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EXPERT SYSTEMS FOR RESERVOIR OPERATION

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Abstract : *Demand for water is increasing continually, whereas available supplies are more or less constant. So there is a necessity to achieve optimal utilization of the available water resources through scientific approaches. This paper deals with the development and application of expert systems for flood moderation and drought management. The use of flood moderation expert system is demonstrated with a case study of Adyar river in the Madras Metropolitan city in obtaining the optimum releases that can be made during the flood situations considering the reservoir inflows and the overland flow from the urban drainage area. The developed expert system will be a valuable tool in reservoir operation decision-making and thereby helps in minimizing the flood levels in the Adyar river. For the drought management expert system, a linear programming model was used to generate optimal cropping patterns from the past drought experiences and also from synthetic drought sequences. These policies together with the knowledge of the experts were incorporated in the expert system. Using this, one can identify the degree of drought in the current situation and its similarity to the identified drought events and can evolve the corresponding management strategy.*

Introduction

Reservoir system operations are complex and often offer substantial increase in benefits for relatively small improvements in operating efficiency. Reservoir operation involves determining operating policies which will optimize certain objectives subject to various constraints. The objective functions, decision variables, and constraints vary for different types of reservoir operating problems. Mathematical simulation and optimization models are used for various purposes in different situations. Many models have been developed for use during project planning and design. Other models are developed for operation including real-time operation.

Reservoir operation is based on the conflicting objectives of maximizing the amount of water available for conservation purposes and maximizing the amount of empty space available for storing flood water to reduce downstream damages due to inundation, Conservation purposes include municipal, industrial, and agricultural water supply, hydropower generation, navigation, recreation and maintenance of downstream flows, Considerable complementary and conflicting interactions occur between conservation purposes.

Computerized decision support systems have been increasingly emphasized in the recent past for use in reservoir operations. A decision support system consists of integrated computer hardware and software packages readily usable by managers as an aid for making implementation and operation decisions.

RESERVOIR OPERATION

Reservoir operations involve a multitude of decision problems and situations. The reservoir operating rules and actual operating decisions can be categorized as follows :

-operations during flood events.

-operations during drought conditions.

-Operations during normal hydrologic conditions for various conservation purposes Present paper mainly considers flood events and draught events,

Reservoir operating policies are based on dividing the total storage capacity into various zones illustrated by Fig. 1. Water releases are normally not made from the inactive pool, except through the natural process of evaporation and seepage.

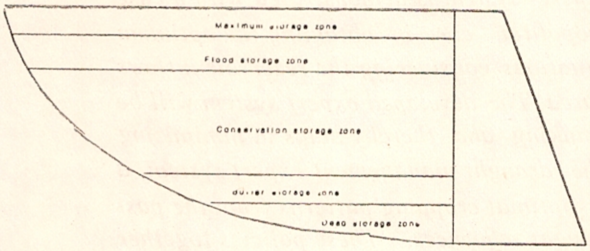

Fig. 1 Reservoir Profile

Conservation purposes, such as drinking water supply, irrigation, hydropower and downstream releases involve storing during periods of high streamflow and low demand for later beneficial use as and when needed.

The surcharge zone is essentially uncontrolled storage capacity above the flood control pool and below the maximum design water level.

The rule curves are used to refer to elevations which define target storage volumes and provide a mechanism for release rules to be specified as a storage content. Objective functions are simply quantitative measures of system performance which can be meaningfully utilized to obtain a better understanding of the system.

Data input

Various types of input data required are (1) a relationship between elevation, storage volume and water surface area. (2) Rule curves, diversion requirements, downstream releases and limits. (3) stream flow data. (4) evaporation from reservoir surface. Since future inflows are unknown, planning studies must be based on historical data. Streamflow characteristics are typically represented in a reservoir system analysis model as an inputted sequence of streamflow at each pertinent locations for each time interval (hour, day, week, month) of the period of analysis. Some reservoir systems modeling approaches are based on representing the reservoir inflows as probabilistic characteristic of the adjusted historical data.

Literature review of the subject of optimization of reservoir operations reveals that no general algorithm exists. The choice of the method depends on the characteristic of the system, availability of data, objectives and constraints specified. System analysis models are commonly classified as being either descriptive or prescriptive. Descriptive models demonstrate what will happen if specified decisions are made. Prescriptive models determine what decisions should be made to achieve a specified objective. Simulation models are descriptive, whereas optimization techniqucs are generally viewed as prescriptive models. The available methods can be classified as follows :

(1) Linear programming including stochestic linear programming and chance constrained linear programming.
(2) Dynamic programming (DP) including incremental DP. discrete differential DP, stochastic DP, differential DP etc.
(3) Nonlinear programming
(4) Simulation.

A simulation model is a representation of a system used to predict the behavior of the system under a given set of conditions. A reservoir system simulation model reproduces the hydrologic and economic performance of reservoir system for given inflows and operating procedures. A simulation model is based on a mass balance accounting procedure for tracking the movement of water through a reservoir-stream system. Series of runs are made to compare system performance for alternative reservoir storage allocations, operating procedures, demand levels and hydrologic inflow sequences.

Optimization models are formulated in terms of determining values for a set of decision variables which will maximize or minimize an objective function subject to constraints. The objective function and constraints are represented by mathematical expressions as a function of the decision variable. For a reservoir operation problem, the decision variables might be release rates and/or end-of-period storage volumes Constraints typically include physical characteristic of the recervoir-stream system, low flow requirements and mass balance. Most of the application of optimization techniques in reservoir system analysis involve a number of variations and extensions of linear programming and dynamic programming.

Linear programming model has been one of the most widely used techniques in water resources management. It is concerned with solv ng problems in which all the relations among the variables of the constraints and the objective function to be optimized are linear.

Dynamic programming, a method formulated by Bellman (1957) is a procedure for optimizing a multi-stage decision process. The popularity and success of the technique can be attributed to the fact that the nonlinear and stochastic features which characterize a large number of water resources system can be translated into a DP formulation. In addition, it has the advantage of effectively decomposing highly complex problems with a large number of variables into a series of subproblems which are solved recursively. However, when DP is applied to a multi-reservoir system, the usefulness of the technique is limited by the so-called "Curse of Dimensionality", whiah is a strong funct ion of the state variables.

Expert System Development

Knowledge based expert systems (KBES) are computer programs based on artificial intelligence techniques, designed to reach the level of performance of a human expert in some specialized problem-solving domain. Expert systems are believed to have great potential in solving ill-structured problem solving domains, where explicit algorithms do not exist or traditional computer programs provide only restricted problem-solving potential. Whereas, a decision support system is defined as an interactive computer based system that helps decision makers utilize data and models to solve unstructured problems.

An expert system essentially consists of (i) a knowled e base (rule base) which contains knowledge that are facts, scientific, analytical or heuristic rules about the domain. (ii) a working memory, which is the active knowledge base (iii) an inference engine, a component which combines user supplied input with knowledge base and searches it to reach conclusions. (iv) a user-interface, which facilitates interaction between the user and the system. The architecture of the expert system combined with the traditional computer models is shown in Fig. 2.

The state-of-the-art of water resources management decision support systems has been examined through a review of a number of examples, including microcomputers, flash-flood warning and regional water monitoring systems, water supply and reservoir operating systems, computer-aided planning, and expert systems by Johnson (1986).

Simonovic and Savic (1989) summarizes some of the important Knowledge based expert systems developed in water resources engineering. It also illustrates with an example an intelligent decision support system for reservoir analysis named REZES. Armijos et at. (1990) described the development of a computer-based decision support system for the real-time operation, incorporating a reasoning system based on

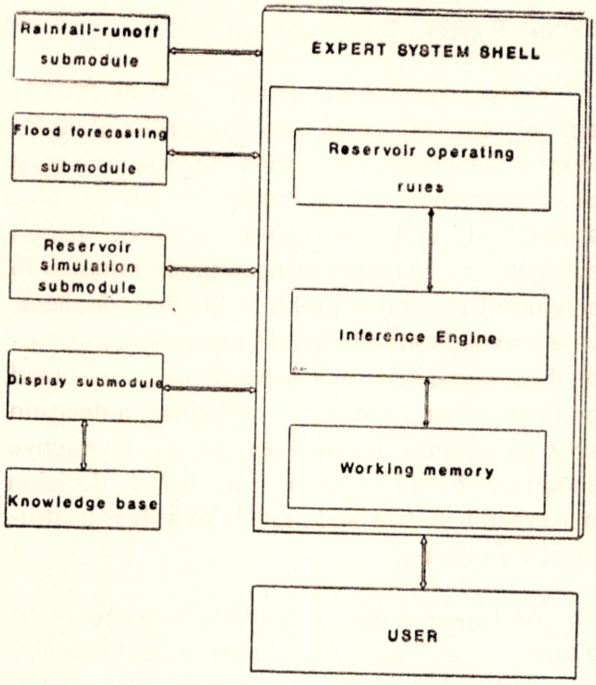

Fig. 2 Architecture of the Flood Managent Expert System

Bayesian techniques, which can provide a subjective judgment about the quality of the release recommended by the rule-based expert system. In particular, the papers by Labadie and Sullivan (1986), Houck (1985), Yazcigil (1983) focused on the application of Knowledge-based systems to real-time reservoir operations to simulate the behaviour of system manager.

The rule based inferencing module follows generally the convention for production systems first proposed by Newell and Simon (1972). Knowledge is represented in the form of action rules of productions. The general structure of such a production is IF & AND antecedent, THEN & OR consequent.

EXPERT SYSTEM FOR REAL-TIME FLOOD MANAGEMENT

An expert system for the real-time flood management is developed for the flood control operation of a reservoir. The procedure uses both expert system tools and traditional computer programming techniques considering the complexity of the reservoir operation problem. The present work has been carried out in four phases namely Flood simulation, Flood forecasting, Reservoir operation, and Expert system development. In the flood simulation phase, rainfall-runoff computation model, and model for computing water surface profiles have been made use of. The use of the developed system is demonstrated with a case study of Adyar river in the Madras Metropolitan city in obtaining the optimum releases that can be made during the flood situations considering the reservoir inflows and the overland flow from the urban drainage area The developed expert system will be a valuable tool in reservoir operation decision-making and thereby helps in minimizing the flood levels in the Adyar river.

Flood control operations

Flood control operations are made based on minimizing the risk and consequences of making releases that contribute to downstream flooding subject to constraint that maximum water surface is never exceeded. The flood control zone remains empty except during and immediately following a flood event.

The proposed operation of a multi-purpose reservoir for flood control requires the formulation and rather strict observance of a set of operating rules, designed to provide flood control while assuring the accomplishment of conservation purposes. Towards this end, in the present study, expert system approach is made use in obtaining the optimum release that can be made during the flood situations considering the reservoir inflows and the local overland flows.

Beard (1963) has described the flood control operation of reservoirs in the Central Valley of California. Windsor (1975) has applied a modified form of linear programming technique for estimating the cost-effective flood control operation of a network of flood control reservoirs. Unver et al. (1987) has developed a real-time flood management model for the flood operation of the Colorado River-Highland lake system in Texas.

The present study is concerned with the development of an expert system for the optimum release that can be made to the Adyar river which has been experiencing floods in the years 1930, 1937, 1943, 1946, 1960, 1966, 1976, and recently in 1985. These floods caused considerable damages to the properties and created a panic to the urban population of Madras city. Tamilnadu The largest peak flow in the river has been estimated by the Public Works Departmant, Tamilnadu at 2200 cumecs and occurred during the flood in 1985.

Water surface profiles have been computed for historic as well as possible floods in the Adyar river using the HEC-2 program package and the results were used to derive the knowledge base in the expert system.

The reservoir has to store the flood flows in the tank to the extent possible when the Aayar river is flowing full and create a time lag of discharges so that the flood peaks in the Adyar river are controlled within the reasonable limits. The overall structure of the real-time flood management model is shown in Fig. 3 The expert system includes the following modules :

1. Flood simulation module.
2. Flood forecasting model.
3. Reservoir simulation model.
4. Expert system rule base.

Data input to the system includes both the physical description of the system and the real-time data. The stored data include.

1. Characteristics of reservoir spillway structures.

2. Drainage area description and hydrologic parameter estimates for rainfall-runoff model.

The real-time data include :

1. Rainfall data
2. Inflow into the reservoir
3. Reservoir storage data

Brief system description

The Adyar river is a short river of about 40 km length and flows through the southern part of Madras city, Tamilnadu. The drainage area of the Adyar river is 857 sq. km. It has it origin at the surplus course of Manimangalam tank on the west side. The system is having one major tank namely Chembarambakkam and other four minor tanks. The index map of the river is Fig. 4.

The Adyar river has two arms, the northern arm coming from the Chembarambakkam tank joint with the southern uncontrolled arm coming from Thambaram at Thiruneermalai. The river enters the city near Nandambakkam bridge. The river traverses 10 km. distance in the Madras city and finally falls into the Bay of Bengal. The Adyar river overflowed is its bank in many places and Caused extensive damages to the properties and created a sense of panic ot the urban population of Madras city in 1976 and 1985. The flood flow had spread to more than about 200 to 300m during 1985 floods beyond the normal course affecting the adjacect low lying area in many places within this stretch of the river. The value of damages to the property has been estimated to several crores of rupees. This 10km stretch of the river is considered for study from the point of view of causing heavy inundation in Madras city.

The only controlled structure in the river system is the Chembarambakkam tank which is situated 26km west of Madras city. It has now been used as a multi-purpose reservoir taking up the flood moderation functtan as well as irrigation.

Hourly rainfall data for the year 1976 and 1985 has been collected from India Meteorological Department. Haurly data on inflows into and releses from the Chembarambakkam tank during 1976 and 1985 flood were collected.

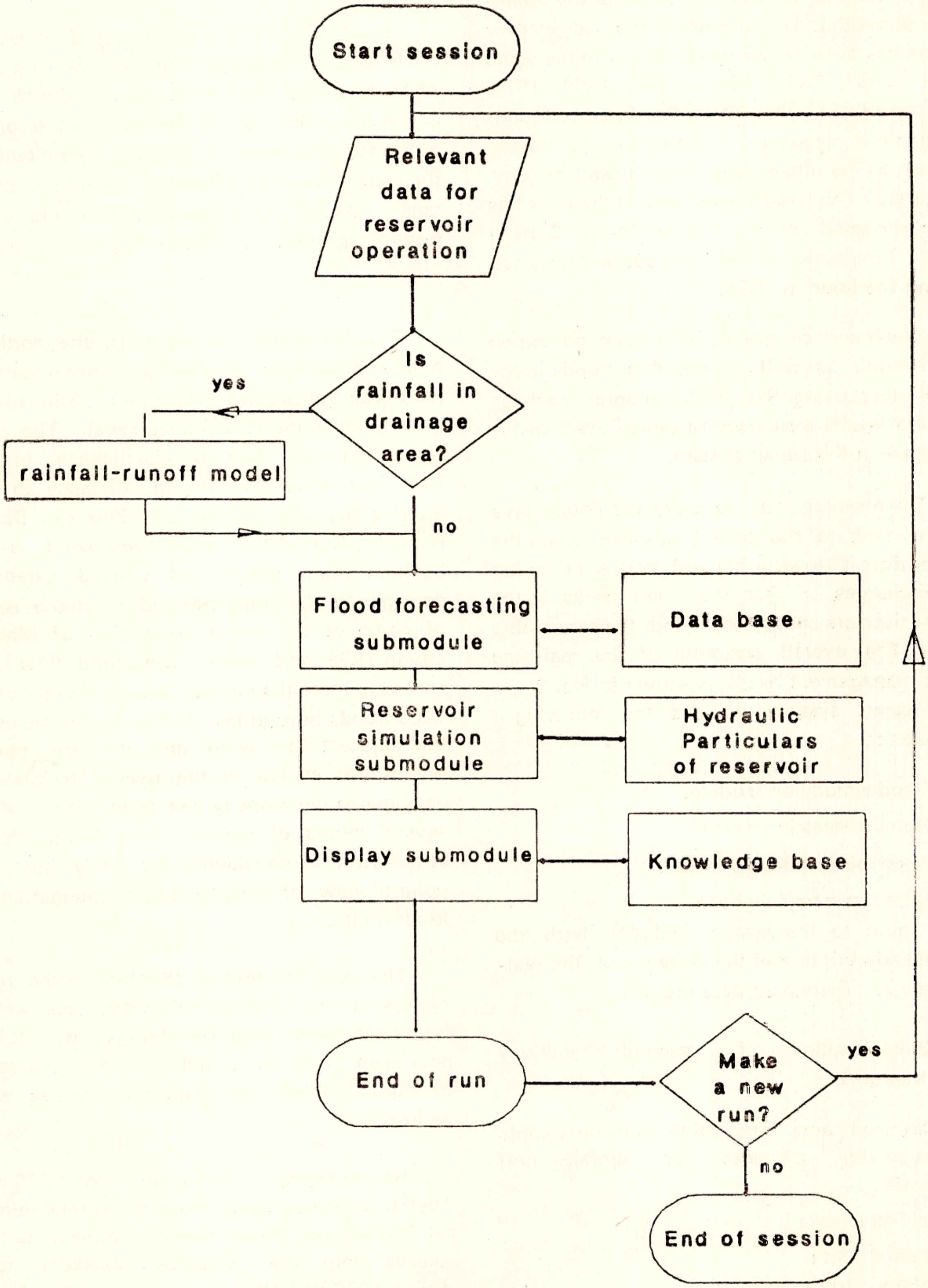

FIG. 3 Schematic Representation of Program Logic

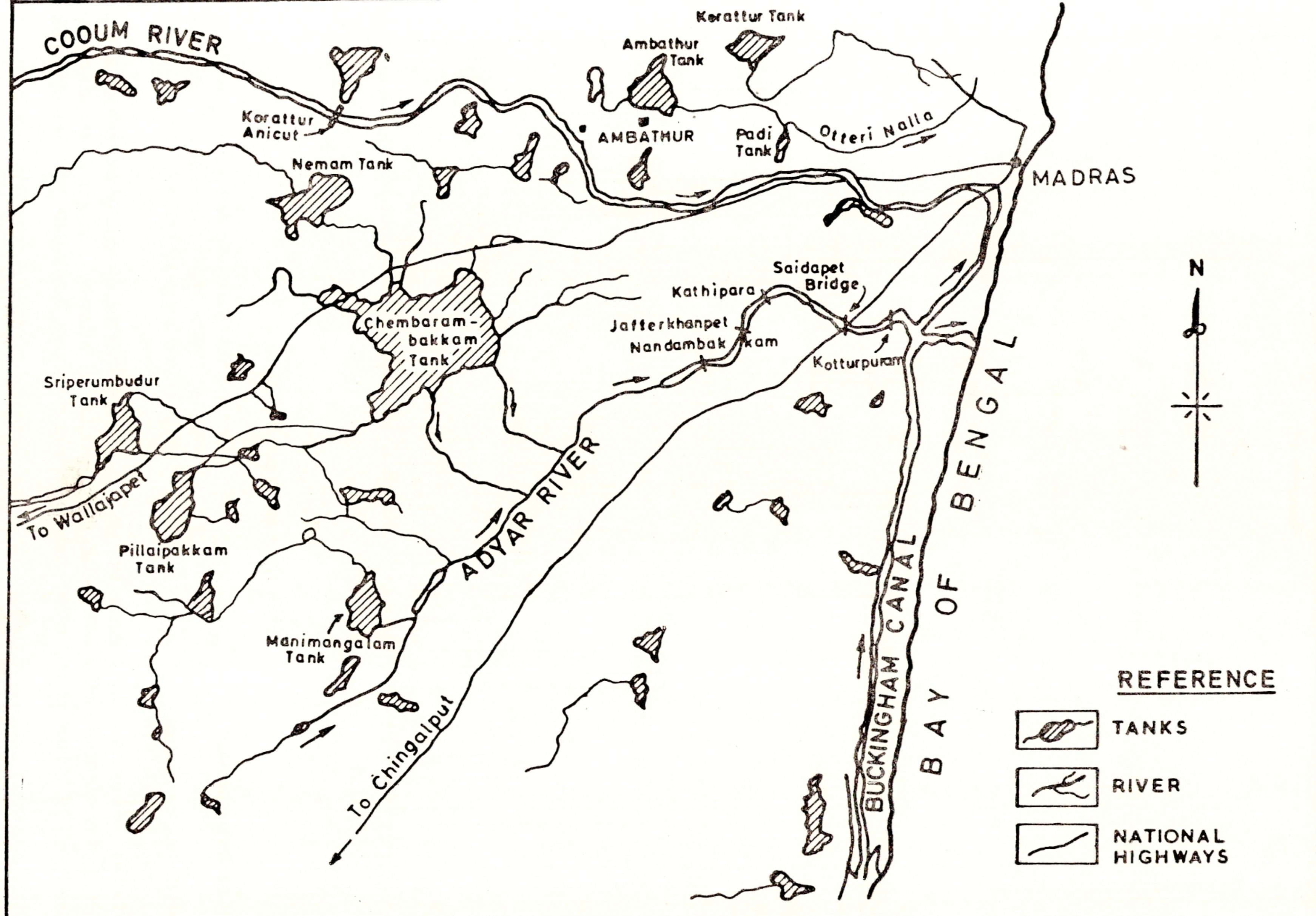

FIG.4-INDEX MAP OF ADYAR RIVER

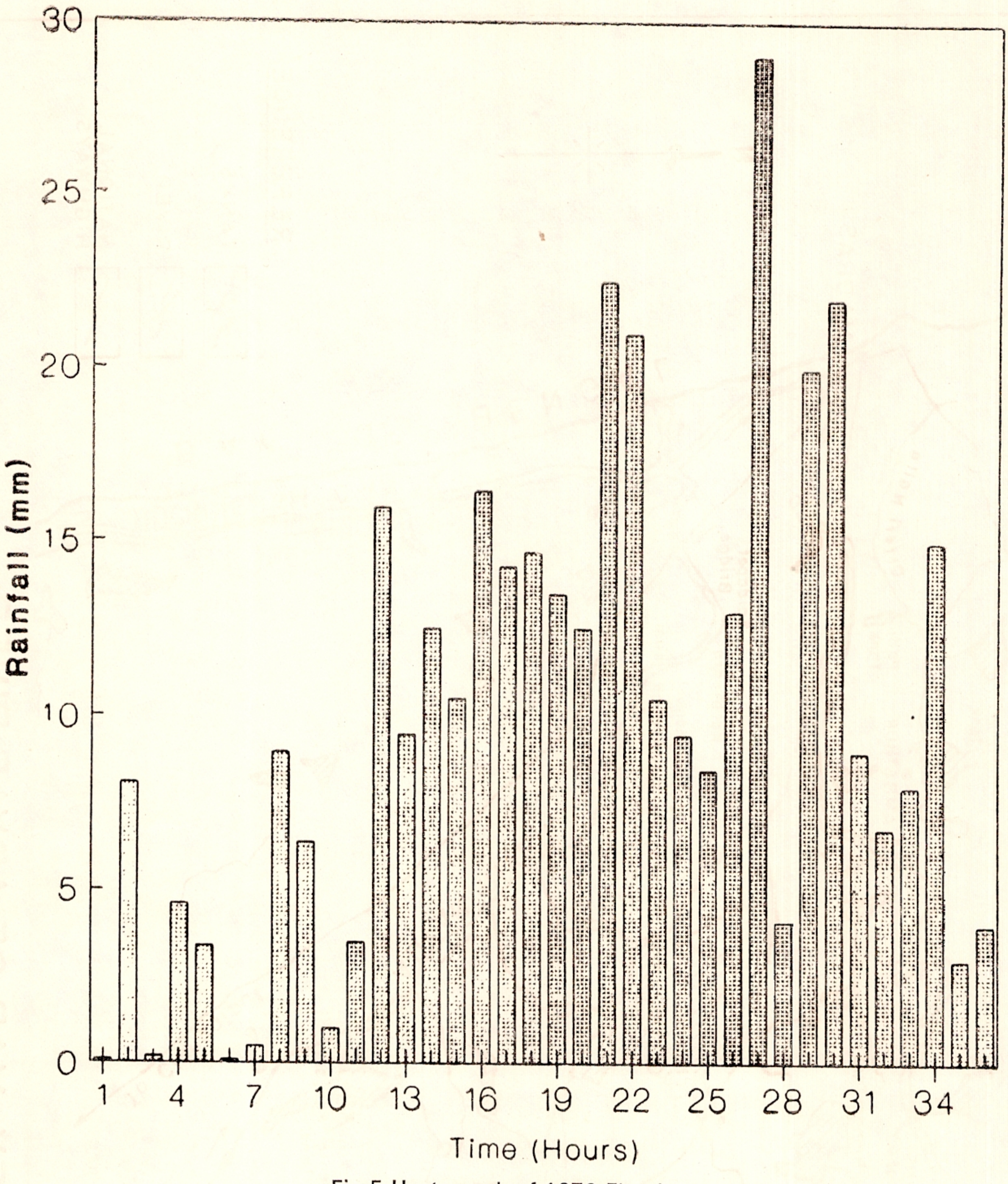

Fig 5 Hyetograph of 1976 Flood

Module Descriptions

Flood Simulation module

In this module, the flood flows are estimated by the rainfall-runoff model using the rationcl method [Chow et al., 1988] and the flood profiles are computed using the HEC2 program [HEC, 1981]. The details of these computations are given below.

The concept of rational method is that if a rainfall of intensity i begins instantanceously and continues indefinitely, the rate of runoff

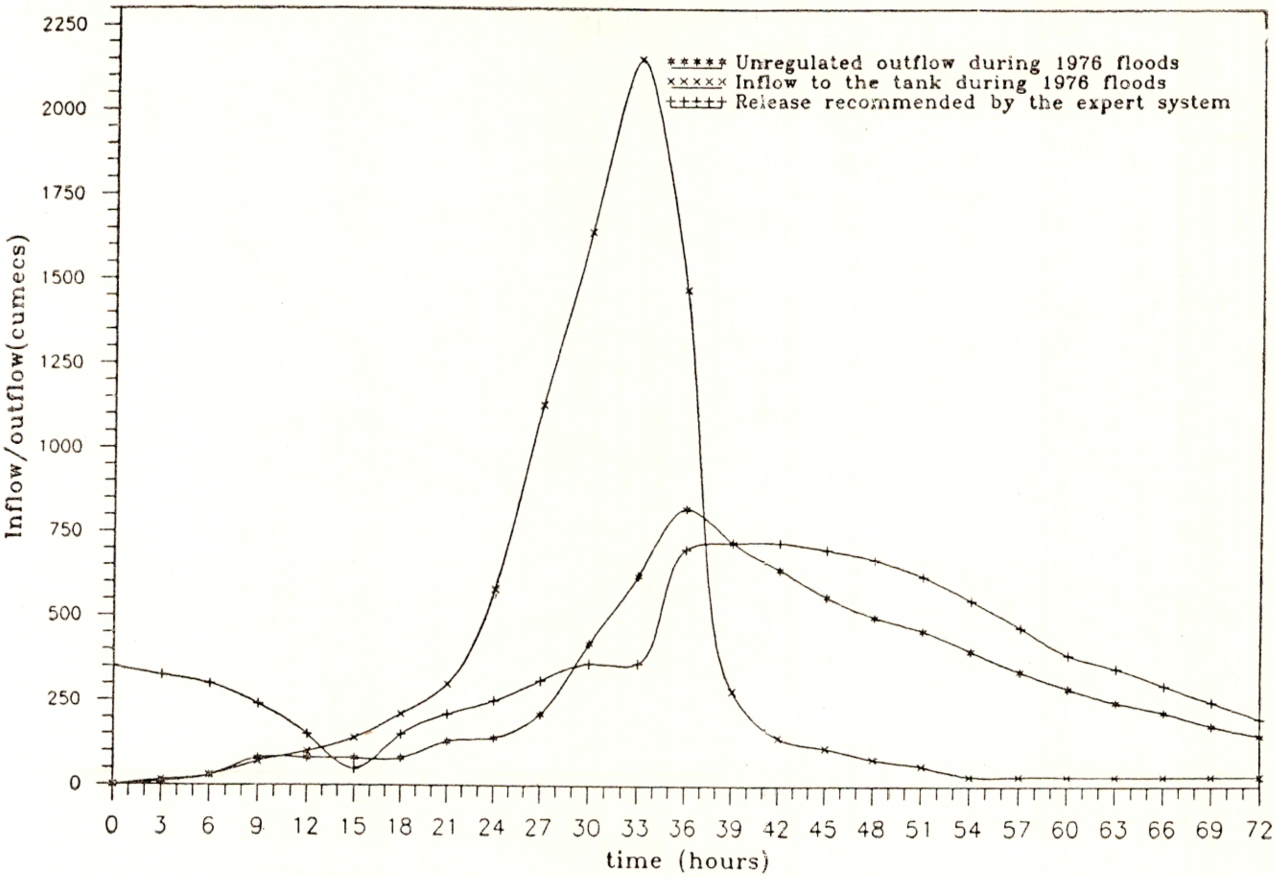

Fig. 6 Inflow & Outflow Hydrographs for Chembarambakkam Tank

will increase until the time of concentration tc, when all the watershed contributing to flow at the outlet. The peak discharge rate is given by.

$$Q = C\,I\,A \qquad \ldots\ldots(1)$$

where C is the runoff coefficient, I is the intensity of rainfall and A is the area of catchment. The runoff coefficient depends on the characteristics and conditions of the soil, rainfall intensity, vegetation etc. The value of runoff coefficient used for the computation is is 0.2 which has been obtained by comparing the rainfall and runoff data of past floods.

The well established comprehensive computer program package developed by the Hydrologic Engineering Centre, U.S. Army Corps of Engineers, Davis, California, USA, [HEC, 1981]. has been advantageously used to compute the water surface profiles in the 10 km stretch of Adyar river taking into effect the presence of two causeways and four bridges by invoking the bridge routine in the HEC-2 program.

For the basic profile calculations, the following equations are solved by the standard step method.

$$WS_2 + \frac{\alpha_2 V_2^2}{2g} = WS_1 + \frac{\alpha_1 V_1^2}{2g} + he \qquad (2)$$

$$he = L s_f + c\left[\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right] \qquad (3)$$

where, ws_1, ws_2 are the water surface elevations at ends of reach; v_1, v_2 are the mean velocities at ends of reach; α_1, α_2 are velocity coefficients of flow at ends of reach; h-energy head loss; L is the discharge-weighted reach length; s_f is the representative friction slope for the reach; c is the expansion or contraction loss coefficient,

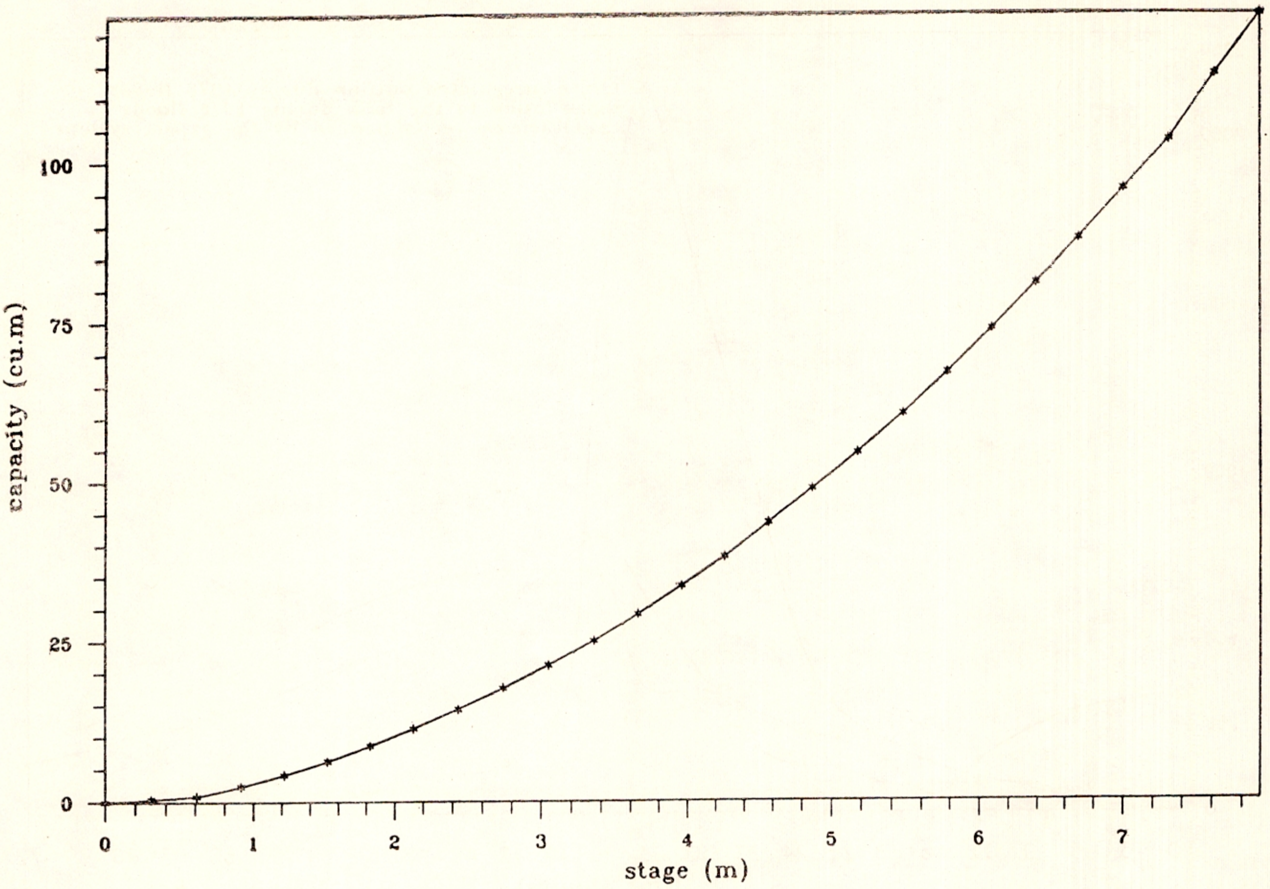

Fig.7 STAGE-CAPACITY CURVE FOR CHEMBARAMBAKKAM TANK

The energy losses that are caused by structures such as bridges and causeways are computed in two parts. First, the losses due to expansion and contraction of the cross section on the upstream and downstream side are computed in the standard step calculations. Secondly, the losses through the structure is computed by special bridge method (HEC, 1981).

The input data for this module inoludes cross section data for both the river channel and flood plain, flow resistance data in the form of Mannings 'n', expansion and contraction loss coefficients at stations wherever applicable. The total length of the river under consideration is divided into a number of cross sections in such a way that the difference between the velocity head between the two sections is not too much to accurately determine the energy gradient. In thjs case, a tatal of 67 cross sections are needed to meet this objective. This system is broken down into subsystems considering the computational aspects and practicality of running the model. For bridges, the cross sections are taken immediately upstream and downstream of the bridges and the bridge losses can be computed by using either normal bridge method or special bridge method. HEC-2 package was run using main frame computer system of SIEMENS 7580 E available at Indian Institute of Technology, Madras.

The HEC2 program was calibrated for two magnitudes of flood discharges namely 2000 cumecs and 2200 cumecs that occurred in 1976 and 1985 respectively. Water surface profiles were computed for discharges that had occurred during the 1976 & 1985 floods and also the probable discharges that may occur in future in the Adyar river. Water surface profiles computed for the discharges equal to 1300 cumecs, 2200 cumecs and the design flood discharge are shown in Fig. 8.

Flood Forecasting module

The unit hydrograph approach is used for the forecasting of flood flows to the reservoir. The technique adopted for the derivation of unit hydrograph is based on the Nash's approach (Chow et al., 1988). Nash considered that the instantaneous unit hydrograph can be obtained by routing the unit hydrograph through a cascade of N linear reservoir of storage coefficient K. Thus the two parameters N & K determine the shape of the unit hydrograph.

The parameters are estimated by method of moments (Chow et. al., 1988). This method requires the first and second moments of excess rainfall and direct surface runoff, which are used in solving the parameters N & K

The date interval for the observed rainfall hyetograph and the observed hydrograph should be the same. The equation which relates the excess rainfall, unit hydrograph and direct surface runoff is given by :

$$Q(i) = \sum_{i=1}^{n} \sum_{j=1}^{i} U(j) * X(i-j+1) \qquad (4)$$

where, Q(i) is the direct surface runoff at basin outlet at the end of computation interval, u (j) is the j^{th} ordinate of unit hydrograph; X(i) is the average rainfall excess for the computational interval i; n is the number of excess ordinates.

For forecasting the flood using unit hydrograph procedure, the probable maximum precipitation is derived using the following procedure

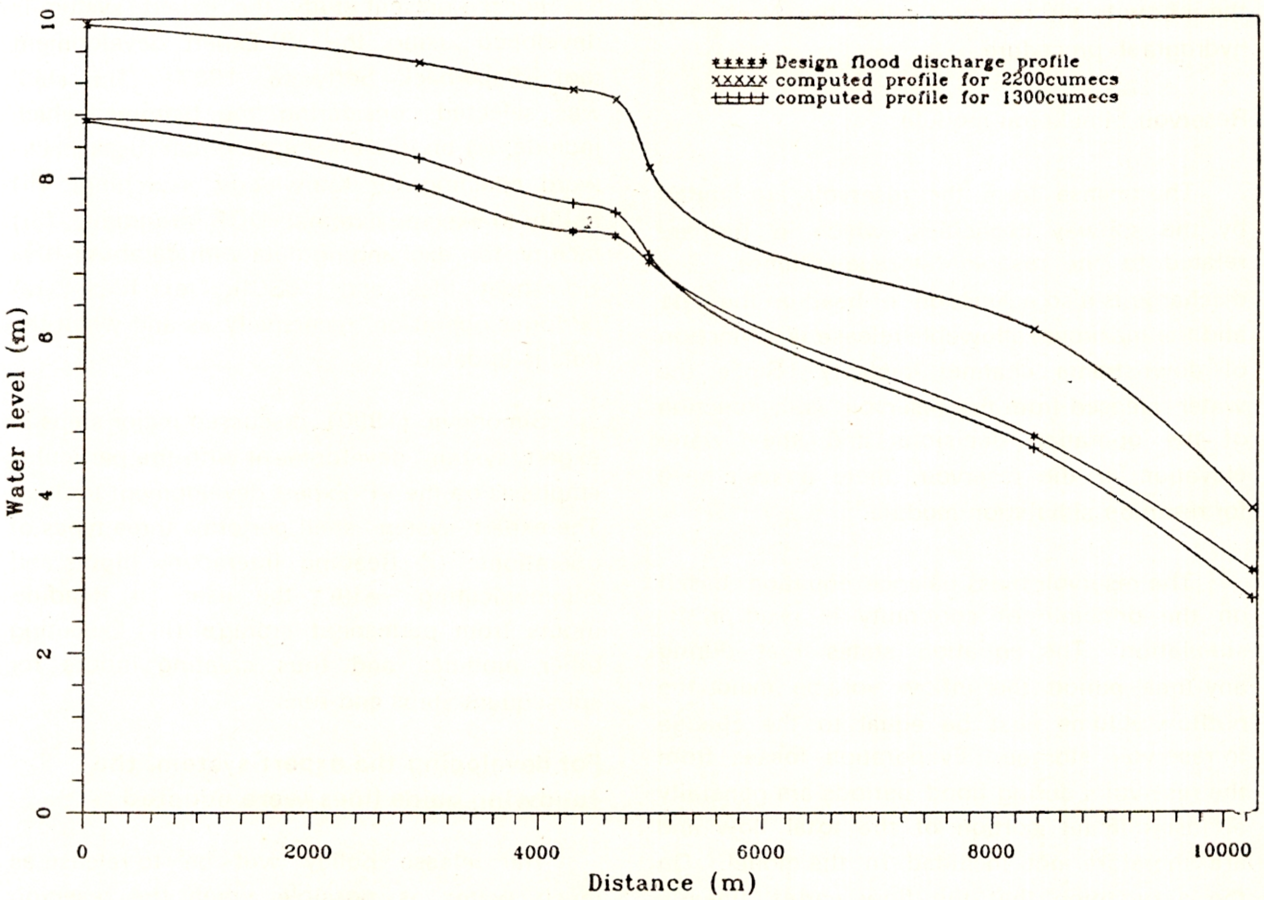

Fig.8 Computed & design water surface profiles

(i) The duration of the critical rainfall is taken as the basin lag.

(ii) DAD analysis is performed and envelope curves representing the maximum-depth duration relation is obtained using the past major floods that has occurred in the basin

(iii) Rainfall depths for one hour interval are scaled from the envelope curve and the increments are arranged to get a critical sequence which produces maximum flood. The precipitation increments are arranged in such a way that the maximum rainfall increment is against the maximum unit hydrograph ordinate, the second highest rainfall increment is against the second largest unit hydrograph and so on. The sequence of rainfall increments arranged above is now reversed which gives the critical rainfall.

This data is stored and used for forecasting the inflow to the reservoir using the Nash unit hydrograph procedure.

Reservoir Simulation module

The release from the reservoir are limited by the spilway capacities, which in turn are related to the reservoir storage volumes. The discharge is also a function of head on the gate and the maximum allowable release is a function of downstream channel capacity. Since the water released from the reservoir is a function of the operation decisions and the water elevation in the reservoir, there arises a need for reservoir simulation module.

The reservoir mass balance equation based on the principle of continuity is used in the simulation. The equation states that during any time period the inflow volume minus the outflow volume must be equal to the change in reservoir storage. Evaporation losses from the reservoirs during flood periods are generally an insignificant portion of the total flow and are therefore not included in the model. On the assumption that the flow varies linearly during each discrete time period t, the continuity equation may be stated as follows.

$$(I_{t+l} + I_t) \frac{\Delta t}{2} (O_{t+l} + O_t) \frac{\Delta t}{2} = S_{t+l} - S_t \quad (5)$$

Where Δt is a short time interval in hours or the selected duration for routing the reservoir inflows; I_t and I_{t+l} are inflows to the reservoir at the start of time intervals t and t+l; O_t and O_{t+l} are outflows from the reservoir or the inflows to the reach at start of time intervals t and t+l; and S_t and S_{t+l} are the reservoir storage volumes at the start of time intervals t and t + l in a consistent units.

Input data to this module includes physical and hydraulic description of the reservoirs in the river system being simulated. Hydraulic characteristics of the gates, reservoir level, and the rating curve.

Rule Base Development

For the present study the expert system is developed using the VP-Expert development tool [Paperback Software, 1987]. This shell was selected considering the features which include; (i) an inference engine that uses backward chaining for Knowledge searching; (ii) ability to execute external DOS programs; (iii) facility for exchanging data with database files worksheet files and ASCII text files. (iv) performs operation recursively as and when the data is updated.

Simonovic (1990) discussed major steps in expert system development with the particular emphasis on the VP-Expert development tool.
The expert system shell performs three types of operations: (i) Reading interacting inputs and communicating with the user (ii) Reading inputs from permanent srorage (iii) Executing other modules and thus creating inpurs for subsequent steps and runs.

For developing the expert system, the following guide lines were adopted

The release policy will be to release as much water as possible when the reservoir water level is in the spill zone and to release as much water as possible without causing flood damages downstream when the reservoir water level is in the flood control zone (Fig. 1). The policy is also aiming at bringing the reservoir level to the top of conservation zone at the earliest possible time. Again, the sum of local flow and the controlled outflow from the Chembarambakkam tank has be checked for feasibility of accommodating flood flow into the Adyar river.

The various operating procedures depending on the following conditions have been considered.

1. Based on current water level condition

(a) below maximum control level (top of conservation storage)
(b) above maximum control level and below extreme flood level
(c) above extreme flood level and below maximum water level
(d) above maximum water level.

2. Based on current location of interest

(a) Entire reach
(b) Nandambakkam
(c) Jafferkhanpet
(d) Kathipara
(e) Saidapet railway bridge
(f) Kotturpuram

3. Based on rainfall criteria

(a) No rainfall in the downstream of reservoir
(b) Rainfall in the downstream of reservoir.

4. Current inflow criteria

(a) current inflow is less than feasible flow in the river
(b) current inflow is more than or equal to feasible flow in the river.

5. Change in the inflow criteria.

(a) increased
(b) unchanged
(c) decreased

6. Based on the releasing capacity of the reservoir

(a) inflow is more than the release capacity of reservoir
(b) inflow is less than the release capacity of reservoir

A sample rule in the developed rule base which encounter during reservoir operation is given below.

RULE to bring the reservoir level to the top of conservation zone

IF overland flow contribution<feasible flow
AND current storage level<top of extreme flood level
AND current storage level>top of conservation level
AND inflow<feasible release
AND nflow<spillway release capacity
THEN release recommended=feasible release

Note : Feasible release is the difference between feasible flow and the overland flow contribution from the draina e area of the river.
In this case, the outflow is kept equal to the inflow, maintaining the stored water level to the top of conservation zone to secure flood control storage space.

Working of the Expert System

The expert system shell controls the operation of other modules during real-time flood control operation. They also coordinate data transfer back and forth between the modules and between the user and different modules.

The rule based system prompts for the values of input attributes such as initial storage, current inflow & forecasted inflow to the reservoir, rainfall intensity etc. The developed system consists of executable version of four computer programs written in C-language One program computes the local flow from the drainage area of the Adyar river as well as compute the water surface profile. Second one computes the forecasted inflow to the reservoir and the third one gives the release that can be made from the reservoir for the current reservoir conditions. In addition, the system also displays the water surface profiles along the river course.

Once input data is given, the expert system invokes the RAINFALL-RUNOFF model and computes the local flow contribution to the river from the downstream area of the tank and the southern arm of the river. The expert system then infers the Knowledge-base and gives the maximum release that can be made considering all the reservoir conditions and the downstream conditions. Then it invokes the RESERVOIR SIMULATION model for computing the maximum discharge that can be made based on the head elevation and it also gives the gate opening for the corresponding discharge. If the reservoir routing release is less than the expert system recommendation, then the expert system accepts the reservoir routing release. The program also gives the gate opening for the expert system recommended release.

Expert system also gives the flood levels and thereby the inundation depths in the flood plain at various locations along the river. Finally, it gives a graphical representation of the computed levels and the feasible levels along the river for the currently made release.

The model was run with the date available for 1976 flood. For calculation of overland flow contribution from the drainage area of Adyar, the rainfall data shown in Fig. 5 was used. Fig. 6 shows the releases recommended by the expert system based on the inflow data to the tank during 1976 flood. Fig. 7 shows the stage-capacity curve for Chembarambakkam tank. The computed water surface profiles for a peak discharge of 2200 cumecs which had occurred during the 1985 floods in Fig. 8.

EXPERT SYSTEM FOR DROUGHT MANAGMENT

Crop planning during drought requires an analysis of historical droughts and this effects on crops. Drought identification is primarily done with statistical analysis of historical data. The optimal cropping pattern was obtained for different drought conditions by using a linear programming (LP) model and the results were used to derive the knowledge base. Identification of drought along with the optimal cropping pattern to be followed during drought were incorporated as a knowledge base in the expert system for management of any predicted drought.

Optimization model

Considering the government's policy of providing irrigation to as large area as possible rather than limiting it to crops that yield more benefits, the objective function in the present study was formulated to maximize total area under irrigation (Z). The objective function of the linear programming model was formulated as maximizing the area under irrigation.

The constraints are the maximum capcity of the reservoir, channel capacities, total command area, minimum area for certain crops during drought period and continuity constraints

Knowledge base development

Using data of 52 years, flows were generated for 500 years using the Thomas-Fiering model by Clarke (1977). Various drought scenarios were identified form the historic and generated flows. For various scenarios of drought the optimal cropping pattern was determined using the linear programming model The model was run for different initial storage conditions and minimum percentage areas for each crop. Thus the model was run assuming the initial storage was dead storage and subsequently increasing in steps of 1/10 of storage capacity and for the cropping pattern, minimum crop area was fixed at 40% and the effect of increasing the area in steps of 5% was also studied. The inferences drawn were incorporated as knowledge base in the expert system referred as Bhadra drought management (BDM) expert system. (H. Raman et al., 1992)

The BDM expert system is primarily designed to aid the decision maker in planning the cropping pattern for a catchment. The input data include inflow to the reservoir, minimum cropping area, drought-initiation month. duration, available storage etc. A very interactive communication between the user and the computer is incorporated.

CONCLUSIONS

Expert system is an area of computer applications for real-world problems in which the computer is programmed not only to perform traditional computations, but also to make use of a knowledge base built into the program to arrive at logical conclusions. The present paper is focussed on the development of two expert systems environment in which one allows for the analysis of the operation of flood control reservoir and the other one for suggesting the optimal cropping pattern to be followed during drought. The objectives have been accomplished through the combined use of expert system tools and traditional computer programming techniques. The versatility of the approach lies in the possibility of updating, modifying, and expanding the knowledge base as and when more experience is gathered based on additional data collected.

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