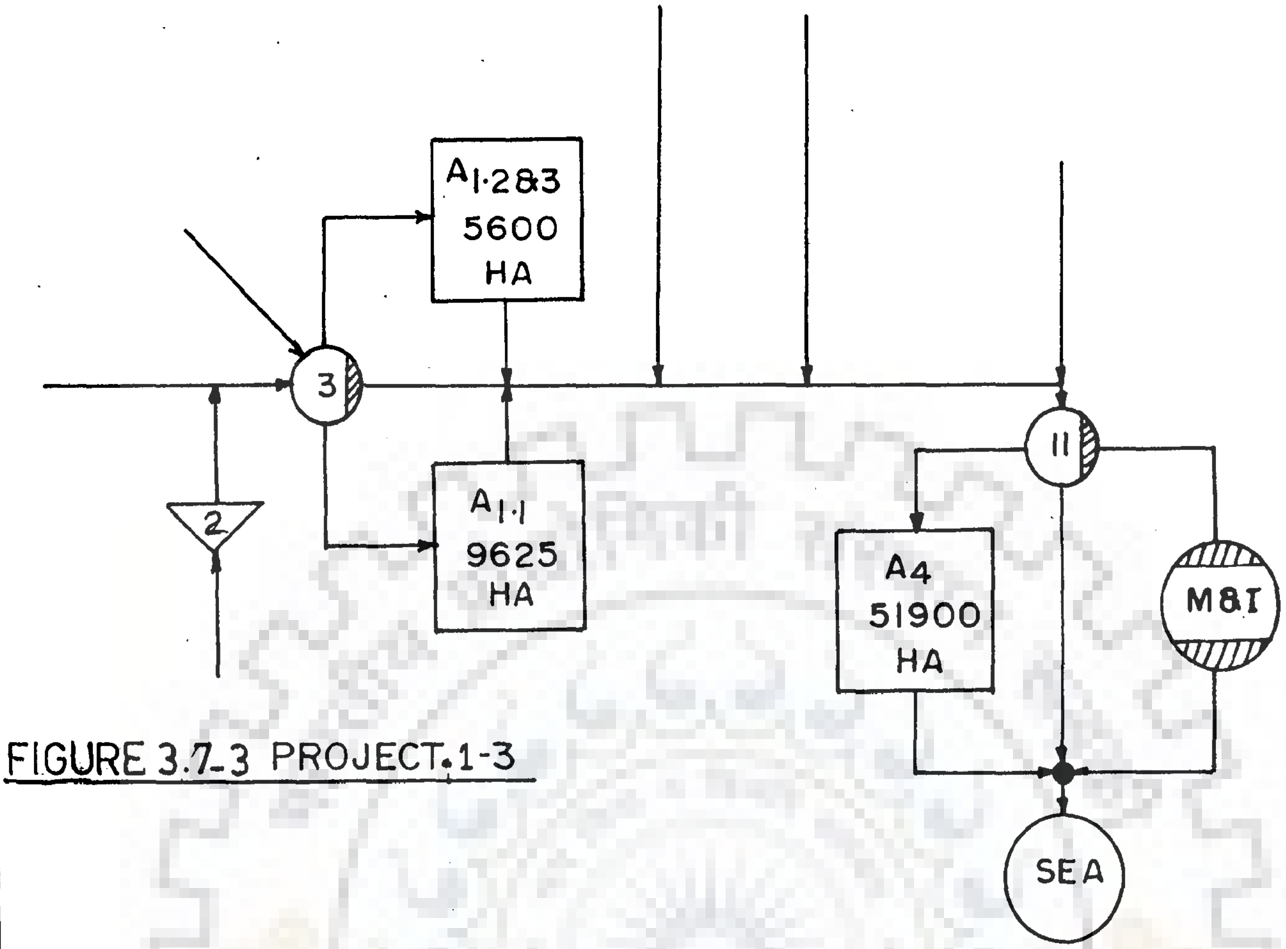


FIGURE 3.7-3 PROJECT.1-3

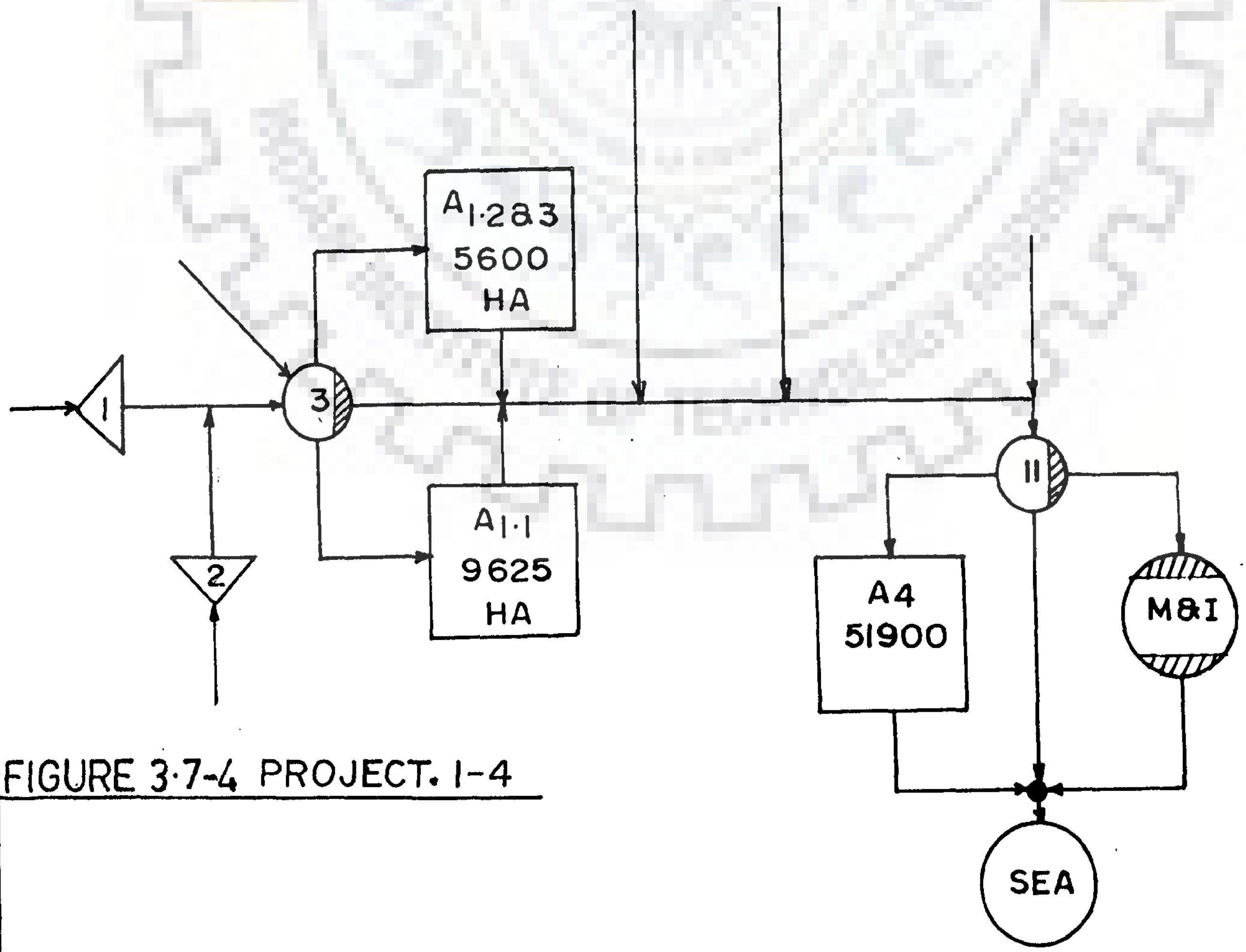


FIGURE 3·7-4 PROJECT. 1-4

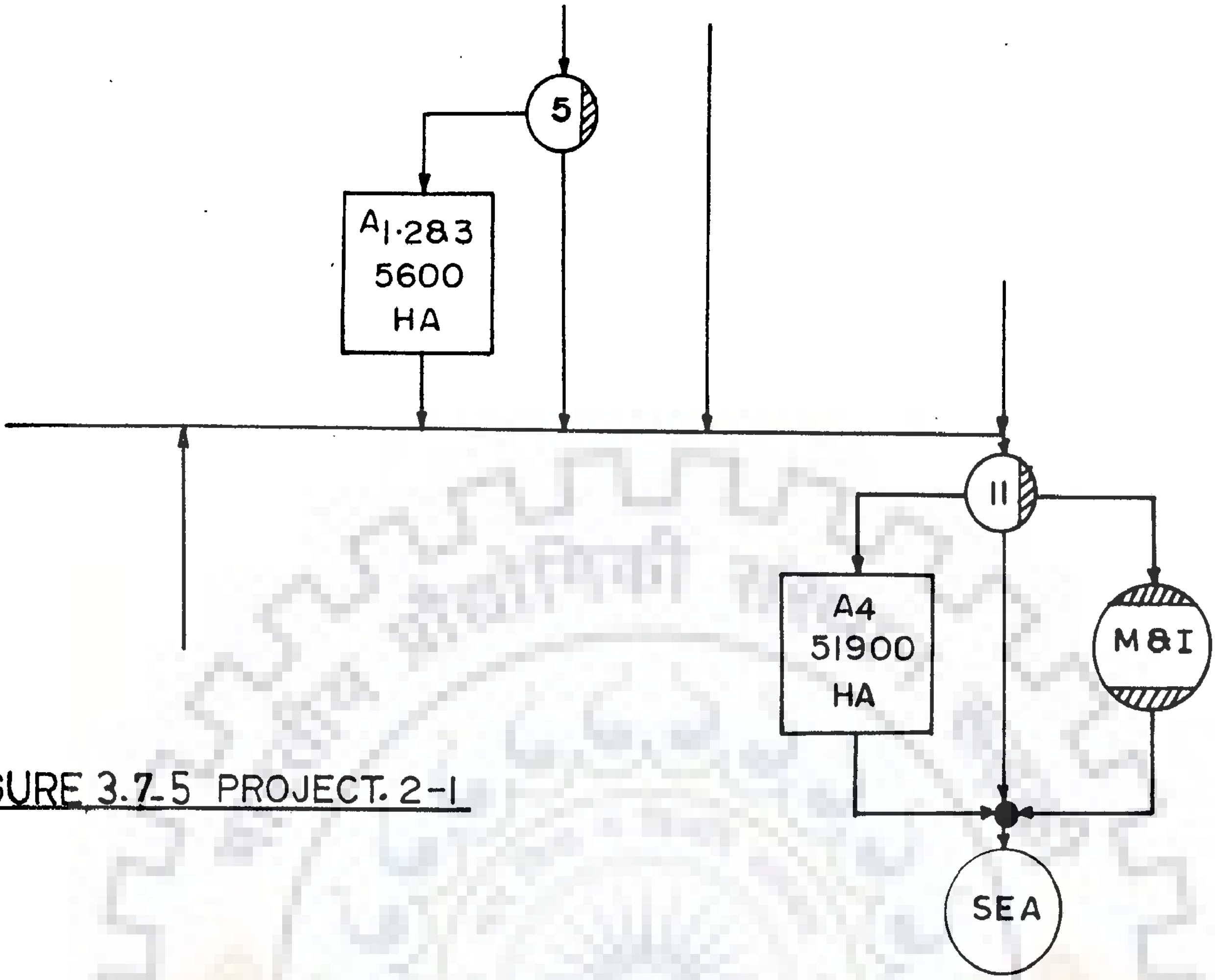


FIGURE 3.7-5 PROJECT. 2-1

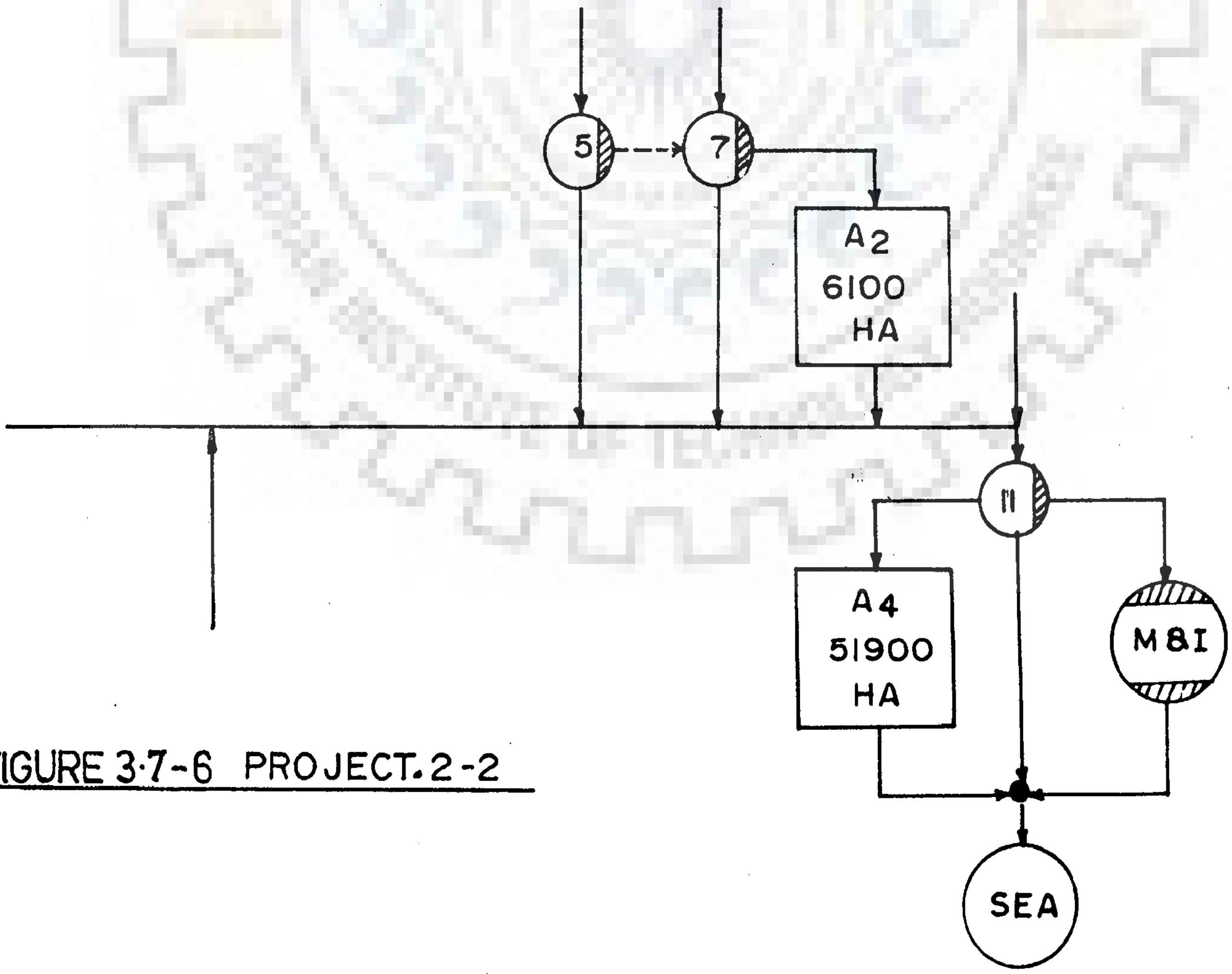


FIGURE 3·7-6 PROJECT. 2-2

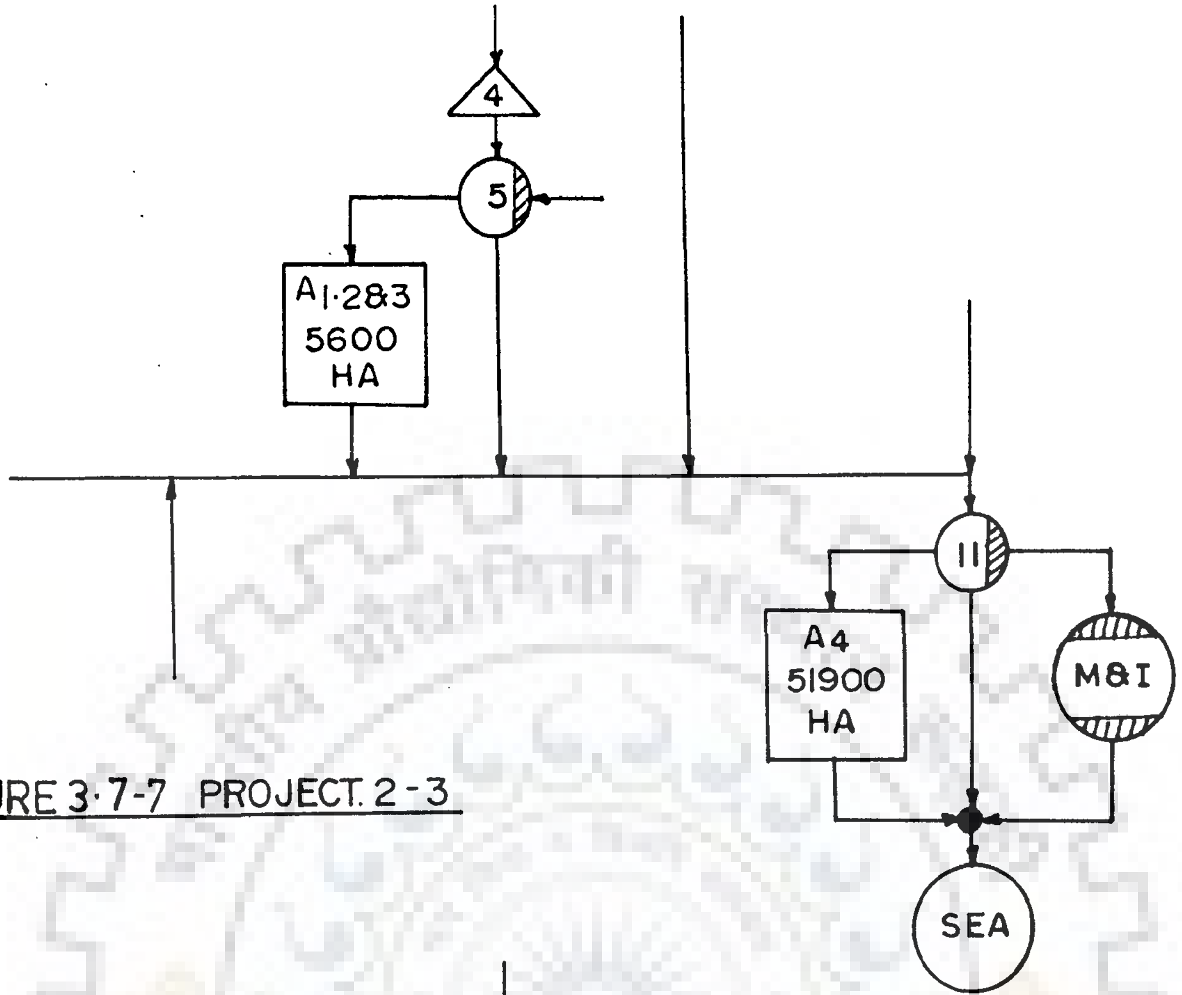


FIGURE 3·7-7 PROJECT. 2-3

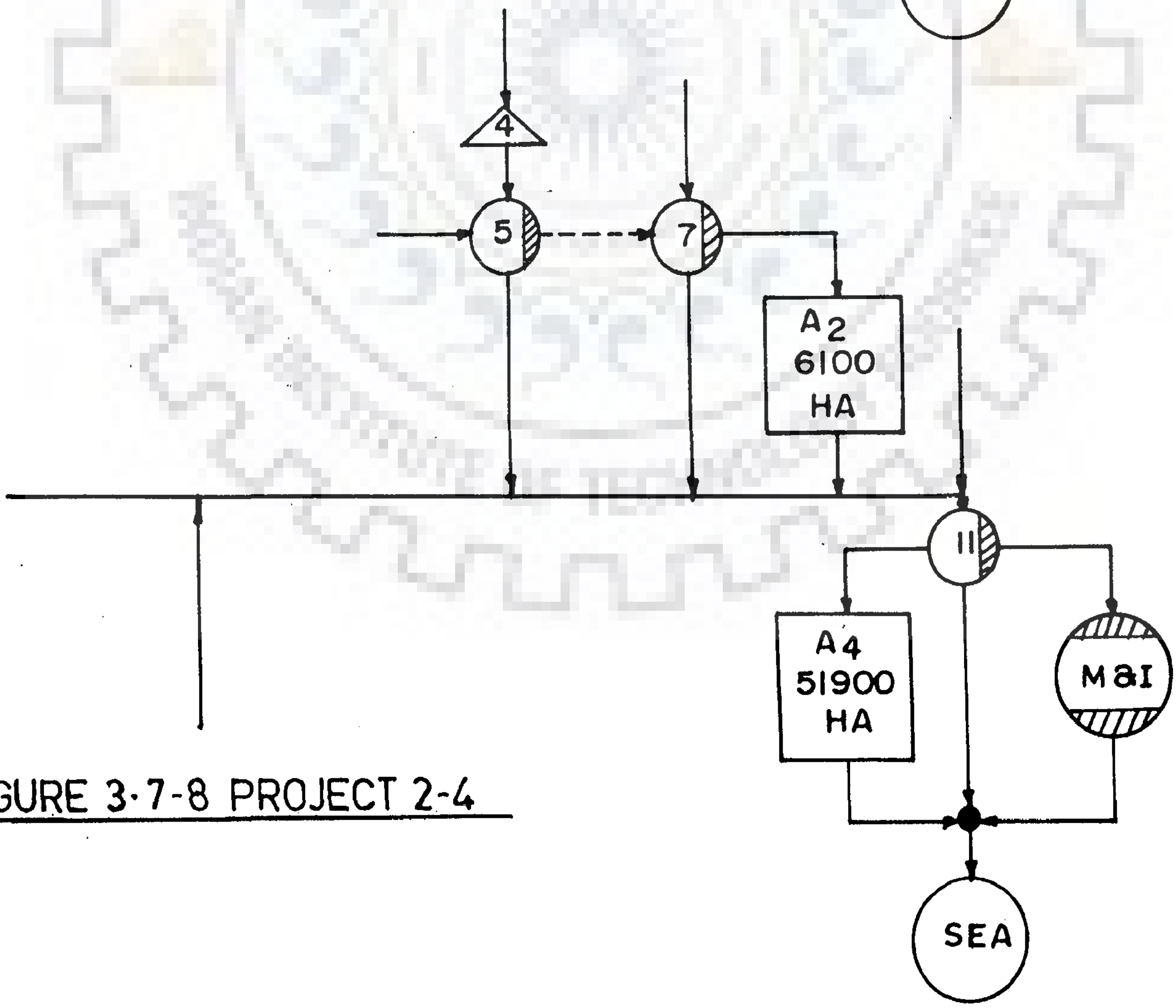


FIGURE 3·7-8 PROJECT 2-4

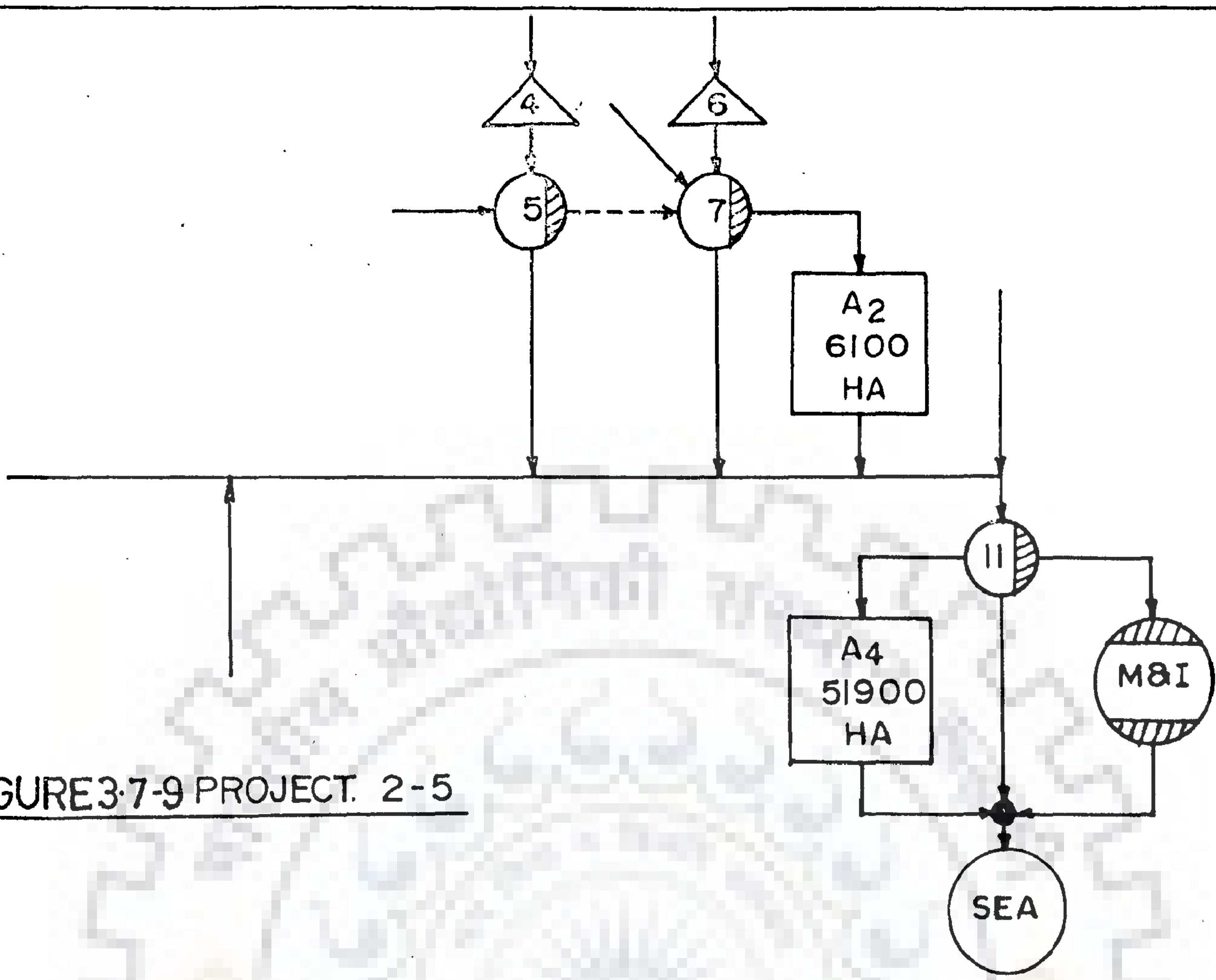


FIGURE 3.7-9 PROJECT. 2-5

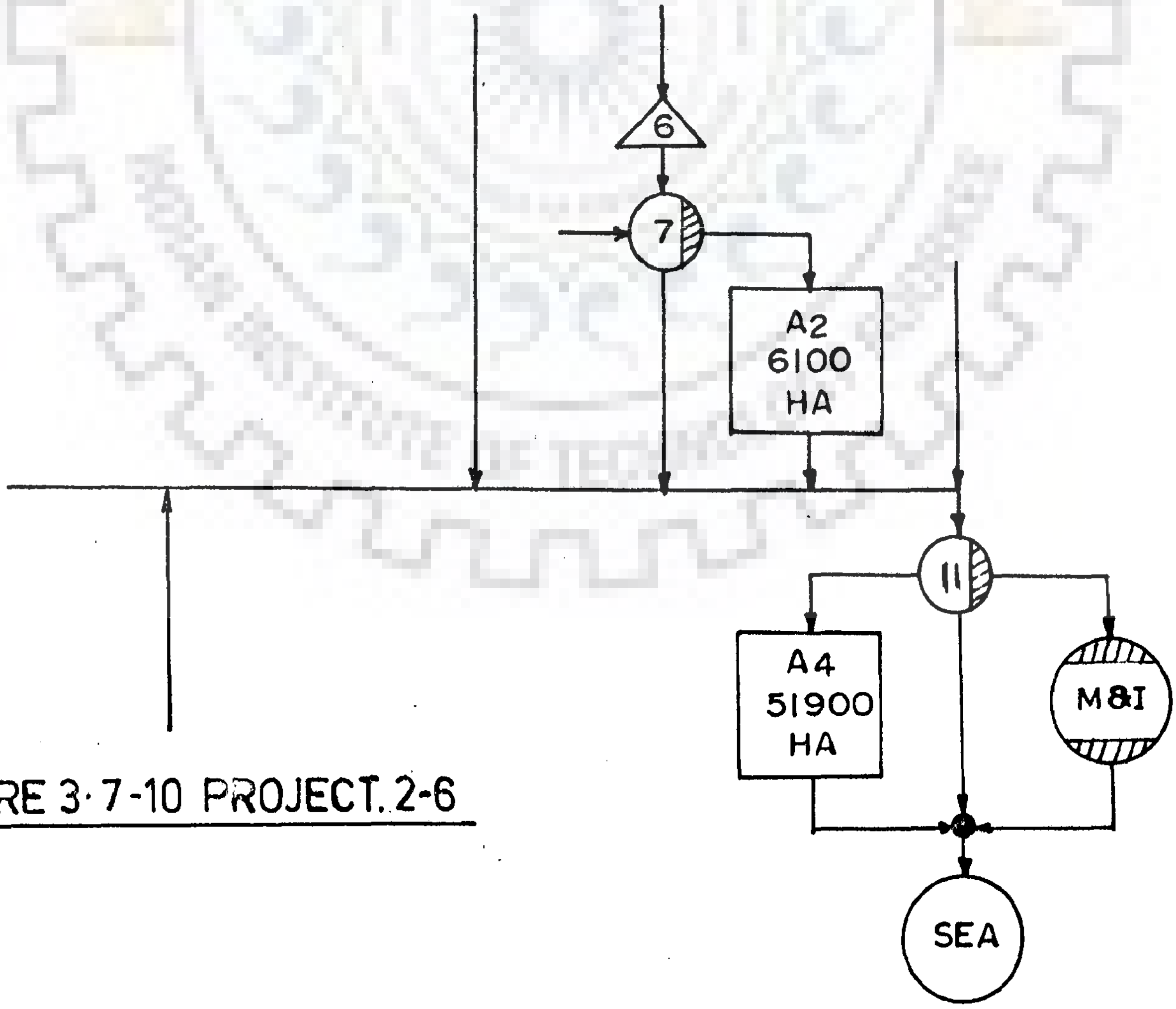


FIGURE 3.7-10 PROJECT. 2-6

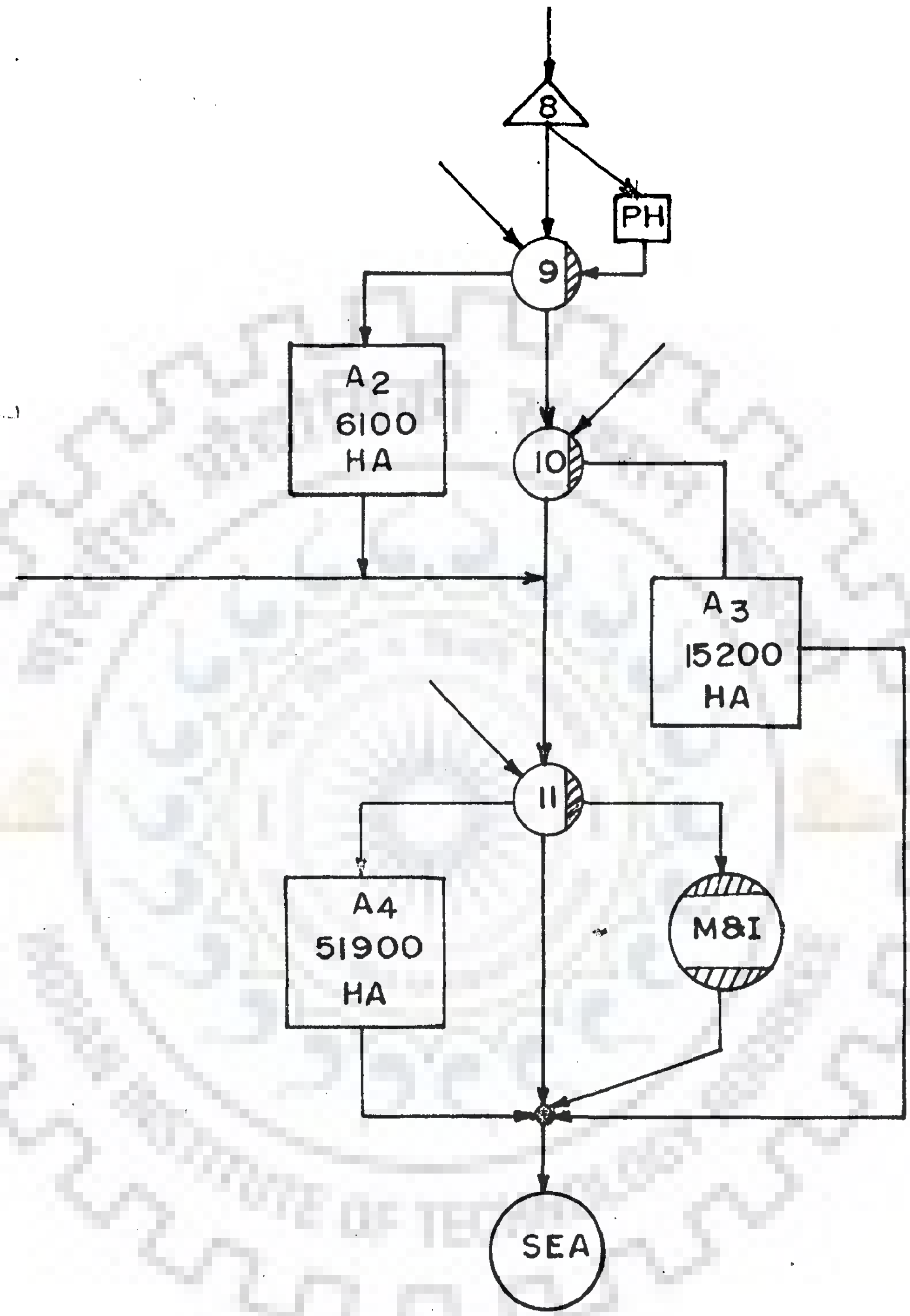


FIGURE 3.7-11 PROJECT, 3-1 up to 3-3

(WITH DIFFERENT HEIGHT OF DAM AT SITE NO. 8)

The results of the Lp programme used in development of discrete version of projects summeried in Table. 3.8 and further refined for sediment, free board to calculate each cost of project. The summary of project costs, yearly expenditures and annual benefits are shown in Table. 3.9.

3.4 COMPUTER PROGRAM :

Based on the algorithm, a computer program is prepared in FORTRAN 77, the listing of which is given in Appendix - A

The data for screening of projects is given in Table. 3.10. The input data consists of the following items:

i) Project serial number and the number of versions of these projects.

ii) Number of years required for implementation of the program and the corresponding estimated budget requirements each year.

iii) Annual budget constraint.

iv) The benefit of the project.

The programme, based on the algorithm prints out the priority of each project which indicates their sequence of construction and thus the timing. and the result is shown in table. 3.11

Each project and its versions are developed by using an Lp and adjusted for sedimentation, flow surcharge and freeboard as necessary.

Table 3.8 SUMMARY RESULT OF OPTIMIZATION OF PROJECT VERSION BY LP

PRO.	VERSION	AREA SITE	IRRIGATION AREA(Ha)			RESERVOIR LIVE STORAGE				
			SEASON 1	SEASON 2	SEASON 3	R-1	R-2	R-3	R-4	R-5
1	2	3	4	5	6	7	8	9	10	11
I	1	A1	15225	165.5	3958.5	-	-	-	-	-
		A4	51900	34.5	9100					
	2	A1	15225	6109	3958.5	77.0	-	-	-	-
		A4	51900	11830	11186.5					
	3	A1	15225	2622.5	3958.5	-	19.0	-	-	-
		A4	51900	1580.5	1186.5					
	4	A1	1689	0	0	-	-	-	-	-
		A4	51900	15134.5	1186.5					
II	1	A1	1689	0	0	-	-	-	-	-
		A4	51900	0	12267					
	2	A2	1600	0	800	-	-	-	-	-
		A4	51900	9684	12851					
	3	A1	425.5	0	209.5	-	-	46.0	-	-
		A4	51900	11407.5	13231.5					
	4	A2	1600	0	800	-	-	49.0	-	-
		A4	51900	10678.5	13494					
	5	A2	1640	0	320	-	-	46.0	-	-
		A4	51900	14565	13148					
	6	A2	775	0	100	-	-	-	22.0	-
		A4	51900	4822	13284					
III	1	A2	6100	5978	480	-	-	-	-	241
		A3	15200	11552.5	1566					
		A4	51900	24177.5	13494					
	2	A2	6100	5757	560	-	-	-	-	386
		A3	15200	1867	851					
		A4	51900	48870	13494					
	3	A2	6100	5978	1586	-	-	-	-	455
		A3	15200	14896	3952					
		A4	51900	50682	13494					

TABLE: 3.9 SUMMARY OF VARIOUS PROJECT VERSIONS

PROJECT	VERSION	COST ($10**6)	YEARLY EXPENDITURE ($ 10**6)									BENEFIT ($10**6)
			1	2	3	4	5	6	7	8	9	
1	1	168.90	16.0	30.0	40.0	50.0	32.9	0	0	0	0	151.30
	2	271.80	20.0	30.0	50.0	60.0	50.0	40.0	15.0	6.8	0	185.80
	3	203.60	15.0	30.0	40.0	50.0	50.0	18.6	0	0	0	161.50
	4	306.50	10.0	30.0	40.0	40.0	50.0	50.0	40.0	30.0	16.5	191.60
2	1	138.40	10.0	25.0	40.0	35.0	20.0	8.4	0	0	0	126.20
	2	149.40	15.0	25.0	40.0	35.0	20.0	14.4	0	0	0	144.70
	3	178.40	15.0	30.0	40.0	50.0	25.0	18.4	0	0	0	146.20
	4	189.40	15.0	30.0	40.0	40.0	30.0	20.0	14.4	0	0	148.0
	5	213.80	15.0	30.0	40.0	50.0	40.0	20.0	18.8	0	0	154.0
	6	162.80	10.0	30.0	40.0	40.0	30.0	12.8	0	0	0	135.10
3	1	328.30	5.0	15.0	30.0	60.0	70.0	60.0	50.0	25.0	13.3	239.00
	2	347.60	5.0	20.0	35.0	60.0	70.0	60.0	50.0	30.0	17.6	264.40
	3	354.60	5.0	20.0	40.0	60.0	70.0	60.0	50.0	30.0	19.6	295.90

Present values of cost and benefit as given are based on 40 years life after start of construction and a discount rate of 12%

TABLE. 3.10 INPUT DATA FOR SCREENING OF PROJECT

3 9
4 6 3 Yearly budget/Expenditure, million dollars

Budget Availability Version		98.0	98.0	98.0	98.0	98.0	98.0	98.0	98.0	98.0	
Project 1	1	16.0	30.0	40.0	50.0	32.9	00.0	00.0	00.0	00.0	151.30
	2	20.0	30.0	50.0	60.0	50.0	40.0	15.0	6.8	00.0	185.80
	3	15.0	30.0	40.0	50.0	50.0	18.6	00.0	00.0	00.0	161.50
	4	10.0	30.0	40.0	40.0	50.0	50.0	40.0	30.0	16.5	191.60
Project 2	1	10.0	25.0	40.0	35.0	20.0	8.4	00.0	00.0	00.0	126.20
	2	15.0	25.0	40.0	35.0	20.0	14.4	00.0	00.0	00.0	144.70
	3	15.0	30.0	40.0	50.0	25.0	18.4	00.0	00.0	00.0	146.20
	4	15.0	30.0	40.0	40.0	30.0	20.0	14.4	00.0	00.0	148.00
	5	15.0	30.0	40.0	50.0	40.0	20.0	18.8	00.0	00.0	153.90
	6	10.0	30.0	40.0	40.0	30.0	12.8	00.0	00.0	00.0	135.10
Project 3	1	5.0	15.0	30.0	60.0	70.0	60.0	50.0	25.0	13.3	239.00
	2	5.0	20.0	35.0	60.0	70.0	60.0	50.0	30.0	17.6	264.40
	3	5.0	20.0	40.0	60.0	70.0	60.0	50.0	30.0	19.6	295.90

TABLE. 3.11 RESULT OF SCREENING OF THE PROJECT VERSION

Project	3 Version	9 1	2	3	4	5	6	7	8	9	BENEFIT ($ 10^6)
		ANNUAL EXPENDITURE ($ 10^6)									
1	1	16.00	30.00	40.00	50.00	32.90	.00	.00	.00	.00	151.30
1	2	20.00	30.00	50.00	60.00	50.00	40.00	15.00	6.80	.00	185.80
1	3	15.00	30.00	40.00	50.00	50.00	18.60	.00	.00	.00	161.50
1	4	10.00	30.00	40.00	40.00	50.00	50.00	40.00	30.00	16.50	191.60
2	1	10.00	25.00	40.00	35.00	20.00	8.40	.00	.00	.00	126.20
2	2	15.00	25.00	40.00	35.00	20.00	14.40	.00	.00	.00	144.70
2	3	15.00	30.00	40.00	50.00	25.00	18.40	.00	.00	.00	146.20
2	4	15.00	30.00	40.00	40.00	30.00	20.00	14.40	.00	.00	148.00
2	5	15.00	30.00	40.00	50.00	40.00	20.00	18.80	.00	.00	153.90
2	6	10.00	30.00	40.00	40.00	30.00	12.80	.00	.00	.00	135.10
3	1	5.00	15.00	30.00	60.00	70.00	60.00	50.00	25.00	13.30	239.00
3	2	5.00	20.00	35.00	60.00	70.00	60.00	50.00	30.00	17.60	264.40
3	3	5.00	20.00	40.00	60.00	70.00	60.00	50.00	30.00	19.60	295.90
		PROPORTION OF ANNUAL AVAILABLE BUDGET									
1	1	.16	.31	.41	.51	.34	.00	.00	.00	.00	151.30
1	2	.20	.31	.51	.61	.51	.41	.15	.07	.00	185.80
1	3	.15	.31	.41	.51	.51	.19	.00	.00	.00	161.50
1	4	.10	.31	.41	.41	.51	.51	.41	.31	.17	191.60
2	1	.10	.26	.41	.36	.20	.09	.00	.00	.00	126.20
2	2	.15	.26	.41	.36	.20	.15	.00	.00	.00	144.70
2	3	.15	.31	.41	.51	.26	.19	.00	.00	.00	146.20
2	4	.15	.31	.41	.41	.31	.20	.15	.00	.00	148.00
2	5	.15	.31	.41	.51	.41	.20	.19	.00	.00	153.90
2	6	.10	.31	.41	.41	.31	.13	.00	.00	.00	135.10
3	1	.05	.15	.31	.61	.71	.61	.51	.26	.14	239.00
3	2	.05	.20	.36	.61	.71	.61	.51	.31	.18	264.40
3	3	.05	.20	.41	.61	.71	.61	.51	.31	.20	295.90

1	1	263.36
1	2	200.98
1	3	233.21
1	4	183.79
2	1	268.08
2	2	284.75
2	3	240.93
2	4	229.74
2	5	211.63
2	6	243.98
3	1	214.03
3	2	223.63
3	3	245.33

263.3641000
200.9757000
233.2073000
183.7860000
268.0838000
284.7510000
240.9350000
229.7360000
211.6305000
243.9767000

Table 3.11 (Contd.)

```
        214.0298000
        223.6294000
        245.3316000
PROJECT SELECTED = 2      VERSION = 2
   .1531   .2551   .4082   .3571   .2041   .1469   .0000   .0000   .0000
   6.677525E-001
   .2292   .3820   .6112   .5348   .3056   .2200   .0000   .0000   .0000
  SUM1 =  7.793429E-001
  SUM1 =         1.0487920
  SUM1 =  8.720968E-001
  SUM1 =  8.763319E-001
  SUM1 =  9.377687E-001
  SUM1 =  9.884463E-001
  SUM1 =         1.0196320
        194.1379000
        177.1563000
        185.1859000
        218.6386000
           .0000000
           .0000000
           .0000000
           .0000000
           .0000000
           .0000000
        254.8603000
        267.4905000
        290.2026000
PROJECT SELECTED = 3      VERSION = 3
   .0510   .2041   .4082   .6122   .7143   .6122   .5102   .3061   .2000
          1.3655620
   .0374   .1494   .2989   .4483   .5231   .4483   .3736   .2242   .1465
  SUM1 =  5.781991E-001
  SUM1 =         1.0029840
  SUM1 =  7.541827E-001
  SUM1 =         1.0959630
        261.6746000
        185.2471000
        214.1391000
        174.8234000
           .0000000
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           .0000000
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           .0000000
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   8.123891E-001
   .2010   .3768   .5024   .6280   .4132   .0000   .0000   .0000   .0000
```

3.5 DISCUSSION OF THE RESULTS :

The priority of projects indicated by the programme are:

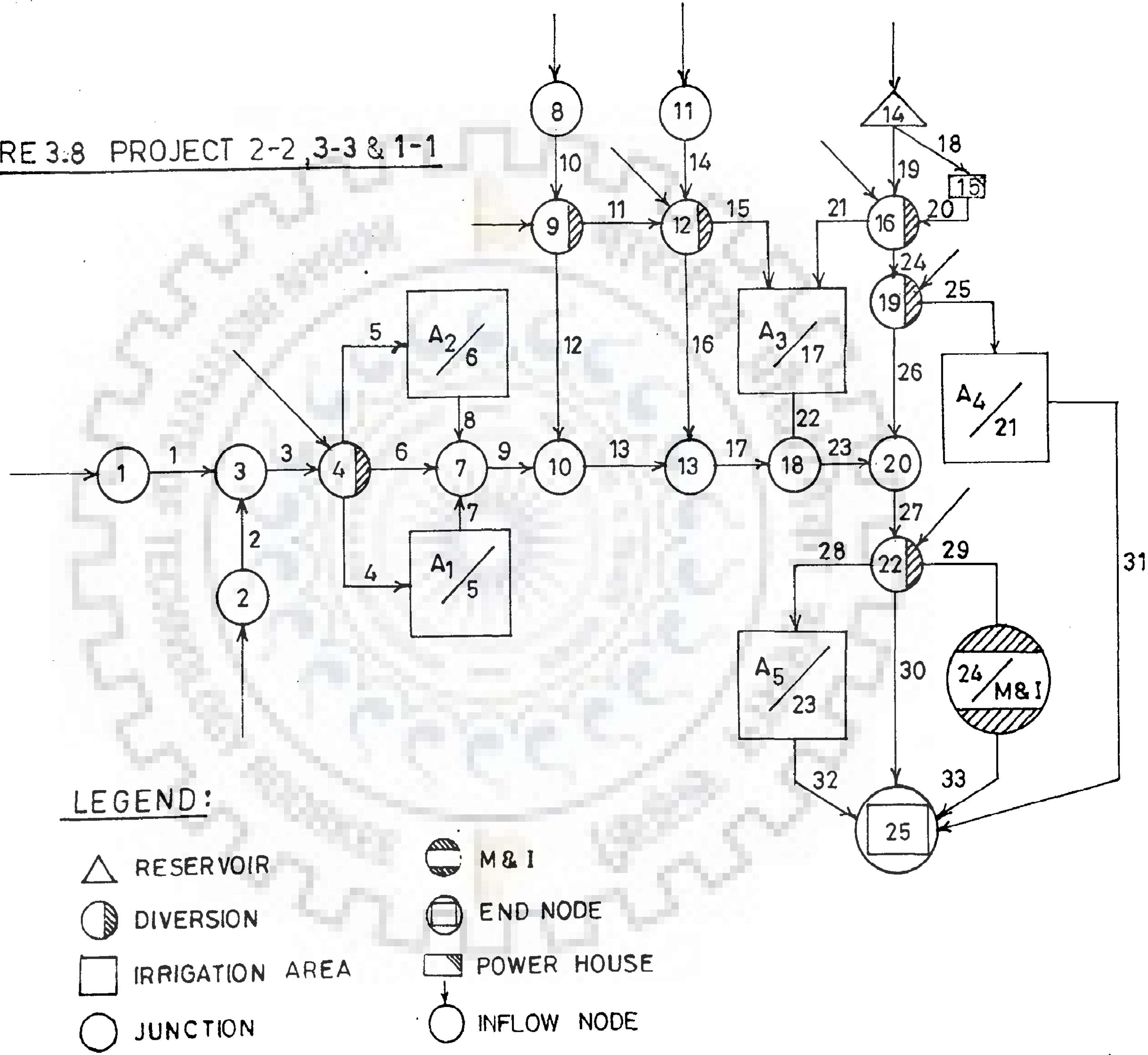
1. Project 2, version 2
2. Project 3, version 3
3. Project 1, version 1

The overall scheme of river basin development as screened by the procedure is shown in Figure. 3.8.

Usual Lp screening model is run for the same river basin and the the results are given in Table. 3.12.

A comparison of the two is not possible, as the projects indicated by the Lp screening model needs further refinement.

FIGURE 3.8 PROJECT 2-2, 3-3 & 1-1



TBAALE.3.12 RESULT OF OPTIMIZATION OF LUSI-SERANG SYTEM BY LP

RESERVOIR NO.	ORIGINAL LIVE STORAGE (MCM)	RESULT LIVE STORAGE (MCM)	IRRN SITE NO.	ORIGINAL AREA IRRIGATION (HA)	RESULT AREA IRRIGATION (HA)
1	77.00	77.00	A-1	15225.00	10612.25
2	19.00	19.00	A-2	6100.00	4062.10
3	68.00	40.50	A-3	15200.00	8947.25
4	22.00	15.60	A-4	51900.00	51900.00
5	634.50	360.00			

CHAPTER 4

RIVER BASIN SIMULATION

4.0 INTRODUCTION

The essence of simulation is to provide a realistic and detailed presentation of the problem under study, which allows the decision maker to test various alternatives under consideration. The simulation model evaluates each alternative by calculating its measure of performance. It is important to emphasize that simulation models do not generate an optimum solution, but simply simulate physical performance and thus enable evaluation of alternative solutions supplied externally by the decision maker.

The river basin simulation models are the Macro level models which are essentially required at the strategic level. It is essentially an allocation model wherein the total available water is allocated to different uses in space and time and the physical and economic consequences of such allocation are duplicated and accounted. The uncertain inflow is taken care of by equally likely sequences of synthetically generated hydrologic data. So this type of simulation models consist of two main components; (i) Sequential generation of hydrological data; and (ii) Hydraulic simulation or the allocation process and the economic evaluation of the consequences allocation.

Unlike the optimization models, the simulation models are transparent in that the decision maker can easily understand the relationships used in processing the raw data and its conversion to finished product. It is the familiarity of the process and nearness of the duplicated process to real world situation which makes the simulation a widely acceptable mode of analysis for river basin planning. Also all the optimization models need to be supported by a simulation model either embedded in the optimization model or external to it either to keep track of the intractable aspects or to refine the preliminary plans obtained by the optimization models.

The historic perspective of the river basin simulation has been reviewed in Chapter - 2. The simulation model developed and illustrated here is an allocation model. This model incorporates the good aspects of other simulation models and some distinctive features. This may be called a 'rough' simulation sufficient to study the overall hydrologic behavior of the river basin operation at the planning stage.

4.1 WIDELY ACCEPTED RESERVOIR RELEASE RULES

4.1.1 SPACE RULE :

This rule was developed by Bower et al (1962) and is designed for a parallel system of resources meeting a common demand of consumptive type. Thus to meet the single downstream monthly demand D with reservoir of capacity K^S at each site S_t^S when initial reservoir storage volumes are S_t^S and the current month's inflows are Q_t^S the release R_t^S from each reservoir S is (if possible) :

$$R_t^S = S_t^S + Q_t^S - K^S + \lambda\ E_t^S \ldots\ldots\ldots\ldots\ \forall s \qquad (4.1)$$

where, $$\lambda = \left[\sum_{s=1}^{S} (K^{s} - S_t^{s} - Q_t^{s}) + D \right] \Big/ \sum_{s=1}^{S} E_t^{s} \qquad (4.2)$$

and E_t^s is the expected value of the inflow into each reservoir from the current month t through the end of the current refill cycle; the E_t^s values are easily computed from the specified mean values of the flows in each month. One could use the conditional means, given available information (Snow pack, ground water elevation and previous flow values etc) at time t. The above equation employs a forecast of the current inflows Q_t^s into each reservoir.

The space rule allocates empty space $(K^s-S_t^s-Q_t^s+R_t^s)$ among the reservoirs so as to minimize the probability of spills, approximately, It does this by making the empty space in each reservoir proportional to the expected inflow to that reservoir, if possible. The common constant of proportionality is λ.

The objective with which this rule is framed makes it unsuitable for universal use in the case of parallel reservoirs. In periods when inflows are negligible and the conservation of water is the sole objective, alternative rules may be more efficient than the space rule. The space rule is only valid when determining the operation of head water reservoirs, the implication being that the inflows into these reservoirs are not regulated by any other reservoirs upstream of these reservoirs. Also the space rule is valid when there is no major streamflow entry point between reservoir (releasing water to meet the demand) and the demand node.

4.1.2 VOLUME RULE :

The volume rule is designed to make releases based on the volume of water in the reservoir system at the beginning of each month. It does not include the water entering the reservoir from upstream in that month. This water is accounted for in the storage at the beginning of the next month. In some cases this rule can be inefficient, allowing spills to take place at one reservoir while another reservoir releases from storage. The release R_{jk} for the j^{th} reservoir in k^{th} month is :

$$R_{jk} = \frac{S_{jk}}{\sum_{j=1}^{m} S_{jk}} R_T \qquad 0 \le R_{jk} \le S_{jk} \tag{4.3}$$

where, S_{jk} is the initial content of the j^{th} reservoir in the k^{th} month and R_T is the sum total of releases required to fulfill the target outputs. This rule is similar to linear decision rule, where release from a reservoir is linearly proportional to the stored water available at the time of release and suffers from the same defects as that of the linear decision rule. What is really achieved by this rule is not clear and also suffers from the limitation of space rule when the objective is conservation of water. Both the space rule and the volume rule can be inefficient when the reservoirs are linked to hydropower stations in one or more reservoirs where the effective head is also important in generating power in addition to releases to meet the downstream demand.

4.1.3 RULE CURVE :

It is essentially a single reservoir rule procedure in which minimum storage levels are set by consideration of a low-flow year or sequence of low flow years and the expected demands from the reservoir. This procedure, if applied to a multireservoir system ignores the possibility of conjunctive use of reservoirs and system operation flexibilities. To set minimum reservoir storage levels, based on consideration of multi-reservoir system operation, a simulation - optimization approach is needed. The problem is quite complex and may require numerous trials to get a good solution.

4.1.4 CONVENTIONAL OPERATION POLICY :

This is a traditional single reservoir operating rule and is shown in Figure. 4.1. The monthly reservoir release is dependent upon the sum of end of month's storage and current month's inflow into the reservoir. The monthly reservoir release target is that amount of water which must be released to meet down stream demands and any low flow requirements for the current month. If the reservoir is empty and current month's inflow is less than the demand, shortage will occur. When the reservoir storage plus the current month's inflow exceeds the maximum reservoir capacity, excess water above demand must be released (the reservoir spills). In between these extremes monthly release requirement can be met exactly. The method is attractive in that monthly releases can be adjusted to the level of demand. However. it is much less flexible in a multi-reservoir system where water may be moved from one storage location to another and thus demands can be satisfied by other system of reservoirs depending upon the total storage in the

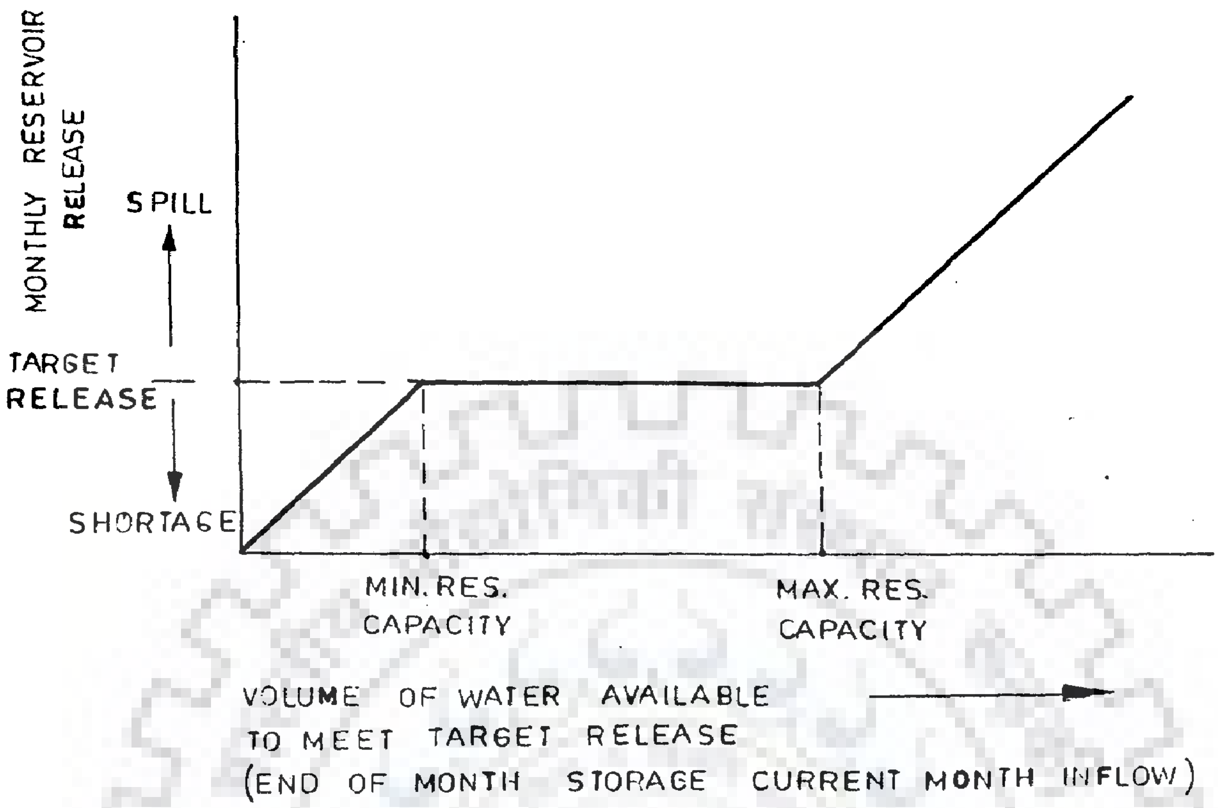


FIGURE 4·1 CONVENTIONAL OPERATING CURVE

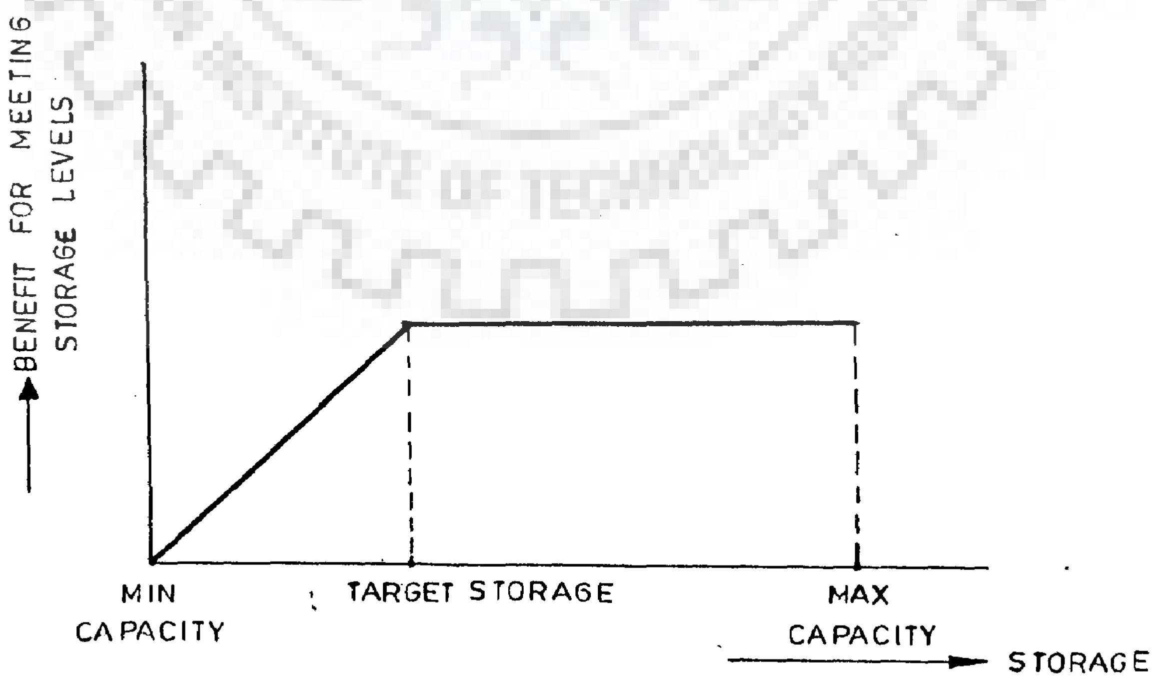


FIGURE 4·2 TWO STEP BENEFIT STORAGE CURVE

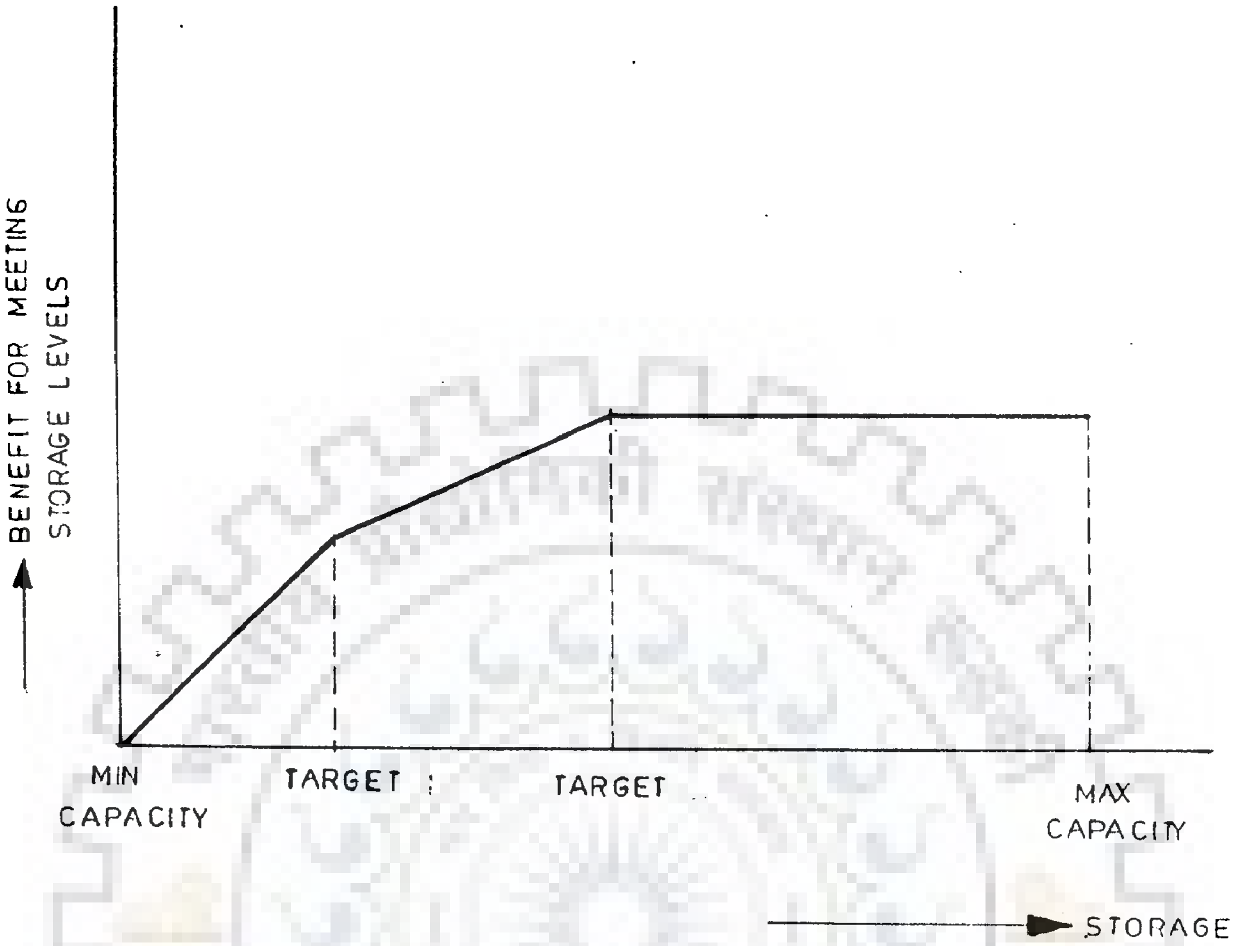


FIGURE 4·3 NON LINEAR BENEFIT STORAGE CURVE entire water resource system.

4.1.5 PENALTY BASED RULE CURVE :

In this approach desired (target) reservoir storage level for each month is associated with a benefit. In this method neither reservoir storage levels nor reservoir releases are fixed, instead desired storage levels compete with the value of water for satisfying demands. Figure. 4.2 represent a possible relationship between storage levels and benefits for maintaining those storages, that could be used in this method. These methods can either be related empirically to the economic benefits derived from different storage levels or can be assigned values that result in efficient operation of system based on minimizing total cost (Excluding capital cost). In the first case, economic benefits for maintaining certain levels accrue from recreation, power generation, flood control and fish and wild life consideration. These may be considered as 'desired' or priority levels also with no benefits attributed in economic terms. Using this concept the benefits may increase for meeting the storage targets linearly until the target level is reached. At this point the curve flattens and excess water may be stored up to reservoir maximum capacity but with no increase in benefits due to additional storage maintenance. A Logical extension is to develop nonlinear benefit storage curves as shown in Figure. 4.3. This type of relationship puts greater value upon the satisfaction of the first target storage level and gradually lowers the importance of subsequent storage increments. The slope of the benefit-storage curve (unit benefit value) and the cost of delivering water to reservoirs decides the order in which storage targets will be satisfied. The method is, however, limited by the ability to develop suitable storage targets and unit benefit costs. Also the operation policy cannot be directly incorporated into simulation. It is necessary to convert into some parametric form through optimization study before incorporating into the simulation model.

Besides the above well reconized rules, there can be other types of rules. One such rule is to minimize evaporation and water is the only output from multi-reservoirs. Evaporation in any month is proportional to reservoir water surface area. If all reservoirs have the same evaporation constant, the evaporation is given by :

$$e = k(S_1 + S_2 + S_3 + \ldots\ldots + S_n) \qquad (4.4)$$

Setting the partial derivatives of e with respect to a change in storage Δq_i equal to zero gives :

$$\frac{dS_1}{dq_1} = \frac{dS_2}{dq_2} = \ldots\ldots\ldots = \frac{dS_n}{dq_n} \qquad (4.5)$$

The proper rule for a water supply system is therefore to maintain a relationship between storage levels $q_1, q_2, q_3, \ldots, q_n$ such that for any $q = \sum_{i=1}^{n} q_i$ is satisfied. Beginning with all reservoirs at a given initial condition, any decrease Δq would be drawn from the reservoir for which dS_i/dq_i is the greatest until $dS_i/dq_i = dS_j/dq_j$, where j represents the second largest derivative. Further decreases Δq in q are apportioned between reservoirs i and j so as to maintain this equality until the derivative drops to the value of the third highest. Decreased Δq are now allocated these ways so as to maintain equality. The process continues until all equalities are met and until one of the reservoirs reaches zero storage. Decrements are then allocated to the remainder of reservoirs satisfying the equality of derivatives until all have reached zero.

4.1.6 PRIORITY NUMBER AND RELEASES:

In case, especially of parallel reservoirs, priority number can be assigned to different storage levels in each reservoir and releases in any time period is based on the reservoir content which is related to the priority number assigned to that storage.

The reservoir storage is divided into intervals and priority is assigned to each interval. This is quite useful in flood control operation with parallel reservoirs.

4.2 SALIENT FEATURES OF THE PRESENT SIMULATION MODEL :

The simulation model RIBS is designed and developed for examination of hydraulic exchanges and the management of reservoirs in a complex environment of multipurpose use of basin water resources and complicated interconnections. The physical facilities that are included in the model are the reservoirs and diversions for redistribution of river waters for Municipal and Industrial water supply, irrigation and generation of hydropower. The flood control aspect is included by reserving empty storage space in reservoirs in the flood season. The model can be implemented on a Personal Computer (P.C) even with large number of reservoirs.

The main components of the models are the hydrologic accounting and the system behaviour and the main model is supplemented by a number of supporting models external to the main model such as reservoir sedimentation and updating area-capacity relation of the reservoirs, effective precipitation computation for rice and non rice crops and the water requirements of crops. These features along with the water allocation and reservoir management procedures make this model distinct from many other existing simulation models and provides a simple and very effective tool for analysis of complicated river basins and in evaluating alternatives of various physical facilities.

The model is designed as a hydraulic net work and the flow routing through the network takes place through a set of consistent rules of allocation of water from the source to demand centres and the hydropower stations so as to attain a uniform, consistent and feasible allocation of water at various points satisfying the social obligations that arise in the system operation, and also the usual priorities of multipurpose use of water and physical facilities to meet the various objectives in a basin context.

4.3 MANAGEMENT RULE :

This mainly consists of two components :

1) water allocation and

2) reservoir operation policy.

Water allocation is through priority rules. The priority of use can be altered. Generally the priority is for M&I water supply, Hydropower production and irrigation in that order. The allocation of water will take place in the order satisfying fully the demand according to the priority. The water allocation is affected from uppermost reservoir down stream. The return flow from the demand centres calculated on a set of parameters reaches the down stream junction and is routed down stream along with other flows available at that point. The return flow parameters can be varied with reference to the type of consumption such as M & I, irrigation and hydropower generation and also time period of the year.

Actual allocation of water takes place in three steps, and in each step priority of water use is given due regard. In the first step uncontrolled water is routed through the net work satisfying the demands at various points. In the next step allocation of stored water for its own demand centres is taken care of and in the third step, releases from reservoirs for down stream purpose and readjustment of allocations from low priority use allocation to high priority use down stream are effected, accounting for the return flows already allocated and for those that may occur after adjusted allocation.

In allocating water at a point, the demand both high and low priority at that point is fully met before further allocation. If the water available is such that it is unable to fully meet the demand at that point, the shortage percentage is maintained constant for the same priority use throughout the system.

The release rules for the reservoir follow the conventional reservoir operation policy with a difference. The main difference from the conventional operation policy is that the procedure combines the storage targets with the conventional policy. The reservoir storage limits are specified for each period. These limits are determined by a number of trial with critical flow sequences.

When water is to be released for a demand centre, the water is released from immediately upstream reservoir and in the case of parallel reservoirs the priority for release from different reservoir, is determined with due regard to the anticipated use of stored water and its priority.

It is possible to change the priority to minimize water evaporation from reservoirs by releasing water from the reservoirs having maximum quantity of water.

4.4 MECHANICS OF SIMULATION :

For the purpose of running the model, the river basin is first conceptualized as a tree with nodes and links. The reservoirs, diversions, junctions, demand centres and the sink are all represented by nodes, and the links connect these recognizing the existing and proposed flow paths, between the nodes. This offers sufficient flexibility by introducing or deleting nodes and links to examine the alternatives. The nodes can be numbered in any arbitrary order; however, for purposes of node processing, the serial order is to be specified and this ordering is based on the flow constraints and the sequence in which the flow occurs in the network. This avoids representing the tree structure of the basin by a matrix. Although matrix form is the most convenient way to represent a tree or network offering a lot of ease in programming effort, the tree structure is identified by strings of nodes and their links resulting in economy in computer storage.

The nodes are typified by their main functions such as storing, diverting, irrigation, hydropower generation, M & I demand and junction, as the nodes may fall into more than one type. The time step used is one month. It can be reduced to 10 days if necessary.

Initially the nodes are scanned in the serial order specified, i.e. from upstream to downstream to utilize fully the uncontrolled flows, return flows and the downstream releases from the upstream nodes. These are all added up and compared with the demand at that point and allocations are made according to the rules, and reservoirs are updated, downstream releases and the return flows are computed. In the second run reservoir releases to meet the immediate downstream demands are effected. At any node, more than one number of demand centres can exist, although more than two of M & I and irrigation and one of hydropower are uncommon. Now all the demand centres are scanned, and if necessary and if water is available, releases are made from the reservoirs. The status of reservoirs as updated. The model accounts for hydropower generation with varying head and reservoir evaporation in the multi-purpose context in an iterative way. In the last phase, adjustments by transfer of low priority needs already satisfied to the downstream high priority needs remaining unsatisfied are also effected giving due consideration to the return flow readjustments.

4.5 SIMULATION PROGRAM :

The riverbasin simulation RIBS has been developed in Fortran 77 and the list of notation used and the program listing is given in Appendix - B and Appendix - C.

Explanation of input data (Based on the Figure. 3.8 given on Chapter - 3) is as follows :

(i) Number of nodes (NON)
Number of links (NOL)
Number of reservoirs (NOR)
Number of Irrigation demand nodes (NDI)
Number of hydropower demand node (NDH)
Number of M&I demand node (NDM)
Number of inflow node (NIN)
Total number of months of simulations (NMS)
Starting month of simulation (NSM)

ii) Node serial number (NS(I))
Note type (NT(I)); 1=Reservoir, 2=Diversion, 3=Irrigation demand, 4=Hydropower 5=M&I demand, and 7=Absorbing node or end node
Variables of 0 - 1 (NIF(I)); 1 = if it is inflow node and 0 otherwise

(iii) link serial number (LS(I))

Beginning node number of the link (LB(I))

Link end node number (LE(I))

Link type (LT(I)): 1 = if link is serving a M&I demand

2 = if link is serving hydropower station

3 = if link is serving irrigation demand

4 = All others

(iv) Reservoir serial number (IRS(I))

Reservoir identity - Actual node number (IDR(I))

Minimum draw-down level (DDL(I))

Number of area capacity point at i^{th} reservoir (NAC(I))

Type of reservoir (NRT(I)):

1 = if serving only downstream

2 = if serving only M&I

3 = if serving only hydropower

4 = if serving only irrigation

5 = if serving M&I and hydropower

6 = if serving M&I and irrigation

7 = if serving irrigation and hydropower

8 = if serving all irrigation, hydropower, and M&I

(v) Elevation of j^{th}at area capacity point of i^{th} reservoir (E(I,J))

Area of reservoir at elevation of j^{th} point of i^{th} reservoir (A(I,J))

Capacity at j^{th} point elevation of i^{th} reservoir (C(I,J))

(vi) Maximum reservoir capacity is to be maintained in the i^{th} reservoir in j^{th} time for flood control (VMX(I,J))

(vii) Minimum reservoir capacity is to be maintained in the i^{th} reservoir in j^{th} month for conservation purposes (VMN(I,J))

(viii) Evaporation constant for i^{th} reservoir in j^{th} month (EVC(I,J))

(ix) Irrigation demand serial number (IDS(I))

Identity of Irrigation Area node number (IDI(I))

Area under irrigation in the i^{th} irrigation demand centre (ARE(I))

(x) Water requirement of crop for i^{th} area in j^{th} period in mm (WRC(I,J))

(xi) Serial number of hydropower station (IHS(I))

Identity of hydropower station node number (IDH(I))

Firm power expected of i^{th} hydropower station (FP(I))

Tail water level of i^{th} hydropower station or canal to constant head in case of constant head hydropower station (TWL(I))

(xii) M&I demand cetre serial number (IMS(I))

Identity of M&I demand centre node number (IDM(I))

(xiii) Demand of i^{th} M&I demand centre in j^{th} period (DEM(I))

(xiv) Number of days in the i^{th} month (DAY(I))

(xv) Full reservoir capacity of i^{th} reservoir (FRC(I))

Full reservoir level of i^{th} reservoir (FRL(I))

Full reservoir area of i^{th} reservoir (FRA(I))

(xvi) Serial number of M&I nodes for adjusment and release from upstream reservoir (DCM(I))

Number of demand centre (NDC(I))

Number of reservoir available for release to satisfy the demand corresponding to the reservoir (NRA)

Number of demand centre for which return flow can happen w.r.t. the demand centre (NRN)

(xvii) Reservoir available for release (IRU)

(xviii) Node number of demand centre in the order; 1,2,3,4.....,k with respect to the demand (DS). The first digit of DS represent the type of node whether it is M&I (=1) or Irrigation (=2). The fractional part represent the flow fraction from upstream demand satisfied.

(xix) Inflow serial number (INS(I))

Identity of inflow node number (IDF(I))

Inflow to i^{th} of inflow node in j^{th} period (FIN(I,J))

4.6 CASE STUDY :

The program is to be provided with the following data and input of simulation program is given in table 4.1, which are site specified and others :

i) Crop water requirement

ii) Municipal and Industrial (M&I) water supply

iii) Evaporation

iv) Number of days of each month (January up to December)

v) Specification of reservoir i.e capacity, area and elevation

vi) Maximum capacity of reservoir

vii) Dead storage

vii) Minimum draw-down level

ix) Firm power

x) Tail water elevation

xi) Inflow data

Lusi - Serang system screened in Chapter 3 is simulated. Historical data of 20 years at several inflow points given in Chapter 3 is used for the purpose. The out put of the program in the table form (for a few months) as well as in the graphical form are given through Table. 4.2 to Table. 4.3 and Figure. 4.4. In the Table. 4.4 demand row 1 is the actual demand, the demand row 2 is the unsatisfied demand and the demand row 3 is the sum of these two. The month serial number, actual month number and the reservoir contents are given on table 4.4.

TABLE 4.1 DATA FOR SIMULATION OF PROJECT COMBINATION : 2-2 ; 3-3 & 1-1

25	33	1	5	1	1	11	240	1
1	1	6	1	0				
2	2	6	1	0				
3	3	6	0	0				
4	4	2	1	0				
5	5	3	0	0				
6	6	3	0	0				
7	7	6	0	0				
8	8	6	1	0				
9	9	2	1	0				
10	10	6	0	0				
11	11	6	1	0				
12	12	2	1	0				
13	13	6	0	0				
14	14	1	1	1				
15	15	4	0	0				
16	16	2	1	0				
17	17	3	0	0				
18	18	6	0	0				
19	19	2	1	0				
20	20	6	0	0				
21	21	3	0	0				
22	22	2	1	0				
23	23	3	0	0				
24	24	5	0	0				
25	25	7	0	0				
1	1	3	4					
2	2	3	4					
3	3	4	4					
4	4	5	3					
5	4	6	3					
6	4	7	4					
7	5	7	4					
8	6	7	4					
9	7	10	4					
10	8	9	4					
11	9	12	4					
12	9	10	4					
13	10	13	4					
14	11	12	4					
15	12	17	3					
16	12	13	4					
17	13	18	4					
18	14	15	2					
19	14	16	4					
20	15	16	4					
21	16	17	3					
22	17	18	4					
23	18	20	4					
24	16	19	4					
25	19	21	3					
26	19	20	4					

Table 4.1 (Contd.)

```
27  20  22   4
28  22  23   3
29  22  24   1
30  22  25   4
31  21  25   4
32  23  25   4
33  24  25   4
1  14   64.44   26    8
   40.0    0.0     0.0
   42.0   40.0     1.0
   44.0   60.0     3.0
   46.0   80.0     5.0
   48.0   150.0    7.0
   50.0   220.0    9.5
   52.0   300.0   12.5
   54.0   370.0   20.0
   56.0   450.0   28.0
   58.0   580.0   38.0
   60.0   700.0   53.0
   62.0   830.0   68.0
   64.0   950.0   85.0
   66.0  1100.0  103.0
   68.0  1250.0  125.0
   70.0  1450.0  155.0
   72.0  1650.0  185.0
   74.0  1900.0  220.0
   76.0  2200.0  260.0
   78.0  2450.0  310.0
   80.0  2750.0  362.5
   82.0  3050.0  415.0
   84.0  3375.0  480.0
   86.0  3750.0  550.0
   88.0  4200.0  630.0
   90.0  4580.0  725.0
723   723   723   723   723   723   723   723   723   723   723   723
88.5  88.5  88.5  88.5  88.5  88.5  88.5  88.5  88.5  88.5  88.5  88.5
 9    9.4   11    11.3  12.1  9.7   10.9  15.1  17.   15.9  11.2  10.0
1    5       9625
2    6       4600
3   17       6100
4   21       15200
5   23       51900
40    0    461  176   147   29   47   75   16  150  420  60
40    0    461  176   147   29   47   75   16  150  420  60
40    0    451  137   147   29   47   75   16  170  400  60
30    0    480  186   176   29   47   75   16  220  470  50
40    0    470  206   176   29   47   73   16  220  480  60
1    14     13.2   43.0
1    24
9.37 8.47 9.38 9.08 9.37 9.07 9.38 9.37 9.07 9.38  9.07 9.37
31   28   31   30   31   30   31   31   30   31    30   31
 178.26   71.55   1605.07
     1       1     0
     1     0     0
```

Table 4.1 (Contd.)

2	0	0
3	1	1
4	1	0
5	1	0

1
0
0
1
1
1
25.2

1	1	87.6	55.4	59.2	72.8	40.7	11.6	10.1	1.0	1.1	1.3	32.9	79.8
		88.9	108.4	49.6	44.8	35.2	10.9	15.2	8.2	4.9	13.9	37.1	38.3
		80.4	92.7	66.7	73.1	45.8	24.1	8.1	8.7	3.2	11.5	59.9	61.9
		72.0	58.7	47.1	38.4	34.2	33.2	10.3	20.6	5.2	13.1	12.4	34.2
		44.2	46.0	110.9	31.9	16.4	11.4	36.5	5.9	0.1	2.6	16.8	85.7
		65.1	117.3	89.5	38.6	7.6	15.3	13.7	11.0	4.6	12.6	19.4	85.2
		34.0	76.4	72.0	34.0	62.5	13.2	8.3	0.9	1.8	2.1	20.7	90.8
		77.7	63.4	56.5	46.7	36.4	9.8	2.6	2.2	2.8	3.5	45.6	64.8
		70.4	83.2	46.9	48.0	18.7	7.8	0.9	0.0	0.6	1.6	16.1	68.6
		72.3	92.9	43.4	81.1	6.6	10.1	9.8	6.9	1.5	21.4	34.0	45.8
		80.4	106.0	50.4	24.1	8.9	22.6	0.0	3.0	1.4	3.2	8.8	74.2
		32.1	41.1	50.6	46.4	35.7	7.3	12.2	4.6	19.0	7.5	46.1	50.1
		81.2	49.8	67.0	41.2	19.7	1.8	5.1	0.6	0.0	1.6	12.7	19.5
		46.9	33.9	79.8	18.1	31.1	12.7	0.9	0.4	3.7	6.4	23.8	80.4
		72.9	33.6	44.5	44.1	6.3	0.0	3.6	0.0	1.9	6.2	21.0	85.2
		69.9	56.1	51.2	41.0	68.8	36.3	31.0	12.7	3.6	7.8	29.7	62.4
		62.9	72.1	79.8	35.8	10.6	8.0	1.3	0.4	6.9	6.2	21.3	34.0
		60.0	49.9	88.7	54.2	23.5	10.9	4.7	0.6	4.5	7.8	19.2	49.0
		85.4	53.2	47.4	22.8	77.9	20.5	13.1	0.0	0.3	13.7	33.7	59.5
		76.3	44.8	76.3	28.5	49.6	2.6	0.0	3.5	0.2	0.5	22.6	50.6
2	2	9.2	8.2	8.0	12.0	4.0	2.9	1.0	0.1	1.8	1.6	7.5	6.5
		11.1	16.3	6.5	9.6	3.8	3.8	1.9	4.9	1.9	2.6	6.7	11.2
		14.4	19.4	13.3	15.3	9.2	4.8	5.3	1.5	0.2	2.5	8.0	11.6
		10.7	10.4	10.5	4.5	4.4	11.4	1.1	3.9	2.1	3.4	5.5	7.6
		6.0	8.1	15.4	7.0	3.7	3.1	9.6	0.9	0.1	1.5	4.0	13.0
		8.5	13.9	25.2	8.9	2.9	1.7	5.5	4.1	0.7	3.0	2.3	17.4
		11.8	18.7	25.4	4.0	14.3	2.2	3.6	0.5	0.5	1.1	3.3	10.0
		18.4	12.8	5.4	10.6	3.7	0.3	0.6	1.2	0.7	0.8	9.3	13.5
		20.2	10.5	7.2	7.6	6.4	1.5	0.1	0.0	0.0	0.6	3.7	7.5
		22.6	13.4	10.0	10.3	1.7	2.0	5.6	5.2	1.3	2.7	6.4	9.8
		16.4	14.8	9.7	4.8	3.5	0.7	0.0	0.0	0.2	1.1	2.4	12.5
		11.2	11.9	10.5	9.9	7.3	2.4	0.4	1.2	4.6	4.0	6.3	8.6
		19.7	10.2	13.3	4.3	3.4	0.4	0.9	0.2	0.1	0.0	1.0	11.8
		15.0	11.7	18.0	3.0	5.1	2.7	0.2	0.4	0.8	1.4	4.0	7.5
		19.1	7.3	8.4	11.6	1.1	0.0	0.0	0.1	0.2	1.4	3.1	16.0
		13.0	8.7	11.5	7.5	10.5	3.6	9.0	4.5	2.1	1.5	6.7	11.7
		9.1	12.5	17.5	9.3	3.6	1.3	1.3	0.6	0.7	1.5	3.5	9.5
		12.4	8.2	13.9	9.8	6.3	1.8	0.8	0.0	1.4	0.6	5.2	8.0
		16.7	14.8	14.1	8.6	9.3	5.7	0.4	0.0	1.1	4.2	4.8	10.2
		18.6	8.7	16.9	5.4	5.7	0.0	0.0	1.6	0.0	0.2	4.8	9.6
3	4	82.0	82.9	53.6	63.7	38.3	0.0	9.5	0.9	0.0	0.5	29.7	74.6
		51.4	96.4	45.1	37.0	32.8	7.5	13.9	3.6	3.2	11.9	31.9	28.6
		69.2	76.7	56.1	60.7	38.4	20.3	3.1	7.5	3.1	9.5	54.3	52.9

Table 4.1 (Contd.)

		64.2	44.4	38.5	35.4	31.2	23.1	9.6	20.6	2.3	10.2	13.1	39.4
		40.0	39.7	96.9	26.2	13.4	8.8	18.0	5.2	0.0	1.2	13.5	76.1
		59.2	108.1	67.9	31.2	5.0	14.2	8.7	7.3	4.1	10.1	17.9	71.2
		23.6	60.6	49.5	31.4	50.7	11.5	5.8	0.4	1.4	1.1	18.2	24.4
		62.4	63.1	63.4	38.0	34.2	9.9	2.1	1.1	2.2	2.8	38.1	53.9
		53.0	76.0	41.6	42.3	13.0	6.6	0.8	0.0	0.6	1.1	13.0	57.8
		52.6	83.2	35.1	74.0	5.2	8.5	4.6	2.0	0.3	19.6	19.0	37.8
		67.2	95.4	42.7	20.3	5.8	2.0	0.0	0.0	1.3	2.0	6.8	64.7
		22.2	30.8	42.1	38.4	29.8	5.2	12.3	3.6	15.7	2.8	11.6	43.5
		64.7	41.6	56.4	38.5	17.1	1.5	4.4	0.4	0.0	1.7	12.2	82.3
		33.8	23.6	65.0	15.8	27.2	10.5	0.7	0.0	5.1	6.6	24.2	53.2
		56.3	62.5	65.5	27.9	7.4	7.0	0.1	0.0	6.5	5.3	20.9	76.1
		56.7	27.6	37.9	34.3	5.5	0.	3.7	0.0	1.8	5.3	16.9	72.6
		59.7	49.6	41.7	35.1	61.1	34.2	23.2	8.7	1.6	4.9	18.7	25.7
		50.0	41.6	78.3	46.6	18.1	9.5	4.1	0.6	3.3	7.5	14.9	43.0
		72.1	40.5	35.2	15.1	71.7	15.6	13.2	0.0	5.5	10.0	30.2	51.7
		60.8	37.9	62.5	24.2	45.9	2.7	0.0	2.0	0.2	8.8	18.7	43.0
4	8	14.3	13.7	9.6	12.6	4.8	1.4	1.6	0.2	3.0	0.4	4.8	8.2
		14.4	13.2	10.3	10.5	5.0	1.6	3.7	2.3	1.1	2.0	10.0	5.7
		14.6	11.6	5.9	7.5	4.3	2.5	4.8	0.7	1.1	3.9	5.2	7.1
		12.8	10.9	10.3	3.4	4.3	8.6	0.4	2.0	1.1	1.4	3.9	10.9
		9.3	9.4	23.5	8.7	1.3	1.8	2.9	0.2	0.0	1.8	4.6	10.9
		10.9	16.4	17.1	7.0	4.5	3.6	6.1	2.7	2.0	4.6	5.7	12.8
		15.5	9.3	11.4	8.2	8.7	5.2	1.4	0.4	0.2	1.4	4.8	8.0
		9.4	9.3	5.9	4.6	5.7	2.1	0.9	0.2	1.1	0.9	6.8	8.6
		10.5	9.8	14.3	3.6	11.2	0.7	0.0	0.0	0.2	1.1	5.7	5.5
		16.4	7.8	8.2	14.3	1.8	4.3	1.8	1.8	2.0	3.2	4.5	9.6
		17.3	11.2	8.7	5.9	0.5	0.5	0.0	0.0	0.0	1.3	3.0	11.6
		4.5	14.6	7.7	5.5	5.3	2.7	0.5	0.9	1.3	2.9	1.6	5.5
		9.6	10.9	10.7	13.9	1.6	1.4	0.5	0.0	0.0	1.6	4.8	8.6
		9.4	6.8	11.0	2.5	2.0	4.3	0.0	0.2	0.0	3.2	4.8	6.1
		14.8	8.4	10.9	7.7	1.1	0.0	0.0	0.7	0.0	1.1	5.0	14.3
		12.1	16.9	8.4	7.3	9.8	2.1	6.4	2.1	1.4	2.1	8.7	6.1
		5.0	11.8	10.0	3.0	0.0	0.5	1.6	0.0	0.0	4.5	4.3	10.7
		12.8	10.7	17.3	6.4	7.0	0.7	1.4	0.0	1.8	3.4	5.2	9.4
		21.2	9.8	10.3	7.7	8.4	5.9	0.2	0.9	0.5	5.7	5.3	9.6
		19.4	10.5	10.3	6.8	5.3	1.6	0.0	0.5	0.0	0.9	7.0	10.7
5	9	3.6	3.4	2.4	3.1	1.2	0.4	0.4	0.1	0.8	0.1	1.2	1.9
		3.6	3.3	2.6	2.6	1.3	0.4	0.9	0.6	0.3	0.5	2.5	1.4
		3.7	2.9	1.5	1.9	1.1	0.6	1.2	0.2	0.3	1.0	1.3	1.8
		3.2	2.7	2.6	0.9	1.1	2.2	0.1	0.5	0.3	0.4	1.0	2.7
		2.3	2.4	5.9	2.2	0.3	0.5	0.7	0.1	0.0	0.5	1.2	2.7
		2.7	4.1	4.3	1.8	1.1	0.9	1.5	0.7	0.5	1.2	1.4	3.2
		3.9	2.3	2.9	2.1	2.2	1.3	0.4	0.1	0.1	0.4	1.2	2.0
		2.4	2.3	1.5	1.2	1.4	0.5	0.2	0.1	0.3	0.2	1.7	2.2
		2.6	2.5	3.6	0.9	2.8	0.2	0.0	0.0	0.1	0.3	1.4	1.4
		4.1	2.0	2.1	3.6	0.5	1.1	0.5	0.2	0.5	0.8	1.1	2.4
		4.3	2.8	2.2	1.5	0.1	0.1	0.0	0.0	0.0	0.3	0.8	2.9
		1.1	3.7	1.9	1.4	1.3	0.7	0.1	0.2	0.3	0.7	0.4	1.4
		2.4	2.2	2.7	3.5	0.4	0.4	0.1	0.0	0.0	0.4	1.2	2.2
		2.4	1.7	2.8	0.6	0.5	1.1	0.0	0.1	0.0	0.8	1.2	1.5
		3.7	2.1	2.7	1.9	0.3	0.0	0.0	0.2	0.0	0.3	1.3	3.6
		3.0	4.2	2.1	1.8	2.5	0.5	1.6	0.5	0.4	0.5	2.2	1.5
		1.3	3.0	2.5	0.8	0.0	0.1	0.4	0.0	0.0	1.1	1.1	2.7

Table 4.1 (Contd.)

		64.2	44.4	38.5	35.4	31.2	23.1	9.6	20.6	2.3	10.2	13.1	39.4
		40.0	39.7	96.9	26.2	13.4	8.8	18.0	5.2	0.0	1.2	13.5	76.1
		59.2	108.1	67.9	31.2	5.0	14.2	8.7	7.3	4.1	10.1	17.9	71.2
		23.6	60.6	49.5	31.4	50.7	11.5	5.8	0.4	1.4	1.1	18.2	24.4
		62.4	63.1	63.4	38.0	34.2	9.9	2.1	1.1	2.2	2.8	38.1	53.9
		53.0	76.0	41.6	42.3	13.0	6.6	0.8	0.0	0.6	1.1	13.0	57.8
		52.6	83.2	35.1	74.0	5.2	8.5	4.6	2.0	0.3	19.6	19.0	37.8
		67.2	95.4	42.7	20.3	5.8	2.0	0.0	0.0	1.3	2.0	6.8	64.7
		22.2	30.8	42.1	38.4	29.8	5.2	12.3	3.6	15.7	2.8	11.6	43.5
		64.7	41.6	56.4	38.5	17.1	1.5	4.4	0.4	0.0	1.7	12.2	82.3
		33.8	23.6	65.0	15.8	27.2	10.5	0.7	0.0	5.1	6.6	24.2	53.2
		56.3	62.5	65.5	27.9	7.4	7.0	0.1	0.0	6.5	5.3	20.9	76.1
		56.7	27.6	37.9	34.3	5.5	0.	3.7	0.0	1.8	5.3	16.9	72.6
		59.7	49.6	41.7	35.1	61.1	34.2	23.2	8.7	1.6	4.9	18.7	25.7
		50.0	41.6	78.3	46.6	18.1	9.5	4.1	0.6	3.3	7.5	14.9	43.0
		72.1	40.5	35.2	15.1	71.7	15.6	13.2	0.0	5.5	10.0	30.2	51.7
		60.8	37.9	62.5	24.2	45.9	2.7	0.0	2.0	0.2	8.8	18.7	43.0
4	8	14.3	13.7	9.6	12.6	4.8	1.4	1.6	0.2	3.0	0.4	4.8	8.2
		14.4	13.2	10.3	10.5	5.0	1.6	3.7	2.3	1.1	2.0	10.0	5.7
		14.6	11.6	5.9	7.5	4.3	2.5	4.8	0.7	1.1	3.9	5.2	7.1
		12.8	10.9	10.3	3.4	4.3	8.6	0.4	2.0	1.1	1.4	3.9	10.9
		9.3	9.4	23.5	8.7	1.3	1.8	2.9	0.2	0.0	1.8	4.6	10.9
		10.9	16.4	17.1	7.0	4.5	3.6	6.1	2.7	2.0	4.6	5.7	12.8
		15.5	9.3	11.4	8.2	8.7	5.2	1.4	0.4	0.2	1.4	4.8	8.0
		9.4	9.3	5.9	4.6	5.7	2.1	0.9	0.2	1.1	0.9	6.8	8.6
		10.5	9.8	14.3	3.6	11.2	0.7	0.0	0.0	0.2	1.1	5.7	5.5
		16.4	7.8	8.2	14.3	1.8	4.3	1.8	1.8	2.0	3.2	4.5	9.6
		17.3	11.2	8.7	5.9	0.5	0.5	0.0	0.0	0.0	1.3	3.0	11.6
		4.5	14.6	7.7	5.5	5.3	2.7	0.5	0.9	1.3	2.9	1.6	5.5
		9.6	10.9	10.7	13.9	1.6	1.4	0.5	0.0	0.0	1.6	4.8	8.6
		9.4	6.8	11.0	2.5	2.0	4.3	0.0	0.2	0.0	3.2	4.8	6.1
		14.8	8.4	10.9	7.7	1.1	0.0	0.0	0.7	0.0	1.1	5.0	14.3
		12.1	16.9	8.4	7.3	9.8	2.1	6.4	2.1	1.4	2.1	8.7	6.1
		5.0	11.8	10.0	3.0	0.0	0.5	1.6	0.0	0.0	4.5	4.3	10.7
		12.8	10.7	17.3	6.4	7.0	0.7	1.4	0.0	1.8	3.4	5.2	9.4
		21.2	9.8	10.3	7.7	8.4	5.9	0.2	0.9	0.5	5.7	5.3	9.6
		19.4	10.5	10.3	6.8	5.3	1.6	0.0	0.5	0.0	0.9	7.0	10.7
5	9	3.6	3.4	2.4	3.1	1.2	0.4	0.4	0.1	0.8	0.1	1.2	1.9
		3.6	3.3	2.6	2.6	1.3	0.4	0.9	0.6	0.3	0.5	2.5	1.4
		3.7	2.9	1.5	1.9	1.1	0.6	1.2	0.2	0.3	1.0	1.3	1.8
		3.2	2.7	2.6	0.9	1.1	2.2	0.1	0.5	0.3	0.4	1.0	2.7
		2.3	2.4	5.9	2.2	0.3	0.5	0.7	0.1	0.0	0.5	1.2	2.7
		2.7	4.1	4.3	1.8	1.1	0.9	1.5	0.7	0.5	1.2	1.4	3.2
		3.9	2.3	2.9	2.1	2.2	1.3	0.4	0.1	0.1	0.4	1.2	2.0
		2.4	2.3	1.5	1.2	1.4	0.5	0.2	0.1	0.3	0.2	1.7	2.2
		2.6	2.5	3.6	0.9	2.8	0.2	0.0	0.0	0.1	0.3	1.4	1.4
		4.1	2.0	2.1	3.6	0.5	1.1	0.5	0.2	0.5	0.8	1.1	2.4
		4.3	2.8	2.2	1.5	0.1	0.1	0.0	0.0	0.0	0.3	0.8	2.9
		1.1	3.7	1.9	1.4	1.3	0.7	0.1	0.2	0.3	0.7	0.4	1.4
		2.4	2.2	2.7	3.5	0.4	0.4	0.1	0.0	0.0	0.4	1.2	2.2
		2.4	1.7	2.8	0.6	0.5	1.1	0.0	0.1	0.0	0.8	1.2	1.5
		3.7	2.1	2.7	1.9	0.3	0.0	0.0	0.2	0.0	0.3	1.3	3.6
		3.0	4.2	2.1	1.8	2.5	0.5	1.6	0.5	0.4	0.5	2.2	1.5
		1.3	3.0	2.5	0.8	0.0	0.1	0.4	0.0	0.0	1.1	1.1	2.7

Table 4.1 (Contd.)

	3.2	2.7	4.3	1.6	1.8	0.2	0.4	0.0	0.5	0.9	1.3	2.4
	5.3	2.5	2.6	1.9	2.1	1.5	0.1	0.2	0.1	1.4	1.3	2.4
	4.9	2.6	2.6	1.7	1.3	0.4	0.0	0.1	0.0	0.2	1.8	2.7
6 11	8.0	7.7	5.4	7.0	2.7	0.8	0.9	0.1	1.7	0.2	2.7	4.3
	8.1	7.4	5.8	5.9	2.8	2.9	2.0	1.3	0.6	1.1	5.6	3.2
	8.2	6.5	3.3	4.2	2.4	1.4	2.7	2.4	2.6	2.2	2.9	4.0
	7.2	6.1	5.8	1.9	2.4	4.8	0.2	1.1	0.6	0.8	2.2	6.1
	5.2	5.3	13.2	4.9	0.7	1.0	1.6	0.1	0.0	1.0	2.6	6.1
	6.1	1.2	1.6	3.9	2.5	2.0	2.4	1.5	1.1	2.6	3.2	7.2
	8.7	5.2	6.4	4.6	4.9	2.9	0.8	0.2	0.1	2.8	2.7	4.5
	5.3	5.2	3.3	2.6	3.2	1.2	0.5	0.1	0.6	0.5	3.8	4.8
	5.9	5.5	8.0	2.0	6.3	0.4	0.0	0.0	0.1	0.6	3.2	3.1
	9.2	4.4	4.6	6.0	1.0	2.4	1.0	1.0	1.1	1.8	2.5	5.4
	9.7	6.3	4.9	3.3	0.3	2.3	3.0	3.0	0.0	2.7	1.7	6.5
	2.5	8.2	4.3	3.1	3.0	1.5	3.3	2.5	0.7	1.6	2.9	3.1
	5.4	6.1	6.0	7.8	0.9	0.8	0.3	0.0	0.0	0.9	2.7	4.8
	5.3	2.8	6.2	1.4	1.1	2.4	0.0	0.1	0.0	1.8	2.7	3.4
	8.3	4.7	6.1	4.3	0.6	0.0	0.0	0.4	0.0	0.6	2.8	8.0
	6.8	9.5	4.7	4.1	5.5	1.2	3.6	1.2	0.8	1.2	4.9	3.4
	2.8	6.8	5.6	1.7	0.0	0.3	0.9	0.0	0.0	2.5	2.4	6.0
	7.2	6.1	9.7	3.6	3.9	0.4	0.8	0.0	1.0	1.9	2.9	5.3
	11.9	5.5	5.8	4.3	4.7	3.3	0.1	0.5	0.3	3.2	3.0	5.4
	10.9	5.9	5.8	3.8	3.0	0.9	0.0	0.3	0.0	0.5	3.9	6.0
7 12	1.6	1.5	1.1	1.4	0.5	0.2	0.2	0.	0.3	0.1	0.5	0.9
	1.6	1.5	1.2	1.2	0.6	0.2	0.4	0.3	0.1	0.2	1.1	0.6
	1.6	1.3	0.7	0.8	0.5	0.3	0.5	0.1	0.1	0.4	0.6	0.8
	1.4	1.2	1.3	0.4	0.5	1.0	0.1	0.2	0.1	0.2	0.4	1.2
	1.0	1.6	2.6	1.0	0.5	0.2	0.3	0.	0.	0.2	0.5	1.2
	1.2	1.8	1.9	0.8	0.5	0.4	0.7	0.3	0.2	0.5	0.6	1.4
	1.7	1.0	1.3	0.9	1.0	0.6	0.2	0.	0.	0.2	0.5	0.9
	1.1	1.0	0.7	0.5	0.6	0.2	0.1	0.	0.1	0.1	0.8	1.0
	1.2	1.1	1.6	0.4	1.3	0.1	0.	0.	0.	0.1	0.6	0.6
	1.8	0.9	0.9	1.6	0.2	0.5	0.2	0.2	0.2	0.4	0.5	1.1
	1.9	1.3	1.0	2.7	0.1	0.1	0.	0.	0.	0.1	0.3	1.3
	0.5	1.6	0.9	0.6	0.6	0.3	0.1	0.1	0.1	0.3	0.2	0.6
	1.1	1.2	1.2	1.6	0.2	0.2	0.1	0.	0.	0.2	0.5	1.0
	1.1	0.4	1.2	0.3	0.2	0.5	0.	0.	0.	0.4	0.5	0.7
	1.7	0.9	1.2	0.9	0.1	0.	0.	0.1	0.	0.1	0.5	1.6
	1.4	2.0	0.9	3.8	1.1	0.2	0.7	0.2	0.2	0.2	1.0	0.7
	0.3	1.4	1.1	0.3	0.	0.1	0.2	0.	0.	0.5	0.5	1.2
	1.4	1.2	1.9	0.7	0.8	0.1	0.2	0.	0.2	0.2	0.6	1.1
	2.4	1.1	1.2	0.9	0.9	0.7	0.	0.1	0.1	0.6	0.6	1.1
	2.2	1.2	1.2	0.8	0.6	0.2	0.	0.1	0.	0.1	0.8	1.2
8 14	93.3	77.3	72.1	92.0	55.6	9.4	17.5	1.8	1.3	0.7	15.7	54.3
	108.8	135.3	77.8	116.3	82.3	16.4	21.4	7.2	11.2	27.6	139.1	91.3
	182.4	107.5	84.7	114.8	25.8	14.0	35.6	12.9	14.0	26.1	82.6	74.2
	150.0	172.8	92.7	25.8	31.8	31.1	11.0	14.7	10.3	21.5	38.5	135.1
	111.1	67.0	173.5	99.7	25.9	8.5	23.2	4.6	3.1	2.8	9.2	81.9
	93.9	205.9	182.0	121.6	115.9	23.6	58.5	65.1	10.9	58.7	66.1	171.1
	187.9	143.0	139.7	105.3	102.2	28.5	40.3	4.2	2.6	6.6	49.0	161.8
	71.8	145.6	78.4	77.8	87.6	18.4	14.4	2.8	1.5	6.1	59.1	52.3
	88.2	86.5	102.9	46.6	108.4	13.0	3.5	0.7	0.4	0.5	44.9	52.8
	121.5	106.4	75.6	122.2	34.1	16.7	13.8	10.7	1.1	6.2	58.9	105.4
	151.6	109.3	146.3	89.4	11.0	3.0	1.8	0.6	0.2	1.2	15.3	49.9

Table 4.1 (Contd.)

	43.1	116.5	104.5	126.8	55.0	25.4	16.2	9.9	0.7	42.1	44.2	37.5
	127.2	135.5	143.5	78.2	18.0	6.1	4.2	0.5	0.4	4.4	29.4	53.0
	109.3	148.0	214.6	63.9	28.7	48.8	13.4	10.7	2.8	37.5	45.3	83.9
	173.2	176.9	87.8	73.4	14.0	2.0	0.2	0.2	0.2	0.2	21.9	95.9
	120.2	179.4	126.6	105.4	103.4	26.1	45.5	31.1	7.9	25.2	91.8	108.9
	102.2	130.5	94.6	73.8	16.4	15.1	6.6	1.8	0.9	20.1	18.9	96.1
	57.0	64.6	97.2	40.8	65.5	18.8	13.6	9.2	29.8	14.5	35.7	90.7
	154.0	105.8	108.6	75.5	83.9	49.9	1.1	0.2	0.2	9.7	25.8	82.8
	131.8	81.5	68.1	41.0	30.4	10.5	9.9	1.8	0.2	0.2	24.9	67.2
9 16	14.0	11.6	10.8	13.8	8.3	1.4	2.6	0.3	0.2	0.1	2.4	8.2
	16.3	23.3	11.7	17.5	12.4	2.5	3.2	1.0	1.7	4.1	20.9	13.7
	27.4	16.2	12.7	17.2	3.9	2.1	5.3	1.9	2.1	3.9	12.4	11.1
	22.5	25.9	13.9	3.9	4.8	4.7	1.7	2.2	1.6	3.2	5.8	20.3
	16.7	10.1	26.0	15.0	3.9	1.3	3.5	0.7	0.5	0.4	1.4	12.3
	14.1	30.9	27.3	18.2	17.4	3.5	8.8	9.8	1.6	8.8	9.9	25.7
	28.2	21.5	21.0	15.8	15.3	4.3	6.0	0.6	0.4	1.0	7.4	24.3
	10.8	21.8	11.8	11.7	13.1	2.8	2.2	0.4	0.2	0.9	9.9	7.9
	13.2	13.0	15.4	7.0	16.3	2.0	0.5	0.1	0.1	0.1	6.7	7.9
	19.2	16.0	11.3	18.3	5.1	2.5	2.1	1.6	0.2	0.9	8.8	15.8
	22.7	16.4	22.0	13.4	1.7	0.5	0.3	0.1	0.0	0.2	2.3	7.5
	6.5	17.5	15.7	19.0	8.3	3.8	2.4	1.5	0.1	6.3	6.6	5.6
	19.1	20.3	21.5	11.7	2.7	0.9	0.6	0.1	0.1	0.7	4.4	6.0
	16.4	22.2	32.2	9.6	4.3	7.3	2.0	1.6	0.4	5.6	6.8	12.6
	26.0	26.5	13.2	11.0	2.1	0.3	0.0	0.0	0.0	0.0	3.3	14.4
	18.0	26.9	19.0	15.8	15.5	3.9	6.9	4.7	1.2	3.9	13.8	16.3
	15.3	19.6	14.2	11.1	2.5	2.3	1.0	0.3	0.1	3.0	2.8	14.4
	8.6	9.7	14.6	6.1	9.8	2.8	2.0	1.4	4.5	2.2	5.4	13.6
	23.1	15.9	16.3	11.3	12.6	7.5	0.2	0.0	0.0	1.5	3.9	12.4
	19.8	12.2	10.2	6.2	4.6	1.6	1.5	0.3	0.0	0.0	3.7	10.1
10 19	24.1	19.9	18.7	23.8	14.4	67.5	4.5	0.5	0.3	0.2	4.0	14.0
	28.1	71.9	20.1	30.0	21.2	4.2	5.5	1.9	2.9	7.2	36.0	23.6
	47.1	27.7	21.8	0.0	6.6	3.6	9.4	1.3	3.6	6.8	21.4	19.2
	37.7	44.7	24.0	6.6	8.2	8.0	2.9	3.8	2.6	5.6	9.9	34.8
	28.7	17.2	43.6	25.7	6.8	2.2	6.0	1.2	0.8	0.7	2.4	21.2
	24.2	53.2	47.1	31.5	30.1	6.1	15.1	16.9	2.8	15.2	17.0	44.3
	48.5	36.9	36.0	27.2	26.4	7.4	10.5	1.2	0.7	1.8	12.6	41.7
	18.5	37.9	20.2	20.1	22.7	4.7	3.6	0.7	0.4	1.6	14.2	13.4
	22.8	22.3	26.6	12.0	27.5	3.4	0.9	0.2	0.0	0.2	11.6	13.6
	30.4	27.4	19.6	31.6	8.8	4.4	3.6	2.7	0.3	1.7	15.1	0.0
	0.0	87.9	0.0	103.2	2.9	0.7	0.5	0.3	0.1	0.3	3.9	12.8
	11.0	107.8	27.0	32.8	14.2	6.6	4.2	2.6	11.4	11.0	11.4	9.7
	0.0	35.0	37.2	20.3	4.7	1.6	1.2	0.2	0.8	1.1	36.7	15.6
	28.2	33.2	55.4	23.7	7.5	12.6	3.5	2.7	0.7	9.7	12.7	21.7
	44.7	45.7	22.6	19.0	3.6	0.5	0.1	0.1	0.1	0.1	5.6	24.7
	31.1	46.4	32.7	27.3	26.8	6.8	11.3	8.0	2.1	6.4	23.7	28.2
	26.4	33.7	24.4	19.0	4.2	3.8	1.8	0.5	0.3	6.2	5.0	24.8
	14.8	16.7	25.1	10.6	17.0	4.8	3.6	2.4	7.8	3.8	9.2	23.5
	38.3	27.4	28.8	19.6	19.7	12.8	0.3	0.1	0.1	3.5	6.6	21.4
	0.0	21.1	17.6	10.6	7.8	2.7	2.6	0.5	0.1	0.1	6.4	17.3
11 22	91.6	105.8	67.8	121.2	57.3	131.2	29.3	1.4	0.1	12.3	85.1	132.5
	138.1	133.1	112.6	103.2	57.0	44.0	20.8	37.1	13.9	33.1	94.3	77.0
	185.1	230.2	97.1	112.6	64.8	83.3	102.7	16.0	4.9	45.7	92.5	137.5
	138.7	120.5	87.1	24.5	20.9	97.3	8.7	21.5	17.0	31.9	42.5	84.7
	45.4	105.0	172.4	113.9	26.2	97.6	87.3	8.7	0.8	22.6	65.8	147.4

Table 4.1 (Contd.)

100.8	228.7	231.6	121.7	45.0	46.6	79.5	39.3	17.4	56.5	82.0	195.4
144.8	236.2	132.6	66.9	124.4	65.3	42.0	12.1	19.0	25.1	63.7	220.7
147.5	176.4	100.8	105.4	34.7	15.9	6.1	7.8	9.7	14.4	114.8	101.3
182.7	156.4	115.1	81.8	108.3	10.0	6.3	0.1	1.7	20.9	60.9	88.8
219.4	216.1	111.0	142.2	12.7	40.3	36.3	27.6	12.3	41.4	87.8	102.3
126.8	145.6	114.2	77.2	28.4	20.2	0.9	0.1	1.1	67.2	59.6	103.6
113.1	140.5	161.7	22.6	2.1	56.1	4.2	29.0	33.7	93.5	79.0	87.6
198.4	144.2	137.1	8.6	19.3	31.3	2.3	0.0	0.3	21.7	80.8	89.1
150.6	144.0	210.2	37.4	35.8	68.5	1.5	10.9	4.6	41.4	59.3	63.9
224.2	64.5	117.0	118.7	5.8	0.2	0.2	7.0	0.0	12.1	56.8	144.7
169.1	224.6	131.9	124.9	164.5	98.4	141.1	67.7	23.2	46.2	147.9	102.4
150.4	217.5	200.6	130.9	1.3	1.2	0.5	0.1	37.6	39.8	80.0	125.7
179.8	138.8	207.6	105.9	107.8	37.3	11.7	3.0	34.3	36.3	104.8	85.0
169.0	184.3	123.1	88.3	115.4	13.1	0.1	6.3	11.0	75.2	70.5	134.7
188.6	114.9	137.7	65.3	52.5	10.7	0.8	11.1	0.0	0.0	87.0	122.7

TABLE. 4.2 SIMULATION RESULT : RESERVOIR ELEVATION

PROJECT: 2-2 ; 3-3 & 1-1 RESERVOIR NO: 5

(UNIT : METRE)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	71.55	76.38	79.31	81.93	84.60	86.05	86.20	86.53	86.43	86.05	81.30	64.39
2	64.39	72.61	78.71	81.55	85.01	87.07	87.38	87.80	87.83	87.93	85.75	88.96
3	88.96	89.87	89.87	89.85	89.85	89.84	89.86	89.85	89.81	89.79	87.33	89.07
4	89.07	89.87	89.87	89.85	89.85	89.84	89.86	89.85	89.81	89.79	87.50	79.10
5	79.10	82.99	84.88	89.04	89.85	89.84	89.86	89.85	89.81	89.52	86.78	86.90
6	86.90	88.97	89.87	89.85	89.85	89.84	89.86	89.85	89.81	89.79	89.81	89.85
7	89.85	89.85	89.87	89.85	89.85	89.84	89.86	89.85	89.80	89.60	86.74	78.11
8	78.11	80.74	85.26	87.20	88.86	89.84	89.86	89.85	88.82	88.55	85.54	86.96
9	86.96	88.90	89.87	89.85	89.85	89.84	89.86	89.23	88.14	87.59	84.31	72.93
10	72.93	78.40	82.28	84.45	87.58	88.26	88.52	88.71	88.80	88.67	88.65	89.79
11	89.79	89.87	89.87	89.85	89.85	89.84	89.81	89.34	88.06	87.46	83.27	83.63
12	83.63	84.80	87.76	89.85	89.85	89.84	89.86	89.85	88.95	88.81	89.54	89.85
13	89.85	89.87	89.87	89.85	89.85	87.96	88.01	88.00	86.71	86.13	82.59	83.38
14	83.38	86.39	89.67	89.85	89.85	89.84	89.86	89.85	88.87	88.75	86.73	87.74
15	87.74	89.87	89.87	89.85	89.85	89.84	89.48	88.50	86.98	86.69	82.56	76.88
16	76.88	81.41	86.63	89.41	89.85	89.84	89.86	89.85	89.81	89.79	87.52	89.42
17	89.42	89.87	89.87	89.85	89.85	89.84	89.86	89.85	88.80	88.34	88.62	88.91
18	88.91	89.87	89.87	89.85	89.85	89.84	89.86	89.85	88.91	89.38	89.54	83.88
19	83.88	87.91	89.87	89.85	89.85	89.84	89.86	89.78	88.70	88.51	85.88	86.43
20	86.43	89.37	89.87	89.85	89.85	89.84	89.86	89.28	88.21	87.87	83.79	71.55

TABLE. 4.3 SIMULATION RESULT : RESERVOIR CAPACITY

PROJECT: 2-2 ; 3-3 & 1-1 RESERVOIR NO: 5

(UNIT : MCM)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	178.26	269.53	344.34	413.09	501.13	552.16	557.87	571.14	567.11	552.19	396.58	88.50
2	88.50	195.74	328.63	403.14	515.40	592.85	605.30	622.16	623.05	627.11	541.27	675.45
3	675.45	718.89	718.71	717.98	717.85	717.48	718.57	718.03	716.12	715.25	603.36	681.02
4	681.02	718.89	718.71	717.98	717.85	717.48	718.57	718.03	716.12	715.25	610.13	338.95
5	338.95	447.15	510.82	679.47	717.85	717.48	718.57	718.03	715.75	702.10	581.38	586.14
6	586.14	676.09	718.71	717.98	717.85	717.48	718.57	718.03	716.12	715.25	715.75	717.89
7	717.89	717.89	718.71	717.98	717.85	717.48	718.57	718.03	715.35	706.01	579.62	312.81
8	312.81	382.03	524.23	598.19	671.05	717.48	718.57	718.03	668.92	656.33	533.75	588.40
9	588.40	672.65	718.71	717.98	717.85	717.48	718.57	688.50	636.79	613.58	490.80	201.36
10	201.36	320.59	424.08	495.86	613.40	642.35	654.87	663.94	668.04	661.76	661.07	714.87
11	714.87	718.89	718.71	717.98	717.85	717.48	716.06	693.74	632.91	608.57	456.33	467.91
12	467.91	507.83	620.42	717.98	717.85	717.48	718.57	718.03	674.98	668.26	703.19	717.89
13	717.89	718.89	718.71	717.98	717.85	628.34	630.36	629.97	578.52	555.25	434.24	459.96
14	459.96	565.80	709.55	717.98	717.85	717.48	718.57	718.03	671.18	665.45	579.15	619.79
15	619.79	718.89	718.71	717.98	717.85	717.48	700.21	653.90	589.03	577.80	433.31	282.08
16	282.08	399.61	575.34	697.01	717.85	717.48	718.57	718.03	716.12	715.25	610.73	697.51
17	697.51	718.89	718.71	717.98	717.85	717.48	718.57	718.03	667.93	646.03	659.24	673.23
18	673.23	718.89	718.71	717.98	717.85	717.48	718.57	718.03	673.42	695.60	702.94	476.12
19	476.12	626.34	718.71	717.98	717.85	717.48	718.57	714.72	663.45	654.10	545.74	567.21
20	567.21	694.99	718.71	717.98	717.85	717.48	718.57	690.82	640.19	624.89	473.26	178.26

Fig. 4.4

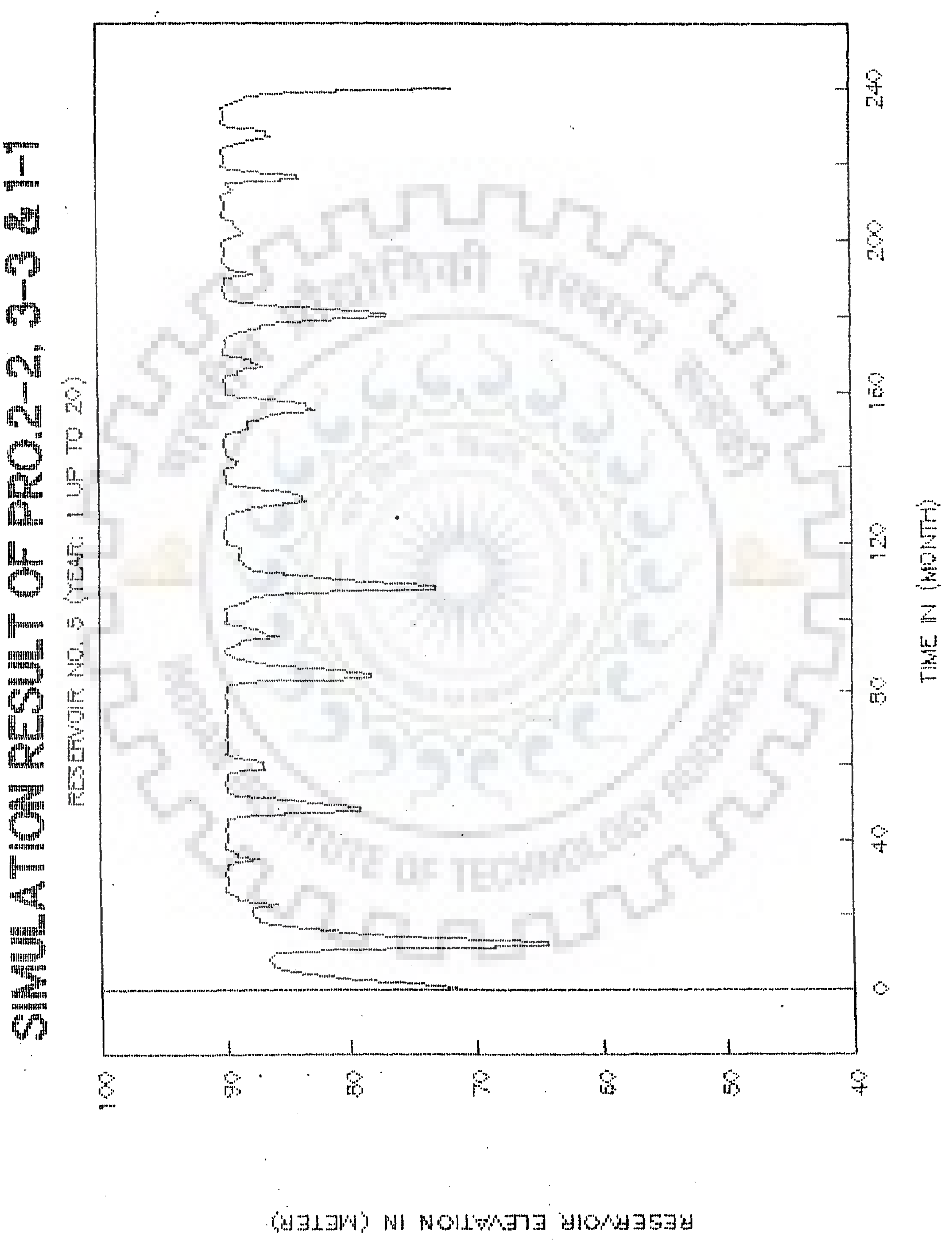

SIMULATION RESULT OF PRO.2-2, 3-3 & 1-1
RESERVOIR NO. 5 (YEAR: 1 UP TO 20)
RESERVOIR ELEVATION IN (METER)
TIME IN (MONTH)
100
90
80
70
60
50
40
0
40
80
120
160
200
240

TABLE. 4.4 OUTPUT OF SIMULATION

178.26					
demand=	3.85	1.84	2.44	4.56	20.76
demand=	.00	.00	.00	.00	.00
demand=	3.85	1.84	2.44	4.55	20.76
1	1	178.26			
demand=	.00	.00	.00	.00	.00
demand=	.00	.00	.00	.00	.00
demand=	.00	.00	.00	.00	.00
2	2	269.53			
demand=	44.37	21.21	27.51	72.96	243.93
demand=	.00	.00	.00	.00	.00
demand=	44.37	21.21	27.51	72.96	243.93
3	3	344.34			
demand=	16.94	8.10	8.36	28.27	106.91
demand=	.00	.00	.00	.00	.00
demand=	16.94	8.10	8.36	28.27	106.91
4	4	413.09			
demand=	14.15	6.76	8.97	26.75	91.34
demand=	.00	.00	.00	.00	.00
demand=	14.15	6.76	8.97	26.75	91.34
5	5	501.13			
demand=	2.79	1.33	1.77	4.41	15.05
demand=	.00	.00	.00	.00	.00
demand=	2.79	1.33	1.77	4.41	15.05
6	6	552.16			
demand=	4.52	2.16	2.87	7.14	24.39
demand=	.00	.00	.00	.00	.00
demand=	4.52	2.16	2.87	7.14	24.39
7	7	557.87			
demand=	7.22	3.45	4.57	11.40	37.89
demand=	.00	.00	.00	.00	.00
demand=	7.22	3.45	4.57	11.40	37.89
8	8	571.14			
demand=	1.54	.74	.98	2.43	8.30
demand=	.00	.00	.00	.00	.00

Table 4.4 (Contd.)

demand=	1.54	.74	.98	2.43	8.30
9	9	567.11			
demand=	14.44	6.90	10.37	33.44	114.18
demand=	.00	0.00	.00	.00	.00
demand=	14.44	6.90	10.37	33.44	114.18
10	10	552.19			
demand=	40.42	19.32	24.40	71.44	249.12
demand=	.00	.00	.00	.00	5.70
demand=	40.42	19.32	23.40	70.44	254.82
11	11	396.58			
demand=	5.78	2.76	3.66	7.60	31.14
demand=	.00	.00	.00	.00	.00
demand=	5.78	2.76	3.66	7.60	31.14
12	12	88.50			
demand=	3.85	1.84	2.44	4.56	20.76
demand=	.00	.00	.00	.00	.00
demand=	3.85	1.84	2.44	4.56	20.76
13	1	88.50			
demand=	.00	.00	.00	.00	.00
demand=	.00	.00	.00	.00	.00
demand=	.00	.00	.00	.00	.00
14	2	195.74			
demand=	44.37	21.21	27.51	72.96	243.93
demand=	.00	.00	.00	.00	.00
demand=	44.37	21.21	27.51	72.96	243.93
15	3	328.63			
demand=	16.94	8.10	8.36	28.27	106.91
demand=	.00	.00	.00	.00	.00
demand=	16.94	8.10	8.36	28.27	106.91
16	4	403.14			
demand=	14.15	6.76	8.97	26.75	91.34
demand=	.00	.00	.00	.00	.00
demand=	14.15	6.76	8.97	26.75	91.34
17	5	515.40			
demand=	2.79	1.33	1.77	4.41	15.05

Table 4.4 (Contd.)

demand=	.00	.00	.00	.00	.00
demand=	2.79	1.33	1.77	4.41	15.05
18	6	592.85			
demand=	4.52	2.16	2.87	7.14	24.39
demand=	.00	.00	.00	.00	.00
demand=	4.52	2.16	2.87	7.14	24.39
19	7	605.30			
demand=	7.22	3.45	4.57	11.40	37.89
demand=	.00	.00	.00	.00	.00
demand=	7.22	3.45	4.57	11.40	37.89
20	8	622.16			
demand=	1.54	.74	.98	2.43	8.30
demand=	.00	.00	.00	.00	.00
demand=	1.54	.74	.98	2.43	8.38
21	9	623.05			
demand=	14.44	6.90	10.37	33.44	114.18
demand=	.00	.00	.00	.00	.00
demand=	14.44	6.90	10.37	33.44	114.18
22	10	627.11			
demand=	40.42	19.32	24.40	71.44	249.12
demand=	.00	.00	.00	.00	.00
demand=	40.42	19.32	24.40	71.44	249.12
23	11	541.27			
demand=	5.78	2.76	3.66	7.60	31.14
demand=	.00	.00	.00	.00	.00
demand=	5.78	2.76	3.66	7.60	31.14
24	12	675.45			
demand=	3.85	1.84	2.44	4.56	20.76
demand=	.00	.00	.00	.00	.00
demand=	3.85	1.84	2.44	4.56	20.76
25	1	675.45			
demand=	.00	.00	.00	.00	.00
demand=	.00	.00	.00	.00	.00
demand=	.00	.00	.00	.00	.00

The simulation program which at this stage is only an allocation model ensure a fair allocation of resources during shortages by scanning the nodes twice once from downstream to upstream for each time step. This allocation process considering the system of reservoirs, diversions and demand centres as an entity is disting from the conventional sequential mode which do not provide flexibility, when fully developed incorporating stream flow generation and economic evaluation, this simulation will be a most useful tool for the decision maker in planning & operation of multi-reservoirs.

CHAPTER 5

RESERVOIR OPERATION

5.0 INTRODUCTION

The development decisions such as creation of new facilities, what, where, and when, management decisions concerning system regulations, such as water pricing principles, effluent standards, legislative measures with respect to water use, user's right and obligation, and the operational decisions determining water releases, water transfer flow rates, in-stream purification intensities, water withdrawal flow rates, pollutant discharge intensities are the interrelated decision problems of water resources system. Each is linked to the other and their time intervals and time spans are different.

In a water resource system which is already in operation, there is an interplay of system management regulations and operational decision; both influencing the current system behavior and the actually obtained performance. The difference is in possible or practical frequency of intervention.

The prices, the standards and other regulation of a rather legislative nature can not be changed too often, they are not being adjusted to actual hydrological conditions and short term forecasts. As compared to it, the operation control decisions need to be varied in time more often.

In practice, the system development is usually the one that is to some extent separable. Nevertheless, in the actual solution of the system development problem, adequate assumptions must be made with respect to how the system will be managed and operated, otherwise, the performance of the proposed system could not be evaluated. As opposed to it, the management, regulation and operational control decision are not easy to separate, because both affect the behavior of water users during actual system operation. A distinction may be made however at least from the point of view of techniques applicable to their solution. Management regulations, since fixed over long periods of time, may be considered on the basis of averaged values of flows, consumptions, gains or loses. In particular one can believe, in this time perspective, in the economic rationality of behavior of water users. For example, that the farmers will plan to use less irrigation water if the price were higher. Correspondingly, the models used to discuss decisions at this level may neglect a large part of system dynamics and a part of stochastic phenomena (although changing continuously), but they have a good knowledge of the economic behavior of the users, hence also of the wider economic environment in which the users operate.

Operational control comprises those decisions and actions that need to be varied in time, adjustment to current operating conditions and actual state of the water resource system. System dynamics plays a dominant role, the randomness of inputs cannot be neglected, physical and environmental constraints make the problem both difficult and challenging.

The problem considered here is the stochastic operation of a single reservoir (i) to decide flood storage capacity useful in developing a discrete project and (ii) to derive optimal operation policy in a multi reservoir context. The rationality of a single reservoir study is governed by the dominant reservoir concept. It means, in multireservoir context, a single reservoir which is relatively big, dominates and governs the operation of the system.

The function of a reservoir is to transform the natural inflow into an outflow whose magnitude and time distribution satisfy the demand for water. A storage facility is required mainly because of the difference between the seasonal characteristics, and the stochastic fluctuation of the natural inflow and the water demand. Generally speaking, a water supply reservoir is operated to store water from " **wet periods** ", when the natural inflow is considerably higher than the demand, for use in " **dry periods** " in which inflow is low relative to demand. The boundaries between the 'wet' and 'dry' periods should be specifically defined for any reservoir, and depend upon the special features of the system.

The problem confronting the reservoir operation is to decide upon the best policy for releases from the reservoir in the face of uncertainties of inflow which are feasible within the physical and technical constraints of the system. The aim is to find that policy which resolves optimally, according to a well defined criteria, the conflict of releases in time and for various uses (power, irrigation, drinking water, flood control, flow regulation etc) while at the same time account for the risk of water loss due to evaporation and spill.

In the present study an attempt is made to solve this type of control problem under some specified conditions. To be precise, the policy of water release to be derived is based on demand, available storage, and a forecast index which can reduce the unknown factor of future inflow.

5.1 DESCRIPTION OF THE CONTROL PROBLEM

A specific water supply system is considered, in which the reservoir receives most of its inputs as river inflow. The rate of inflows has a stochastic nature and its probabilistic properties vary significantly with the season throughout the year. The discharge fluctuations are very high in some of the months, when considerable amounts of water enter the reservoir in a short time. The reservoir outputs include hydropower, down stream releases for irrigation and M & I water supply and losses through evaporation and uncontrolled spills. The amount of water released are decided according to some operating rules which are to be determined. As the rate of inflow is a random variable and the system behavior can not be deterministically predicted, it is not a satisfactory solution to formulate rules in the form of explicit values of the controlled releases as a function of time. Rather, releases should depend on the demand, and on the random parameters which are observed before the control decision is made. This can be achieved by establishing the functional relationship between the controlled release and any information on the state of the system which is available at the time. It is assumed here that the state of the system at any time t, can be represented by two variables ; S the reservoir storage level, and J the available information concerning the probabilistic properties of the natural inflows.

The change of storage level with time is given by the continuity equation :

$$\frac{dS(t)}{dt} = X(t) - U(t) - Y(S,t) \; ; \; t \in [0,T] \; , \; s \geq 0 \qquad (5.1)$$

where, X(t) and U(t) are the values of the time functions X and U, respectively at time t; X is the random process describing the rate of inflow, U is the controlled discharge. Y denotes overflow and evaporation losses. A feasible control function $U(S,J,t)$ is a function, defined for $S \geq 0$, $J \in \{J\}$ and $t \in [0,T]$ whose value in any point of definition is a feasible control.

Unlike the first state variable S of the system, which represents a physical quantity, the second one J has a more abstract meaning. It represents the conclusions that can be made on the basis of the available data at any time t concerning the probability distribution of the random variable $X(\tau)$ for $\tau > \tau$. It is assumed that any state of information can be mapped on a one dimensional real space, and corresponding to specific value of J from a given set {J}. Whereas the time transformation of the state variable S is defined by the deterministic relationship (5.1) (though it does involve a random factor) the transformation of J can be described just by a probability function. It is assumed that {X(t), J(t)} defines a Markov process, and that the joint transition probability function:

$$J(x,j,\tau;y,i,t) = \text{Prob}\,\{X(\tau) \leq X, J(\tau) \leq j \mid X(t) = y.J(t) = i\}$$

is known for any $t < \tau$, $\{t,\tau\} \in [0,T]$ (5.2)

It follows that given the initial condition S(0), J(0), X(0), and a feasible control function, $U(\mathfrak{S},\mathfrak{J},t)$, the absolute distribution of the stochastic process S(t), and the marginal distribution of J(t) may be computed at least theoretically, for the entire process.

To complete the presentation of the control problem, one should define the criterion by which the optimal control function $U^*(\mathfrak{S},\mathfrak{J},t)$ is determined. Usually this criteria has the form of a scalar value objective function (although multi objectives are not uncommon) which ranks the various policies according to their desirability, and a set of constraints defining the feasible controls. In water resources problems, a variety of objectives like maximization of economic benefits and safe yield, and minimization of cost, risk of violating demands and deviations from rule curve targets are commonly used at the operational level.

In this study, two different stochastic dynamic programming models are formulated. The first model is useful in fixing the full reservoir level in a single multipurpose reservoir with both conservation and flood storage and so can be used in developing discrete project alternatives discussed in Chapter 3. The second model is useful in strategic operation planning of a single reservoir and determination of target storage levels in different periods in a year. These target levels form the input to the simulation model discussed in Chapter 4.

5.2. FORMULATION - 1

The principle means of counteracting the flood risk during flood season through reservoirs is a deliberate partial emptying of reservoir through the regulation gate shortly before the expected arrival of potentially damaging floods. The problem arising in this situation is to establish the rules for controlling the spills during the flood season. The maximum rate of release from the reservoir is restricted by the maximum release capacities of the various outlets, and in practice is smaller than some of the inflow rates that occur in flood season (excluding spillway). In case the reservoir water level is not low enough at the beginning of a flood, there is a risk that the reservoir will overflow. Moreover, the reservoir in question is dammed natural lake, and undue rise of its water level above a certain elevation will cause damages to the populated areas along its banks. The problem arising in this situation is to establish the rules for controlling the spill during the flood season.

The system has two relevant components: the reservoir with maximum capacity SM and the outlet through which the discharge U may be controlled up to a maximum rate UM, which depends on the water head in the reservoir. Let t denote the time elapsed since the beginning of flood season ; $t \in [0,T]$, where T is the length of the flood season.

The continuity equation governing the storage is

$$\frac{dS(t)}{dt} = X(t) - U(t) - Y(S,t) \; ; \; t \in [0,T], \; S \geq 0 \qquad (5.3)$$

Here $X(t)$ and $U(t)$ are the time function of X and U respectively, at time t, X is the random process describing the rate of inflow into the reservoir and U is the controlled discharge. Y denotes the sum of mandatory release, pumpage from reservoirs, if any, overflow and evaporation losses. It is assumed that the function $Y(\mathcal{S}, t)$ is known for all values of $S \geq 0$ and $t \in [0,T]$ and that Y is continuous and non decreasing with the storage level S, and it vanishes for S=0.

Whenever the reservoir is not empty there is a schedule $Um(t)$ of minimum discharge through the control gate, released to meet downstream demands. On the other hand, there is maximum limit to the rate of release which is a function of the head on the gate. The maximum release rate can be expressed as a function of the storage level S through the head-capacity curve. Expressed mathematically, the control variable U at any point in time must be selected from the set $\{U(\mathcal{S},t)\}$ of all feasible controls:

$$U(\mathcal{S},t) \equiv \left\{ U(t) \,\middle|\, \text{Min}\left[Um(t), UM(\underline{\mathcal{S}}) \leq U(t) \leq UM(\bar{\mathcal{S}})\right] \right\} \tag{5.4}$$

A feasible control function $U(\mathcal{S}, \mathfrak{J}, t)$ is a function, defined for each $S \geq 0$, $\mathfrak{J} \in [J]$ and $t \in [0,T]$, whose value in any point of definition is a feasible control.

5.2.1. OBJECTIVE FUNCTION

In this model the feasibility of the realization of a physical quantity is used in formulating the objective function. It is required to maximize the expected storage level at the end of flood season. This objective is to be achieved keeping the risk that the probability of an overflow should be below a certain prescribed value.

If PM(t) represents the probability of having at least one overflow irrespective of its magnitude during the time interval [t,T], which corresponds to the maximum risk a decision maker can take in control decision at time t, given a function $U(S, J, t)$, it is possible to compute for any $t' \in [0,T]$, $S' \in [0,SM]$, $J' \in \{J\}$ the probability $p(t', S', J')$ of having at least one over flow in the time interval $[t',T]$, if at time t' the state of the system was (S', J').

The problem is to find a feasible control function $U(, j, t)$ which, for any initial condition

$$\text{Max } z : \underline{E}(S(T)) \tag{5.5}$$

$$\text{S.T. } P(t, S, J) \leq PM(t) \text{ for each } t \in [0,T], \quad S \in \{0, SM\}, \; J \in \{J\} \tag{5.6}$$

$$\text{or } U = UM(S) \tag{5.7}$$

E is expectation operator taken with respect to all random variables involved in the process. Equation (5.6) represents all the feasible controls defined already and Equation (5.7) describes the states the system may reach, as a consequence of extreme values that the random variables take, for which no feasible control exist. All that the operator can do in such a situation is to try shifting the state of the system back to the condition governed by Equation (5.6). This means, in practical terms, to open the gates to their maximum capacity.

5.2.2. ANALYSIS OF THE MODEL

A discrete approximation of the continuous process is essential to simplify the analysis. Following discretization and assumption are relevant ;

(i) Time is considered as a series of discrete periods $t = 1, 2, \ldots, T$. where T is the number of unit periods in flood season. It is assumed that within this period the water inflow and outflow rates from the reservoir are constant.

(ii) The state variable J_t representing the level of information is discretized by a set $\{J\} \equiv \left[0, 1, \ldots, j, \ldots \bar{J}\right]$ with finite $\bar{J}$. The stochastic nature of transformation of this state variable is described in the form of a set of conditional probabilities for the values of J_t, given the values of the initial level of information, J_{t-1} and the natural inflow in the previous period, X_{t-1} :-

$$g_t(j \mid k) = \mathrm{Prob}(J_t = j \mid J_{t-1} = k, X_{t-1} = x) \qquad (5.8)$$

With the above discretization, one can write the continuity equation in discrete form as :

$$S_{t+1} = S_t - Y_t - U_t + X_t = H_t + X_t \qquad \forall t = 1, 2, \ldots\ldots T \qquad (5.9)$$

Here, H_t is the planned storage at the end of time period t. Also for short time periods.

$$0 \leq \frac{dY_t(S)}{ds} + \frac{dUM(S)}{ds} < 1 \quad \text{for } S\in[0, SM] \quad t=1,2,\ldots,T \quad (5.10)$$

Solving the above problem, is to derive a set of T optimal control functions, $U_t^*(S,J)$, $t=1,2,\ \ldots\ldots,T$ according to the specified criterion. The problem is divided into T sub problems, solved in sequence by dynamic programming - backward procedure. The problem is first solved for the last time period T, and proceed backwards to the first period.

For the time period T : The problem to be solved is to find a feasible control function $U_t(S,J)$ for $S\in[0,SM]$, $j\in\{J\}$ which maximizes the expected value of final storage, $E_{X_T|J}[S_{T+1}]$ and when possible, keeping the probability that an overflow occur during the period not greater than the given level PM_t. i.e.,

$$\text{Prob}\ (S_{T+1} > SM \mid S_T = S, J_T = J\ ; U_T = U\ ) \equiv P_T(S,J;U)$$

$$= \int_{SM-H}^{\infty} f_T\ (x \mid J)dx \leq PM_T \qquad (5.12)$$

Where; $H = S-Y(S)-U$ represents the controlled part of storage and $(SM-H)$ is the storage space available for containing the forth coming inflow. f_T represents the probability distribution of x given a value of the information variable j.

If for some J, it is obtained that $P_T(o,J;o) \geq PM_T$. Then $U^*(S,J) = UM(S)$ for each s; for this state of information, regardless of what was the initial storage, the operator should release as much as possible.

For any value of $\mathcal{J}$ there exists a unique storage level $\underline{S}_T(\mathcal{J})$ for which $P_T(\underline{S}_T\ \mathcal{J};\ Um_T) = PM_T$. This is the lower value for which some water should be deliberately released in order not to exceed the desired level of risk. For $S < \underline{S}_T(\mathcal{J})$ the optimal control is to spill the minimum.

$$U_T^*(S,\mathcal{J}) = \text{Min}\left[\, Um_T,\ S-Y(S),\ UM(S)\right] \qquad \ldots\ldots\ldots \quad (5.13)$$

Since $P_T(S,\mathcal{J};U^*) \equiv P_T^*(S,\mathcal{J}) < PM_T$,

$P_T^*(S,\mathcal{J})$ denotes the value of risk when beginning the last period in the season with state $(S,\mathcal{J})$ and using the optimal control.

For any value of S in the interval $[\,\underline{S}_T(\mathcal{J}),\bar{S}_T(\mathcal{J})\,]$ the control policy is to save water by letting the risk level approach its upper permissible limit. In this interval the following relationship holds:

$$P_T^*(S,\mathcal{J}) = PM_T \qquad (5.14)$$

$$\text{and } U^*(S,\mathcal{J}) = Um_T + \int_{\underline{S}_T(\mathcal{J})}^{S} \left(1 - \frac{d\Psi_T(s)}{ds}\right) ds \qquad (5.15)$$

Thus by determining $\underline{S}_t(\mathcal{J})$ and $\bar{S}_t(\mathcal{J})$ for each $\mathcal{J} \in \{J\}$ the complete functional form of the optimal control for the last period is established.

For the typical period t, the probability that at least one overflow would occur from the beginning of time period t, defined as $P_t(S, J; U)$, is given by :

$$P_t(S, J; U) = \int_{SM-H}^{\infty} f_t(x|J)dx + \int_{o}^{SM-H} \left[\sum_{k\in\{J\}} P^{*}_{t+1}(H+X, K)\; \vartheta_{t+1}(K/J, x)\right] f_t(x|J)\, dx \qquad ..\quad (5.16)$$

The two terms on the right hand side denote, respectively, the probability of first overflow occurring in the period and the second term is the probability of that occurring in the remaining periods in the season.

As for the final period, the above equation can be solved, by computing two critical values of S for each of the finite values which the parameter J takes. We define $\underline{S}_t(J)$ as the unique value which solves $P_t(S, J; Um_t) = PM_t$ and $\bar{S}_t(J)$ as the value which solves $P_t[s, J; Um(S)] = PM_t$. The corresponding value of H is the same for both $\underline{S}_t(J)$ and $S_t(J)$. This value of, $\bar{H}_t(J)$ is the portion of initial storage which is most advantageous to retain in the reservoir, at the end of the period. The optimal control is determined at the beginning of the period so as to maintain the level of H as close as possible to $\bar{H}_t(J)$.

The set of possible states S, J, which is the domain of definition of the control function, is thus partitioned into three subsets;

$$\text{Subset 1 : } (S, J_1) \equiv \left[(S, J) \;\middle|\; 0 \le S \le \underline{S}_t(J) \right] \qquad (5.17)$$

In this case there always exists, a feasible control for which $P_t\ (S,\mathfrak{J};U) < PM_t$. Since this relation holds even for the control having the minimum feasible value, which is the one that minimizes H_t, and

$$U_t^*\ (S,\mathfrak{J}) = \text{Min}\ [Um(t),\ S-Y(S),\ UM(S)] \qquad (5.18)$$

Subset 2 :

$$(\ S,\mathfrak{J}_2) \equiv \left[\ (S,\mathfrak{J})\ \middle|\ \underline{S}_t\ (\mathfrak{J}) \le S \le \bar{S}_t(\mathfrak{J})\ \right] \qquad (5.19)$$

Each element of this Subset Corresponds to a unique feasible control so that $H_t = \bar{H}_t\ (j)$; therefore, it would be the optimal control. In order to maintain for each j, the constant value of $\bar{H}_t$, which means $P_t^*\ (S,\mathfrak{J}) = PM_t$, the optimal control function should have the properly

$$\frac{\partial U_t^*\ (S,\mathfrak{J})}{\partial S} = 1 - \frac{dY_t(S)}{dS} \qquad (5.20)$$

at all points where the derivative is defined.

Subset 3 :

$$(\ S,\mathfrak{J}_3) \equiv \left[\ (S,\mathfrak{J})\ \middle|\ \bar{S}_t\ (\mathfrak{J}) \le S \le SM\ \right] \qquad (5.21)$$

In this region the increasing of H_t with S cannot be prevented because of the properties of UM(S). For each element in this Subset

$$S-UM(S) - Y(S) > \bar{H}_t\ (\mathfrak{J}) \quad \text{and therefore}$$

$$U_t^*\ (S,\mathfrak{J}) = UM(S) \qquad (5.22)$$

while $P_t^*\ (S,\mathfrak{J}) > PM_t$

Based on the above analysis, one can derive a procedure for solving each of the T sub problems using recurrence relationship and establishing the function : $U_t^*(\mathfrak{S},\mathfrak{J})$. The computation procedure is given in the flow diagram Figure. 5.1.

By repeating the basic computation with different values of the parameters UM and SM, a relationship can be established between the increase in the physical characteristic of the system and the expected increase in the volume of water available in storage at the end of the flood season. These results are useful for economic evaluation and in deciding on the full reservoir and outlet capacities to provide from flood control point of view. The risk parameters PM_t can be related to the physical facilities by parameterizing on PM_t.

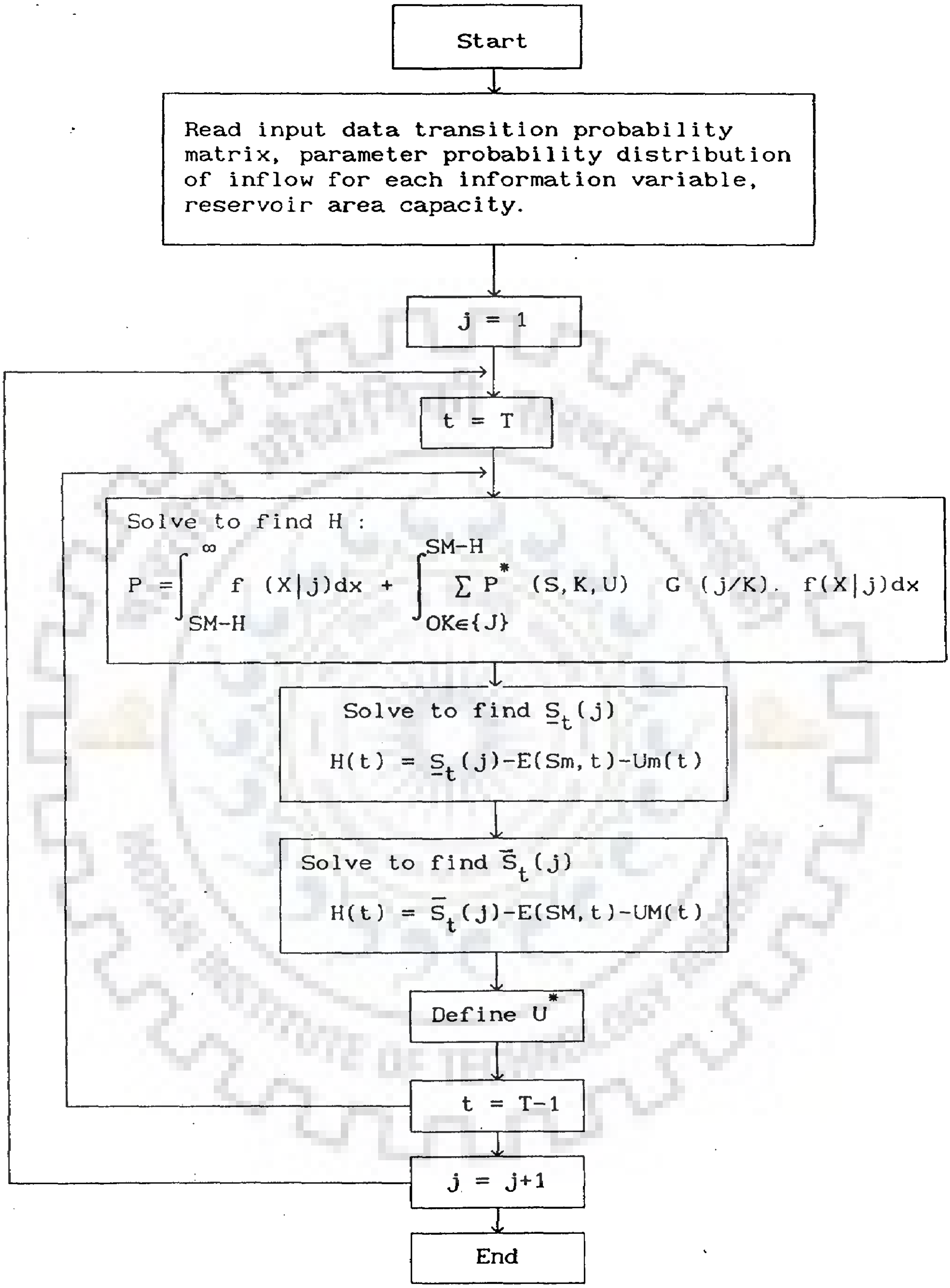


Figure: 5.1 **Flow chart for computation of Reservoir operation policy**

Case Study :

The Kedungombo reservoir design is used for testing of this formulation. The salient features of this reservoir as constructed is given ;

Salient features of Kedungombo reservoir :

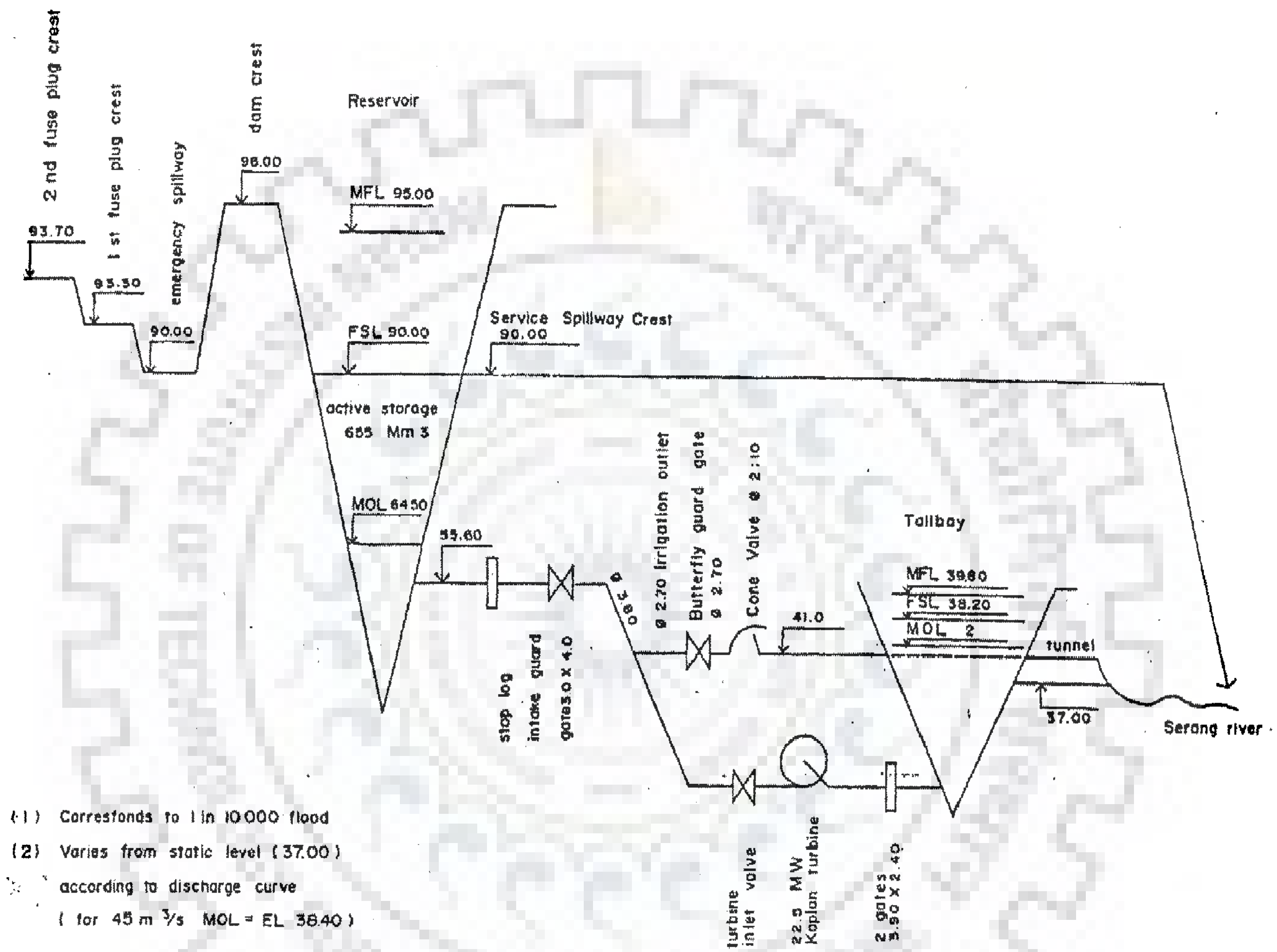
Kedung Ombo Dam and Reservoir

General :

The main characteristics of the dam and reservoir are given below and shown in schematic from in Figure 5.2. Outlet works are made for the controlled release of up to 83.5 m^3/s which is the peak demand for the irrigable area. In general, releases will be made through the turbine. When demand exceeds turbine capacity, the excess will be released via the irrigation valve.

The power station is equipped with a single Kaplan turbine (22.5 MW). The annual average energy generated will be 74 GWh. Of this about 18 GWh will be available as peak energy. The operation studies showed that the extension of the irrigated area in the Juana valley resulted in the inability of the power plant to be designed for a firm power generation; thereby they recommended an energy only alternative with re-regulation provided at Sidorejo weir.

A service spillway (passing the 10,000 year return period flood) and an emergency spillway (with a fuse plug consisting in 2 elements with crests at different levels) are provided. The total



(1) Corresfonds to 1 in 10.000 flood

(2) Varies from static level (37.00)

according to discharge curve

(for 45 m ³/s MOL = EL 38.40)

FIG. 5·2 - MAIN CHARACTERISTICS OF KEDUNGOMBO DAM AND RESERVOIR peak discharge the 2 spillways are capable to pass is limited at 5,540 m^3/s.

Operation levels :

The reservoir Full Supply Level (FSL) is EL 90.00. Peak irrigation demand (83.50 m^3/s) is ensured while the reservoir water level is higher than 67.1. The minimum operating level (MOL) which is exceeded 90% of the time is EL 64.50. At this level the turbine must be shut down and the discharge limited to 55 m^3/s, maximum capacity of the irrigation outlet. The rated level which is '' level which is exceeded 50% of the time is EL 81.6.

Effective Rainfall :

The effective rainfall was computed from the recorded rainfall using an effective rainfall relationship as shown below. The 10-day effective rainfall relationship is given below.

10-day Effective relationship

Rainfall (Ra) (mm)	Effective Rainfall (Re) (mm)
Ra < 6.7	Re = 0
6.7 < Ra < 30	Re = Ra - 6.7
30 < Ra < 100	Re = SQR(43*Ra-747)
Ra > 100	Re = 0.3*(Ra - 100) + 60

Irrigation Diversion Requirements :

On the above basis the total Water Requirements, without taking into account the rainfall contribution, were estimated at about 2,130 mm per year for 200% rice and 30% palawija.

It was decided not to charge any cost of Kedung Ombo to flood mitigation and therefore flood mitigation is only an incidental benefit. Nevertheless the studies concluded that Kedung Ombo will provide useful flood mitigation for the area between the dam and Lusi river junction (100 year flood will be contained within the river banks) and for the downstream area where the design flood will be reduced in peak by at least 15%.

Municipal and Industrial Demands

Present consumptive use demand for domestic and industrial water supply are small in comparison with the irrigation requirement. In the future, the imbalance is likely to reduce, putting greater reliability constraints on the supply of water. Additional requirements for domestic supply will also impact on the operation of the irrigation systems themselves, since canal closures will not be so freely permissible.

The irrigation canals will form the basis for the primary water supply distribution systems to the towns and villages in the project area. A separate intake at Klambu Barrage is proposed for the augmentation of the Semarang water supply.

With the inclusion of domestic water supply component, the need for water quality monitoring becomes evident. IHE Bandung have undertaken a water quality monitoring study in association with SEATEC Consultants concerning the impact of the Kedung Ombo dam on environmental issues. The report recommends a comprehensive program of water quality and environmental monitoring together with a wide-ranging institutional setup to manage such issues.

The water management system will be required to interface with this program in whatever form it is developed, although the monitoring of certain parameters will be outside the scope of the Water Management Centre.

Power Generation

Kedung Ombo dam will be capable of generating hydro-electric power by means of a Kaplan type turbine, rated at 22.5 MW, installed in the dam. This will generate annual average power of some 74 GWh, of which 18 GWh are available as peak power. Power production at the dam is regarded as secondary, the first priority being for irrigation and domestic water supply. It will be possible, however, to generate additional power during the wet season through a "dump energy' rule, which will minimize spills from the dam.

The minimum operating level of Kedung Ombo dam for irrigation is given as 64.5 m. An additional MOL below this for drinking water supplies is also postulated. It is required to know the policy on the adoption of the appropriate MOL.

The inclusion of a significant water supply component to Semarang has resulted in potential reductions to the cropping intensities throughout the basin. This supply, together with the 700 1/s for Rembang has a significant effect on the cropping intensity potential for the irrigation areas.

Data : The monthly inflow data at the reservoir site is given in table 3.6-8. It may be seen that the flood months, that is the months of considerable inflow are from December to May.

A transition probability matrix is worked out with number of states equal to 5. For each period, and for each state the parameters of the lognormal distribution are worked out. The transition probability matrix and the parameters of lognormal distribution are given in tables 5.1 and 5.2 below.

The results of the release policy obtained by the Dynamic programming is given in table 5.3 below.

TABLE 5.1 TRANSITION PROBABILITY MATRIX.

	1	2	3	4	5
1	0.1796	0.3214	0.2500	0.1786	0.0714
2	0.2286	0.2286	0.1571	0.1429	0.1428
3	0.1892	0.2162	0.2703	0.1622	0.1622
4	0.1739	0.3043	0.3043	0.1739	0.0435
5	0.0	0.2143	0.2857	0.4286	0.0714

Maximum Inflow = 214 MCM
Minimum inflow = 11 MCM
States are defined at equal intervals.
State 1 corresponds to the lowest inflow block.

TABLE 5.2 LOGNORMAL DISTRIBUTION PARAMETERS

Month - November

State	1	2	3	4	5
$\bar{x}$	1.9821	2.9810	3.4029	3.8006	3.9830
σ	0.0383	0.0485	0.0549	0.06	0.0720

Month - December

State	1	2	3	4	5
$\bar{x}$	2.8477	3.3666	3.7066	3.9533	4.1624
σ	0.0568	0.0671	0.0683	0.0601	0.0709

Month - January

State	1	2	3	4	5
$\bar{x}$	2.9143	3.3211	3.6342	3.9483	4.2426
σ	0.0469	0.0501	0.0558	0.0655	0.0607

Month - February

State	1	2	3	4	5
$\bar{x}$	3.3320	3.6805	3.9815	4.2186	4.3751
σ	0.0388	0.0576	0.0510	0.0006	0.0601

Month - **March**

State	**1**	**2**	**3**	**4**	**5**
$\bar{x}$	3.3955	3.7344	4.1595	4.2278	4.4163
σ	0.0424	0.0518	0.0577	0.0480	0.0601

Month - **April**

State	1	2	3	4	5
$\bar{x}$	2.2966	2.8228	3.2059	3.5262	3.7989
σ	0.0210	0.0218	0.0559	0.0413	0.0308

Month - **May**

State	1	2	3	4	5
$\bar{x}$	1.8729	2.4397	3.1427	3.5731	3.7849
σ	0.1412	0.0454	0.0291	0.0378	0.0172

TABLE 5.3 RELEASE POLICY FOR FLOOD CONTROL PURPOSES - AND DETERMINATION OF FULL RESERVOIR LEVEL - RESULT OF MODEL - 1.

Release Policy for the Month of November

State of Reservoir	Information Variable 1	2	3	4	5
1	3.9	3.9	3.9	3.9	3.9
2	3.9	3.9	3.9	3.9	3.9
3	3.9	3.9	3.9	3.9	3.9
4	3.9	3.9	3.9	3.9	3.9
5	3.9	3.9	3.9	3.9	3.9
6	3.9	3.9	3.9	3.9	10.6
7	3.9	3.9	3.9	7.3	22.5
8	3.9	3.9	3.9	19.1	34.3
9	3.9	3.9	15.8	31.0	46.1
10	3.9	12.4	27.6	42.8	58.0
11	237.9	237.9	237.9	237.9	237.9

Release Policy for the Month of December.

State of Reservoir	Information Variable 1	2	3	4	5
1	3.9	3.9	3.9	3.9	3.9
2	3.9	3.9	3.9	3.9	3.9
3	3.9	3.9	3.9	3.9	3.9
4	3.9	3.9	3.9	3.9	3.9
5	3.9	3.9	3.9	3.9	14.0
6	3.9	3.9	3.9	10.6	25.8
7	3.9	3.9	7.3	22.5	37.6
8	3.9	3.9	19.1	34.3	49.5
9	3.9	15.8	31.0	46.1	61.3
10	12.4	27.6	42.8	58.0	73.2
11	237.9	237.9	237.9	237.9	237.9

Release Policy for the Month of January

State of Reservoir	Information Variable 1	2	3	4	5
1	3.9	3.9	3.9	3.9	3.9
2	3.9	3.9	3.9	3.9	3.9
3	3.9	3.9	3.9	3.9	3.9
4	3.9	3.9	3.9	3.9	3.9
5	3.9	3.9	3.9	3.9	14.0
6	3.9	3.9	3.9	10.6	25.8
7	3.9	3.9	3.9	22.5	37.6
8	3.9	3.9	11.5	34.3	49.5
9	3.9	15.8	23.4	46.1	61.3
10	12.4	27.6	35.2	58.0	73.2
11	237.9	237.9	237.9	237.9	237.9

Release Policy for the Month of Feb.

State of Reservoir	Information Variable 1	2	3	4	5
1	3.9	3.9	3.9	3.9	3.9
2	3.9	3.9	3.9	3.9	3.9
3	3.9	3.9	3.9	3.9	5.5
4	3.9	3.9	3.9	3.9	17.3
5	3.9	3.9	3.9	3.9	29.1
6	3.9	3.9	10.6	10.6	41.0
7	3.9	7.3	22.5	22.5	52.8
8	3.9	19.1	34.3	34.3	64.7
9	8.2	31.0	46.1	46.1	76.5
10	20.0	42.8	58.0	58.0	88.3
11	237.9	237.9	237.9	237.9	237.9

Release Policy for the Month of March.

State of Reservoir	Information Variable 1	2	3	4	5
1	3.9	3.9	3.9	3.9	3.9
2	3.9	3.9	3.9	3.9	3.9
3	3.9	3.9	3.9	3.9	5.5
4	3.9	3.9	3.9	3.9	17.3
5	3.9	3.9	6.4	14.0	29.1
6	3.9	3.9	18.2	25.8	41.0
7	3.9	7.3	30.1	37.6	52.8
8	3.9	19.1	41.9	49.5	64.7
9	15.8	31.0	53.7	61.3	76.5
10	27.6	42.8	65.6	73.2	88.3
11	237.9	237.9	237.9	237.9	237.9

Release Policy for the Month of April.

State of Reservoir	Information Variable 1	2	3	4	5
1	3.9	3.9	3.9	3.9	3.9
2	3.9	3.9	3.9	3.9	3.9
3	3.9	3.9	3.9	3.9	3.9
4	3.9	3.9	3.9	3.9	3.9
5	3.9	3.9	3.9	3.9	3.9
6	3.9	3.9	3.9	3.9	3.9
7	3.9	3.9	3.9	3.9	7.3
8	3.9	3.9	3.9	3.9	19.1
9	3.9	3.9	8.2	15.8	31.0
10	4.9	12.4	20.0	27.6	42.8
11	237.9	237.9	237.9	237.9	237.9

Release Policy for the Month of May.

State of Reservoir	Information Variable 1	2	3	4	5
1	3.9	3.9	3.9	3.9	3.9
2	3.9	3.9	3.9	3.9	3.9
3	3.9	3.9	3.9	3.9	3.9
4	3.9	3.9	3.9	3.9	3.9
5	3.9	3.9	3.9	3.9	3.9
6	3.9	3.9	3.9	3.9	3.9
7	3.9	3.9	3.9	3.9	3.9
8	3.9	3.9	3.9	11.5	11.5
9	3.9	3.9	8.2	23.4	23.4
10	4.9	4.9	20.0	35.2	35.2
11	237.9	237.9	237.9	237.9	237.9

State 1 Corresponds to Reservoir Capacity at MDDL.
State 11 Corresponds to Full Reservoir Capacity.

5.3. FORMULATION - 2

This formulation of the stochastic reservoir operation model is somewhat similar to the Formulation-1, but differs in objective function, probability distribution description of the random inflow and the solution steps. The result of this model can be used to fix targets levels of storage in different periods.

5.3.1. STATEMENT OF THE PROBLEM :

Given a time step ΔT , the reservoir is described by :

$$S_{t+1} = S_t + a_t - U_t^*(S_t, a_t, u_t) \tag{5.23}$$

where

S_t = storage volume at time t [system state] ($S_t \geq 0$)

a_t = inflow volume during [t, t+1] ($a_t \geq 0$)

U_t = decision at time t (control variable) ($U_t \geq 0$)

The decision U_t taken is the volume, one is willing to release during [t, t+1], whereas U_t^* is the volume actually released in the same interval. In general the decision U_t is feasible i.e. $U_t^*(S_t, a_t, u_t) = u_t$. However there may be situation in which it is not feasible. $U_t^*(S_t, a_t, u_t)$ may be greater than U_t during flood condition when the volume of water entering the reservoir is high and the storage content of the reservoir is also high. Similarly $U_t^*(S_t, a_t, u_t)$ may be less than u_t when draught situation prevails and thus preventing realization of the decision U_t. The function U_* embeds thus the description of the release from a reservoir and it is such to guarantee that $S_{t+1} \geq 0$ for any feasible S_t, a_t, and u_t.

Further it may also represent the effect of legal constraints, if any, on the reservoir management for every $t = 0,1,2,\ldots,$ a finite space $S_t=(1,2,\ldots\ldots i,\ldots.N_t)$ is obtained by partitioning the set $S_t=\{S_t \geq 0\}$ into an arbitrary number N_t of classes.

Mathematical Background :

For every $t = 0,1,2, \ \ldots,$ a finite state space $S_t = (1,2, \ldots,i,\ldots.,N_t)$ is obtained by partitioning the set $S_t = (s_t \geq 0)$ into an arbitrary number N_t of classes, class i for $i=1,2, \ \ldots, \ N_{t-1}$, is defined as the set $(S_t : \underline{S}_t^i \leq S_t \leq \bar{S}_t^{\,i})$ where $\underline{S}_t^i = 0$ and $\bar{S}_t^i$ is the upper bound on storage.

A finite control space C_t can be obtained selecting an appropriate number of values of the control $C_t = \{U_t \geq 0\}$.

It is assumed that the system is periodic with period T (one year) Accordingly

$$C_t = C_{t+KT}$$
$$N_t = N_{t+KT}$$
$$S_t = S_{t+KT}$$

The reservoir transition probability can be described by

$$\Pi'_{t+1} = \Pi'_t . P'_t(r_t) \qquad (5.24)$$

where, $\Pi_t = \left| \Pi_t^1, \Pi_t^2, \ \ldots, \ \Pi_t^i, \ldots\ldots \Pi_t^{N_t} \right|'$

(The apex means transposition)

The discrete version of the operating rule :

$$r_t = \left[r_t(1), r_t(2), \dots , r_t(N_t) \right]' \dots\dots r_t(i) \in C_t \;\; \forall i \in S_t \qquad (5.25)$$

The transition probability matrix in which the i^{th} row and j^{th} column element is the probability that the process will be in state J at time t+1 given that it is in state i at time t and the decision : $u = r_t(i)$ is taken given by :

$$P_t(r_t) = \left[P_t^{ij}(r_t(i)) \right] \dots\dots i=1,2, \dots, N_t$$
$$j \in (1,2,\dots, N_{t+1}) \qquad (5.26)$$

These probabilities are derived from the reservoir continuity equation in the following way (assuming that the integrals are well defined)

$$P_t^{ij}(u) = \lim_{S \to \bar{S}_t^1} \int_{\underline{S}_t^1}^{S} F_t(\xi) \, P_t^{\xi j}(u) \, d\xi \qquad (5.27)$$

where, $$P_t^{\xi j}(u) = \int_{W_t^{\xi j}(u)} \mathcal{f}_t(x)dx, \qquad (5.28)$$

with $$W_t^{\xi j}(u) = \left[a \geq 0 \;\; : \;\; \underline{S}_{t+1}^{j} \leq \xi + a - u_t^*(\xi, a, u) < \bar{S}_{t+1}^{j} \right] \qquad (5.29)$$

and F_t is the probability density function of state $S_t = \xi$ conditioned to the fact that S_t is inside class i. The function F_t is not known because it depends on the policy used which, in turn is the solution to the problem. It is thus compulsory to make some arbitrary assumption on it. For example one can assume that F_t is an uniform distribution, or , more simply, that it is a unit impulse located in an arbitrarily fixed point ξ_t^i inside the class. It is evident that the practical implication of different assumptions depend on the class width. From the definition of S_t and assumption of periodicity;

$$\sum_{j=1}^{N_{t+1}} P_t^{ij} (r_t(i)) = 1 \qquad \forall i \in S_t$$

$$t=0,1,2,\ldots \qquad (5.30)$$

also $$P_t^{ij} [u] = P_{t+KT}^{ij} [u] \qquad (5.31)$$

$$P_t (r) = P_{t+KT} (r) \qquad \forall K=1,2,\ldots$$

$$(5.32)$$

The state probability vector Π_t must satisfy the condition

$$\sum_{i=1}^{N_t} \Pi_t^i \quad 1 \qquad {}_t^i\Pi \geq 0 \qquad \forall \int \underset{t}{\in} S , \quad t=0,1,2,\ldots \qquad (5.33)$$

The cost or the benefit $g_t(i,u)$ associated with a couple (i,u), $i \in S_t$, $u \in C_t$ is given by :

$$j_t(i,u_t) = \underset{S \; \bar{S}_t}{\text{LIM}} \, i \int_{\underline{S}_t^1}^{S} F_t \, (\xi) \left[\; \underset{a_t}{E} \; [\, \bar{j}_t(\xi,u,a_t)] \right] d\xi \quad (5.34)$$

where, a_t = inflow at time t

Therefore the optimal control problem is:

$$\text{Max } Z = \left[\sum^{T-1} \Pi'_v \, G_v(r_v) \right] \tag{5.35}$$

That is to maximize the expected benefit and this is subject to the following constraints :-

$$\Pi'_{v+1} = \Pi'_v \; P_v \; (r_v) \tag{5.36}$$

$$\Pi'_o = \Pi'_{T-1} \; P_{T-1} \; (r_{T-1}) \tag{5.37}$$

$$R_c = \{r_o, r_1, \ldots, r_{T-1}\} \tag{5.38}$$

$$\lim_{n \to \infty} \Pi^*_{nT+v} \left[\cdot \middle| i_o = i,\ R = \{Rc, Rc, \ldots\} \right] = \Pi_v \tag{5.39}$$

where÷ $\Pi^*_{nT+v}(.)$, $(n=0, 1, \ldots,\ )$ is computed recursively from the continuity equation with initial state probability vector $\Pi_o[0, 0, \ldots, 1, \ldots, 0]'$ where 1 is in the i^{th} position when $i \in S_o$ for t=0 is the initial state (given) of the system.

5.3.2. OBJECTIVE FUNCTION

The value of water released at any time period T is a function of the state of the system which can be expressed either in terms of the volume of water in store or the water level in the reservoir (for hydropower, it is better to express the state of the purposes, the strategy of use of the released water. If :

T - represent the period under consideration.

Z - represent the average water level in the reservoir during the time period.

S - represents the strategy of water use, i.e, the specified quantity for M&I water supply and specified cropping pattern.

R - represents the volume of water released during the period.

Q - represents the intermediate uncontrolled inflow available for use down stream.

The elementary benefit for the time period T is :

$$BEL = F\ (R, Q, S, Z, T) \qquad (5.40)$$

This functional form can take a variety of forms and very often, the benefits of release of water in a particular period may not be independent of the releases in the other time periods.

The specific reservoir under consideration (Same reservoir as that in Formulation I Case study) has to release water for irrigation and power generation and the region in which this reservoir is located has three distinct crop seasons, and the crops grown in these seasons are also more or less fixed. The crop seasons are :

Season	Period	Crop pattern
1	Oct to Jan	Rice
2	Feb to May	Rice
3	Jun to Sept	Palawija *)

*) Palawija - is upland crops and it can be maize or soybean or mixed.

Further, although the power generation is incidental, the firm power is more valuable than the energy as available. Also the reservoir has to supply water for M&I use.

In view of the above consideration, the period considered for operation is that corresponding to crop periods. The benefits of energy and irrigation in any period are assumed to be a linear function of the energy produced and the amount of water released for irrigation respectively. Penalty terms are introduced for the short fall in the M&I water supply and the firm power generation. The expression for the elementary benefits for any time periods t is written as :

$$BEL = B_1(t)\ R_1(t) + B_2(t)\ G(t) - C_1(t) \left[RMIN(t) - R(t) \right]^+$$

$$-C_2(t) \left[FP - P(t) \right]^+ \tag{5.41}$$

where ;

$B_1(t)$ = Benefit per unit of water released for irrigation in period t

$R_1(t)$ = Quantity of water released for irrigation

$B_2(t)$ = Benefit per unit of Energy produced from energy generation in time period t

$G(t)$ = units of energy generated.

$RM1N(t)$= Minimum quantity of water to be released in period t for M&I water supply.

$R(t)$ = actual quantity of water released from the reservoir.

$C_1(t)$ = penalty cost per unit shortage in M&I water supply.

The superscript (+) indicates that the penalty is to be computed if and only if the term within the bracket is positive. If R(t) is less than or equal to RMIN(t), there is a penalty proportional to short fall in M & I supply and the quantity of irrigation water supplied is zero. If R(t) is greater than RMIN(t) then, the penalty terms corresponding to M&I supply is zero, and the quantity of irrigation water supplied is equal to:

$$R_1(t) = R(t) - RMIN(t) \tag{5.42}$$

$C_2(t)$ = represent the unit penalty cost for deviating from the specified Firm power level Fp.

P(t) = is the power generation level in the time period t . This is a function of volume of water released from reservoir and the effective head for power generation. The effective head is computed assuming an average tail water level and a fictional loss of effective head as losses in the water conductor system.

The system configuration and the quantity required for irrigation, M&I water supply are shown in figure 3.8 and Table 3.5 and Table 3.7 in Chapter 3.

The objective function can be written as :

$$\text{Max } z : \sum (B_1(t).\ R_1(t) + B_2(t).G(t) - C_1(t)\left[RMIN(t) - R(t)\right]^+$$

$$- C_2(t)\left[FP - P(t)\right]^+ \tag{5.43}$$

Subject to :

(i) Continuity constraint:

$$S(t+1) = S(t)+I(t)-R(t)-EVP(t) \ldots\ldots\ldots \forall t \qquad (5.44)$$

where, $S(t+1)$ - denote the storage at the beginning of time period t+1

$S(t)$ - denote the storage at the beginning of time period t

$R(t)$ - total volume of water released in the time period t

$I(t)$ - volume of water flow into the reservoir in the period t from time t to time (t+1).

$Evp(t)$- total volume of water evaporated in time period t which is a function of the average water spread area in time period t.

(ii) Power Generation Equation :

$$G(t) = K(t) * R(t) * H(t) \qquad (5.45)$$

where , $G(t)$ = Energy generated in time period t

$K(t)$ = Constant which includes the gravitation constant, unit conversion, efficiency and the number of hours in the time period t.

$H(t)$ = Head in time period t

The inflow is stochastic and so, the objective function to be maximized will be in terms of the expected value and the reservoir transitions are to be represented by the probability relations as discussed under mathematical background.

The problem is dealt within the framework of Markov chain and the dynamic programming method of successive approximation is used for solving the problem. Accordingly the function to be maximized is :

$$B = BEL\ (R, Q, I, Z, S, T_{n-1})$$

$$+ \iint P\ Z(i, Z_1)\ P\ T(i, j)\ EB(Z_1, j, S, T_n)\ dz_i, dj \qquad (5.46)$$

Where the first term on RHS represents the elementary gain for the current period and the second term represents the expected gain from the reservoir state resulting from the decision in the current period.

Where;

$PZ(i, Z_1)$ = probability that the reservoir attains a state Z_1 with the forecast index equal to i in the previous time period.

$PT(i, j)$ = probability that the forecast index of the current period is equal to j given the same in the previous period is equal to i.

$EB(Z_1, J, S, T_n)$ = value of stored water at the end of the time period.

5.3.4. DETAILS OF COMPUTATION

For the purpose of computation, discretized version of the above equation is used. Reservoir states are described by the reservoir level. The height between the minimum draw down level and the full reservoir level is divided into specified number of point and thereby reservoir states are defined.

From the analysis of hydrologic data, number of discretized versions of states of inflow are defined and for each time period the transition probability matrix indicating the transition of the inflow state from i to inflow state j, P(j/i) is defined. Similarly for each time period the probability that the inflow is in class CQ for a given forecast index j, P(CQ|j) is defined. Also the representative discharge value for the class CQ for each time period is also defined. This schematization for the description the inflow can incorporate variations of inflow and provides sufficient flexibility in describing the natural inflow.

If the inflow data is not long enough to describe the various statistics mentioned above, it may be necessary to resort to sequential/statistical generation of data and use the same to calculate the necessary statistics.

5.3.5. STEPS IN THE COMPUTATION :

1. Define P(j/i), P(CQ/j), QC for each period, where P(j/i) is the transition probability matrix defining the probability that the forecast index is j in time t given the forecast index at time t-1 is equal to i.

   P(CQ/j) is the probability that the inflow is in the class interval CQ given the forecast index is equal to j in time period t. QC is the representative value of inflow of the class CQ.

2. Define the functional form of elementary gain G, for each period, which is a function of time period, the reservoir state, the volume of water released and the strategy of water use.

3. Discretize the live storage into a number of states represented by either volume of water stored (live) or by its corresponding reservoir level.

4. Choose a convenient time for starting the computation. (It is convenient if this time corresponds to the end of an irrigation season) and at this set U(K) = 0 for all states, and also set a quantity IND(K) = 0, IND(k) is an information variable required to keep track of this optimal trajectory and its determination is elaborated in a later step.

5. Set time t=t-1. Fix the state of the system at j=1,2,...,NST where NST is the total number of the discretized states of the reservoir, represented either by level of the reservoir or the volume of water stored. It is found convenient to represent the state by the reservoir level when a power house is linked to the reservoir. For each value of j, vary the state of the system K, at time t from 1 to NST. Find the maximum expected gain for each state j and the corresponding state of the reservoir from which this maximum expected value of the gain is obtained. This gives the expected gain for the state j and the trajectory information IND(K), the state of the system at the previous time, which gave the maximum expected gain. Repeat the computation for all the system states j.

6. Repeat step 5, for all the stages, i.e. up to the time t=1 (beginning of the year).

7. Compute the annual expected gain and repeat the computation for next year with the value of each state and the trajectory information obtained for the previous year as the initial value, again compute the annual value and trajectory for the year.

8. Stop computation when the two successive annual values computed or the trajector computed is same for a specified information variable.

9. Repeat computation for all the information variable (IV)

5.4. Computation Scheme :

State transition from S_1 to S_2 in any time period is defined by the continuity equation:

$$S_2 = S_1 + \text{INFLOW} - \text{EVP} - \text{RELEASE} \tag{5.47}$$

Given j : the inflow is defined probability P(CQ/j)

For a specified CQ, representative inflow QC is defined.

$$\text{Expected gain for a given } j = \sum_{j}\sum_{CQ} P(j/i)\ P(CQ/j)\ EB(Z,S,j) \tag{5.48}$$

5.4.1. Computation Details :

The problem in solved with a dynamic programming algorithm. The following variable discretization is used, reserve supply level, Z, the discretization for reserve is a constant reservoir step. Ten or fifteen points suffice for accurate analysis. Reservoir level rather than volume is used because it is better adapted to the gradient of the function to be optimized (which changes quickly when reserve supply is low).

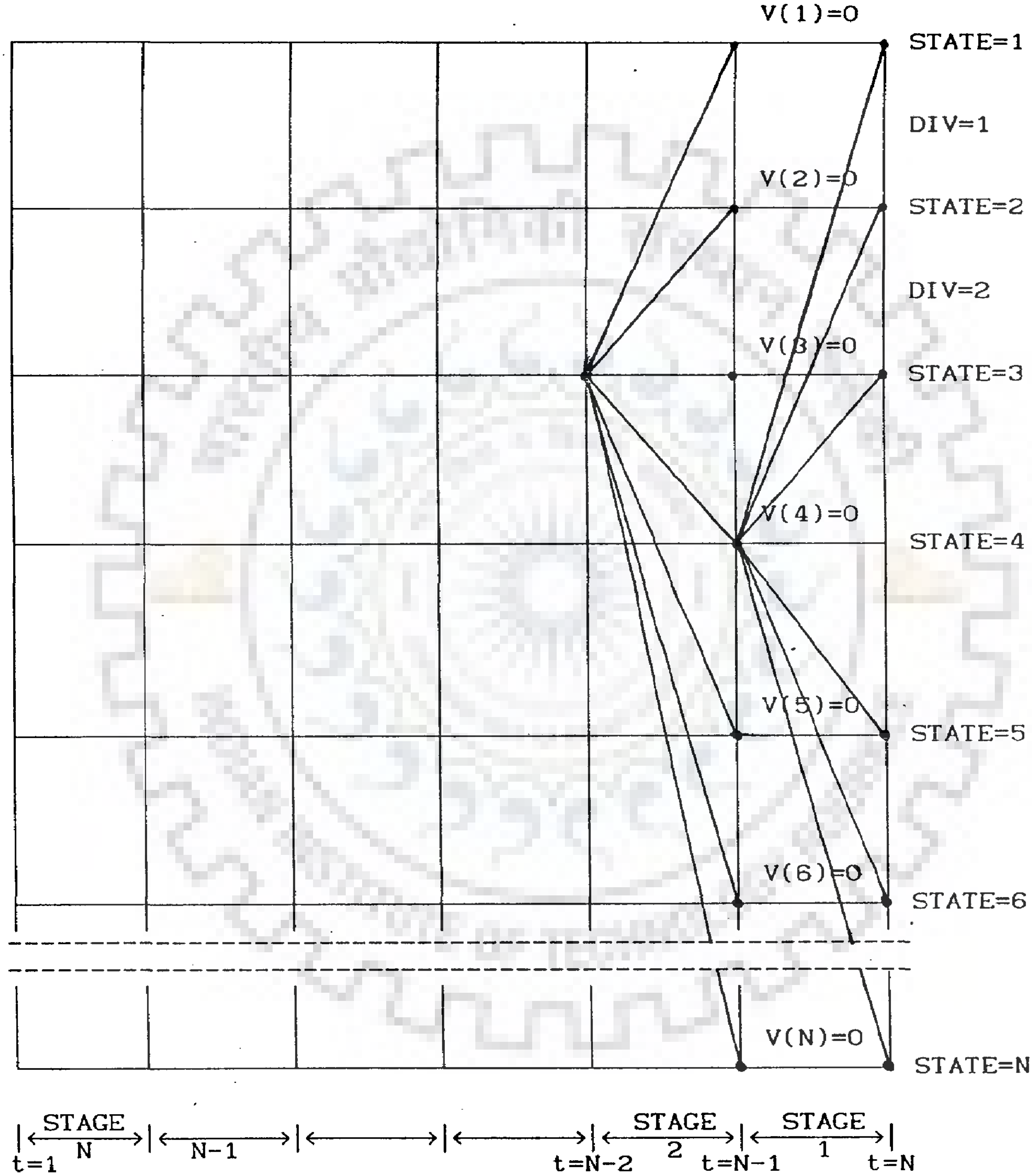


FIG : 5.3 COMPUTATION SCHEME

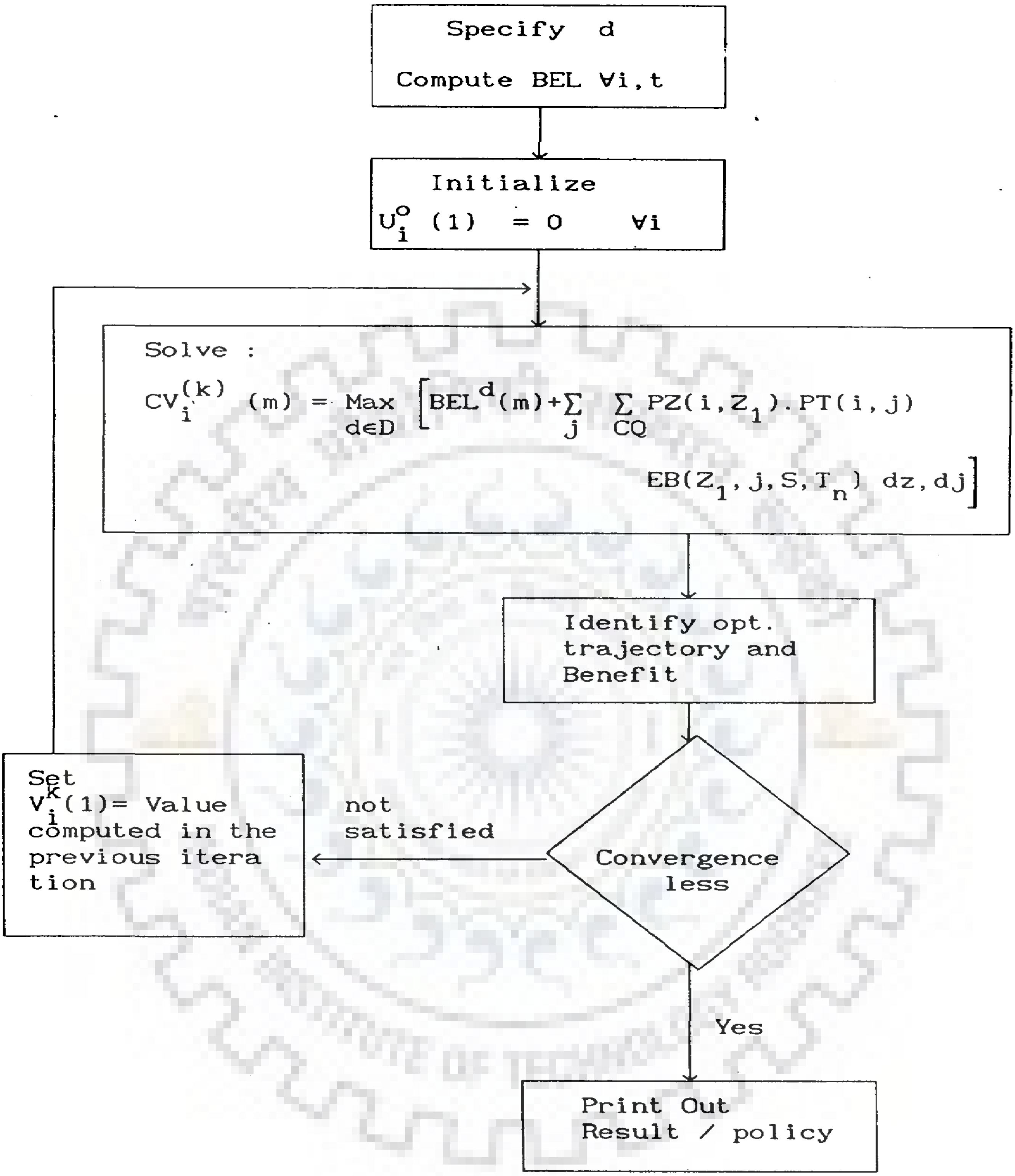


FIG: 5.4 FLOW DIAGRAM OF RESERVOIR OPERATION.

(iii). Decision for volume release:

1) For water demand (potable water, irrigation, regulation etc) water demand can in some cases use unregulated intermediate inflow. The discrete decisions test is :

$$QB^*_k = K/N * (DMAX - QI) \qquad K = 1,2,3, \ldots N \qquad (5.49)$$

Where N is the number of discrete decisions tested (generally 10 or So, the number depending on the objective function).

2) For power Demand : Power is assumed to be produced from releases from the dam at the toe of the dam. It therefore can not use intermediate inflows, but the water discharge can contribute to meet the demand of other types.

Time : The time unit is one month. It is further considered that the resultant objective function has a yearly return period F(...T) = F(...T+12 month).

(iv). Optimum Routine:

The gain expectancy for each state and for each decision is then calculated time step by time step and the optimal trajectory is identified.

For any adopted strategy, the gain expectancy is initialized as zero at moment T_n, once every 12 time steps (one year) have been calculated, the monthly optimum management routines for that year are compared to those of the preceding year. Calculation stops when two yearly sets of optimum routines are similar. The optimum routines obtained for each month are then no longer influenced by the reality of T_n. The number of annual situations is directly linked to the regulating potential of the reservoir, which is physically normal (the better the reservoir regulating potential, the longer the effects of a decision will be).

Case Study :

The operation of kedungombo reservoir is studied through the formulation 2 to define the operation policy. The transition probability matrix are given in table numbers 5.4 and 5.5 below.

The policy as determined by the dynamic programming is given in table number 5.7.

TABLE 5.4 STATE TRANSITION PROBABILITY MATRIX P(I,J).

Season 1	.1429	.7143	.1428
	.3286	.3857	.2857
	.4286	.0000	.5714
Season 2	.7143	.1429	.1428
	.1428	.4286	.4286
	.1428	.6286	.2286
Season 3	.6571	.1429	.2000
	.1429	.5714	.2857
	.0000	.2817	.7143

TABLE. 5.5 INFLOW DESCRIPTION AND P(CQ/J) MATRIX.

Discrete Values if Inflow (million m^3

Season 1 :	460,	333,	263,	193,	118
Season 2 :	510,	433,	371,	365,	238
Season 3 :	158,	110,	77,	41,	10

P(CQ,J) matrix

Season 1 :	0.2857	0.7143	0.0000	0.0000	0.0000
	0.0000	0.0000	0.8571	0.1429	0.0000
	0.0000	0.0000	0.0000	0.5714	0.4286
Season 2 :	0.2857	0.4826	0.2857	0.0000	0.0000
	0.0000	0.0000	0.5714	0.4286	0.000Q
	0.0000	0.0000	0.0000	0.5286	0.4714
Season 3 :	0.2857	0.1429	0.5714	0.0000	0.0000
	0.0000	0.0000	0.2857	0.7143	0.0000
	0.0000	0.0000	0.0000	0.2857	0.7143

TABLE 5.6 AREA CAPACITY CURVE OF KEDUNGOMBO RESERVOIR.

Elevation (m)	Area (HA)	Capacity (n.m^3)
44.0	60.0	2.0
48.0	150.0	7.0
52.0	300.0	12.5
56.0	450.0	28.0
60.0	700.0	53.0
64.0	950.0	85.0
68.0	1250.0	125.0
72.0	1650.0	185.0
76.0	2200.0	260.0
80.0	2750.0	362.5
84.0	3875.0	400.0
88.0	4200.0	630.0
92.0	5050.0	812.5

TABLE 5.7 RESULTS OF THE DYNAMIC PROGRAMMING - FORMULATION 2 FOR RESERVOIR OPERATION.

Full Reservoir Content = 90.00 million m^3

Minimum Draw Down Level = 64.50

Period - 1
Value of forecast Index 1
Releases Corresponding to State of the Reservoir 1 to 16

952.8694000	532.3007000	520.2569000	508.2131000
488.4517000	453.8067000	433.0333000	416.1559000
390.9067000	365.6575000	342.8583000	322.6317000
302.4049000	258.9734000	272.5117000	259.0500000

Period - 1
Value of forecast Index 2
Releases Corresponding to State of the Reservoir 1 to 16

555.1945000	515.3991000	503.3553000	491.3116000
471.5501000	436.9051000	402.2601000	371.5109000
346.2617000	321.0125000	298.2134000	277.9867000
257.7600000	241.3284000	227.8668000	82.6122000

Period - 1
Value of forecast Index 3
Releases Corresponding to State of the Reservoir 1 to 16

505.9679000	445.3991000	433.3553000	421.3116000
401.5501000	366.9051000	322.2601000	301.5109000
276.2617000	251.0125000	245.1150000	224.8883000
204.6616000	188.2300000	174.7683000	144.4051000

Period - 2
Value of forecast Index 1
Releases Corresponding to State of the Reservoir 1 to 16

707.1909000	667.2350000	654.9991000	642.7631000
622.8430000	588.1041000	574.0701000	543.2270000
517.8838000	492.5406000	469.6601000	449.3651000
429.0700000	412.5797000	399.0667000	385.5538000

Period - 2
Value of forecast Index 2
Releases Corresponding to State of the Reservoir 1 to 16

659.8959000	619.9400000	607.7041000	574.7631000

TABLE 5.7 (Contd.)

554.8430000	540.8091000	506.0701000	475.2270000
449.8838000	424.5406000	404.6601000	381.3651000
361.0700000	344.5797000	331.0667000	317.5538000

Period - 2
Value of forecast Index 3
Releases Corresponding to State of the Reservoir 1 to 16

420.4353000	359.6844000	347.4484000	335.2125000
315.2924000	280.5534000	245.8144000	214.9713000
189.6282000	164.2850000	141.4044000	121.1094000
100.8144000	84.3240400	9.5970100	58.0840700

Period - 3
Value of forecast Index 1
Releases Corresponding to State of the Reservoir 1 to 16

432.1409000	371.6643000	359.8128000	347.9612000
328.3584000	293.8073000	259.2563000	228.6011000
203.4458000	178.2906000	155.5729000	135.4146000
155.2562000	98.8838000	85.4729500	72.0625200

Period - 3
Value of forecast Index 2
Releases Corresponding to State of the Reservoir 1 to 16

396.1409000	335.6643000	323.8128000	311.6912000
292.3584000	257.8073000	223.2563000	192.6011000
167.4458000	142.2706000	119.5729000	99.4145700
79.2562000	62.8822700	49.4729500	36.0625100

Period - 3
Value of forecast Index 3
Releases Corresponding to State of the Reservoir 1 to 16

365.1409000	304.6643000	292.8128000	280.9612000
261.3584000	226.8070000	192.2563000	161.6011000
136.4458000	111.2906000	88.5729300	68.4145700
48.2562000	31.8833800	18.4729500	5.0625110

The State 1 of the reservoir corresponds to full reservoir level.

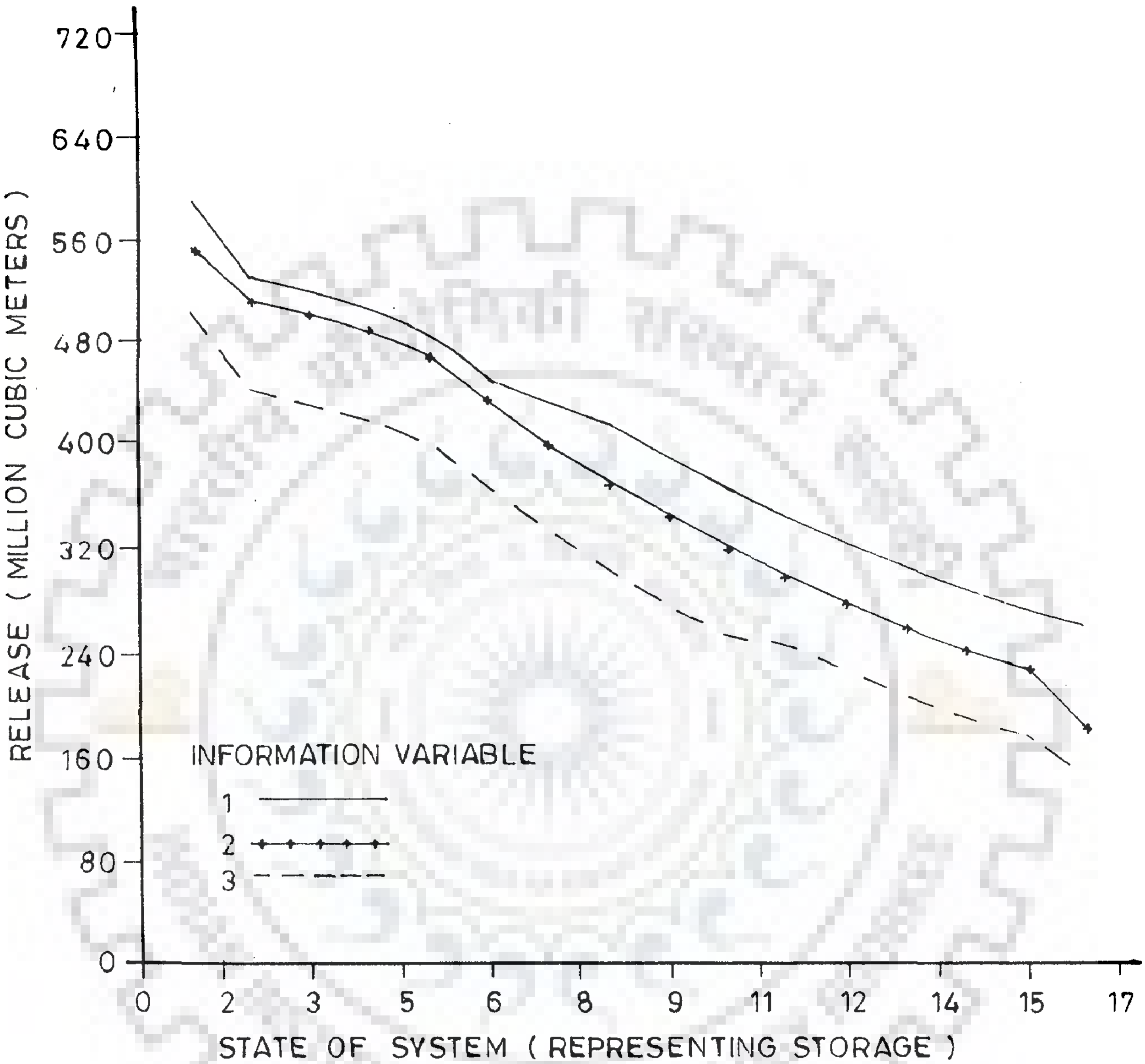


FIG.5·5(a)-RELEASE POLICY FOR SEASON 1, OCT. TO JAN.

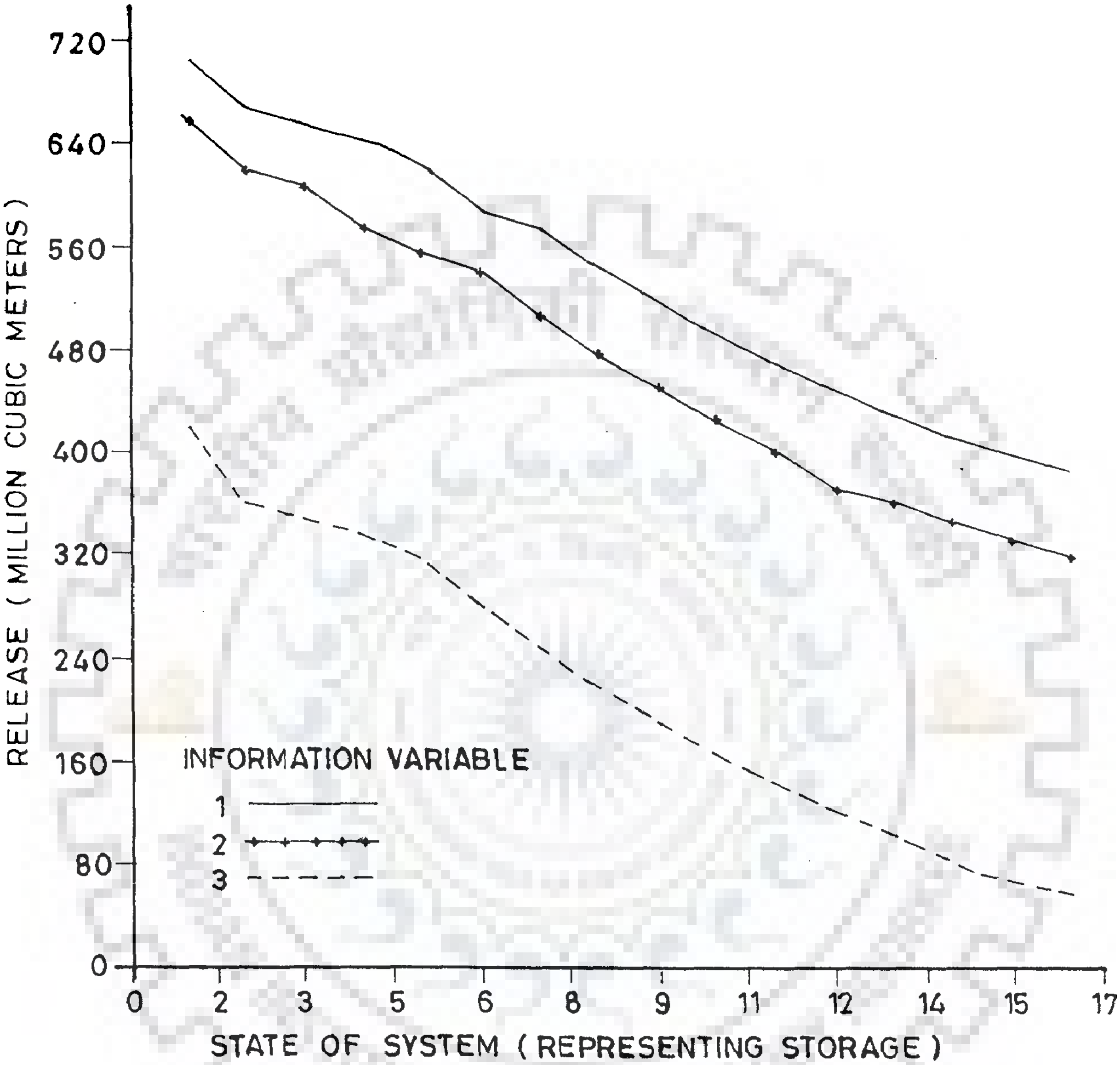


FIG.5·5(b)-RELEASE POLICY FOR SEASON 2, FEB TO MAY

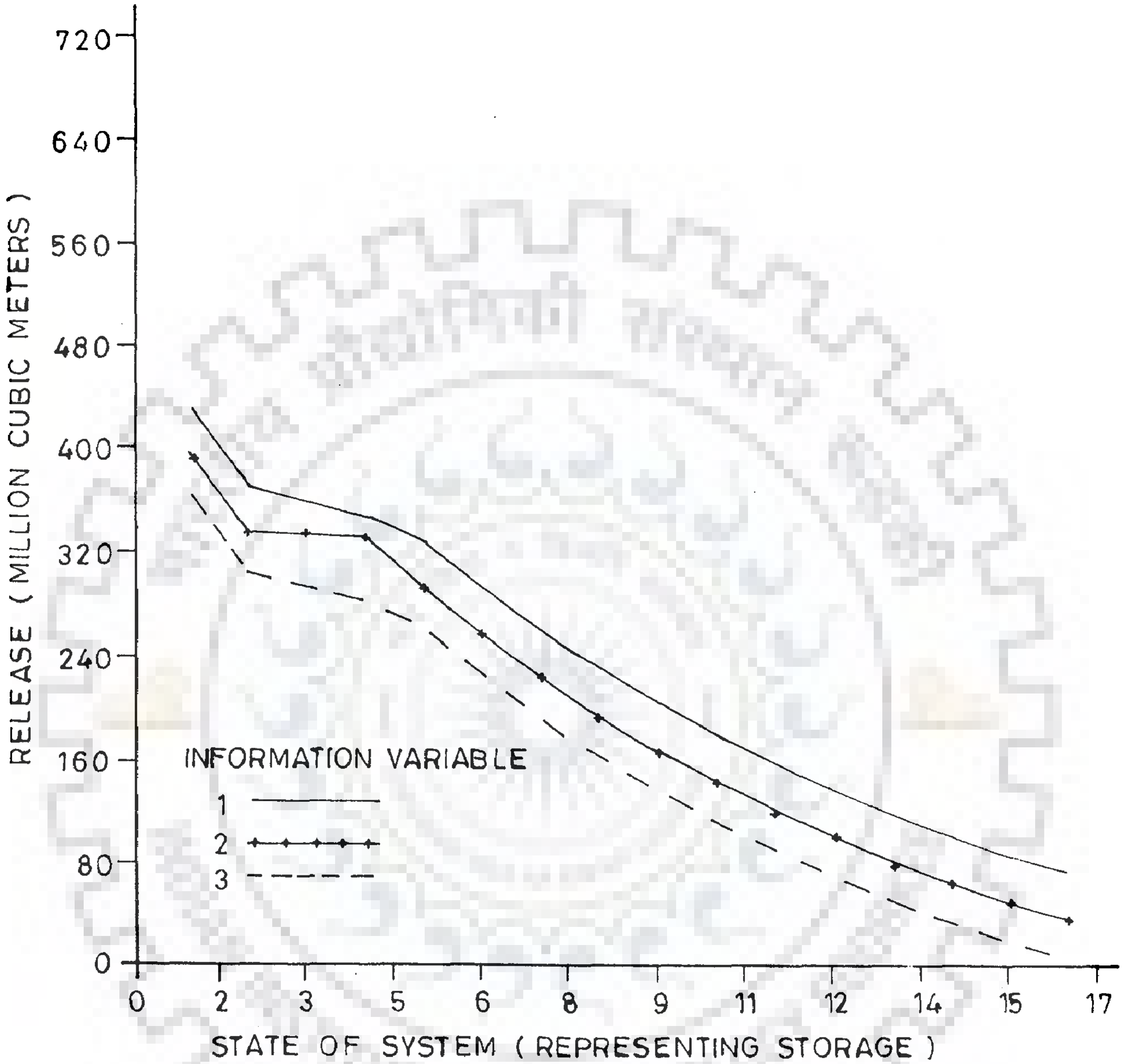


FIG.5·5(c)-RELEASE POLICY FOR SEASON 3, JUNE TO SEPT.

CHAPTER 6

CONCLUSIONS

6.1 Conclusions :

In the context of riverbasin, screening and sequencing of projects form the core of the planning process for the water resource development. The study reported here is a subset of riverbasin planning dealing with screening of multireservoirs, diversions and sequencing of the same based on economic criteria.

The linear programming, linear decision rule based formulations network based models, and hierarchical methods have been the most popular techniques for screening of projects and the dynamic programming for project sequencing. Although these are compact, the simplifying assumptions in fitting the problem to the well known models are not convincing to the users of such solutions and thus there exist a gap between theory and practice. The attempt is to close this gap to make the analysis as realistic as possible. A two phase two level solution combining screening and sequencing of projects is proposed and illustrated through a case study. In the first phase each project and its versions are developed and in the second phase the alternative versions are refined considering all aspects of technical nature which can not be incorporated directly into the problem formulation in the first phase, Socio - Economic and Environmental Considerations. These two phases are in the first level. These project versions are integrated together into a 0-1 programming problem and solved by Toyoda's Algorithm which is a gradient procedure. The solution gives both project selection and sequencing solution that is the order in which they are to be implemented with a budget constraint.

The procedure is illustrated through a case study of the development studies of the Lusi-Serang basin in Indonesia. The various alternatives considered are listed in chapter 3 and the final solution obtained are as under :

The priority of projects indicated by the programme are:

1. Project 2, version 2
2. Project 3, version 3
3. Project 1, version 1

The overall scheme of river basin development as screened by the procedure is shown in Figure. 3.8.

It means to implement in order of priority the following;

i) Diversion Ngemplak and diversion Bandung.

ii) Storage Kedungombo and diversions South Grobogan, Sedadi, and Kelambu.

iii) Mid Lusi Diversion.

Further a resource allocation type of simulation model has been developed to figure out the behaviour of reservoirs and the system.

The proposed system configuration of the Screening - Sequencing model is again used here as a case study and the reservoir bahaviour is traced.

Further in chapter 5, two different models of reservoir operation are formulated within the frame work of stochastic dynamic programming. The important difference from the existing similar models is the introduction of an information variable in terms of forecast. The first formulation is designed for use in the determination of an optimal full reservoir level to maximize the average annual yield. The full reservoir level can be used as a parameter and the corresponding increased average annual yield can be estimated. The model provides only the release policy as related to reservoir content (the state of the system) and a forecast index. This operation policy is to be incorporated into a simple reservoir operation model and the annual yield and thus the long term average annual yield can be calculated. This model is extremely useful in working out the discrete project versions. The incremental cost verses the incremental average annual yield provides a necessary trade off information.

One of the major reservoirs i.e. Kedungombo is used as a case study to illustrate the capability of the model and the policy resulting from a particular full reservoir level is given in table 6.1 below.

TABLE 6.1 RELEASE POLICY FOR FLOOD CONTROL PURPOSES - AND DETERMINATION OF FULL RESERVOIR LEVEL - RESULT OF MODEL - 1.

Release Policy for the Month of November

State of Reservoir	Information Variable 1	2	3	4	5
1	3.9	3.9	3.9	3.9	3.9
2	3.9	3.9	3.9	3.9	3.9
3	3.9	3.9	3.9	3.9	3.9
4	3.9	3.9	3.9	3.9	3.9
5	3.9	3.9	3.9	3.9	3.9
6	3.9	3.9	3.9	3.9	10.6
7	3.9	3.9	3.9	7.3	22.5
8	3.9	3.9	3.9	19.1	34.3
9	3.9	3.9	15.8	31.0	46.1
10	3.9	12.4	27.6	42.8	58.0
11	237.9	237.9	237.9	237.9	237.9

Release Policy for the Month of December.

State of Reservoir	Information Variable 1	2	3	4	5
1	3.9	3.9	3.9	3.9	3.9
2	3.9	3.9	3.9	3.9	3.9
3	3.9	3.9	3.9	3.9	3.9
4	3.9	3.9	3.9	3.9	3.9
5	3.9	3.9	3.9	3.9	14.0
6	3.9	3.9	3.9	10.6	25.8
7	3.9	3.9	7.3	22.5	37.6
8	3.9	3.9	19.1	34.3	49.5
9	3.9	15.8	31.0	46.1	61.3
10	12.4	27.6	42.8	58.0	73.2
11	237.9	237.9	237.9	237.9	237.9

Release Policy for the Month of January

State of Reservoir	Information Variable 1	2	3	4	5
1	3.9	3.9	3.9	3.9	3.9
2	3.9	3.9	3.9	3.9	3.9
3	3.9	3.9	3.9	3.9	3.9
4	3.9	3.9	3.9	3.9	3.9
5	3.9	3.9	3.9	3.9	14.0
6	3.9	3.9	3.9	10.6	25.8
7	3.9	3.9	3.9	22.5	37.6
8	3.9	3.9	11.5	34.3	49.5
9	3.9	15.8	23.4	46.1	61.3
10	12.4	27.6	35.2	58.0	73.2
11	237.9	237.9	237.9	237.9	237.9

Release Policy for the Month of Feb.

State of Reservoir	Information Variable 1	2	3	4	5
1	3.9	3.9	3.9	3.9	3.9
2	3.9	3.9	3.9	3.9	3.9
3	3.9	3.9	3.9	3.9	5.5
4	3.9	3.9	3.9	3.9	17.3
5	3.9	3.9	3.9	3.9	29.1
6	3.9	3.9	10.6	10.6	41.0
7	3.9	7.3	22.5	22.5	52.8
8	3.9	19.1	34.3	34.3	64.7
9	8.2	31.0	46.1	46.1	76.5
10	20.0	42.8	58.0	58.0	88.3
11	237.9	237.9	237.9	237.9	237.9

Release Policy for the Month of May.

State of Reservoir	Information Variable 1	2	3	4	5
1	3.9	3.9	3.9	3.9	3.9
2	3.9	3.9	3.9	3.9	3.9
3	3.9	3.9	3.9	3.9	3.9
4	3.9	3.9	3.9	3.9	3.9
5	3.9	3.9	3.9	3.9	3.9
6	3.9	3.9	3.9	3.9	3.9
7	3.9	3.9	3.9	3.9	3.9
8	3.9	3.9	3.9	11.5	11.5
9	3.9	3.9	8.2	23.4	23.4
10	4.9	4.9	20.0	35.2	35.2
11	237.9	237.9	237.9	237.9	237.9

State 1 Corresponds to Reservoir Capacity at MDDL.
State 11 Corresponds to Full Reservoir Capacity.

The second formulation is different from the first in that the objective function is framed for strategic operation planning. The inflow probability distribution description is discrete in form and different from that in the first model (lognormal distribution). The results of the case study is again the operation policy useful in planning releases from the reservoir. To avoid the 0-1 nature of the benefits of irrigation, the time step used in the model is a season of 4 months and the releases in different months within the season are to be apportioned proportional to evapotranspiration requirements. The results of this model can be used in the general simulation model discussed in chapter 2 to derive the target reservoir levels for operation. The results of this model for the particular reservoir under consideration is presented in table 6.2.

It is to be impressed that the results of this study is not recommended for implementation because of two reasons (i) the study is of conceptual nature and is in a development stage (ii)the study is to be further supported by a number of studies as detailed under suggestions for future study.

6.2 Suggestions for Future Work :

The research report is conceptual in nature and so provides scope for verification and further development.

1. The algorithm proposed for screening and sequencing may provide optimal or near optimal solution and this needs to be substantiated.

2. The simulation model developed is only an allocation model and needs to be further developed to incorporate economic performance and evaluation.

3. The operation models suggested in chapter 3 needs to be studied extensively with regard to data description and their proposed utility.

4. Studies on description of data and the corresponding probability distribution and their validation needs further detailed investigation.

TABLE 6.2 RESULTS OF THE DYNAMIC PROGRAMMING - FORMULATION 2 FOR RESERVOIR OPERATION.

Full Reservoir Content = 90.00 million m^3

Minimum Draw Down Level = 64.50

Period - 1
Value of forecast Index 1
Releases Corresponding to State of the Reservoir 1 to 16

952.8694000	532.3007000	520.2569000	508.2131000
488.4517000	453.8067000	433.0333000	416.1559000
390.9067000	365.6575000	342.8583000	322.6317000
302.4049000	258.9734000	272.5117000	259.0500000

Period - 1
Value of forecast Index 2
Releases Corresponding to State of the Reservoir 1 to 16

555.1945000	515.3991000	503.3553000	491.3116000
471.5501000	436.9051000	402.2601000	371.5109000
346.2617000	321.0125000	298.2134000	277.9867000
257.7600000	241.3284000	227.8668000	82.6122000

Period - 1
Value of forecast Index 3
Releases Corresponding to State of the Reservoir 1 to 16

505.9679000	445.3991000	433.3553000	421.3116000
401.5501000	366.9051000	322.2601000	301.5109000
276.2617000	251.0125000	245.1150000	224.8883000
204.6616000	188.2300000	174.7683000	144.4051000

Period - 2
Value of forecast Index 1
Releases Corresponding to State of the Reservoir 1 to 16

707.1909000	667.2350000	654.9991000	642.7631000
622.8430000	588.1041000	574.0701000	543.2270000
517.8838000	492.5406000	469.6601000	449.3651000
429.0700000	412.5797000	399.0667000	385.5538000

Period - 2
Value of forecast Index 2
Releases Corresponding to State of the Reservoir 1 to 16

659.8959000	619.9400000	607.7041000	574.7631000

TABLE 6.2 (Contd.)

554.8430000	540.8091000	506.0701000	475.2270000
449.8838000	424.5406000	404.6601000	381.3651000
361.0700000	344.5797000	331.0667000	317.5538000

Period - 2
Value of forecast Index 3
Releases Corresponding to State of the Reservoir 1 to 16

420.4353000	359.6844000	347.4484000	335.2125000
315.2924000	280.5534000	245.8144000	214.9713000
189.6282000	164.2850000	141.4044000	121.1094000
100.8144000	84.3240400	9.5970100	58.0840700

Period - 3
Value of forecast Index 1
Releases Corresponding to State of the Reservoir 1 to 16

432.1409000	371.6643000	359.8128000	347.9612000
328.3584000	293.8073000	259.2563000	228.6011000
203.4458000	178.2906000	155.5729000	135.4146000
155.2562000	98.8838000	85.4729500	72.0625200

Period - 3
Value of forecast Index 2
Releases Corresponding to State of the Reservoir 1 to 16

396.1409000	335.6643000	323.8128000	311.6912000
292.3584000	257.8073000	223.2563000	192.6011000
167.4458000	142.2706000	119.5729000	99.4145700
79.2562000	62.8822700	49.4729500	36.0625100

Period - 3
Value of forecast Index 3
Releases Corresponding to State of the Reservoir 1 to 16

365.1409000	304.6643000	292.8128000	280.9612000
261.3584000	226.8070000	192.2563000	161.6011000
136.4458000	111.2906000	88.5729300	68.4145700
48.2562000	31.8833800	18.4729500	5.0625110

The State 1 of the reservoir corresponds to full reservoir level.

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APPENDIX - A

```
$LARGE
$DEBUG
C       ******************************************************************
C       *                                                                *
C       *        PROGRAMME  FOR  SCREENING  OF  THE  PROJECT             *
C       *                                                                *
C       ******************************************************************
C
C       PROGRAMME FOR SCREENING
        DIMENSION NOV(10), B(20), RR(10,10,20),V(10,10)
        DIMENSION RRR(10,10,20), G(10,10), L(10),M(10),A(20)
        DIMENSION C(20), U(10,10)
        OPEN(UNIT=1,FILE='SCR.DAT')
        OPEN(UNIT=2,FILE='SCR.RES')
        READ(1,*) NOP,NP
        write (2,101) nop,np
101     format (2x,2i5)
        READ (1,*) (NOV(I),I=1,NOP)
        READ (1,*) (B(I),I=1,NP)
        DO 100 I=1,NOP
        JN= NOV(I)
        DO 10 J=1,JN
        READ (1,*) (RR(I,J,K),K=1,NP),V(I,J)
        WRITE(2,200) I,J,(RR(I,J,K),K=1,NP),V(I,J)
200     FORMAT (2I4,9F7.2,F9.2)
10      CONTINUE
100     CONTINUE
        DO 13 I=1,NOP
        JN=NOV(I)
        DO 11 J=1,JN
        SUM=0.
        ITER=1
        DO 12 K=1,NP
        RRR(I,J,K)=RR(I,J,K)/B(K)
        SUM=SUM+RRR(I,J,K)
12      CONTINUE
        WRITE(2,201) I,J,(RRR(I,J,K),K=1,NP),V(I,J)
201     FORMAT (2I4,9F7.2,F9.2)
        G(I,J)=(V(I,J)*NP**0.5)/SUM
11      CONTINUE
13      CONTINUE
        DO 110 I=1,NOP
        DO 110 J=1,NOV(I)
110     WRITE(2,202) I,J,G(I,J)
202     FORMAT(2I4,F10.2)
22      SMAX=-100.
        DO 20 I=1,NOP
        JN= NOV(I)
        DO 20 J=1,JN
        IF (ITER.GE.2)THEN
        DO 21 K=1,ITER-1
        IF (I.EQ.L(K))THEN
```

```
      G(I,J)=0.
      ENDIF
21    CONTINUE
      ENDIF
      IF (G(I,J).GT.SMAX) THEN
      SMAX= G(I,J)
      L(ITER)=I
      M(ITER)=J
      ENDIF
20    CONTINUE
      DO 55 I=1,NOP
      DO 55 J=1,NOV(I)
55    WRITE(2,*) G(I,J)
      WRITE(2,203)L(ITER),M(ITER)
203   FORMAT('PROJECT SELECTED =',I2,5X,'VERSION =',I2)
      SUM=0.
      DO 33 K=1,NP
      C(K)= RR(L(ITER),M(ITER),K)/B(K)
      SUM=SUM+C(K)**2
33    CONTINUE
      WRITE(2,35)(C(K),K=1,NP)
35    format (10f8.4)
      ABC= SUM**0.5
      WRITE(2,*)ABC
      DO 45 K=1,NP
      A(K)=C(K)/ABC
45    CONTINUE
      WRITE(2,35) (A(K),K=1,NP)
      DO 30 I=1,NOP
      DO 31 K=1,ITER
      IF (I.EQ.L(K)) GO TO 30
31    CONTINUE
      JN= NOV(I)
      DO 34 J=1,JN
      SUM1=0.
      DO 32 N=1,NP
      SUM1= SUM1+RRR(I,J,N)*A(N)
32    CONTINUE
      WRITE(2,*) ' SUM1 =',SUM1
      U(I,J)=SUM1
      G(I,J)=V(I,J)/U(I,J)
      IF (G(I,J).EQ.0.) G(I,J)=99999.
34    CONTINUE
30    CONTINUE
      ITER=ITER+1
      DO 40 I=1,NP
      B(I) =B(I)-RR(L(ITER),M(ITER),I)
40    CONTINUE
      IF (ITER.LE.NOP) GO TO 22
      STOP
      END
```

LIST OF NOTATIONS

NON = Number of Nodes

NOL = Number of Link

NOR = Number of Reservoir

NDI = Number of Irrigation Demands Nodes

NDH = Number of Hydropower Demands Nodes

NDM = Number of M&I Demands Nodes

NIN = Number of Inflow Nodes

NMS = Total Number of Months of Simulations

NSM = Starting Month of Simulation

NS(I) = Node Serial Number

NN(I) = Actual Node Number

NT(I) = Node Type

1 = Reservoir

2 = Diversion

3 = Irrigation Demand

4 = Hydropower

5 = M&I Demand

6 = Junction

7 = Absorbing Node or End Node

NIF(I) = 0 - 1 Variable

= 1 ⟶ If node is an inflow node

= 0 ⟶ Otherwise

NFI(I) = 0 - 1 Variable

= 1 ⟶ If it is starting node

= 0 ⟶ Otherwise

LS(I) = Link Serial Number

LB(I) = Beginning Node Number of the Link

LE(I) = Link End Node Number

LT(I) = Link Type

1 = If link is serving a M&I demand

2 = If link is serving Hydropower Station

3 = If link is serving Irrigation demand

4 = All others

IRS(I) = Reservoir Serial Number

IDR(I) = Reservoir Identity - Actual Node Number

DDL(I) = Minimum Draw Down Level

NAC(I) = Number of Area Capacity Point at i^{th} Reservoir

NRT(I) = Type of Reservoir

1 = If serving only downstream

2 = If serving only M&I

3 = If serving only Hydropower

4 = If serving only Irrigation

5 = If serving M&I and Hydropower

6 = If serving M&I and Irrigation

7 = If serving Irrigation and Hydropower

8 = If serving all Irrigation, Hydropower, and M&I

E(I,J) = Elevation of j^{th} Area - Capacity point of i^{th} Reservoir

A(I,J) = Area Of Reservoir at Elevation of j^{th} point of i^{th} Reservoir

C(I,J) = Capacity at j^{th} point Elevation of i^{th} Reservoir

VMX(I,J) = Maximum reservoir that is to be maintained in the i^{th} reservoir in j^{th} time for flood control.

VMN(I,J) = Minimum reservoir to be maintained in the i^{th}reservoir in j^{th} month for conservation purposes.

EVC(I,J) = Evaporation constant for i^{th} reservoir in j^{th} month.

IDS(I) = Irrigation Demand Serial

IDI(I) = Identity of Irrigation Area Node Number

ARE(I) = Area under Irrigation in the i^{th} Irrigation Demand Center.

WRC(I,J) = Water Requirement of Crop for i^{th}area in j^{th}period in mm.

IHS(I) = Serial Number of Hydropower Station

IDH(I) = Identity of Hydropower Station Node Number

FP(I) = Firm Power expected of i^{th} Hydropower Station

TWL(I) = Tail Water Level of i^{th}Hydropower Station or canal to constant head in case of constant head Hydropower Station.

IMS(I) = M&I Demand Center Serial Number

IDM(I) = Identity of M&I Demand Center Node Number

DEM(I,J) = Demand of i^{th} M&I Demand Center in j^{th} period

DAY(I) = Number of Days in the i^{th} month

INS(I) =. Inflow Node Serial Number

IDF(I) = Identity of Inflow Node Number

FIN(I,J) = Inflow to i^{th} Inflow Node in j^{th} period

FRC(I) = Full Reservoir Capacity of i^{th} Reservoir

FRL(I) = Full Reservoir Level of i^{th} Reservoir

FRA(I) = Full Reservoir Area of i^{th} Reservoir

DCM(I) = Serial Number of M&I Nodes for Adjustment and Release from upstream Reservoir.

NDC(I) = Number of Demand Center

NRA = Number of Reservoir Available for release to satisfy the demand corresponding to the Reservoir

IRV = Reservoir Available for Release

NRN = Number of Demand Center for which return flow can happen w.r.t the demand center.

DS = Node Number of Demand Center in the order 1,2,3,4,.....k with respect to the demand.

The first digit of DS represent the type of node wether it is M&I (=1) or Irrigation (=2). The fractional part represent the return flow fraction from upstream demand satisfied.

APPENDIX - C

```
$LARGE
$DEBUG
C ********************************************************************
C
C        POGRAMME  FOR  SIMULATION
C
C ********************************************************************
C
      DIMENSION NS(50), NN(50), NT(50), NIF(50),NFI(50)
      DIMENSION LS(50), LB(50), LE(50), LT(50)
      DIMENSION IRS(5), IDR(5), DDL(5), NAC(5), NRT(5)
      DIMENSION E(5,30), A(5,30), C(5,30)
      DIMENSION VMX(5,12), VMN(5,12), EVC(5,12)
      DIMENSION IDS(6), IDI(6), ARE(6), WRC(6,12)
      DIMENSION IHS(2), IDH(2), FP(2), TWL(2)
      DIMENSION IMS(2), IDM(2), DEM(2,12), DAYS(12)
      DIMENSION INS(10), IDF(10), FIN(10,240)
      DIMENSION M1(5), M2(5)
      DIMENSION I1(5), I2(5)
      DIMENSION NDC(8), NRA(8), NRN(8), FLOW(50)
      DIMENSION IRU(8,4), DS(8,4)
      DIMENSION DMU(2,12), DMS(2,12), DEI(6,12), DIU(6,12), DIS(6,12)
      DIMENSION FRC(6), FRL(6), FRA(6)
      DIMENSION RVI(6,12), RVF(6,12)
      DIMENSION RAI(6,12), RAF(6,12)
      DIMENSION REI(6,12), REF(6,12)
      DIMENSION FAC(10)
      OPEN(UNIT=1, FILE='SIM.DAT')
      OPEN(UNIT=2,FILE='SIM.RES', STATUS='NEW')
      READ(1,*) NON, NOL, NOR, NDI, NDH, NDM, NIN, NMS, nsm
      write(2,400) NON, NOL, NOR, NDI, NDH, NDM, NIN, NMS, nsm
400   FORMAT(5X,9I5)
      DO 1 I=1,NON
      READ(1,*) NS(I), NN(I), NT(I), NIF(I),NFI(I)
      write(2,401) NS(I), NN(I), NT(I), NIF(I), NFI(I)
401   FORMAT(5X,5I7)
1     CONTINUE
      DO 2 I=1,NOL
      READ(1,*) LS(I), LB(I),LE(I),LT(I)
      write(2,402) LS(I), LB(I),LE(I),LT(I)
402   FORMAT (5X,4I6)
2     CONTINUE
c
      if (nor.eq.0) go to 399
      DO 3 I=1, NOR
      READ(1,*) IRS(I), IDR(I),DDL(I), NAC(I), NRT(I)
      write(2,403) IRS(I), IDR(I),DDL(I), NAC(I), NRT(I)
403   FORMAT (5X,2I7,F8.2,2I7)
3     CONTINUE
      DO 4 I=1, NOR
      K=NAC(I)
```

```
        DO 4 J=1, K
        READ(1,*) E(I,J), A(I,J), C(I,J)
        write(2,404) E(I,J), A(I,J), C(I,J)
404     FORMAT (5X,3F10.2)
4       CONTINUE
        DO 5 I=1,NOR
        READ(1,*) (VMX(I,J), J=1,12)
        write(2,405) (VMX(I,J), J=1,12)
        READ(1,*) (VMN(I,J), J=1,12)
        write(2,405) (VMN(I,J), J=1,12)
        READ(1,*) (EVC(I,J),J=1,12)
        write(2,405) (EVC(I,J),J=1,12)
405     FORMAT (5X,12F6.1)
5       CONTINUE
c
399     DO 6 I=1, NDI
        READ(1,*) IDS(I), IDI(I), ARE(I)
        write(2,406) IDS(I), IDI(I), ARE(I)
406     FORMAT (5X,2I7,F10.2)
6       CONTINUE
        DO 7 I=1, NDI
        READ(1,*) (WRC(I,J), J=1,12)
        write(2,416) (WRC(I,J), J=1,12)
416     FORMAT (5X,12F6.1)
7       CONTINUE
        DO 15 I=1, NDI
        DO 15 J=1,12
        DEI(I,J)=ARE(I)*WRC(I,J)/(10**5)
15      CONTINUE
c
        if (ndh.eq.0) go to 398
        DO 8 I=1, NDH
        READ(1,*) IHS(I),IDH(I),FP(I),TWL(I)
        write(2,408) IHS(I),IDH(I),FP(I),TWL(I)
408     FORMAT (5X,2I7,2F8.2)
8       CONTINUE
c
398     DO 9 I=1,NDM
        READ(1,*) IMS(I), IDM(I)
        write(2,409) IMS(I), IDM(I)
409     FORMAT (5X,2I6)
9       CONTINUE
        DO 10 I=1,NDM
        READ(1,*) (DEM(I,J), J=1,12)
        write(2,410) (DEM(I,J), J=1,12)
410     FORMAT (5X,12F6.2)
10      CONTINUE
        READ(1,*) (DAYS(I), I=1,12)
c
        if (nor.eq.0) go to 397
        DO 11 I=1,NOR
        READ(1,*) FRC(I), FRL(I), FRA(I)
        write(2,411) FRC(I), FRL(I), FRA(I)
411     FORMAT (5X,3F10.2)
11      CONTINUE
```

```
c
397       M=NDI + NDM
          DO 12 I=1,M
          READ(1,*) NDC(I), NRA(I), NRN(I)
          write(2,412) NDC(I), NRA(I), NRN(I)
412       FORMAT (5X,3I7)
12        CONTINUE
          IF (NOR.EQ.0) GO TO 396
          DO 13 I=1, M
          K=NRA(I)
          READ(1,*) (IRU(I,J), J=1, K)
          write(2,413) (IRU(I,J), J=1, K)
413       FORMAT (5X,6I6)
13        CONTINUE
          DO 14 I=1,M
          K=NRN(I)
          IF(K.EQ.0) GOTO 14
          READ(1,*) (DS(I,J), J=1,K)
          write(2,414) (DS(I,J), J=1,K)
414       FORMAT (5X,F8.2)
14        CONTINUE
C
396       DO 18 I=1,NIN
          READ(1,*) INS(I), IDF(I),(fin(i,j), j=1,nms)
          write(2,415) (fin(i,j),j=1,nms)
415      FORMAT (12F6.1)
18        CONTINUE
          RFI=0.1
          RFM=0.6
          RFH=1.0
          DO 19 I=1, NOR
          RVI(I,NSM)=FRC(I)
          REI(I,NSM)=FRL(I)
          RAI(I,NSM)=FRA(I)
          WRITE(2,700) RVI(I,NSM)
700       FORMAT(F10.2)
19        CONTINUE
          DO 22 JS=1,NMS
c750       DO 22 JS=1,NMS
          J=NSM+JS-1
          JX=(J-1)/12
          J=J-JX*12
          DO 188 IR=1, NOR
          RVI(IR,J+1)=RVF(IR,J)
          RAI(IR,J+1)=RAF(IR,J)
          REI(IR,J+1)=REF(IR,J)
          RVF(IR,J)=RVI(IR,J+1)
          RAF(IR,J)=RAI(IR,J+1)
          REF(IR,J)=REI(IR,J+1)
188       CONTINUE
          do 701 in=1,ndi
          diu(in,j)=dei(in,j)
701       continue
          do 702 in=1,ndm
          dmu(in,j)=dem(in,j)
```

```
702     continue
        DO 200 NL=1,NOL
        FLOW(NL)=0.
200     CONTINUE
65      DO 123 IS=1, NON
        I=NN(IS)
        SIF=0.
        IF (NIF(IS).EQ.1) THEN
        DO 23 K=1,NIN
        IF (IDF(K).EQ.I) GO TO 223
23      CONTINUE
223     SIF=SIF+FIN(K,JS)
        ELSE
        SIF=0.
        ENDIF
        IF(NFI(IS).EQ.1)GO TO 270
        DO 24 L=1,NOL
        IF(LE(L).NE.I)GO TO 24
        SIF=SIF+FLOW(L)
24      CONTINUE
        IF (SIF.LE.0) THEN
        SIF=0.
        GO TO 123
        ENDIF
270     IF (NT(IS).GT.2) GO TO 40
        IF(NT(IS).EQ.2) GOTO 25
        DO 26 IR=1,NOR
        IF(IDR(IR).NE.I) GO TO 26
        K=IRS(IR)
        GO TO 27
26      CONTINUE
        ST=0.
27      ST=RVI(K,J)+SIF
        IF (ST.GT.VMX(K,J)) THEN
        SIF=ST-VMX(K,J)
        RVF(K,J)=VMX(K,J)
        ELSE
        RVF(K,J)=ST
        SIF=0.
        ENDIF
        IF(NRT(K).EQ.1) THEN
        DO 500 NL=1,NOL
        IF(LB(NL).EQ.I.AND.LT(NL).EQ.4) THEN
        FLOW(NL)=SIF
        GO TO 124
        ENDIF
500     CONTINUE
        ENDIF
25      M=0
        SM=0.
        DO 28 IL=1,NOL
        IF(LB(IL).EQ.I.AND.LT(IL).EQ.1)THEN
        N1=LE(IL)
        M=M+1
        M1(M)=IL
```

```
      DO 29 NM=1,NDM
      IF(IDM(NM).EQ.N1)THEN
      M2(M)=NM
      SM=SM+DMU(NM,J)
      GO TO 28
      endif
29    CONTINUE
      endif
28    CONTINUE
      IF(M.EQ.0.OR.SM.EQ.0) THEN
      CON=0.
      GO TO 30
      ENDIF
      IF(SIF.GE.SM) F=1.
      IF(SIF.GT.0.AND.SIF.LT.SM)THEN
      F=SIF/SM
      ENDIF
301   CON=0.
      DO 31 IX=1,M
      K1=M1(IX)
      K2=M2(IX)
      DMS(K2,J)=F*DMU(K2,J)
      CON=CON+DMS(K2,J)
      FLOW(K1)=DMS(K2,J)
      DMU(K2,J)=DMU(K2,J)-DMS(K2,J)
31    CONTINUE
      IF (M.EQ.0) CON=0.
30    SIF=SIF-CON
      IF (SIF.LE.0) GO TO 35
      MI=0
      SI=0.
      DO 32 IL=1, NOL
      IF(LT(IL).EQ.3.AND.LB(IL).EQ.I) THEN
      N2=LE(IL)
      MI=MI+1
      I1(MI)=IL
      DO 33 NM=1,NDI
      IF(IDI(NM).EQ.N2) THEN
      I2(MI)=NM
      SI=SI+DIU(NM,J)
      GOTO 32
      ENDIF
33    CONTINUE
      endif
32    CONTINUE
      IF (MI.EQ.0.OR.SI.EQ.0) GOTO 35
      IF(SIF.GE.SI) F1=1.
      IF(SIF.GT.0. AND.SIF.LT.SM) F1=SIF/SI
304   DO 34 IX=1,MI
      L1=I1(IX)
      L2=I2(IX)
      DIS(L2,J)=F1*DIU(L2,J)
      DIU(L2,J)=DIU(L2,J)-DIS(L2,J)
      CON=CON+DIS(L2,J)
      FLOW(L1)=DIS(L2,J)
```

```
      SIF=SIF-FLOW(L1)
34    CONTINUE
35    IF (SIF.LE.0) THEN
      SIF=0.
      ENDIF
      DO 37 IL=1,NOL
      IF(LT(IL).EQ.4.AND.LB(IL).EQ.I) THEN
      FLOW(IL)=SIF
      GO TO 424
      endif
37    CONTINUE
424   IF(NT(IS).NE.1) GOTO 123
124   NP=NAC(K)
      DO 17 NX=1,NP
      IF (C(K,NX).GE.RVF(K,J)) GOTO 16
17    CONTINUE
16    DF=RVF(K,J)-C(K,NX-1)
      DV=C(K,NX)-C(K,NX-1)
      DA=A(K,NX)-A(K,NX-1)
      DE=E(K,NX)-E(K,NX-1)
      RAF(K,J)=A(K,NX-1)+DF*DA/DV
      REF(K,J)=E(K,NX-1)+DF*DE/DV
      GOTO 123
40    IF(NT(IS).EQ.3) THEN
      F=RFI
      GO TO 309
      ENDIF
      IF(NT(IS).EQ.4)THEN
      F=RFH
      GO TO 309
      endif
      IF(NT(IS).EQ.5) THEN
      F=RFM
      GO TO 309
      ENDIF
      IF(NT(IS).EQ.6) THEN
      F=1.
      GO TO 309
      ENDIF
      IF(NT(IS).EQ.7) F=0
309   DO 39 NL=1,NOL
      IF(LB(NL).EQ.I.AND.LT(NL).EQ.4)THEN
      FLOW(NL)=F*SIF
      GOTO 123
      ENDIF
39    CONTINUE
123   CONTINUE
      DO 42 L=1,NOL
      FLOW(L)=0.
42    CONTINUE
      DO 41 IS=1, NON
      I=NN(IS)
      SIF=0.
      DO 43 NL=1,NOL
      IF(LE(NL).NE.I) GO TO 43
```

```
      SIF=SIF+FLOW(NL)
43    CONTINUE
      IF (NT(IS).GT.2) GO TO 90
      IF (NT(IS).EQ.2) GO TO 44
      IF(NT(IS).EQ.1) THEN
      DO 45 NR=1,NOR
      IF (IDR(NR).NE.I) GOTO 45
      K=IRS(NR)
45    CONTINUE
      RVF(K,J)=RVF(K,J)+SIF
      IF(RVF(K,J).GE.VMX(K,J)) THEN
      SPL=RVF(K,J)-VMX(K,J)
      RVF(K,J)=VMX(K,J)
      ELSE
      SPL=0.
      ENDIF
      DO 145 NL=1,NOL
      IF(LB(NL).EQ.I.AND.LT(NL).EQ.4) THEN
      FLOW(NL)=SPL
      ENDIF
145   CONTINUE
      IF(NRT(K).EQ.1) THEN
      M=0
      MI=0
      P=0
      GOTO 60
      ENDIF
      IF(NRT(K).EQ.4) THEN
      M=0
      P=0
      GOTO 407
      ENDIF
      IF(NRT(K).EQ.3) THEN
      M=0
      MI=0
      GOTO 501
      ENDIF
46    M=0
      SM=0.
      DO 47 IJ=1,NOL
      IF(LB(IJ).EQ.I.AND.LT(IJ).EQ.1) THEN
      N1=LE(IJ)
      M=M+1
      M1(M)=IJ
      DO 48 IK=1,NDM
      IF(IDM(IK).EQ.N1) THEN
      M2(M)=IK
      SM=SM+DMU(IK,J)
      ENDIF
48    CONTINUE
      ENDIF
47    CONTINUE
      IF(NRT(K).EQ.2) GOTO 60
407   MI=0
      SI=0.
```

```
      DO 49 IJ=1,NOL
      IF(LB(IJ).EQ.I.AND.LT(IJ).EQ.3) THEN
      N2=LE(IJ)
      MI=MI+1
      I1(MI)=IJ
      DO 50 IK=1,NDI
      IF(IDI(IK).EQ.N2) THEN
      I2(MI)=IK
      SI=SI+DIU(IK,J)
      ENDIF
50    CONTINUE
      ENDIF
49    CONTINUE
      IF (NRT(K).EQ.4.OR.NRT(K).EQ.5) THEN
      P=0.
      GO TO 60
      ENDIF
501   MH=0
      DO 51 IJ=1, NOL
      IF(LB(IJ).EQ.I.AND.LT(IJ).EQ.2) THEN
      MH=MH+1
      IH=LE(IJ)
      IL=IJ
      DO 52 IK=1,NDH
      IF(IDH(IK).EQ.IH) THEN
      NH=IK
      GOTO 53
      ENDIF
52    CONTINUE
      ENDIF
51    CONTINUE
53    IF(MH.EQ.0) GOTO 60
      P=FP(NH)
      TW=TWL(NH)
60    REVI=RVF(K,J)
      REAI=RAF(K,J)
      REEI=REF(K,J)
      REEF=REEI
      REAF=REAI
54    AE=(REEF+REEI)/2.
      EH=AE-TW
      EH=EH*0.9
      AVA=(REAF+REAI)/2.
      EVP=AVA*EVC(K,J)/(10**4)
      IF (NRT(K).EQ.1) THEN
      CON=0.
      GO TO 58
      ENDIF
      Q=(P*1000.)/(EH*9.806*0.85)
      V=Q*DAYS(J)*24.*3600./(10**6)
      WAR=RVF(K,J)-VMN(K,J)
      CON=0.
      IF(M.EQ.0) GOTO 56
      IF(WAR.GE.SM) F=1
      IF (SM.EQ.0) THEN
```

```
      F=0
      GOTO 507
      ENDIF
      IF(WAR.LT.SM) F=WAR/SM
507   DO 57 IX=1,M
      K1=M1(IX)
      K2=M2(IX)
      DMS(K2,J)=F*DMU(K2,J)
      DMU(K2,J)=DMU(K2,J)-DMS(K2,J)
      FLOW(K1)=DMS(K2,J)
      CON=CON+FLOW(K1)
57    CONTINUE
      WAR=WAR-CON
      IF(WAR.LE.0.) GOTO 58
56    IF(MH.EQ.0) GOTO 59
      IF(WAR.LT.V) P=0.
      IF(WAR.GE.V) WAR=WAR-V
      CON=CON+V
      IF(WAR.LE.0) GOTO 58
      FLOW(IL)=V
      IF(P.EQ.0) FLOW(IL)=0.
59    if(mi.eq.0) goto 58
      IF(SI.EQ.0) THEN
      F1=0
      GOTO 601
      ENDIF
      IF(SI.GT.WAR) F1=WAR/SI
      IF(SI.LE.WAR) F1=1.
601   DO 61 IX=1,MI
      K1=I1(IX)
      K2=I2(IX)
      DIS(K2,J)=F1*DIU(K2,J)
      DIU(K2,J)=DIU(K2,J)-DIS(K2,J)
      FLOW(K1)=DIS(K2,J)
      CON=CON+FLOW(K1)
61    CONTINUE
58    REL=CON
      FV=RVF(K,J)-REL-EVP
      NC=NAC(K)
      DO 62 KC=1,NC
      IF(C(K,KC).GE.FV) GOTO 63
62    CONTINUE
63    DF=FV-C(K,KC-1)
      DV=C(K,KC)-C(K,KC-1)
      if (dv.eq.0) go to 41
      DE=E(K,KC)-E(K,KC-1)
      DA=A(K,KC)-A(K,KC-1)
      FA=A(K,KC-1)+DF*DA/DV
      FE=E(K,KC-1)+DF*DE/DV
      IF (ABS(FE-REEF).LT.0.01) GOTO 64
      REAF=FA
      REEF=FE
      GOTO 54
64    RVF(K,J)=FV
      RAF(K,J)=FA
```

```
      REF(K,J)=FE
      GOTO 41
      ENDIF
44    IF(NT(IS).EQ.2) THEN
      M=0
      SM=0.
      DO 91 IL=1,NOL
      IF(LB(IL).EQ.I.AND.LT(IL).EQ.1) THEN
      N1=LE(IL)
      M=M+1
      M1(M)=IL
      DO 92 NM=1,NDM
      IF(IDM(NM).EQ.N1) THEN
      M2(M)=NM
      SM=SM+DMU(NM,J)
      ENDIF
92    CONTINUE
      ENDIF
91    CONTINUE
      IF(M.EQ.0) GOTO 94
      IF(SIF.GE.SM) F=1.
      IF(SM.EQ.0) THEN
      F=0
      GOTO 903
      ENDIF
      IF(SIF.LT.SM) F=SIF/SM
      CON=0.
903   DO 93 IX=1,M
      K1=M1(IX)
      K2=M2(IX)
      DMS(K2,J)=F*DMU(K2,J)
      FLOW(K1)=DMS(K2,J)
      DMU(K2,J)=DMU(K2,J)-DMS(K2,J)
93    CONTINUE
94    IF (M.EQ.0) CON=0.
      SIF=SIF-CON
      IF (SIF.LE.0) GO TO 41
      MH=0
      DO 98 IL=1,NOL
      IF(LT(IL).EQ.2.AND.LB(IL).EQ.I) THEN
      N2=LE(IL)
      MH=MH+1
      ID=IL
      ENDIF
98    CONTINUE
      IF(MH.EQ.0) GOTO 99
      DO 95 IH=1,NOH
      IF(IDH(IH).EQ.N2) THEN
      IQ=IH
      ENDIF
95    CONTINUE
96    PD=FP(IQ)
      EH=TWL(IQ)
      EH=0.99*EH
      Q=(PD*1000.)/(9.806*EH*0.85)
```

```
        V=Q*DAYS(J)*24.*3600./(10**6)
        IF(SIF.GE.V) REL=V
        IF(SIF.LT.V) REL=0.
        SIF=SIF-REL
        IF (SIF.LE.0) THEN
        SIF=0.
        GO TO 41
        ENDIF
        FLOW(ID)=REL
99      MI=0
        SI=0.
        DO 100 IL=1,NOL
        IF(LT(IL).EQ.3.AND.LB(IL).EQ.I) THEN
        N3=LE(IL)
        MI=MI+1
        I1(MI)=IL
        DO 101 NM=1,NDI
        IF(IDI(NM).EQ.N3) THEN
        SI=SI+DIU(NM,J)
        ENDIF
101     CONTINUE
        ENDIF
100     CONTINUE
        IF(MI.EQ.0) GOTO 102
        IF(SIF.GE.SI) F1=1
        IF(SI.EQ.0) THEN
        F1=0
        GOTO 1003
        ENDIF
        IF(SIF.LT.SI) F1=SIF/SI
1003    DO 103 IX=1, MI
        L1=I1(IX)
        L2=I2(IX)
        DIS(L2,J)=F1*DIU(L2,J)
        DIU(L2,J)=DIU(L2,J)-DIS(L2,J)
        FLOW(L1)=DIS(L2,J)
        SIF=SIF-FLOW(L1)
        IF (SIF.LE.0) THEN
        SIF=0.
        GO TO 41
        ENDIF
103     CONTINUE
102     DO 104 NL=1,NOL
        IF(LT(NL).EQ.4.AND.LB(NL).EQ.I) THEN
        FLOW(NL)=SIF
        ENDIF
104     CONTINUE
        GOTO 41
        ENDIF
90      IF(NT(IS).EQ.3)THEN
        F=RFI
        GO TO 310
        ENDIF
        IF(NT(IS).EQ.4) THEN
        F=RFH
```

```
      GO TO 310
      ENDIF
      IF(NT(IS).EQ.5) THEN
      F=RFM
      GO TO 310
      ENDIF
      IF(NT(IS).EQ.6) THEN
      F=1.
      GO TO 310
      ENDIF
      IF(NT(IS).EQ.7) GOTO 41
310   DO 139 NL=1,NOL
      IF(LB(NL).EQ.I) THEN
      FLOW(NL)=F*SIF
      GOTO 41
      ENDIF
139   CONTINUE
41    CONTINUE
66    SUM=0.
      IU=NDM+NDI
      DO 80 IA=1,IU
      DO 81 IB=1,NRA(IA)
      K=IRU(IA,IB)
      IF(RVF(K,J).LE.VMN(K,J)) GOTO 81
      AW=RVF(K,J)-VMN(K,J)
      IC=NDC(IA)
      IF(IA.LE.NDM) GOTO 82
      IF(IA.GT.NDM) GOTO 84
82    IF(DMU(IC,J).GT.AW) GOTO 83
      DMS(IC,J)=DMU(IC,J)
      DMU(IC,J)=0
      SUM=SUM+DMS(IC,J)
      RVF(K,J)=RVF(K,J)-DMS(IC,J)
      GOTO 81
83    DMS(IC,J)=AW
      DMU(IC,J)=DMU(IC,J)-DMS(IC,J)
      SUM=SUM+DMS(IC,J)
      RVF(k,J)=VMN(K,J)
      GOTO 81
84    IF (DIU(IC,J).GT.AW) GO TO 87
      DIS(IC,J)=DIU(IC,J)
      DIU(IC,J)=0.
      SUM=SUM+DIS(IC,J)
      RVF(K,J)=RVF(K,J)-DIS(IC,J)
      GOTO 81
87    DIS(IC,J)=AW
      DIU(IC,J)=DIU(IC,J)-DIS(IC,J)
      SUM=SUM+DIS(K,J)
      RVF(K,J)=VMN(K,J)
81    CONTINUE
      EX=0.
182   DO 183 JA=1,NRN(IA)
      INT=DS(IA,JA)
      FAC(JA)=DS(IA,JA)-INT
      FA=FAC(JA)
```

```
          MDS=INT/10
          L=INT-MDS*10
          IF(MDS.EQ.1) GOTO 184
          IF(MDS.EQ.2) GOTO 185
184       IF(DMU(L,J).LE.0) GOTO 183
          X=F*SUM
          IF(DMU(L,J).LE.X) THEN
          DMS(L,J)=DMU(L,J)
          EX=X-DMS(L,J)
          DMU(L,J)=0
          ENDIF
          IF(DMU(L,J).GT.X) THEN
          DMS(L,J)=X
          EX=0
          DMU(L,J)=DMU(L,J)*F+EX
          ENDIF
          GOTO 183
185       IF(DIU(L,J).LE.0) GOTO 183
          X=F*SUM
          IF(DIU(L,J).LE.X) THEN
          DIS(L,J)=DIU(L,J)
          DIU(L,J)=0
          EX=X-DIS(L,J)
          ENDIF
          IF(DIU(L,J).GT.X) THEN
          DIS(L,J)=X
          EX=0.
          DIU(L,J)=DIU(L,J)-DIS(L,J)
          ENDIF
          SUM=DIS(L,J)*F+EX
183       CONTINUE
          SUM=0.
80        CONTINUE
999       DO 187 IR=1, NOR
          RVI(IR,J+1)=RVF(IR,J)
          RAI(IR,J+1)=RAF(IR,J)
          REI(IR,J+1)=REF(IR,J)
187       CONTINUE
          write(2,805)(dei(ik,j),ik=1,ndi)
          write(2,805)(diu(ik,j),ik=1,ndi)
          write(2,805)(dis(ik,j),ik=1,ndi)
805       format('demand='6f10.2)
          WRITE(2,996)JS,J,(RVI(IR,J),IR=1,NOR)
996       FORMAT(//I5,5X,I5,4F10.2)
          IF((J+1).EQ.12) THEN
          DO 189 IIR=1,NOR
          RVI(IIR,1)=RVI(IIR,12)
189       CONTINUE
          ELSE
          ENDIF
22        CONTINUE
          STOP
          END
```

APPENDIX - D

```
$large
$debug
c ***********************************************************************
c
C       PROGRAM FOR DETERMINATION OF RELEASES IN THE FLOOD SEASON
C                   AND NAME OF PROGRAMME POL.FOR
C
C ***********************************************************************
C
C       NP   = NUMBER OF PERIOD
C       INV  = NUMBER OF INFORMATION VARIABLES
C       NDV  = NUMBER OF DIVISION OF RESRVOIR USED IN THE COMPUTATION
C       DTIM = NUMBER OF HOURS IN THE PERIOD
C       NN   = NUMBER OF POINT IN THE AREA CAPACITY CURVE
C       SMAX = MAXIMUM LIFE STORAGE CORRESPONDING TO FRL IN CUBIC METRES
C       SMIN = CAPACITY OF RESERVOIR AT MDDL IN CUBIC METRES
C       RMIN = MINIMUM RELEASE IN CUMEC
C       ELEV = ELEVATION (M); AREA = RESERVOIR AREA (SQ.M);
C       SCAP = CAPACITY (CU.M)
C       RELC = RELEASE CAPACITY (CUMEC)
C       GT   = TRANSITION  PROBABILITY MATRIX
C       APM  = ACCEPTED RISK LEVEL
C       II   = SERIAL NUMBER
C       F    = PARAMETERS OF THE PROBABILITY DISTRIBUTION
C
C ***********************************************************************
C
      dimension stbl(20,10), stbh(20,10), rel(20,40,10)
      common/pro/ apm(20), f(20,10,3), optp(20,40,10),stor(20),
     * htt(20,10), gt(20,20)
      common/ps/smax, smin, dtim, rmin, inv, ndv, ifl
      COMMON /ACT/ ELEV(30), AREA(30), SCAP(30), RELC(30), NN
      OPEN(unit=2,FILE='POL.RES',status='new')
      OPEN(unit=1,FILE='POL.INP')
      READ(1,*) NP, INV, NDV, DTIM, NN, SMAX, SMIN, RMIN
      WRITE(2,21) NP, INV,NDV,DTIM, NN, SMAX, SMIN, RMIN
21    format(2x,3i5,2x,f8.2,2x,i5,e12.3,2x,e12.3,2x,f8.2)
      DO 2 i=1,NN
      READ(1,*) ELEV(I), AREA(I), SCAP(I), RELC(I)
2     WRITE(2,8) ELEV(I), AREA(I), SCAP(I), RELC(I)
8     FORMAT(3e10.2, f10.2)
      READ(1,*) ((GT(I,J), J=1,INV), I=1, INV)
      READ(1,*) (APM(I),I=1,NP)
      DO 3 I=1,NP
3     READ(1,*) II,((F(I,J,K),K=1,2), J=1,INV)
      DTIM=DTIM*3600
      DS=(SMAX-SMIN)/NDV
      STOR(1)=SMIN
      DO 10 I=2, NDV+1
10    STOR(I)=STOR(I-1)+DS
      WRITE(2,11) (STOR(I),I=1,NDV+1)
11    format(6e12.4)
```

```
      ix=np+1
      do 200  m=1,ndv+1
      do 200  n=1,inv
      optp(ix,m,n)=0
200   continue
      DO 100 IP=NP,1,-1
      DO  100 INJ=1,INV
      IFL=0
      CALL SOLV(HT,IP,INJ)
      HTT(IP,INJ)=HT
      STBL(IP,INJ)=HT+RMIN*DTIM
      IF(STBL(IP,INJ).LT.SMIN) STBL(IP,INJ)=SMIN
      IF(STBL(IP,INJ).GE.SMAX) THEN
      STBL(IP,INJ)=SMAX
      STBH(IP,INJ)=SMAX
      GOTO 22
      ENDIF
      CALL BOUND(HT,SB)
      STBH(IP,INJ)=SB
22    IFL=10
      DO 100 I=1,NDV+1
      RMAX=FINT(SCAP,RELC,STOR(I), NN)
      IF (STOR(I).LE.STBL(IP,INJ)) THEN
      REL(IP,I,INJ)=AMIN1(RMIN,RMAX)
      EVOL=SMAX-STOR(I)+rel(ip,i,inj)*dtim
      CALL TPR(PRO, IP, INJ, EVOL)
      OPTP(IP,I,INJ)=PRO
      ELSEIF (STOR(I).GT.STBL(IP,INJ).AND.STOR(I).LE.STBH(IP,
     * THEN
      RELL=(STOR(I)-STBL(IP,INJ))/DTIM+RMIN
      REL(ip,i,inj)=amin1(rmax,rell)
      OPTP(IP,I,INJ)=apm(ip)
      elseif (stor(i).gt.stbl(ip,inj)) then
      rel(ip,i,inj)=rmax
      EVOL=SMAX-STOR(I)+REL(IP,I,INJ)*DTIM
      CALL TPR(PRO,IP,INJ,EVOL)
      OPTP(IP,I,INJ)=PRO
      ENDIF
100   CONTINUE
      DO 410 IJ=1,INV
      WRITE(2,*) 'INV : ', IJ
      WRITE(2,26)(STBL(I,IJ),I=1,NP)
26    format('STBL =',6E12.4)
      WRITE(2,27)(STBH(I,IJ),I=1,NP)
27    format('STBH =',6e12.4)
405   FORMAT(I4, 2E10.3)
410   CONTINUE
415   FORMAT('T',I3,'SL',E12.4,'SH',E12.4,'PAR'2F9.4,'H'E12.
444   FORMAT(13G10.3/2X,6G10.4)
       write(2,23)
23    format(/)
      DO 450 I=1,NP
      DO 450 IJ=1,INV
450   WRITE(2,440) I,IJ,(REL(I,K,IJ),K=1,NDV+1)
440   FORMAT(I2,2x,I2,15F6.1/15F6.1)
```

```
      STOP
      END
C
C
C*****************************************************************
      SUBROUTINE BOUND(HT,SB)
C*****************************************************************
      COMMON /ACT/ ELEV(30), AREA(30), SCAP(30), RELC(30), NN
      COMMON /PS/ SMAX, SMIN, DTIM, RMIN, INV, NDV, IFL
      ITL=0
      AF=0.01*SMAX
      SH=SMAX
      DO 11 I=1,1000
      SH=SH-AF
      RL=FINT(SCAP,RELC,SH,NN)
      HH=SH-RL*DTIM
      IF(HH.LT.HT.AND.ITL.EQ.0) THEN
      ITL=1
      SH=SH+AF
      AF=0.001*SMAX
      GOTO 11
      ENDIF
      IF(HH.LT.HT.AND.ITL.EQ.1) THEN
      ITL=2
      SH=SH+AF
      AF=0.00005*SMAX
      GOTO 11
      ENDIF
      IF(HH.LT.HT) GOTO 21
11    CONTINUE
21    SB=SH-AF/2.0
      IF(SB.LT.SMIN) SB=SMIN
      RETURN
      END
C
C*****************************************************************
      SUBROUTINE SOLV(STB,IP,INJ)
C*****************************************************************
      COMMON /PRO/ APM(20),F(20,10,3),OPTP(20,40,10),STOR(20),
     * HTT(20,10), GT(20,20)
      COMMON /PS/ SMAX, SMIN, DTIM, RMIN, INV, NDV, IFL
      PM=APM(IP)
      ITL=0
      HS=SMAX*0.99
      SMH=(SMAX-HS)
      CALL TPR(PRB,IP,INJ,SMH)
      IF(PRB.LT.PM) THEN
      STB=SMAX
      RETURN
      ENDIF
      AF=.05*SMAX
      DO 10 I=1,1000
      HS=HS-AF
      IF(HS.LT.0) THEN
      STB=0
```

```
      RETURN
      ENDIF
      SMH=(SMAX-HS)
      CALL TPR(PRB,IP,INJ,SMH)
      IF(ABS(PM-ABS(PRB)).LT.0.001) GOTO 11
      IF(ITL.EQ.0.AND.ABS(PRB).LT.PM) THEN
      HS=HS+AF
      ITL=1
      AF=0.01*SMAX
      GOTO 10
      ENDIF
      IF(ITL.EQ.1.AND.ABS(PRB).LT.PM) THEN
      HS=HS+AF
      ITL=2
      AF=0.001*SMAX
      GOTO 10
      ENDIF
      IF(ITL.EQ.2.AND.ABS(PRB).LT.PM) THEN
      HS=HS+AF
      AF=0.00005*SMAX
      GOTO 10
      ENDIF
10    CONTINUE
11    STB=HS
      RETURN
      END
C
C*****************************************************************
      SUBROUTINE TPR(PRB,IP,INJ,SMH)
C*****************************************************************
      COMMON /PRO/ APM(20),F(20,10,3),OPTP(20,40,10),
     *  STOR(20),HTT(20,10),GT(20,20)
      COMMON /PS/ SMAX, SMIN, DTIM, RMIN, INV, NDV, IFL
      DIMENSION TM(20)
      PRB=0
      POUR=0
      HSK=SMAX-SMH
      IF(IFL.GT.0) HSK=HTT(IP,INJ)
      SSK=HSK+RMIN*DTIM
      SMH=SMH/DTIM
      CALL FUNC(SMH,POUR,IP, INJ)
      PPT=0
      DO 100 j=1,INV
      DO 15 l=1,NDV+1
15    TM(l)=OPTP(IP+1,l,j)
      PLS=FINT(STOR,TM,SSK,ndv+1)
      PPT=PPT+PLS*GT(inj,j)
100   CONTINUE
      PRB=POUR+PPT*(1.-POUR)
      RETURN
      END
C
C*****************************************************************
      SUBROUTINE FUNC(SMH,PRO,IP,INJ)
C*****************************************************************
```

```
      COMMON /PRO/ APM(20),F(20,10,3),OPTP(20,40,10),STOR(20),
     * HTT(20,10), GT(20,20)
      COMMON /PS/ SMAX, SMIN, DTIM, RMIN, INV, NDV, IFL
      PRO=0
      AJ=F(IP,INJ,1)
      AK=F(IP,INJ,2)
      X=(ALOG(SMH)-AJ)/AK
      AX=ABS(X)
      T=1./(1.0+0.2316419*AX)
      D=0.3989423*EXP(-X*X/2.)
      PRO=1.0-D*T*((((1.3302*T-1.821256)*T+1.781478)*T-0.3565638)*T+
     * 0.3193815)
      IF(X.LT.0) PRO=1.-PRO
      PRO=1.-PRO
      RETURN
      END
C
      FUNCTION FINT(A,B,AVAL,NN)
      DIMENSION A(20), B(20)
      IF(AVAL.LT.A(1)) THEN
      FINT=B(1)
      RETURN
      ENDIF
      IF(AVAL.GT.A(NN)) THEN
      FINT=B(NN)
      RETURN
      ENDIF
      DO 10 I=2,NN
      IF(AVAL.EQ.A(I)) THEN
      FINT=B(I)
      RETURN
      ENDIF
      IF(A(I-1).LT.AVAL.AND.A(I).GT.AVAL) THEN
      FINT=B(I-1)+(B(I)-B(I-1))/(A(I)-a(i-1))*(aval-a(i-1))
      return
      ENDIF
10    CONTINUE
      END
```

APPENDIX - E

```
$large
$debug
c ****************************************************************************
c
c        programme for reservoir operation
c            name of programme dynp.for
c
c ****************************************************************************
c
c       dynamic programming for reservoir operation
      dimension e(15),a(15),c(15),days(3),pij(5,5,5),pjq(5,5,5)
      dimension dis(5,5),ncq(5),v(5,5,20),p(5,5,20)
      dimension rel(5,5,20),nno(5,5,20),ev(3)
      dimension c1(5),c2(5),b1(5),b2(5),ri(5),rmin(5),sta(25)
      dimension nn(20),rf(20)
      dimension va(20),pro(20),rrr(20),xla(20),prob(20)
      open(unit=1,file='dyn.dat',status='old')
      open(unit=2,file='dyn.res',status='new')
c
      read(1,*)nsg,ndv,nsi
      read(1,*)frl,dsl,nac,fp
      read(1,*)(rmin(i),i=1,nsg)
      read(1,*)(days(i),i=1,nsg)
      do 1 i=1,nsg
      read(1,*)c1(i),b1(i),b2(i),c2(i)
1     continue
      nst=ndv+1
      nt=nsg+1
      do 2 i=1,nsg
      do 2 j=1,nsi
      read(1,*)(pij(i,j,k),k=1,nsi)
2     continue
      read(1,*)(ncq(i),i=1,nsg)
      do 3 i=1,nsg
      do 3 j=1,nsi
      read(1,*)(pjq(i,j,k),k=1,ncq(i))
3     continue
      do 4 i=1,nsg
      read(1,*)(dis(i,k),k=1,ncq(i))
4     continue
      read(1,*)(ri(i),i=1,nsg)
      do 5 i=1,nac
      read(1,*) e(i),a(i),c(i)
5     continue
      read(1,*)(ev(i),i=1,nsg)
      d=(frl-dsl)/ndv
      sta(1)=frl
      Do 10 i=2,nst
      sta(i)=sta(i-1)-d
10    continue
      do 11 i=1,nsi
      do 11 j=1,nst
```

```
      v(nt,i,j)=0
      p(nt,i,1)=1.
      nno(nt,i,j)=0
11    continue
      iter=1
401   do 100 isg=nsg,1,-1
      do 200 iv=1,nsi
      do 30 j=1,nst
      sl1=sta(j)
      xla(j)=0.
      do 40 k=1,nst
      sl2=sta(k)
      do 51 ll=1,2
      if(ll.eq.1)s=sl1
      if(ll.eq.2)s=sl2
      do 50 l=1,nac
      if(s.le.e(l)) go to 52
50    continue
52    ed=s-e(l-1)
      de=e(l)-e(l-1)
      dc=c(l)-c(l-1)
      da=a(l)-a(l-1)
      ss=c(l-1)+ed*dc/de
      aa=a(l-1)+da*ed/de
      if(ll.eq.1)then
      st1=ss
      a1=aa
      endif
      if(ll.eq.2)then
      st2=ss
      a2=aa
      endif
51    continue
      evp=ev(isg)*(a1+a2)/(2.*10**5.)
      x1=0
      Do 60 l2=1,ncq(isg)
c
      r=st1-st2+dis(isg,l2)-evp
c
      if(r.lt.0)then
      b=0
      go to 40
      endif
      if(r.le.rmin(isg))then
      r1=rmin(isg)-r
      r2=0
      bf1=c1(isg)*r1
      bf2=0
      bf3=0
      go to 42
      endif
      if(r.gt.rmin(isg))then
      bf1=0.
      r2=r-rmin(isg)
      if(r2.gt.ri(isg))r2=ri(isg)
```

```
      endif
      bf2=b1(isg)*r2
 42   avrl=(sl1+sl2)/2.
      twl=50.
      eh=(avrl-twl)*0.98
      pr=9.806*r*eh*(10**6)/(days(isg)*24.*3600.)
      pr=pr/1000.
      if(pr.ge.fp)then
      bf4=0
      go to 44
      else
      bf4=(fp-pr)*c2(isg)
      endif
 44   en=pr*days(isg)*24.
      bf3=en*b2(isg)
      b=-bf1+bf2+bf3-bf4
 69     sum=0
      sum1=0
      do 62 m=1,nsi
      sum=sum+pij(isg,iv,m)*pjq(isg,m,12)
c
 62   continue


      ssum=0
 49     ssum=b*sum+v(isg+1,iv,k)*p(isg+1,iv,k)

      if(ssum.gt.xla(j))then
      xla(j)=ssum
      prob(j)=sum
      nn(j)=k
      rf(j)=r
      endif
 60   continue
 40   continue
c
      nno(isg,iv,j)=nn(j)
      p(isg,iv,j)=sum
      v(isg,iv,j)=xla(j)
c
      rel(isg,iv,j)=rf(j)
 30   continue
 200  continue
 100  continue
      iter=iter+1
      if(iter.le.25)then
      do 400 i=1,nsi
      do 400 j=1,nst
      v(nsg+1,i,j)=v(1,i,j)
 400  p(nsg+1,i,j)=p(1,i,j)
      go to 401
      endif
      do 300 is=1,nsg
      do 300 iv=1,nsi
 300  write(2,*)is,iv,(rel(is,iv,j),j=1,nst)
      stop
      end
```