STATE OF ART REPORT

Scientific Contribution
No. : INCOH/SAR-21/2000

APPLICATION OF EXPERT SYSTEMS IN WATER RESOURCES MANAGEMENT

H. Raman
S. Mohan

INDIAN NATIONAL COMMITTEE ON HYDROLOGY
(Committee Constituted by Ministry of Water Resources, Govt. of India

INCOH SECRETARIAT
NATIONAL INSTITUTE OF HYDROLOGY
ROORKEE - 247 667, INDIA

April, 2000

Scientific Contribution
No. : INCOH/SAR-21/2000

APPLICATION OF EXPERT SYSTEMS IN WATER RESOURCES MANAGEMENT

Prof. H. Raman

and

Dr. S. Mohan

Department of Civil Engineering
INDIAN INSTITUTE OF TECHNOLOGY
Chennai

INCOH SECRETARIAT
NATIONAL INSTITUTE OF HYDROLOGY
ROORKEE - 247 667, INDIA

April, 2000

The presentation of material throughout the publication does not imply the expression of any opinion whatsoever on the part of Indian National Committee on Hydrology (INCOH) or the publishers.

Published by :

Dr. K.K.S. Bhatia
Member Secretary, INCOH &
Scientist F
National Institute of Hydrology
Roorkee - 247 667, India

Printed by :

Cambridge Printing Press
Civil Lines, Roorkee
Phone : 70405, 72089
Fax : 01332 - 70405

PREAMBLE

Land and water resources are the greatest assets of our country and only by their proper utilisation we can banish poverty and raise the standards of living for millions of our people. In view of the latest trends of increase in population, the water as a resource would in very near future become a constraint on all other activities. This calls for optimal development and management of our water resources in both quality and quantity. The science and technology of hydrology has an important and crucial role in this task. It is the responsibility of engineers and scientists working in the water field and also politicians to assure that the water resources of their country are utilised efficiently and optimally.

It is urgent to question as to whether the fields of hydrology and water resources management have the appropriate methods in place to meet the rising demands that will be made on the water resources. Hence, it becomes very important and expeditious to review and update the state-of-art in different facets of hydrology and component processes. This calls for compiling and reporting present day technology in assessment of water resources and determining the quality of these water resources.

Efficient use of water resources becomes a major concern due to increased food production requirements, power requirements, industrial requirements, etc. Limited supply of available water resources due to frequent failures of rain makes it imperative that greater attention must be paid to the management of existing water resources than the development of new water resources. For maximum efficiency, water resource systems must be operated and managed more elegantly under practical situations. There is a great potential obtainable through increased efficiency of operation and management of existing water resources systems using appropriate techniques.

The Indian National Committee on Hydrology is the apex body on hydrology constituted by the Government of India with the responsibility of coordinating the various activities concerning hydrology in the country. The committee is also effectively participating in the activities of UNESCO and is the National Committee for International Hydrology Programme (IHP) of UNESCO. In pursuance of its objective of preparing and periodically updating the state-of-art in hydrology in the world in general and India in particular, the committee invites experts in the country to prepare these reports on important areas of hydrology.

The Indian National Committee on Hydrology with the assistance of its erstwhile Panel on Surface Water has identified this important topic "Application of Expert Systems in Water Resources Management" for preparation of this state-of-art report and the report has been prepared by Prof. H Raman and Dr. S. Mohan of IIT, Chennai. The guidance, assistance and review etc. provided by the Panel are worth mentioning. This state-of-art report presents the use of Expert Systems in water management by evolving optimal reservoir operation policies using operation research techniques.

It is hoped that this state-of-art report would serve as a useful reference material to practising engineers, researchers, field engineers, planners and implementation authorities, who are involved in correct estimation and optimal utilisation of the water resources of the country.

(S.M. SETH)
Executive Member, INCOH
& Director, NIH
Roorkee

CONTENTS

LIST OF TABLES

Page No.

LIST OF FIGURES

Figure No. Page No.

CHAPTER 1

INTRODUCTION

1.1 General

Water is essentially required for domestic, industrial, navigation, hydropower generation and irrigation activities. The overall development, prosperity and stability of a country are largely dovetailed to the availability and utilization of water resources.

India has a tropical climate and experiences erratic rainfall. Though the total annual rainfall is about 400 M.ha.m, about 180 M.ha.m flows as runoff. Reservoirs and small tanks are the major storage structures which have been constructed to harness and utilize the rainwater. Presently, development of new water resource systems is constrained due to a number of reasons. Difficulty in acquiring land for construction, high cost involved in construction, selection of suitable sites etc. are some of the problems that preclude the development of new water resource systems. Since many systems have already been constructed, the planning and design of new systems assume a low dimension. Management of water resources with maximum efficiency has become an essential paradigm in the current activities. The demand for water goes on increasing, warranting proper management of existing water resources. Table 1 shows the demand for water by various sectors in India in different time periods (*Mistry, 1992*).

1.2 Importance of Water Management

Efficient use of water resources becomes a major concern due to increased food production requirements, power requirements, industrial requirements, etc., as evidenced from Table 1. Further, limited supply of available water resources due to frequent failures of rain makes it imperative that greater attention must be paid to the management of existing water resources than the development of new water resources. For maximum efficiency, water resource systems must be operated and managed more elegantly under practical situations. There is a great potential obtainable through increased efficiency of operation and management of existing water resources systems using appropriate techniques.

In order to obtain maximum efficiency from the water resources system, the quality of decision-making which is a major area, needs to be improved. Computers play a significant role to assist water managers in decision-making. Use of computers for water management will have several objectives including the following:

- to provide efficient distribution of water especially under water-shortage situations;
- to quantify the water demands more accurately in order to conserve the limited water resources; and
- to reduce dependence on the experience and skill of the system managers which are many times difficult to obtain and retain.

There are two levels of decision-making in water management, strategic and tactical. Strategic decisions are related to planning activities such as deciding upon cropping plan over the seasons. Tactical decisions are made for a short-time period such as adjusting irrigation in a given time period under water-deficient situations. Computers are the best means of storing and implementing these kind of decisions.

1.3 Need for Expert Systems for Water Management

The use of computers involving mathematical models will result in efficient management of the water resource systems. The mathematical models can greatly aid in providing a good insight into the intricacies of various problems involved in water management. A number of system simulation and optimization models have been applied to derive better operation and management strategies for reservoir systems [e.g. *Anderson and Mass, 1974*; *Loucks et al; 1981*; *Kumar and Pathak, 1989; Yeh, 1985; Vedula and Mohan, 1990; Yakowitz, 1982*]. These models can represent the system behaviour and its features, but may not incorporate assumptions or any rules of thumb etc. Even if the assumptions are incorporated in the mathematical models, they lie hidden and become unclear to reservoir operators and engineers. They may not properly reflect more subjective information related to the experience and judgment of the water managers and engineers, which is difficult to represent in conventional algorithmic programs/models. Towards this goal, *Loucks et al. (1985)* proposed a methodology that combines classical optimization with heuristic programming. Labadie and Sullivan (1986) also discussed the need to develop procedures that attempt to incorporate experience and subjective judgement of water system managers and decision-makers.

The conventional algorithmic programs require a complete set of data to obtain a unique solution. The results are greatly dependent on the quality and quantity of data. The algorithmic models do not provide a means of representing the management policies in a flexible way that can be handled by a user. They may not be capable of solving a problem that depends on knowledge and ideas emanating from experts who are the specialists working in a problem domain for a considerable period of time. Knowledge, common sense and experience play an important role in many aspects of water resource management. Inclusion of experiential knowledge in conventional programs/models which are not really designed to represent this kind of information might result in inefficient use of computers for decision-making. The optimal policies resulting from optimization models are rigid and need to be flexible. If the operator/water manager is experienced, he/she can alter the rigid operating rules according to additional knowledge that is made available. However an inexperienced manager/ operator needs a guidance for decision-making when the system behaves dynamically. This warrants the need for incorporating the experiential knowledge of the experts. It is important to note that there is no substitute for experiential or judgemental knowledge in water management. These special knowledge or expertise are prone to be lost if the experts retire. Hence, the expertise needs to be stored properly and utilized by any user. A task of this kind is well addressed by expert systems.

Expert system technique is found to be the best tool to handle problems characterized with incomplete data, requiring extensive expertise of the experts for decision-making. Expert systems are the effective means to elegantly capture, represent, and store the brittle knowledge and use the knowledge for decision-making. In other words, expert systems can access the special knowledge possessed by experts and from other sources using a human-like approach to make decisions. Fig. 1.1 shows the main elements that constitute a knowledge-base. Three significant chunks of knowledge, namely, heuristic knowledge gained from experience, conventional knowledge regarding facts and inferential knowledge obtained after a study of results can be put into the expert system.

In recent years, expert systems are found to be amenable to handle the task of water resources planners and managers. This report gives details on the various expert systems developed at Hydraulic and Water Resources Engineering division of Department of Civil Engineering, Indian Institute of Technology, Madras.

1.4 Organization of this Report

Expert systems developed at Indian Institute of Technology, Madras, are presented in this report. A brief background information pertaining to expert systems is given in the next chapter. A review of literature on relevant areas is provided in the third chapter. Based on the literature, it was observed that the ES technique has a great potential in solving many problems in the field of water resource management. The successful applications of many expert systems gave a great motivation for the development of expert systems in the Indian context. The expert systems developed at the Hydraulic and Water Resources Engineering Division of the Department of Civil Engineering, Indian Institute of Technology, Madras are briefly presented in the fourth chapter. Conclusions based on the experience gained from the developed expert systems are summarized in the last chapter.

Table 1.1. Water demands (km^3) for different purposes in different time periods.

Purpose	1990	2000	2025
Domestic use	25	33	52
Irrigation	460	630	770
Energy	19	27	71
Industrial use	15	30	120
Others	33	30	37

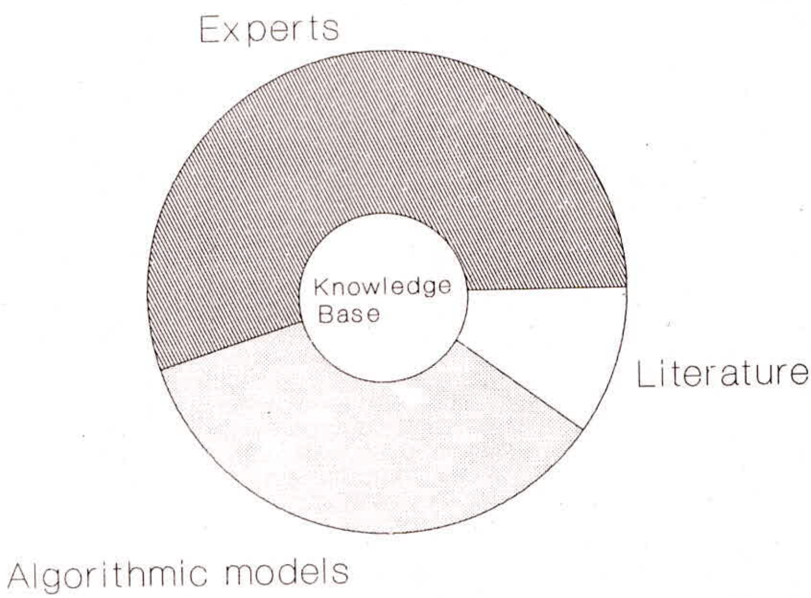


Fig. 1.1 Elements of a comprehensive knowledge-base

CHAPTER 2

EXPERT SYSTEMS

2.1 Background

Expert system (ES) technique is a division of Artificial Intelligence (AI) technology. Artificial Intelligence is the use of programs as tools in the study of intelligent processes, tools that help in the discovery of thinking procedures and epistemological structures employed by intelligent creatures. It is a branch of computer science concerned with the computer systems that exhibit some form of intelligence, systems that learn new concepts and tasks, systems that can reason and draw useful conclusions, systems that can understand natural language, and systems that perform other types of feats that require human type of intelligence (*Nebendahl, 1988*). Besides expert systems, robotics and natural language processing systems are the major divisions of the AI technology. Robotics deal with developing smart robots that recognize objects. Robots are built to manipulate their physical surroundings in an intelligent way as humans do. Natural language processing systems involve developing programs that can read, speak or understand conversational language. Their goal is to allow fluent communication between a user and the machine in the user's conversational language.

An expert system is a program designed to emulate the logic and reasoning processes that are used by human experts to solve a problem in their field of expertise. It is a knowledge-intensive program that solves problems that normally require human expertise (*Waterman, 1988*). The main characteristics of an expert system are given below:

- Experts retire, taking away their valuable knowledge with them; such a brittle knowledge is preserved by an ES.
- An ES functions as an assistant to an expert; a partner to an expert; or a replacement for whole/ part of an expert's knowledge.
- An ES uses knowledge rather than data to control the solution process.

- An ES uses rules, heuristics, and other techniques to represent knowledge in a symbolic manner.
- An ES interacts with humans in ways that are suitable to humans to understand.
- An ES can explain why it is asking questions and can justify conclusions.

As shown in Fig. 2.1, the following issues need to be addressed before developing an expert system to tackle the problem at hand: (a) assessment of the problem; and (b) assessment of resources. Waterman (1986) suggests that the ES technology should be used to solve a problem (a) that is narrow; (b) that requires the expertise; (c) that involves heuristic factors and uncertain information; and (d) that is mostly a complex one.

2.2. Advantages and Limitations of ES

The major advantages of expert systems are the following:

- Expert systems can minimise or avoid errors in complex routine tasks.
- Expert systems can disseminate specialized knowledge faster and accelerate the complex decision-making process.
- Expert systems can elegantly protect the perishable knowledge of experts and make it readily available when and where required.
- Expert systems would be less expensive to consult than human experts.

Expert systems have a few limitations, as listed below:

- The over-importance of one individual expert in building the knowledge-base gives too strong a personal stamp (*Nebendahl, 1988*). This could be reduced by appealing to other experts for evaluation and criticism of the expert system, but the basic knowledge remains that of the leading expert.
- Success in developing an ES greatly depends on the co-ordination between an expert and a knowledge engineer. The expert will be a busy man and may not be easily available. The knowledge engineer is poised to importune him.

The performance level of an ES is primarily a function of the size and quality of the knowledge-base what it owns. Any inadequacy or deficiency in knowledge extraction is likely to affect the performance of the expert system.

These limitations can be avoided by putting more efforts and skills. To minimize some of the above limitations, expert systems can also be used in conjunction with the conventional programs to take advantage of both.

2.3 Architecture of an Expert System

An expert system consists of the following components: a knowledge acquisition mechanism involving an expert and a knowledge engineer, a knowledge-base, an inference engine and an explanation facility (Fig. 2.2). The knowledge engineer acquires the knowledge from the domain expert and other pertinent sources, and transfers to build the expert system. The other sources of knowledge might be from optimization and simulation models, technical reports and similar case studies etc.

Knowledge-base is the central component of an ES and is the store house of the problem-specific knowledge. Knowledge might consist of a body of facts, principles, prejudices, beliefs, concepts and heuristics accumulated by humans. Acquiring knowledge is the most difficult task in any ES development. Knowledge acquisition requires a lot of time and efforts to capture a chunk of knowledge on various issues involved in a problem domain. Production rules in the form of IF....THEN rules are the easiest way of codifying the knowledge in the knowledge-base. Other forms of knowledge representation are semantic nets and frames.

Inference engine, being a rule interpreter, inspects the contents of the knowledge-base. It performs searching using two strategies, namely, backward chaining and forward chaining. Backward chaining engines (goal-driven engines) arrive at conclusions by evaluating what supporting conditions must be true to arrive at a specific goal. Forward chaining engines (rule-driven engines) require establishment of known initial conditions, when they are evaluated to determine what final solutions these conditions support (*Nebendahl, 1988*).

Explanation facility of an ES facilitates to provide reasoning to the user. The question/ answer dialogue between the ES and the user during a consultation is accomplished through the user-interface. The user-interface is provided with step-by-step instructions to make the ES transparent which is crucial to the ultimate acceptance by the users.

2.4 ES Development Tools

The tools for developing an expert system can be divided into three main classes: (i) general purpose languages; (ii) representational languages; and (iii) expert system building shells. The general purpose programming languages for ES development are FORTRAN, C, PASCAL or C++. With these languages, the developer has complete flexibility, but the entire expert system structure must be created and this is very costly in time and resources. Representational languages, such as LISP, PROLOG, or OPS5, require only organization and expression of the domain knowledge. As with the programming languages, a significant portion of the code necessary to produce an expert system must be written by the developer.

Expert system building shells are packages that aid in rapid prototyping of the knowledge. Using these shells, the level of effort that must be applied to develop expert systems is greatly reduced, allowing the developer to focus on acquiring knowledge and refining the system behaviour. The primary functions of the shells are to: (1) develop the knowledge-base, including adding, modifying, deleting, and generally maintaining the rules and facts in a very user-friendly way; (2) provide an inference engine; and (3) report the reasons and final outcome. More than 50 shells are available. Among these shells the popular shells are VP-EXPERT, LEVEL-5 OBJECT, PC-PLUS, and INSIGHT 2 PLUS.

THE PROBLEM

ASSESSMENT

- Is the problem suitable for an ES appraoch?
- Is the problem worth solving?
  - Will the intended system result in a savings of time?
  - Will the system preserve perishable knowledge?
  - Will the system proliferate knowledge?
  - Will the system improve or enhance decision-making process?
  - Will the system be used as a training tool?

THE RESOURCES

PERSONNEL

- Does there exist a source of knowledge?
- Is there someone who can transfer the knowledge into the system?

HARDWARE/SOFTWARE

- What hardware is or can be made available?
- What are the requirements of the development tool?

Fig. 2.1 Check-list before developing an expert system.

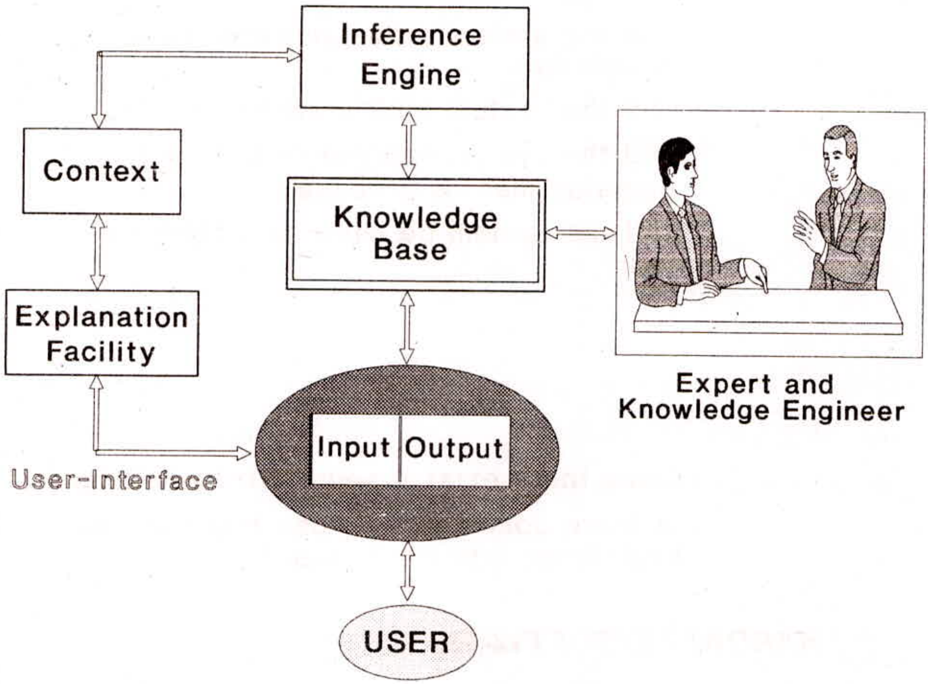


Fig. 2.2 Basic structure of an expert system.

CHAPTER 3

EXISTING EXPERT SYSTEMS IN WATER RESOURCES

3.1 General

With a capability to assist and even sometimes replace human experts, development of expert system is considered as a major achievement in the recent past. Two often cited examples of successful expert systems are MYCIN and PROSPECTOR. The Stanford Research Institute (SRI) developed MYCIN to diagnose and suggest treatment of certain infectious blood diseases (*Shortliffe, 1976*). SRI also developed PROSPECTOR (*Duda et al., 1979*) to aid geologists in evaluating mineral sites for potential ore deposits. PROSPECTOR accurately predicted the location of a molybdenum deposit worth millions of dollars in Washington, USA. Other earlier expert systems include DENDRAL, which identifies candidate molecular structures from mass spectral and nuclear magnetic response data (*Brachman, 1983*); MACSYMA, which solves mathematical problems such as algebraic simplication and integration (*Martin, 1985*); and XCON, which configures VAX hardware (*McDermott, 1981*).

The successful implementation of these expert systems motivated researchers to apply this technique to a number of problem domains in water resources management also. The steps shown in Fig. 3.1 have been used in constructing expert systems. The steps are (a) problem identification, (b) conceptualization, (c) formalization, (d) implementation and (e) testing and validation. Fig. 3.2 presents the role of an expert system in water management. *Simonovic (1991)* defined a water resource expert system as a computer application that assists in solving complicated water resource problems by incorporating the multi-disciplinary engineering knowledge, principles of systems analysis, experience, intution and engineering judgement in the solution procedure. Heuristic/ experiential knowledge and inferential knowledge obtained from relevant models have been used to construct many of the water resource expert systems. A brief review of the ES applications in the field of water resources management is discussed hereunder.

3.2 Water Resources Design

A few expert systems have been reported for the design of water resource systems. HYSIZE and its simple modification HYSTOR are expert systems for determining the optimum layout for a particular hydroelectric site. These expert systems can rank alternatives in order of economic priority and to test the sensitivity of assumed variables (*Dotan and Willer, 1986*). SISES is an expert system used for selecting an appropriate site for a specific water use (*Findikaki, 1986*). *Rouhani and Kangari (1987)* presented an ES for waste disposal site selection. This system is a self-explanatory system based on the rules suggested by the US Environmental Protection Agency (USEPA). This system can be utilized by hydrogeologists for preliminary site selection processes. The rules were developed by the MITRE corporation and extensively reviewed by the US Environmental Protection Agency personnel and state officials. The factors considered were: (1) groundwater route characteristics; (2) waste characteristics; (3) facility characteristics, and (4) targets. DMWW is an expert system for designing a municipal water well. The design process can be very complex and require more information on procedures and related knowledge (*Russell, 1989*). The design is created in the first phase and then modified in the second phase until the user is satisfied with the design.

3.3 Water Resources Planning

RAISIN is an ES developed for the analysis of acid rain data (*Swayne and Fraser, 1986*). It is designed to examine the relationship between the terrain sensitivity index, which assesses susceptibility to acid rain deposition and possible deposition levels. WATQUAS is an ES for extracting knowledge from a large quantity of available historical water quality data and interpreting it in a useful form (*Allen, 1986*). SID, Seatlle Water Department's integrated drought management expert system (*Palmer and Holmes, 1988*) is designed to evaluate and display information for drought management planning. A linear programming model is used to generate optimal operating policies as a function of numerous past drought experiences. These policies are incorporated into the ES and the user is required to identify the degree to which the current drought situation is similar to past events.

Simonovic (1990) presented an ES for the selection of a method for flow measurement in open channels. The developed ES mainly consists of three phases. In phase 1, the ES checks all the important physical conditions and required data accuracy. The final recommendation of the first phase contains a number of methods applicable for site-specific conditions. The second system, phase 2, selects from the multiple choice provided by the first system, the most appropriate method considering the available equipment and measurement structures at the particular site. The third system, phase 3 contains detailed descriptions of available methods, and after final method selection, the relevant description is available for the user. The description contains basic methodology, necessary theoretical background, equipment description and the procedure to follow during the measurement.

3.4 Water Resources Systems Operation

There are a number of applications of ES for the operation of water resource systems. In an earlier paper, *Cuena (1983)* suggested a conceptual framework for an expert system to aid in the operation of flood control and plan civil defence in flood prone areas. JOE is an expert system designed to aid in operations of the Jenpeg generating station in Manitoba (*Raban, 1989*). The operation of Jenpeg during the freeze-up periods is very complex, involving many judgmental calls, and has a major impact on hydropower generation in the downstream. EMMAES is an expert system built around the EMMA model used within Manitoba Hydro to plan the integrated operation of hydro and thermal power generation and tie lines as well as with maintenance considerations. The system is designed for three purposes: (i) preparation of an annual budget; (ii) preparation of weekly schedules for releases, thermal and hydropower generation and imports and exports of energy; and (iii) long-term planning that includes such task as evaluation of benefits from installing additional capacity, and examining particular operational conditions that may occur in the system (*Nagy et al., 1989*).

CAPI is a prototype expert system developed by *Akoundi and Karamouz (1988)* to train novice water managers by clearly explaining the theory and operation of reservoirs. The primary reservoir system parameters explained in this expert system are dynamic interactions of available reservoir capacity, water levels, inflows, demands and losses. *Antunes et al. (1987)* reported a reservoir simulation methodology which can incorporate subjective knowledge through expert system production rules.

Floris (1988) et al. developed a knowledge-based expert system for real-time operation of a particular reservoir system operated by the US Army Corps of Engineers. It utilizes real-time hydrometeorological inputs, manipulates them by heuristics and produces real-time reservoir operational guidelines. The Operations Assistant and Simulated Intelligent System (OASIS) is an expert system developed in the ART environment by the South Florida Water Management District (*Goforth and Macvicer, 1988*). This knowledge-based system is designed to help water managers coordinate the operation of over 200 water control structures. It provides real-time display of important hydrometeorological data and system status and generates various alternative water control schemes.

Farley et al. (1988) presented an expert system called REGUSE which combines heuristics and network flow algorithm for system regulation. *Savic and Simonovic (1988)* described an expert system called REZES which aids reservoir system planners and operators in selecting appropriate optimization tools for their tasks. An expert system approach was used by *Clarkson and Hartigan (1989)* for evaluating storage and water quality information on a pumped storage water supply system and guiding reservoir operating decisions for the City of Newport News, Virginia, USA.

Bhatty (1990) developed a hybrid ES that is aimed for the operation of a multi-purpose reservoir system in Pakistan. While irrigation demand is taken as a constant quantity, maximization of hydropower generation is treated as the primary objective. The hybrid ES contains the static knowledge of reservoir operators and is linked with optimization and forecasting models. This ES can aid in real-time operation of the reservoir system. Another ES was developed by *Fischer and Schultz (1991)* for real-time operation of a multi-purpose reservoir system in Germany. However, this ES is not a hybrid ES in that it does not use the knowledge emanating from optimization or forecasting models. The rigid rules used by the operators have been encoded with additional heuristic knowledge in the developed ES.

3.5 Hydrological Analysis

An ES, called, HYDRO was developed to aid in determining appropriate numerical values for various parameters that describe the physical characteristics of a watershed (*Gashing et al., 1981*). The values computed by HYDRO serve as input to the Hydrocomp HSPF simulation program for evaluating various hydrological aspects of a region. The HYDRO system is intended to provide advice comparable to that of an expert hydrologist in selecting parameter values characteristic of the watershed. FLOOD ADVISOR was developed by *Fayegh (1985)* to provide interactive advice about flow estimation under five generalised situations. The situations are: (1) a long period of data available at or in the vicinity of the location of interest; (2) a long period of record is available on the stream of interest downstream or upstream of the location of interest; (3) a short streamflow record is available on the stream of interest; (4) no records are available on the stream of interest but records are available for nearby streams in the region of interest; (5) no streamflow records are available for the region. The ES suggests a flow computation model based on the type and quantity of available data and also gives advice on how to use the recommended model properly.

EXSRM is the ES incorporating snowmelt runoff simulation model (SRM) to assist an unfamiliar user to set up and run the simulation model (*Engman et al., 1989*). At the front-end of EXSRM, a series of help windows and menus assist the user in setting up the model and loading hydrologic and climatologic data. After the user enters certain basin-specific data, the system provides initial estimates of the SRM parameters and executes the SRM (FORTRAN) program. Depending upon how good the initial simulations were and what types of discrepancies exist between the measured and simulated hydrographs, the user chooses different strategies to improve the simulations. *Baffaut and Delleur (1989)* developed an ES for calibration of the hydrologic parameters of the runoff block of the USEPA's storm water management model (SWMM). The SWMM model can simulate all aspects of the hydrologic cycle and water quality aspects. The expert system is developed with three tasks in mind: (i) to select computational options and provide reasonable initial values of the input parameters; (ii) to evaluate the simulation results by comparison with observed hydrographs; and (iii) to modify the parameters to provide for a better fit between the simulated and the observed hydrograph. The ES prompts and guides the user for the values of all hydrologic parameters that are required.

3.6 Irrigation Management

Irrigation systems behave dynamically and become ill-structured due to rapid changes in the environment. Water availability, and water demand become uncertain and largely influence the performance of irrigation systems. In this context, a number of expert systems have been developed to tackle the management problems involved in irrigation systems operation.

COMAX is an ES for irrigation scheduling that is linked with a crop growth simulation model (*Lemmon, 1986*). This ES utilizes the crop growth simulation model to determine irrigation schedules and nitrogen requirements. *Plant et al. (1992)* developed an ES called CALEX/Cotton for irrigation scheduling. This ES first selects a method for scheduling based on the assessment of current state of crop, previous irrigations, and availability of water. The next irrigation indicating time and amount to be applied is then determined. A similar ES, IRRIGATOR, was reported by *Clarke et al. (1992)*. An advantage of this ES is that it has a sub-system to select an appropriate method for estimating evapotranspiration.

Not many expert systems are available to deal with irrigation scheduling at the macro-level. Scheduling at the macro-level was first addressed by *Hershauer et al. (1989)*. They developed an ES for canal operation. The domain knowledge was gathered from supervisors through interviews and inferential knowledge taken from optimization models was not incorporated in the knowledge-base. *Srinivasan et al. (1991)* presented a comprehensive ES that addresses irrigation management problems at the field level and and also at the macro level. At the first level, a decision on the type of scheduling in the main canals (eg. rotational or continuous) is provided. At the second level, the suggested water delivery type can be changed considering information about the type of structure in the main and branch canals, types of crops grown, availability of main canal operators, type of communication between the farmers and the water authorities, and organization set-up. At the third level, the ES requires more information about the branch canal area, soil uniformity, crops, canal capacity, possibilities of irrigations at all times and water rights policy to allocate irrigation water.

Nakamura and Tsukiyama (1992) analysed the decision processes conducted by irrigation planning experts for irrigation canal renovation projects using an ES which was designed to simulate these decision processes. The ES contains six steps: (i) canal evaluation; (ii) classification of canal type; (iii) estimation of future degradation; (iv) selection of appropriate task elements; (v) combination of task elements; and (vi) approximate description of costs. The developed ES was practically applied to three canals located in the Tone river basin, Japan. The ES produced results which were subsequently concluded by irrigation experts as correct when making initial project plans.

3.7 Diagnostic Expert Systems

Diagnostic analysis is performed by diagnostic experts who try to find the reasons for malfunctioning of water resource systems and also to identify possible remedial measures. The feasibility of using an ES for the diagnostic analysis of a small reservoir system (tank irrigation system) was studied by *Oswald (1990)*. This ES contains the diagnostic knowledge derived from field experts. The causal factors that control the functioning of the reservoir system were embedded in the knowledge-base. A similar ES for land drainage diagnosis was earlier described by *Haie and Irwin (1988)*.

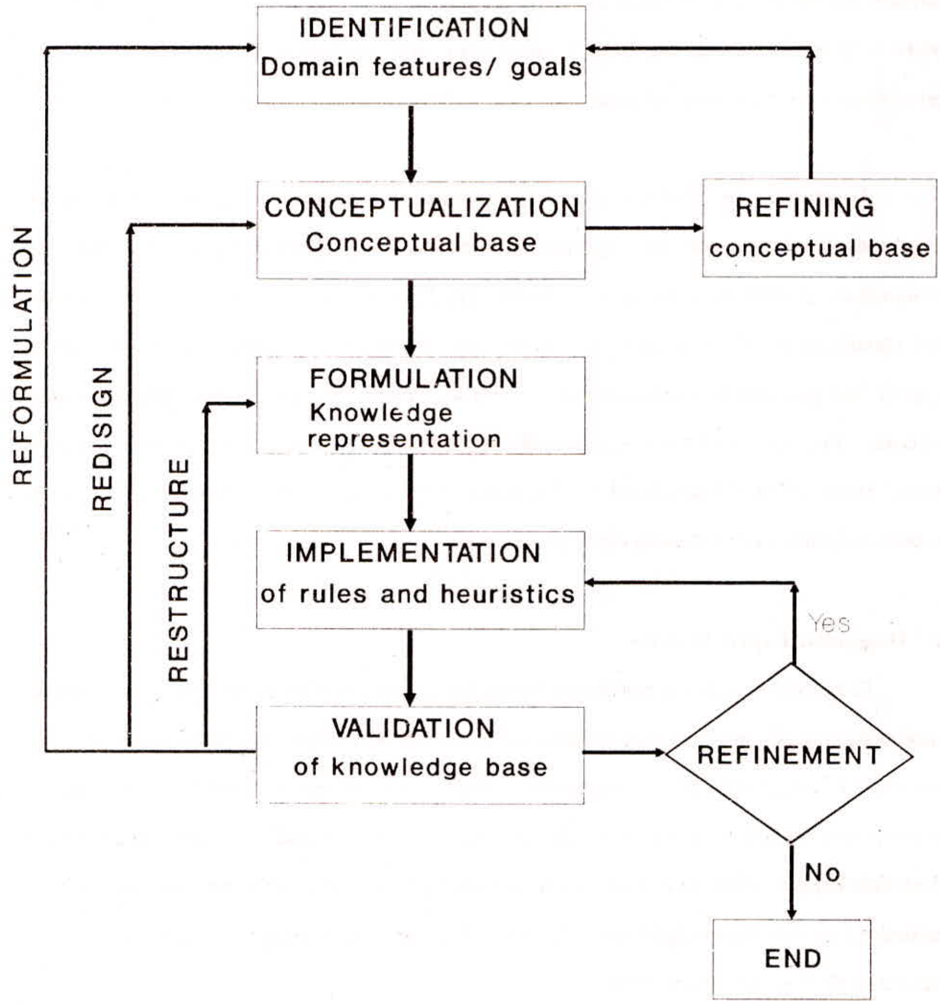


Fig. 3.1 Main stages in the development of an expert system.

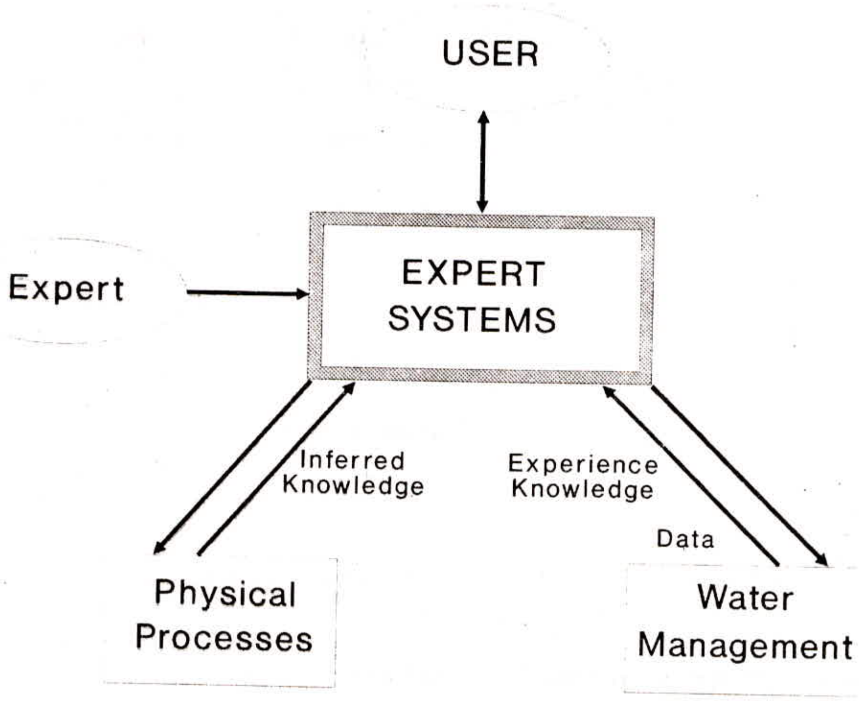


Fig. 3.2 Role of expert systems in water management.

CHAPTER 4

EXPERT SYSTEMS DEVELOPED AT IIT, CHENNAI

In this chapter, the expert systems developed at the Hydraulic and Water Division of the Dept. of Civil Engineering, IIT, Madras, are described. The background, development process and application of these expert systems are briefly discussed. Six expert systems were developed for the following tasks:

- Drought management
- Flood control operation
- City water supply management
- Tank irrigation system operation
- Irrigation supplies during water shortages
- Irrigated crop selection

Each of these expert systems are presented in the following sub-sections.

4.1 Expert System for Crop Planning During Droughts

4.1.1 Drought Management

Crop planning during droughts requires an analysis of historical droughts and their effects on crops. Drought identification is primarily done with statistical analysis of historical data. If the methodology for the identification of drought along with the cropping pattern to be followed during a drought are presented to the decision maker in a compact module, the decision maker can use it for management of any predicted future drought. Traditional computer programs can be used for drought identification. However, experiences during droughts that are qualitative in nature are difficult to incorporate in traditional computer programs. In these situations, expert systems are very useful since they provide an easy way to represent such knowledge. Hence, there is a need for combining traditional computer programs and expert systems for drought management. Palmer and Tull (1987) reported that a combination of traditional program with expert systems is desirable since drought identification requires considerable numerical calculations.

4.1.2 Case Study

Bhadra reservoir command area, situated in Karnataka State, south India, was considered as a case study. This reservoir project is a multipurpose river valley project operated for irrigation and hydropower in the state of Karnataka, India. There are two canals from the reservoir. The left-bank canal is 80 km long and irrigates 6,367 ha. The right-bank canal with its branches is 268 km long and irrigates 87,512 ha of land. Water released for irrigation can be used for hydropower by two turbines, one on each canal. Releases downstream of the reservoir alone can be used to produce power from a bed turbine. For obtaining the optimal policies during drought, the bed turbine is excluded from the system under consideration since during drought there is no possibility of releasing any water through the bed turbine.

Monthly streamflow data at the reservoir site for 52 years (1930-31 to 1981-82) and evaporation loss data for the period 1930-81 were used in this study. A downstream release of 8.565×10^6 m^3 is provided on a constant basis in almost all the months.

In this case study, drought is identified using inflow data by the methodology proposed by the Mohan and Rangacharya (1988). The optimal cropping pattern was obtained for different drought conditions using a linear programming (LP) model and the results were used to derive the knowledge base. The objective of the LP model was to find the optimal cropping pattern for maximization of area under cultivation. To take into account the effect of preparedness for drought, the optimal cropping pattern was obtained for various initial water availability (storage) conditions. In addition, the minimum area for each crop is specified to take into account the requirements of agro-based industries and the local consumption pattern. The inferences drawn from the results were incorporated as a knowledge base in the expert system.

4.1.3 Optimzation of Crop Pattern

Considering the government's policy of providing irrigation to as large area as possible rather than limiting it to the crop that yield more benefits, the objective function was formulated to maximize total area under irrigation. The crops considered are rice, sugarcane, grapes (permenant garden), and maize.

The constraints of the optimization are the following:

(a) The initial storage volume is bounded by the minimum drawdown storage and the maximum capacity of the reservoir;

(b) The monthly irrigation releases on left and right banks must be at least equal to irrigation demands in left- and right-bank areas, respectively;

(c) The irrigation release cannot be greater than the respective channel capacities;

(d) The present practice being followed is given due consideration, and the area under irrigation for each crop is restricted to the present area. A minimum percentage of i^{th} crop expressed as fraction of total available area is used to specify a minimum area for crops during a drought period; and

(e) The monthly irrigation demand depends on the area of the crop and the type of crop.

(f) The continuity constraint specifies that the final storage at any time period 't' will be equal to the initial storage plus inflow minus release, evaporation loss, and overflows. Downstream minimum release is also taken into account.

The methodology reported by Mohan and Rangacharya (1988) was applied for the 52 years of inflow data available for Bhadra reservoir for the identification of droughts. A total of 10 drought scenarios were identified and found concurrent with the historically realized droughts as reported by Chakraborty and Roy (1979). Further, using this data of 52 years, flows were generated for 500 years using the Thomas-Fiering model discussed by Clarke (1977). Various drought scenarios in these generated flows were also identified. For various scenarios of drought (historic and generated), the optimal cropping pattern was determined using the optimization algorithm mentioned in the previous section. To take into account the effects of preparedness, 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. Similarly, 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. Thus, a total of 84 different permutations and combinations were studied for getting an optimal cropping pattern for a single drought scenario. Each of these 84 models consists of 93 variables and 124 constraints, thus proving the complexity of the problem. The solution is obtained using a Siemens 7580E mainframe computer system. A total of 504 runs was made and the following inferences were drawn. For all initial conditions, if the total annual inflow is greater than 1,800 x 10^6 m^3 the cropping pattern as presently practiced may be adopted. This may be because 90% of the annual flow occurs between June and November, which is the base period for rice and maize crops. Thus, agriculture gets affected only when annual inflow is less than 1,800 x 10^6 m^3. In the historical data, three such drought scenarios have been identified. They have been classified as severe, moderate, and mild droughts. A total of 19 droughts were identified from the generated flows. Among these, three droughts were more severe than the historic droughts and they were included in the analysis. In these six drought scenarios, it was observed that rice and maize crops can be grown fully even when the initial storage is at dead storage level. But, there was a trade-off between areas irrigated under sugarcane and grapes. Thus, for various minimum areas of sugarcane, the optimal cropping patterns were obtained.

4.1.4 Knowledge-base for Drought Planning

A look at the generated results reveals several inferences, summarized as follows:

When annual inflows is greater than 1,800 x 10^6 m^3, no reduction of any crop area is necessary.

- If the initial storage at the beginning of the year in the reservoir is greater than 700 x 10^6 m^3 then the entire area, as is presently practiced, can be irrigated even in the worst drought condition.
- Rice and maize crops can be grown fully even in the worst drought condition. Only sugarcane and grapes, which require water for all the 12 months, cannot be grown fully and hence their areas must be reduced during the drought condition.
- In case of moderate drought, if the initial storage lies between dead storage (240 x 10^6 m^3) and 1.5 times the dead storage (360 x 10^6 m^3), maximum area can be drought under irrigation if the sugarcane area is restricted to 55% of the present practice. However, if the sugarcane area has to be increased, the grapes garden area has to be decreased. An approximately 5% increase in sugarcane area causes a 6% decrease in the grapes garden area, resulting in a reduction of total area that can be irrigated with available water by 0.1%, or 100 ha.
- In case of mild drought, if the initial storage is greater than 360 x10^6 m^3 and less than 450 x 10^6 m^3 then 90% of the sugarcane area can be irrigated without causing any irrigation shortage to other crops.

Since obtaining an optimal cropping pattern for each identified drought is very difficult, as seen earlier, and since these inferences are obtained after careful study of different possible droughts for the catchment area, it is suggested that these inferences be used as the knowledge base in addition to the opinions of the experts in developing the expert system. The decision-maker can use these inferences for managing an identified drought by comparing the present drought with past scenarios. Thus, the optimal cropping pattern corresponding to the past scenario that it closest to the present one can be adopted. For selecting the appropriate scenario, computer graphics are used for better representation; thus, the expert system was also designed to invoke a graphical toolbox.

INSIGHT 2+ shell developed by Level Five Research (INSIGHT 1985) was found to be the most convenient for this problem. INSIGHT 2 is a rule-based expert-system shell and was selected based on its ability to perform mathematical operations, incorporate uncertainty and partial information, and explain its decision logic. INSIGHT 2+ also provides a convenient interface with programs written in other languages, including TURBO PASCAL and Microsoft FORTRAN. This feature was extremely valuable in development of specialized components of the expert system for Bhadra drought management (BDM).

The knowledge-base consists of in linguistic form. These linguistic interpretations are in the form of IF-THEN rules, which when put into the shell form the crore of the knowledge base of the expert system. For developing the rules, first a drought scenario is selected, which proceeded as follows:

IF the annual inflow < 1300
AND scenario selected IS one
THEN drought is severe

The other rules for the first scenario are developed by using the inferences. For example, if the initial storage is equal to 240 x 10^6 m^3, then the maximum sugarcane area that can be grown without affecting other crops is 47%. The percentage of area of other crops is 100%. The rule that signifies this is as follows.

IF Drought is severe
AND initial storage IS 240
AND sugarcane area < 47
THEN optimal cropping pattern is obtained.
AND DISPLAY TABLE

For the same case, if the sugarcane area is increased to 65% then the grapes garden area is reduced to 80% while the areas of rice and maize are not affected. In this case the expert system has a rule that advises not to increase sugarcane area more than 47%, because it badly affects the grapes garden area. However, if the user still insists on having the same area, then only does the system proceed further. The rule that signifies this is as follows.

IF Drought is severe

AND Initial storage IS 240

AND sugarcane area = 65

AND DISPLAY ADVICE 1

AND shall I proceed ?

THEN Optimal cropping pattern is obtained

AND DISPLAY TABLE

ELSE Optimal Cropping pattern is obtained

AND DISPLAY TABLE

In addition, certain rules were formulated subjectively and were incorporated in the BDM expert system. For example, it is felt that if the drought duration is less than two months and starts at the beginning of the water year, then it would be better to postpone planting by a month. There is a consequent risk of reduction in yield under such a situation; however, this decision is preferable to planting at the beginning of the drought period. Similarly, for a drought that occurs during non-irrigation period, no conservative measures need be made. Thus, the BDM system contains not only inferential knowledge but also contains heuristic knowledge. Similarly, the opinions of the experts in-charge of the system were collected and incorporated in the system. This knowledge includes rules regarding minimum downstream requirement, riparian rights, over-flow, and so forth.

To improve readability and to facilitate easy addition of knowledge, the knowledge base of the BDM expert system was divided into various sub-bases with a primary metaknowleddge base that activates the necessary knowledge base depending upon the context.

4.1.5 Working of the BDM Expert System

The BDM expert system is primarily designed to aid a decision-maker in planning the cropping pattern for a catchment. Thus, the major input is the monthly inflows into the reservoir.

However, the system also requires other information, such as minimum cropping area, drought-initiation month, duration, available storage, and so forth. Thus, a very interactive communication between the user and the computer is incorporated.

The expert system itself asks all the information required by it. At any point of time, the user can ask why such a query is being posed and he can get the explanation. As soon as the BDM expert system is started, it welcomes the user and asks for further annual inflow, as shown in Fig. 4.1. The next screen asks about initial storage. Similarly, in subsequent screens, the system asks for monthly flows, drought duration, initiation, and so forth. All the input are stored in a data base.

The BDM ES consists of two program libraries; one that identifies drought (FORTRAN program) and one that gives a graphical representation of scenarios (PASACAL program). The working of the program library is as follows.

Once input data are given, the expert system invokes a program called DRT.EXE to determine the onset and duration of drought. This is a FORTRAN program developed for the identification of drought. The program gives an output regarding drought initiation and duration that is accepted as input by the expert system.

Knowing the drought initiation month and the duration, the expert system determines the severity of the drought. Once the severity is known, the only parameter left for determination of the optimal cropping pattern is the selection of an appropriate scenario from the historical droughts. For this selection, the expert system invokes SCENARIO.EXE, a PASCAL program, which gives a graphical representation of the inflow of the past and present droughts side by side in different colors for each scenario (Fig. 4.2). It also simultaneously displays the percentage difference for each month. One can select the scenario nearest to the present one. If the user is not able to select, he/she can direct the expert system to select the closest drought scenario by itself.

With the drought severity, initial storage, monthly inflow, and the selected scenario, the expert system gives the optimal cropping pattern, as shown in the Fig. 4.3 If the user wants to run for different input data he/she can do so, otherwise the program comes to an end.

Using this ES, one can identify the degree of drought in the current situation and its similarity to the identified drought events and be able to get the corresponding management strategy. The versaiity of the approach lies in the possibility of updating, modifying, and expanding the knowledge-base whenever needed.

4.2 Expert System for Flood Control and Reservoir Operation

4.2.1 Flood Control 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. 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 normal hydrological conditions
- operations during drought conditions
- operations during flood events.

A flood control reservoir stores flood water temporarily to reduce the damage it might cause downstream if it were not retained. The procedure generally consists of securing flood control storage, storing flood temporarily and releasing stored flood water with a time lag. Water from flood control reservoirs should be released without causing damage to the downstream flood plains. If more water can be released, less water needs to be planned for flood control. For these reasons, the operation of a multi-purpose reservoir for flood control requires explicit formulation of operating rules designed to provide flood control while assuring the accomplishment of conservation. An expert system was developed for flood management problem in the Adyar river which runs through the city of Madras, south India. This is designed to assist in the determination of releases during flood situations.

4.2.2 The Adyar River System

The Adyar river is a short river of about 40 km length and flows through the southern part of Madras city. The drainage area of the Adyar river is 857 Km^2. The system has one major tank, namely, Chembarambakkam and other four minor tanks. The Adyar river has two arms, the northern arm coming from the Chembarambakkam tank joins with the southern uncontrolled arm coming from Thambaram at Thiruneermalai. The river enters the city near Nandambakkam bridge. It traverses 10 kms distance in Madras city and finally falls into the Bay of Bengal.

The Adyar river overflowed its bank in many places and caused extensive damages to the properties and also created a sense of panic to the urban population of Madras city in 1976 and 1985. During 1985 floods, the flood flow had spread to more than 200 to 300 m beyond the normal course affecting the adjacent low-lying area in many places within this stretch of the river. The value of damages to the property was estimated to be several millions of rupees. This 10 km stretch of the river was considered for the 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 26 km West of Madras city. It is being used as a reservoir for the dual functions of flood moderation and irrigation. Hourly rainfall data for the year 1976 and 1985 were collected from Indian Meteorological Department. Hourly data on inflows into and released from the Chembarambakkam tank during 1976 and 1985 flood were collected. Thus, the objective is to develop an expert system for the flood control operation of the Chembarambakkam tank under flooding conditions and to compute the flood levels and thereby inundation depths in the flood plains of the Adyar river. The reservoir has to store the flood flows in the tank to the extent possible when the Adyar river is flowing full and create a time lag of discharge so that the flood peaks in the Adyar river are controlled within reasonable limits.

4.2.3 Description of the Expert System

The overall logic of the flood management model is shown in Fig. 4.4. The basic structure of the flood management expert system is pictured in Fig. 4.5. The expert system includes the modules: (1) flood estimation module (rainfall-runoff model); (2) flood simulation module; (3) reservoir simulation module; and (4) expert system rule-base. Data input to the system includes both the physical description of the system and the hydrologic data. The stored data include characteristics of reservoir spillway structures; and drainage area description and hydrologic parameter estimates for rainfall-runoff model. The hydrologic data include rainfall data and inflow into the reservoir. The details of the modules are given below.

4.2.3.1 Flood Estimation Module

The unit hydrograph approach is used for the estimation of flood flows to the reservoir. The technique adopted for the derivation of unit hydrograph is based on the Nash's approach. Nash considered that the instantaneous unit hydrograph can be obtained by routing the unit hydrograph through a cascade of n linear reservoirs of storage coefficient K. Thus, the two parameters n and K determine the shape of the unit hydrograph. The parameters are estimated by method of moments. This method requires the first and second moments of excess rainfall and direct surface runoff, which are used in solving for the parameters n and K.

For estimating the flood for the next period using unit hydrograph procedure, the probable maximum precipitation is derived using the following procedure:

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

(ii) Depth-area-duration analysis is performed and envelope curves representing the maximum depth-duration relation is obtained using the past major floods that had 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 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 was stored and used for estimating the inflow to the reservoir for the next period using the Nash unit hydrograph procedure.

4.2.3.2 Flood Simulation Module

In this module, the flood flows from the urban area are estimated by the rainfall-runoff model using the rational method and the flood profiles are computed using the HEC2 program. The details of these computations are as follows:

The concept of rational method is that if a rainfall of intensity 'i' begins instantaneously and continues indefinitely, the rate of runoff will increase until the time of concentration t_c, when all the watershed is contributing to flow at the outlet. HEC2, which is a well established comprehensive computer program package developed by the US Army Corps of Engineers (HEC2, 1981) was advantageously used to compute the water surface profiles in the 10 km stretch of the Adyar river taking into account the presence of two causeways and four bridges by invoking the bridge routine in the HEC-2 program.

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.

The input data for this module includes 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 c, 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 velocity head between the two sections is not too much to accurately determine the energy gradient. In this case, a total of 67 cross-sections are needed to meet this objective. This system was 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. The computations were carried out starting from the farthest downstream cross-section of the river proceeding to the upstream side.

The HEC-2 program was calibrated for two magnitudes of flood discharges, namely, 2000 m^3/s and 2200 m^3/s that occurred in 1976 and 1985, respectively. Water surface profiles were computed for discharges that occurred during the 1976 and 1985 floods and also the probable discharge that may occur in future in the Adyar river.

4.2.3.3 Reservoir Simulation Model

The release from the reservoir is limited by the spillway capacities, which in turn are related to the reservoir storage volumes. The discharge is also a function of head over the regulator; and the maximum allowable release is a function of downstream channel capacity. Since the water released from the reservoir is a function of the reservoir storage, head over the regulator, and the estimated inflow, there arises a need for reservoir simulation. The release obtained from this module is compared with the release obtained from the expert system rule-base which takes into account both upstream and downstream conditions of the reservoir to arrive at the safe operation policies.

The reservoir mass balance based on the principle of continuity was 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 reservoir during flood periods were generally an insignificant portion of the total flow and therefore they were not included in the model. Input data to this module includes physical and hydraulic description of the reservoir in the river system being simulated, hydraulic characteristic of the regulator, reservoir level, and the rating curve.

4.2.3.4 Rule-base Development

For developing the expert system, the following guidelines were adopted:

(a) The logic of the model would reflect the operators decisions and monitoring process;

(b) The model would apply to reservoir operation for hourly (or any time interval) operations;

(c) The model implementation data would be readily available to the user; and

(d) Inputs to the model be updated at each time step to reflect the changing hydrologic conditions.

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

The following operating procedures depending on different conditions were 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

3. Based on rainfall criteria.

(a) No rainfall in the drainage area downstream of reservoir

(b) Rainfall in the drainage area downstream of reservoir

4. Current inflow criteria

(a) current inflow into the reservoir is less than the carrying capacity of the river.

(b) current inflow into the reservoir is more than or equal to the carrying capacity of the river.

5. Change in the current inflow criteria

(a) increased

(b) unchanged

(c) decreased

6. Based on the releasing capacity of the regulator

(a) inflow into the reservoir is more than the release capacity of the regulator.

(b)inflow into the reservoir is less than the release capacity of regulator.

Decisions are taken based on minimizing the flood levels downstream of the tank. The rule-bases were developed using VP-EXPERT shell (*Paperback Software, 1987*). A sample rule in the developed rule-base which is encountered during reservoir operation is given below:

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

IF overland flow contribution < carrying capacity of the river

AND current storage level < top of extreme flood level

AND current storage level > top of conservation level

AND current inflow < maximum carrying capacity of the river

AND current inflow < release capacity of the regulator

THEN release recommended = feasible release

It should be noted that feasible release is the difference between the carrying capacity of the river and the overland flow contribution from the drainage area of the river downstream of the Chembarambakkam tank. In this example, the outflow is kept equal to the inflow, maintaining the stored water level to the top of the conservation zone to secure flood control storage space.

4.2.4 Working of the Flood Management Expert System

The expert system shell controls the operation of other modules during 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, rainfall intensity, etc. The developed module consists of executable versions of four computer programs written in C-language. One program computes the local flow from the drainage area of the Adyar river. The second one computes the estimated inflow to the reservoir for the next period and the third one gives the release that can be made from the reservoir for the current reservoir conditions. The release indicated by this module is compared with the release indicated by the expert system rule-base which takes into account both upstream and downstream conditions of the reservoir, to arrive at safe operation policies. 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. These local flows are added to the river flows at appropriate sections of the river for water surface profile computation. Then, the expert system invokes the RESERVOIR SIMULATION model for computing the maximum discharge that can be made from the reservoir based on the head over the regulator. The expert system then infers the knowledge-base and gives the maximum release that can be made considering the reservoir conditions and the downstream conditions. If the release indicated by RESERVOIR SIMULATION model is less than the expert system recommendation, then the expert system adopts and implements the reservoir simulation model release in this time step. The program also specifies the regulator opening to be made for the release recommended by the expert system.

The 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 display of the computed levels and the feasible levels along the river for the release that has currently been made.

4.3 An Integrated Expert System for Water Distribution Management

4.3.1 City Water Supply Management

The main objective of water supply management is to provide a reliable water supply under varied availability conditions. This management is difficult because of highly variable nature of demands and multi-objective and multi-institutional characteristics of water supply systems. Further, water supply management problems are semi-structured and ill-defined. Water supply is largely influenced by vagaries of water availability and heuristic nature of demand. Water resources planners, managers and other decision makers require a flexible tool that can assist them in making wiser decisions on water resources problems even when confronted with conflicting objectives and demands.

In view of the complexities involved in the water supply management domain, an integrated knowledge-based decision support system, namely, Water Supply Management Decision Support System (WSMDSS) was developed for improving the effectiveness of decision-making in water supply management for a medium size city, namely, Coimbatore in south India. This city has a population of about 12 lakhs and covers an area of about 105 km^2. It has both surface and ground water sources. The water supply distribution system is found to be complex. The quantity of water available from the present water supply scheme is

101.4 million litres per day (Mld) of which 20 Mld. is supplied to the wayside villages. The system receives 4 Mld. of supply from ground water sources. The present supply is inadequate to meet the water demands of the existing population. The limited supply of water not only hampers the growth potential of the city, but also gradually leads to the degradation of the socio-economic pattern of living. Further, the pressure available in the distribution system is very low. The water supply distribution system is facing many complex problems, especially during droughts. In the light of these, an integrated decision support system involving expert system approach was developed. The developed tool is capable of computing the potential water supply deficits. It would identify problem areas like pressure drops, leakages etc. or interruptions in supply and can suggest efficient alternatives to tackle the problems in the system.

4.3.2 Integrated Expert System

Several models, an intelligent knowledge base, graphic interface and user-interface are embedded in the integrated decision support tool (WSMDSS). The main structural elements of the developed system are: (a) dialogue management subsystem; (b) model management subsystem; (c) data management subsystem; and (d) knowledge-base. Fig. 4.6 portrays the relationship among different components of the WSMDSS system. By the inclusion of the knowledge-base in the system, it is possible to replicate the valuable expertise and also selection of task-appropriate models and parameters. The details of the different modules are given below.

4.3.2.1. Data Management Subsystem

It stores and manipulates the DSS database, as directed by the model management or by the dialogue management components. It maintains an interface with external data sources also. Database component can supply input data for models. After the models are run, the resulting output can be written to the database for later display using the user interface in tabular or graphical form.

A graphical interface with zoom capability has been integrated in the WSMDSS. It would help in visualizing the physical system ie. the system network, location of pumps, valves, reservoir, tanks and data and results from the various models. The problem areas or nodes in the network can be easily by identified by the graphical interface.

In the knowledge acquisition module, expertise is duly gathered from the water managers, staff of various departments, practicing engineers and designers working in this related field. It has the capability to incrementally acquire the knowledge at various level of knowledge abstraction and update the knowledge base.

4.3.2.2 Model Management Subsystem

The model management sub-system consists of a command processor which receives commands from the dialogue management component and directs those commands either to the model management system or to the model execution system. Model management system stores the different models or modules. The model execution system invokes the model and causes data to be retrieved from the data management component and processed by different models. Results from the execution system can be stored in the DSS database via. the database management component and communicated to user via. the dialogue management component.

The model-base of the WSMDSS consists of five modules: (i) demand prediction module; (ii) water distribution simulation module; (ii) maintenance module; (iv) optimization module; and (v) an operational module. Besides, a knowledge-base that delineates the knowledge from experts and the inferences of different modules in the model-base is incorporated. A brief discussion on the different modules is given below.

4.3.2.2.1 Demand Prediction Module

A demand forecasting methodology based on time series analysis of water use data was adopted for demand prediction. The developed software can divide a time series into trend, periodic and stochastic components and forecasting can also be carried out using this. The software has an in-built graphical facility to view the different components and the forecasted values.

Time series analysis was done on weekly water use data for the years 1981-1990. Using this module, it is possible to determine water deficits in the region in future years, given the available quantity. This information will be stored in the knowledge-base to evolve alternate management strategies.

4.3.2.2.2 Water Distribution Simulation Module

The network of the system is analysed by this module using the WADISO (Water distribution simulation and optimization) package. This package developed by US Army Corps of Engineers utilizes nodal method for pipe network analysis. It uses Hazen-Williams friction loss equation to calculate losses in pipes. Another feature of this package is that it can incorporate pumps, pressure reducing valves and check valves in the network system for analysis.

The main input parameters include the link and node data. Link data include details regarding pipes such as length, diameter, roughness characteristics, characteristic curve of pumps and details of valves. Node data comprise the elevation, discharge at various nodes and also elevation of water surface in tanks or reservoirs. Topology of the network is also be needed. The output parameters include pressure, elevation of energy gradient line and output at each node and flow, velocity and head loss for each pipeline.

The main aim is to identify the areas or nodes which are affected by low or high pressure, low or high velocity, low discharge and to spot out links which have high losses. The output is presented in a graphical form using a graphical interface. By this graphical interface, the problem areas or zones in the network can easily be visualized.

4.3.2.2.3 Maintenance Module

The main objective of this module is to diagnose the causes of interruption in the system. This module mainly consists of three sub-divisions:

(i) to spot out defects or anomalies in the system;

(ii) to identify the causes of the problem; and

(iii) to give recommendation for the defect.

This module is developed for proper good maintenance of the water supply distribution system. The DSS poses a series of questions and performs a diagnosis. Knowledge from experts working in related fields and also from manuals were elicited and stored in the knowledge-base enabling the DSS to suggest possible causes and assist in the problem diagnosis. Once the exact cause is identified, the DSS would provide assistance with remedial action and recovery.

Graphical interface enables to give the portions of the interruptions or bottlenecks in the system. The main defects that are considered for diagnosis include bursts in mains, pump troubles, pressure problems, leakages, discharge problems, stress in pipes, and various losses. The significant advantage by the inclusion of this module is that chance of forgetting an exceptional diagnosis can be avoided. The system also proposes a list of actions intended to eliminate the causes of malfunctioning or defects once the nature and cause of the problem are identified.

4.3.2.2.4 Optimization Module

The objective of the optimization is to select the least-cost combination of pipes. That is, specific pipes in the system are sized. The constraints of the optimization are minimum pressures, ranges of pipe sizes and energy cost for pumping. The data for optimization include cost information, size list, loading pattern and pressure constraint. The optimization also allows the user to consider the cleaning and relining of existing pipes. It can be carried out for more than one output/ input pattern of flows.

The optimization module also determines Pareto optimal solutions that are close to the original solution in terms of costs and minimum pressure. A combination of pipe sizes is said to be Pareto optimal solution if there is no other solution that has better pressure at a lower cost. The module can relax minimum pressure constraint to allow other solutions that result in costs within a certain percentage of the original cost. Pressure is judged at the node with the lowest pressure compared with the required pressure. The degree to which pressure constraint is relaxed and the allowable percentage variation in cost are values that can be specified.

4.3.2.2.5 Operational Module

This module is intended to generate management and operating policies to assist the decision-makers under varied availability conditions. Analysis was carried out for different conditions by varying the water levels in tanks/ reservoirs for different sets of demands and by varying the demands for different sets of water levels. Analyses were also carried out for different stages of the network by introducing valves at various salient points with an aim to have desirable pressure and quantity of flow at all points.

From various combinations, a relationship between the level of water use restriction for different sets of demands and availability was generated. An optimal operating policy for the stages by maintaining the network pressure at all times within the limits to meet user requirements regardless of variation in the consumption condition was formulated. The effect of introducing pressure reducing valves in the network where high pressure is noticed was studied. Similarly, the effect of introducing booster pumps with different characteristic curves where there is low pressure were also studied in the analysis. The inferences from the analyses were used for the formulation of decision tables and rules of the knowledge-base.

4.3.2.3 Dialogue Management Sub-system

The dialogue management sub-system has three components: user interface, dialogue control and request transformer. The dialogue control maintains a processing context with the user.

The request transformer component translates user's command into actions for the model or data management component and translates responses from those components into a format and vocabulary understandable by the user. Communication between the user and system is maintained through user-interface. This enables user to provide the system with necessary information about the problem being analyzed. Using this component, the user answers questions posed by the system. The system uses answers to build a formulation for problem to choose the appropriate model and to prepare necessary data for solving the problem. The design of user interface is intended to make data entry and function choices as simple as possible.

The user-interface of this system is simple and elegant. Interactive graphic tools such as multiple windows, menus, dialogue boxes, explanations, warning messages, graphic icons, pushbuttons, hyperregions and zoom capabilities offer an enormous variety of user support possibilities. A menu driven interface with a mouse to make selections is an integral part of the system. This point and click interface for various actions speeds up the man-machine communication. By integrating graphical user interface in the system, the interpretation of the solution results can be done easily. Integration of the graphical user interface enhances the user-friendliness. Using this, rapid and effective display of information is made possible.

4.3.2.4 Development of the Knowledge-base

An intelligent knoledge-base that includes heuristic knowledge, inferences of model results along with experts' experiential knowledge and intuitive decisions was incorporated. An object orient expert system shell, namely, LEVEL 5 OBJECT was used to develop the knowledge-base. It is a hybrid application development environment (LEVEL 5, 1990). It integrates object oriented techniques and expert system technology with traditional, procedural programming, relational databases models, hypertext capabilities, and graphical development tools. LEVEL 5 runs under the Microsoft Windows environment. A LEVEL 5 OBJECT knowledge-base may contain class declarations, backward chaining rules, forward chaining demons, an agenda, methods, displays and databases. Rules and demons describe the operational logic, rule sof thumb and cause-and-effect relationaship needed to make decisions and trigger certain events or actions during a session.

The knowledge of experienced water managers was acquired and encoded into the knowledge-base. The knowledge-base development was a time consuming task, but the product justified the efforts, because tapping the knowledge of the system was equivalent to tapping the collective knowledge of a group of experienced managers to supplement an individual's own experience. The knowledge acquired from various sources was organised into decision paths and rules. The knowledge-base was configured in a very simple manner with each path through the decision tree represented by a different rule.

4.3.3 Working of the WSMDSS System

The WSMDSS itself asks for all information required for a consultation. At any point of time, the user can ask a why a query is being posed and he/she can get the explanation. The WSMDSS shows bit maps of the network. Any individual component/ area can be zoomed and the relevant information is displayed to the user. All the input are stored in a database file.

The WSMDSS components are strongly integrated with each other. The flow of information is sequential and step-by-step instructions are available for the use during a run-time. External databases are accessed in addition to the user input and the current data is used by the model managenent sub-system. New data, if any, can be added to the existing database. The results obtained in the model management subsystem are combined with the knowledge-base in an integrated manner. Rerun of the WSMDSS is made, if requested by the user, for a change in the data.

4.4 Hybrid Expert System for Tank Irrigation System Operation

4.4.1 Tank Irrigation in South India

Tanks are considered to be the most economical water storage systems and require less expenditure for construction and relatively small area needs to be submerged for impounding water. Irrigation tanks account for over 30 percent of the total irrigated area in south India and over 40 percent of the irrigated rice in Sri Lanka (*Palanisami and Easter, 1983*). An irrigation tank with a capacity of 100 ha.m irrigates about 90-100 ha. of paddy rice in a command area below the tank sluice. There are large number of irrigation tanks with a total capacity of 30,00,000 ha.m in India (*CWC, 1988*). Tanks in the south Indian states, namely, Andhra Pradesh, Karnataka and Tamilnadu supply water to nearly one-third of the total irrigated area in these states. They harness about 10 percent of the annual rainfall over this area. The depth of most tanks is approximately 4 to 5 meters at the deepest point. The capacity of tanks ranges from 50 ha.m to 9000 ha.m. (*Prasad, 1979*).

The magnitude and frequency of water shortages are higher in the case of tank irrigation systems. Rice is usually grown under tank systems and very little area is allotted to other crops such as groundnut, cotton, maize etc. Double cropping is risky and largely influenced by tank storage and inflows into the tank. Efficiency of operation of tank systems needs to be maximized considering their significant role in the irrigated agriculture. However, for tank irrigation systems, very less attention has been paid to evolve efficient operating strategies. Mathematical models are of use to develop policies for optimal operation. However, these models may not incorporate heuristic, subjective, and judgmental information which are also essential for efficient operation of the system. Therefore, an appropriate tool that can combine the knowledge derived from these models with the experience gained by water managers is required. Towards this end, a hybird expert system that integrates algorithmic technique with the expert system approach is considered to be suitable. This section presents the development of a hybrid ES for operation of Veeranam tank system. The details of this tank system are given in the next sub-section.

4.4.2 Veeranam Tank Irrigation System

Veeranam tank irrigation system is located in Chidambaram Taluk, south Arcot district, at 245 kms south of Madras in Tamilnadu State, south India. It is one of the largest tank irrigation systems in south India. The primary purpose of this tank is to provide irrigation to 18167 ha. of land. The tank is supplied by Vadavar river that branches from Cauvery river (a major river in south India). The tank also gets local flows from a catchment area of 443.8 km^2. It provides irrigation through 34 channels that take off directly from the tank. The area served by the channels ranges from 12 ha. to 2954 ha. Out of the total irrigated area, an extent of 7509 ha. is envisaged for raising double crops of rice. About 120 villages are benefited from irrigation by this tank system.

The original capacity of the tank was 40 Mm^3 and the present capacity is 26 Mm^3 due to siltation. Rice is grown in three seasons and these three different seasons are locally referred to as *Kuruvai*, *Thaladi*, and *Samba*. The irrigation season commences from July and extends until the middle of February. In the beginning of irrigation seasons, the crop areas are determined based on 75% dependable inflows obtained from past data. However, if the actual flows in those years do not match with these dependable flows, water shortages would occur in some of the periods. Hence, the crop areas need to be planned in accordance with the water availability based on forecasted inflows and water demand. Water authorities decide the irrigation releases based on a constant demand pattern. This demand pattern is not varied from year to year. Hence, it is necessary to consider crop stages in addition to meteorological conditions while making irrigation releases so that the irrigation water supplied matches the crop water requirements. Further, adequate storage in the tank needs to be maintained to meet future demands for optimal utilization of available water.

The above problems are addressed by a hybrid expert system approach. An optimization of the tank irrigation system is first carried out and combined with expert system concepts with the overall objective of improving the efficiency of operation. The methodology concerning the optimization of the irrigation system is provided in the next sub-section.

4.4.3 Optimal Cropping and Irrigation Releases

Two major issues that were identified for the tank irrigation system are: (i) the decision on the crop areas to be irrigated; and (ii) derivation of optimal operating policies. A three-step procedure was devised to address these issues. Fig. 4.7 shows the details of this procedure. These steps are sequentially done to determine optimal irrigation releases from the system.

In the first step, optimal crop areas are obtained using a linear programming (LP) model. The LP optimization model, referred to as area allocation model, has the objective of maximizing the crop areas. The results of this model become the input to the second-step optimization model (Fig. 4.7). In the second step, optimal irrigation release schedules are derived on a weekly basis. A discrete dynamic programming (DP) model is used for this purpose. The DP optimization model, referred to as water allocation model, provides optimal releases for given system demands, known initial storage, and inflows during different time periods. In the third step, real-time operation of the system is performed (Fig. 4.7).

4.4.3.1 Optimization of Crop Areas

Determination of optimal crop areas that would guarantee assured irrigation is an important step in the management of tank water resources. Supplying sufficient amount of water to meet the irrigation requirements of rice is a vital element in the operation of the tank irrigation system under study. If a larger area is considered for irrigation than the optimal area, then the effect of water supply shortages will be severe on the crop growth and the yield. Hence, optimal areas need to be considered in the operation of the system to guarantee assured irrigation.

The area allocation model is a monthly model and run on a water year (1st June to 31st May) basis. The objective function considers the maximization of crop areas, subject to the following constraints:

(1) Land area constraints: The land area constraints indicate that the area that can be irrigated must not exceed the available land in the system. The total area of crops for any channel must not exceed the total area available for that channel.

(2) Water requirements constraints: The water requirements of crops must not exceed the total water supply in each month.

(3) Channel capacity constraints: These constraints specify that the amount of water released in a channel should not exceed the capacity of that channel in any month.

(4) Tank capacity constraints: The storage in the tank at any time must be above the dead storage for releasing water through irrigation channel sluices to the areas to be irrigated. It is also limited by the capacity of the tank.

(5) Mass balance constraints: The mass balance of the tank states that the final storage at any time period will be equal to the initial storage plus inflows minus release, evaporation loss, and excess release to a nearby system.

The area allocation model was run for 18 years (1969-70 to 1986-87) to compute the optimal areas for irrigation. The continuity between the years was maintained by giving the final storage in the last month (May) of any year as the initial storage for the first month of the next year and so on.

4.4.3.2 Derivation of Optimal Releases

Water allocation model provides optimal irrigation releases based on current inflow and irrigation demand and also the initial storage. It utilizes the optimal crop areas provided by the area allocation model and considers these as the areas to be provided with assured irrigation. Weekly irrigation requirements are multiplied by the respective optimal crop areas to estimate irrigation demands for each crop. These demands are input to the water allocation model in order to derive optimal release strategy for each stage (week). A dynamic programming model is developed following *Loucks et al. (1981)*. It is constituted with weeks as the stages. Each stage has a number of possible states associated with it. A single state variable, namely, tank storage is used to describe the system. For rice, the objective function is expressed as a loss function that should be minimized. The objective function minimizes the sum of squared deviation of releases from their respective irrigation demands.

The DP problem is solved backwards starting at the last stage and finding the optimal return function and optimal operating policy at each stage until a stationary solution is obtained. Both the state and decision variables were discretized, meaning that they can take on a finite number of values. The tank storage (26 $\times 10^6$ m^3) was discretized in 1 $\times 10^6$ m^3 interval. The decision variable, namely, the release was discretized in a finer interval (0.1 $\times 10^6$ m^3) to match the release with small irrigation demands.

Optimal release policies were generated for each decision stage over 18 years (1969-70 to 1986-87). These policies were analysed and thus become the basic knowledge concerning the optimal operation of the tank system. The optimal operational knowledge were put into the expert system shell, VP-EXPERT for effective decision-making. Other sources of knowledge and information are integrated with the knowledge-base to make a bybrid system. This aspect is discussed in the next section.

4.4.4 Hybrid Expert System Development

The optimal operational policies were combined with the procedural, judgmental, and other heuristic knowledge pertaining to the operation of the tank system. The development process is depicted in Fig. 4.8. The domain knowledge is a collection of optimal operational knowledge, facts, and other heuristics. While the optimal operational knowledge was obtained from the results of the water allocation model, the heuristic knowledge was collected from the experts. The optimal operating policies for the years 1968-69 through 1986-87 were analyzed and transformed into the optimal operational knowledge in the IF...THEN format rules. Rules representing different scenarios were synthesized for each decision period (week).

This knowledge was implemented in the VP-EXPERT shell (Paperback Software, 1987). Optimal operating rules were developed by establishing a relationship between the water availability (current storage and inflow) and optimal release. Some of the rules in the knowledge-base are listed below for illustration.

RULE 35

IF PERIOD = 2 **AND**
DEMAND > WAT_AVAILABLE
THEN RELEASE = (1* WAT_AVAILABLE);
ASK DEMAND: "Enter the value of demand ($x10^6$ m^3) during this period";

RULE 79

IF PERIOD = 5 **AND**
WAT_AVAILABLE > 14
THEN RELEASE = (0.9 * DEMAND);

RULE 126

IF PERIOD = 11 **AND**
WAT_AVAILABLE >= 22 **AND**
DEMAND >= 12 **AND**
DEMAND <= 13 **AND**
THEN RELEASE = (0.97 * DEMAND);

RULE 155

IF PERIOD = 15 **AND**
WAT_AVAILABLE > 15
THEN RELEASE = (1.15 * DEMAND);

According to rule 35, if water availability is less than the demand, then the release is restricted to the available water, irrespective of the demand. In some periods in which the water availability is more, the release can be slightly higher than the demand so as to keep the storage within the capacity. Rule 155 indicates this typical policy of operation. Rules were also synthesized considering the rainfall in each time period. The experience knowledge possessed by the tank authorities (experts) was acquired from them during frequent field visits.

The rules derived from the optimization of the system were also examined by the field experts and suitably modified. Their decisions were included in the ES as heuristic rules.

The expert system (TANKES) was developed as a hybrid system to accomplish real-time operation. For real-time operation, one needs to know the values of inflow, evapotranspiration (ET), and rainfall during any period at the beginning of the period itself. However, these values will be available only at the end of that period. Hence, there is a need to forecast these variables to accomplish real-time operation. In this context, forecasting models such as autoregressive integrated moving average models and Winter's exponential smoothing models were tried to forecast inflows and ET. The forecasts are used by the ES to provide release decisions in a real-time context.

4.4.5 Working of the TANKES system

Fig. 4.9 shows the working details of the TANKES system. The basic inputs and output are shown in this figure. In its operation, the TANKES system asks for the initial storage at the beginning of the first week. Forecasts of both inflows and ET during this week are obtained. Forecasts of inflow are obtained from an autoregressive integrated moving average model. Winter's exponential smoothing model which is a simple statistical model, is used to forecast ET. Rainfall is estimated using gamma probability distribution function.

The actual value of inflow is known at the end of the week. This value is used by the TANKES system to update final storage. This final storage is taken as the initial storage for the second week. The forecasts for the second week are then obtained and used by the DSS to provide a release decision for the second week. The above procedure is repeated for all weeks for real-time operation of the tank system. At any point of time, the user can ask why a query is being posed and he/she can get the answer.

4.5 Knowledge-based Management Game for Irrigated Farming

Irrigated farming is often affected by the problems especially due to limited water supplies. It is of interest if such situations are simulated in a game model environment. A game model was developed for addressing the problem of decision making faced by a typical farmer in southern India, emphasizing the role of water inadequacy. This PC-based version is called CASIMBOL (Computer Aided Simulation of Irrigation Management Below Outlet).

Lotus 1-2-3 is chosen as a suitable spreadsheet to build the model. An expert system shell IITMRULE (Nodal Center on Expert Systems, 1990), developed at the Indian Institute of Technology, Madras, is used to represent an associated knowledge base. Provision is made at selected stages, to move out of the spreadsheet and enter into the expert system shell for consultation, if so desired and then to revert back to and continue with the game. The essential features of the game model and the role of the expert system are discussed in the following sections.

4.5.1 Feature of the Manual Game

The various aspects considered in the game are based on the conditions prevailing in a typical critically irrigated area in southern India. The location of the land with respect to the main canal and distributary plays an important role in the amount of water available. In this context, the land may lie in any of the three different reaches, namely head, middle and tail reaches. The implications appear in terms of labour availability and the grain and monetary requirements of the family members.

The growth of paddy is divided into three phases namely vegetative phase, reproductive phase and ripening phases. The amount of water available during each of these phases together affect the yield in a complex manner. There are three sources of water available for the crops: effective rainfall, irrigation supply, and the much more expensive supplementation with purchased water.

The game model provides for purchase of water 0,1,2,3 or 4 units (depending upon the conditions prevailing at any growth stage). Herein one unit is discretized as 25% of the crop water requirement in that growth stage. The resulting water availability in any growth stage can be classified into one of the four conditions, namely very good, good, fair or poor. The application of fertilizer could be at one of the three quanta, namely nil, medium of high.

The probability of incidence of pest attack is found. The engagement of machinery is considered in a simplistic way in terms of a certain cost per ha and a definite percentage increase in yield when machinery is employed. The selling price of the produce is also a random entity. Facing such complex as well as random multitude of factors, the farmer has to make a series of decisions hoping to achieve the best in terms of crop output and the resulting net monetary returns.

4.5.2 Decisions to be Made in the Game

The fortunes of the game player as a farmer are dictated basically by the extent of land that he gets assigned with, its location vis-a-vis the main canal and the distributary. Also randomly assigned to the player is the family size and its composition. Every year, in the two cropping seasons, the farmer may choose to a cultivate a mix of high-yielding and traditional varieties of paddy rice. Since the crop yield is dependent upon the variety cultivated, water availability, fertilizer applied, engagement of machinery and the approach to pest control, the player (farmer) has to decide on these aspects for every cropping season.

The decision to purchase supplemental water requires a specification of number of units of water purchased at rates prevailing in the locality after taking stock of the water availability at every stage. The game thus serves as a vehicle to experience the complicated nature of the decisions to be made by a farmer.

4.5.3 Development of the Expert System Segment

The game model (CASIMBOL) is built using Lotus 1-2-3. An expert system is designed and appended to CASIMBOL, as a consultation facility. This serves to duplicate the role of an agricultural/agronomic expert whose advice may be solicited by the farmer. The gaming simulation and expert system segments are combined as shown in Fig. 4.10 so as to perform a game in cooperation. Fig. 4.11 shows various stages at which this advice facility is accessible.

The expert system was created with four mini knowledge bases; one to advise on the level of fertilizer to be applied and the rest for the amount of additional water that may be purchased in each of the three growth stages. The knowledge-base was formulated in terms of the rules in the IF...THEN format. It was organized in the IITMRULE shell.

The concerned knowledge was acquired through the study of results of a large number of simulations ('what -if') of cases identified by systematic enumeration. Thus, these knowledge bases may be considered as 'synthetic', since they have been acquired from the results of a simulation model in contrast to the usual acquisition from human experts. The factors that form the basis of advice from the ES are identified heuristically. Then, CASIMBOL is systematically played in its 'what-if' mode to generate a large number of outcomes. These outcomes are analysed to identify the best strategies under different conditions. These results are used in formulating the rules of the knowledge bases.

Typical rules of the knowledge base that advise on the level of fertilizer to use include:

RULES 1

IF

LOCATION Wrt CANAL IS 'HEAD'

AND LOCATION Wrt DISTRIBUTARY IS 'HEAD'

THEN

FERTILIZER APPLICATION IS 'HIGH'

CONFIDENCE 0.90

RULE 10

IF

LOCATION Wrt CANAL IS 'TAIL'

AND LOCATION Wrt DISTRIBUTARY IS 'HEAD'

AND NOT TRACTOR IS USED

AND SEASON IS 'SUMMER'

AND FARMER ECONOMY IS 'SOUND'

THEN

FERTILIZER APPLICATION IS 'MEDIUM'

CONFIDENCE 0.60

4.5.4 Working of the Software

CASIMBOL is designed such that the player is navigated through the game ny menu-driven macros. The player can choose the menu options similar to the Lotus 1-2-3 menus. The player is guided through various phases covering assets assignment, precultivation, three crop growth stages, post harvest and the economic evaluation. The player has to respond with his/her decision for each query interactively.

A player can seek advice through the expert system segments. For instance, during the precultivation segment, if the player wants to seek the advice of the ES, the spreadsheet work gets suspended temporarily and the command switches over to the ES shell IITMRULE. Inferencing is carried out therein and IITMRULE terminates with the display of a suitable suggestion (eg. go for a high level of fertilizer application). The command again switches back to Lotus 1-2-3 and the session continues from the point where it exited the spreadsheet previously.

Table 4.1 shows the sample results during trial sessions. Net income obtainable at the end of the crop seasons are simulated. The expert system advice is sought whenever necessary to take a decision, which ultimately influence the farm income.

4.6 Expert System for Crop Selection

4.6.1 Need for ES for Crop Selection

The decisions that farmers and farm production managers make may fall into the category of decisions which can be best made by experts. Reliable decision guidelines are needed for many phases of crop management including crop selection. Crop selection is an important problem in irrigation planning. Proper utilization of land, water, and other resources is achieved when a suitable crop is cultivated and well managed. A crop selection process involves selecting an appropriate crop which is best suited for the location, season, and other field conditions. The best suited crop for a particular situation is difficult to determine especially if there are several acceptable crops. A number of crops are cultivated with little knowledge of their adoptability to different soil, climate, and management factors.

Although many factors must be taken into account simultaneously, farmers usually consider a few factors. The traditional crop selection practices followed by farmers are not adequate and have many disadvantages including the following: (a) crop rotations are not always followed; (b) growing a crop continuosly does not facilitate nutrient recycling; and (c) an unsuitable crop might be stressed due to shortage of water. In this context, an expert system is considered to be a good tool that can reduce the requirement of a qualified expert and also reduce the shortcomings due to incorrect selection of crops.

This section presents the development of an expert system for crop selection. This ES was developed for a region in Tamilnadu, south India. Fig. 4.12 presents the overall architecture of this ES. Target users of this ES are agricultural service personnel, farmers, or other individuals who are involved in crop production.

4.6.2 Conceptualization of the Crop Selection Process

Aliyar basin in Tamilnadu, south India, was chosen as the application area. The basin is benefitted by a canal irrigation scheme which is used to supply irrigation water to farmers on the basis of a zonal rotational system. In addition, groundwater is used to supplement canal irrigation. There are twenty crops which commonly are commonly cultivated in the area. They include cereals, millets, pulses, oil seeds, sugar crops, vegetables, fibre crops, and forage crops. The factors involved in the selection process were defined at the beginning stage. In consultation with domain experts, important variables were identified and conceptualized to structure the problem. Table 4.2 gives the list of variables considered in the expert system for crop selection (CROPES).

Water availability and rainfall patterns are important factors for crop selection since water requirements among crop vary significantly. Location and land type requirements are typically different foı wet crops, dry crops, and semidry crops. Physical and chemical properties of soils which influence crops must also be given due consideration. Total cost of cultivation of a crop mainly depends upon the interactions of farmer's financial status with land size and labor availability. Available resources such as tractors, equipment, and storage facilities also play a major role in choosing the best crop.

4.6.3 Knowledge Acquisition and Organisation

All variables identified in the problem conceptualization stage were considered for expert system development to represent a comprehensive view of crop selection process. Knowledge was obtained from field agronomists (domain experts) by interviews and also through questionnaires. Besides, information available from technical reports and crop production manuals was also utilized to obtain additional knowledge. In Table 4.2, the qualitative values and corresponding selection variables codes are listed.

Rules were synthesized from the domain knowledge to represent the crop selection process. Decision tables were constructed to frame the rules. The rule-base was organised into two levels, as shown in Fig. 4.13. At the first level, an initial screering is done. At the second level, fine tuning of the results obtained at the first level is carried out to select a most suited crop for the given conditions. As a preliminary screening, a set of possible crops is identified at the first level mainly based on season, location, land details such as size and soil type, and water availability. Each possible case requires an input option for the following variables: location, season, land type, water source, available water, farm size, labor, and soil type. Each variable needs a value to be supplied, all of which constitute a particular case. Thus, each possible case eventually leads to the identification of a crop group.

The set of possible crops is further reduced at the second level when factors such as soil fertility, available equipment, and other facilities are considered. For example, if the crop group suggested at the first level consists of groundnut, cotton, and soybean, one or more crop from this crop group is selected by considering the micro-level data. Thus, the CROPES system has two levels of selection. A confidence factor equal to 1.00 is assigned for a selected crop if information on all variables is available. Otherwise, it would be reduced from 1.00 depending upon the importance of variables for which values are not available. Rules were implemented in the ES development shell, IITM RULE (*Nodal Centre on Expert Systems, 1990*). Variables can be explained using the template facility of the shell in order to facilitate effective user-interface. The shell can also present the user with a menu to display the set of possible values a variable can take.

4.6.4 Working of the CROPES System

The CROPES displays an introductory screen that explains in short what the ES is all about. It then asks the user, the following:

- Option for the use of confidence factors
- Control on help menu
- Goal options
- Input data

The ES provides step-by step instructions to the user. At any time during the session, the user can get the explanation using the HELP facility. The input data can be either supplied by the user or retrieved from an existing data file. For manual data entry, the field conditions must be at least approximately known. The CROPES system poses sequentially queries related to the following characteristics:

- Location of the farm
- Crop season
- Type of soil
- Available water from canal, tanks, wells and other sources
- Size of farm and labor availability

At this level, the CROPES system identifies a crop group that corresponds to the first level of crop selection. The second level processing needs additional information to shortlist the selected crops. The ES, proceeding to the second level, asks further the following field conditions:

- Characteristics of soils
- Availability of natural manure (farm yard manure)
- Availability of fertilizer and pesticides
- Storage facilities

All acceptable responses, ie., user choices are numbered, allowing the user to input the appropriate response quickly. The questioning and answering process is continued to reach a conclusion. The ES would alert the user if incorrect responses are entered. The processing is continued until the last variable is answered. When all pertinent questions posed by the CROPES system are responded to by the user, the CROPES system displays the results in its output mode.

The final result screen is shown in Fig. 4.14. The final selection of the crop is based on rule 155. For this rule to be fired, it is necessary that the previous rules need to be satisfied. 'Cotton' is suggested with a confidence factor equal to 1.00 for the given conditions. Fig. 4.14 also shows that crops other than cotton are not suggested. If the user wants to run again for different input data he/she can do so using 'Rerun', otherwise the session comes to an end.

Table 4.1 Sample results obtained from CASIMBOL by different players.

Player	Randomly assigned values					Net income (Rs/ha/season)	
	Land (ha)	Location of land with respect to		Family size		Season 1	Season 2
		Canal	Distributory	Adults	Children		
1	2	Head	Tail	2	2	3114	3336
2	1	Head	Tail	2	1	7624	8798
3	1	Head	Middle	4	4	5765	10356
4	4	Middle	Middle	3	4	4744	5336

Table 4.2 Variables and their codes considered for the development of CROPES.

Variable	Values	Code	Variable	Values	Code
Location	Humid	1	Soil fertility	High	1
	Sub-humid	2		Medium	2
	Semi-arid	3		Low	3
	Arid	4			
			Soil pH	Strongly alkaline	1
Water source	Canal	1		Alkaline	2
	Wells	2		Neutral	3
	Others	3		Acid	4
				Strongly acid	5
Available water	Very small	1			
	Small	2	Farm yard manure	Very small	1
	Large	3		Small	2
	Very large	4		Average	3
				Large	4
Season	Summer	1		Very large	5
	Kharif	2			
	Rabi	3	Fertiliser	Nil	1
				Small	2
Rainfall	< 30 cm	1		Average	3
	30-75 cm	2		Large	4
	75-125 cm	3			
	> 125 cm	4	Pesticides	Nil	1
				Small	2
Farm size	> 15 acres	1		Average	3
	10-15 acres	2		Large	4
	3-10 acres	3			
	< 3 acres	4	Tractor	Not available	1
				Available	2
Labour	Large	1			
	Medium	2	Planting equipment	Not available	1
	Small	3		Available	2
Soil	Alluvial	1	Grain storage	Conventional	1
	Laterite	2		Silo	2
	Black soil	3			
	Red soil	4	Fodder storage	Conventional	1
				Silo	2

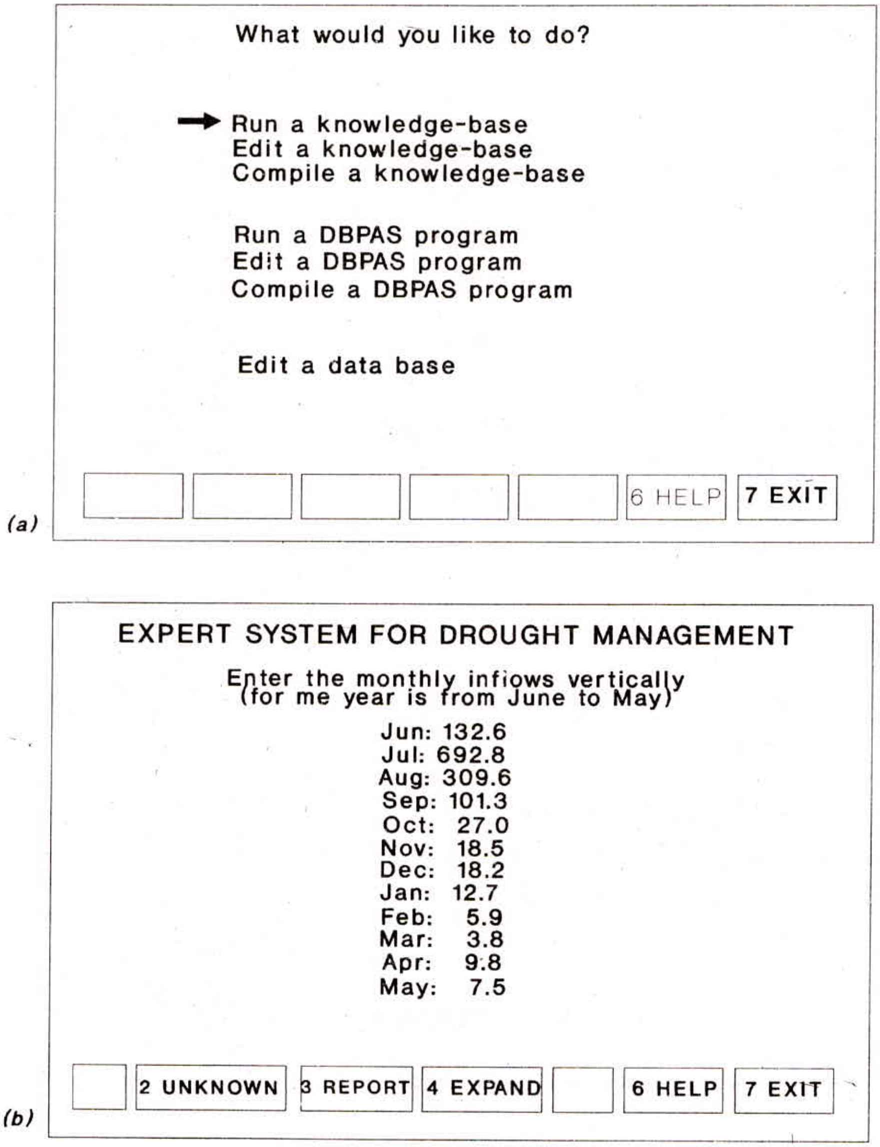


Fig. 4.1 First and second screen displays by the BDM expert system.

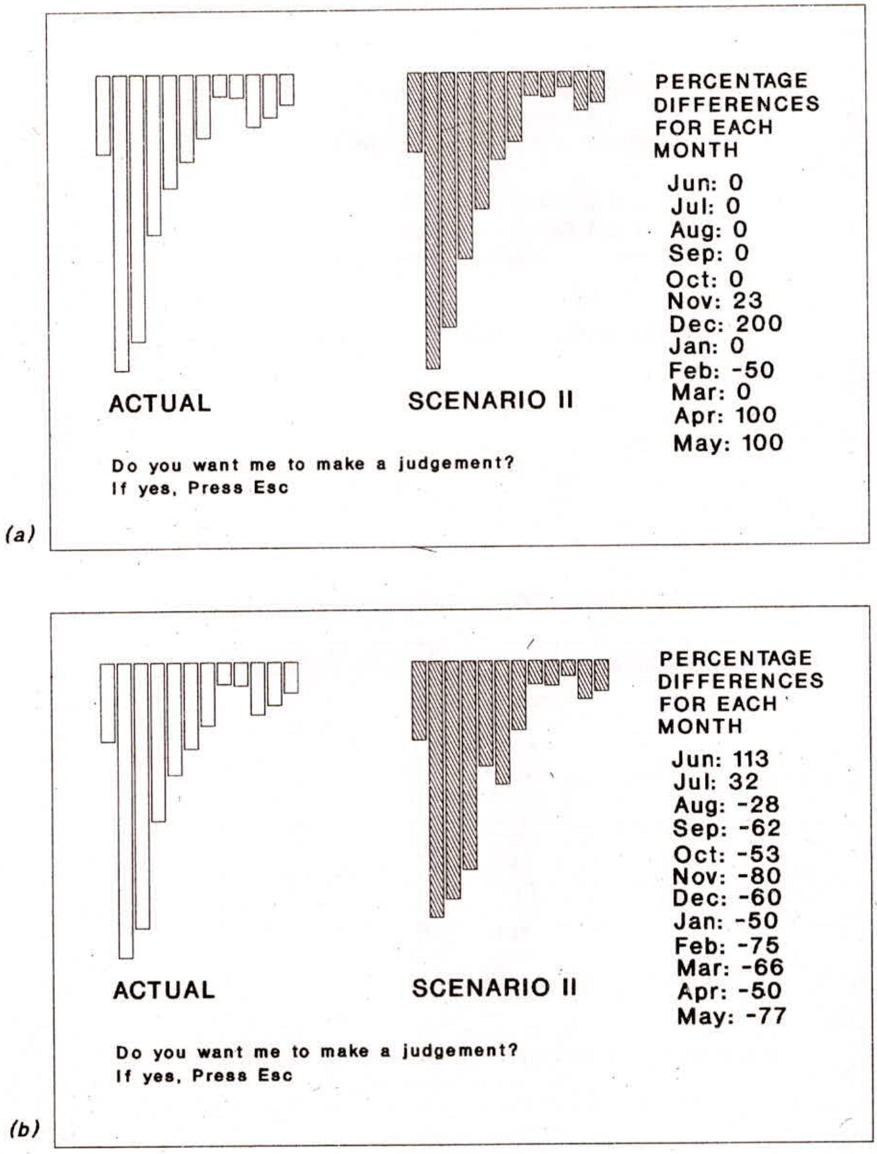


Fig. 4.2 Present and past drought scenarios.

EXPERT SYSTEM FOR DROUGHT MANAGEMENT

Would you like to reduce the area of paady crop?

TRUE | NO

Would min. percentage of sugarcane would you like to grow?
(Kindly give your value between 40 and 70)

Press F4 for explanation

| 2 UNKNOWN | 3 REPORT | 4 EXPAND | 5 GO BACK | 6 HELP | 7 EXIT |

(a)

EXPERT SYSTEM FOR DROUGHT MANAGEMENT

OPTIMAL CROPPING PATTERN

CROP	LEFT BANK (ha)	RIGHT BANK (ha)	PERCENTAGE
RICE	3484	29374	100
SUGARCANE	685	12439	56
GRAPES	303	17534	100
MAIZE	867	18847	100

SUGARCANE AREA CAN BE INCREASED BY
IMPROVING THE IRRIGATION EFFICIENCY

| 2 CONTINUE | 3 REPORT | | 5 MENU | 6 HELP | 7 EXIT |

(b)

Fig. 4.3 Optimal cropping pattern resulting from BDM expert system.

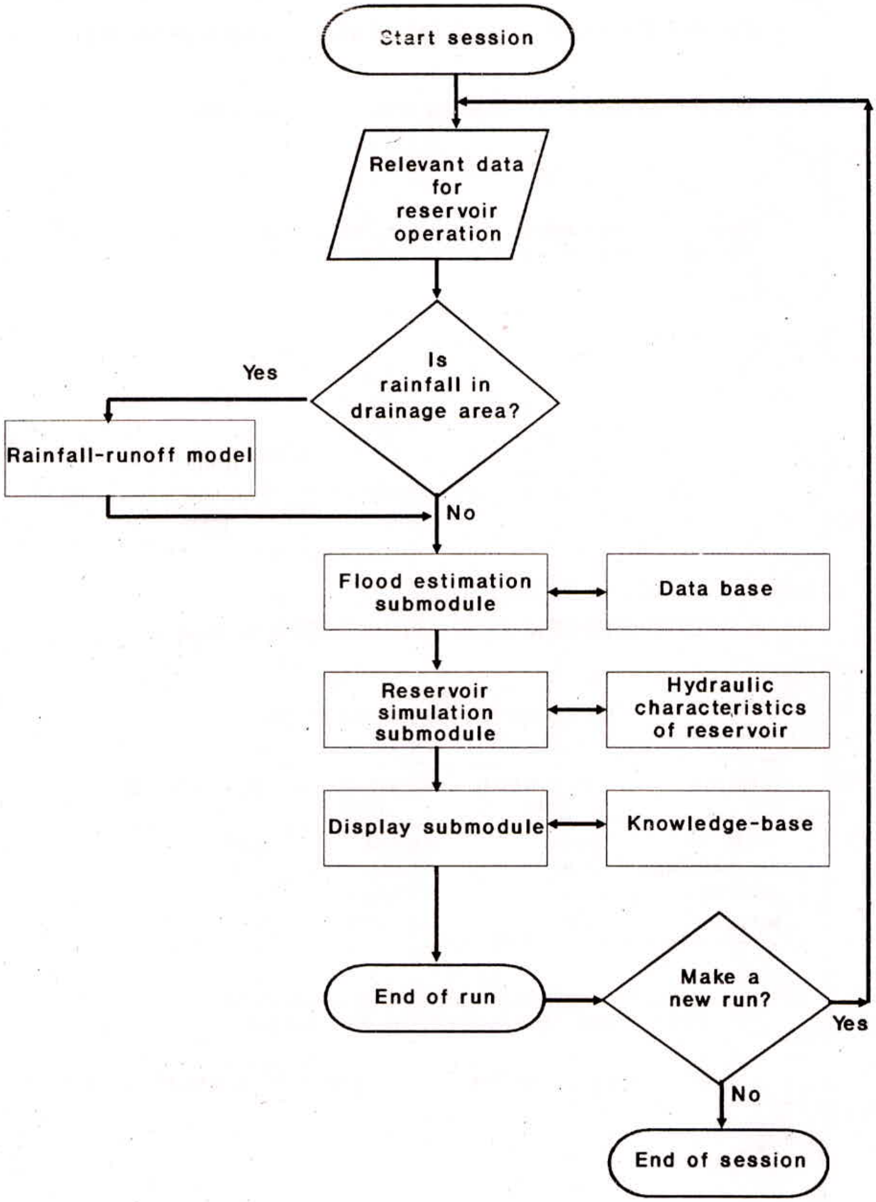


Fig. 4. 4. Schematic of the program logic for flood management.

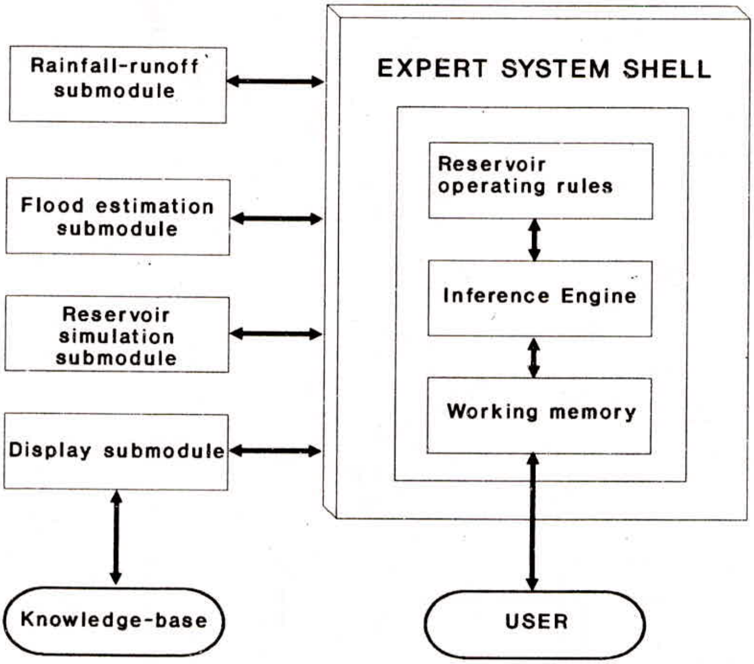


Fig. 4.5 Architecture of the flood management expert system.

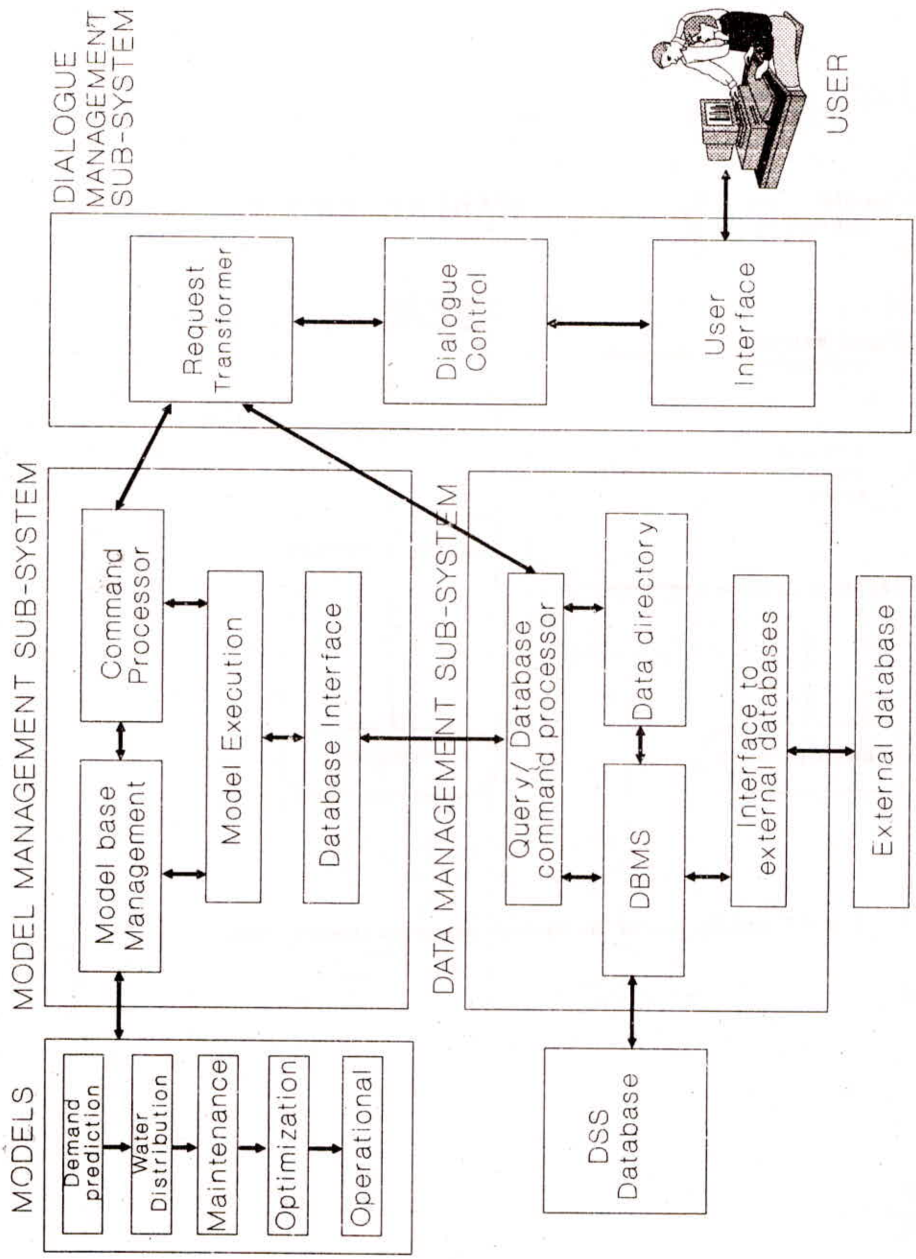


Fig. 4.6 Architecture of the integrated expert system for water supply management.

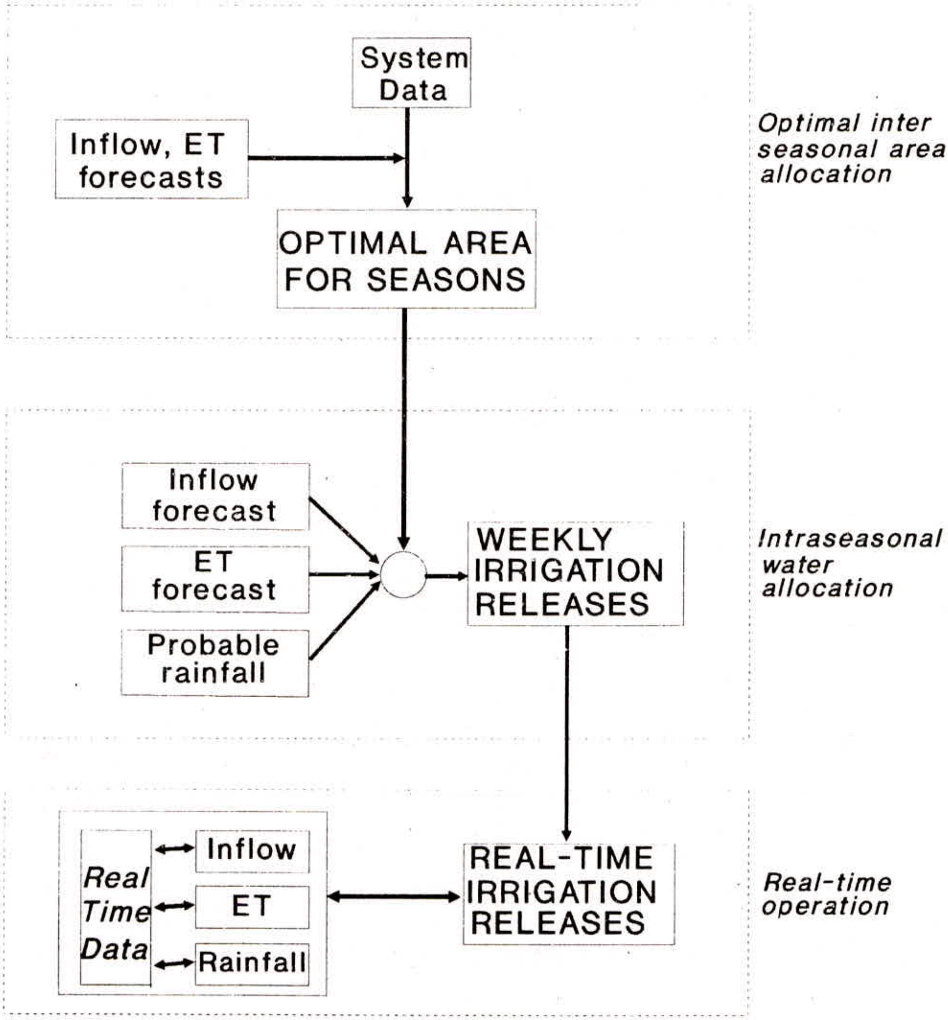


Fig. 4.7 Three-step procedure for optimal operation of tank irrigation system.

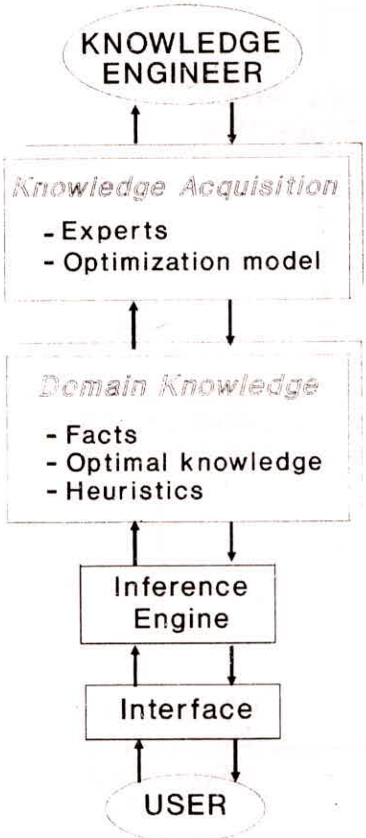


Fig. 4.8 Development of the hybrid expert system.

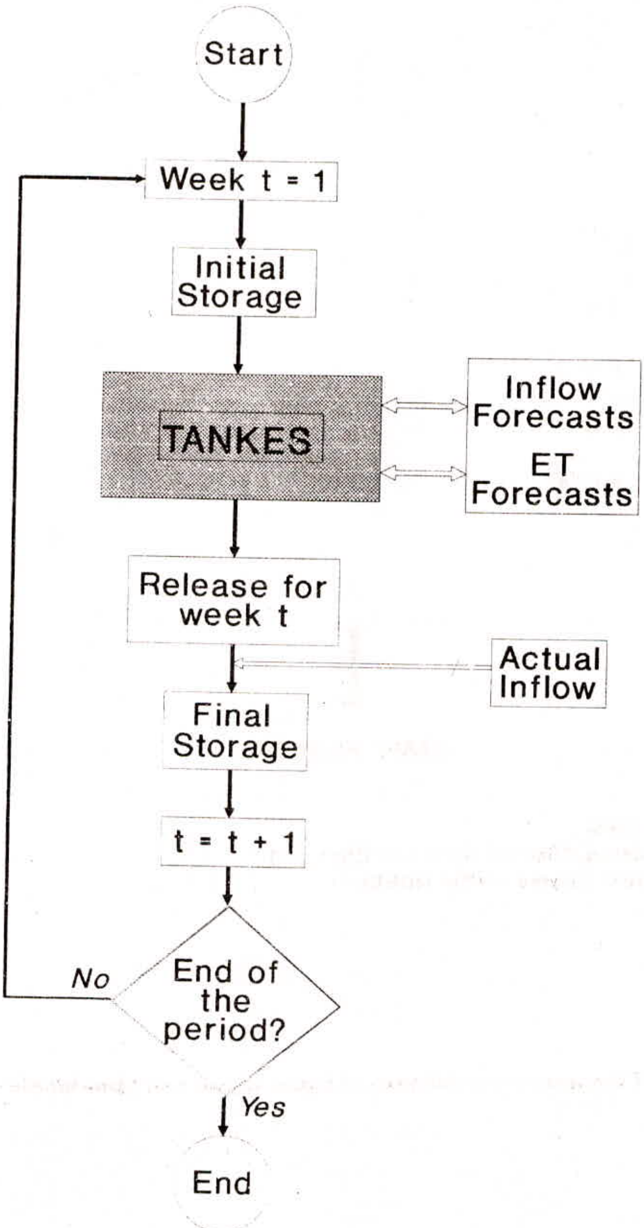
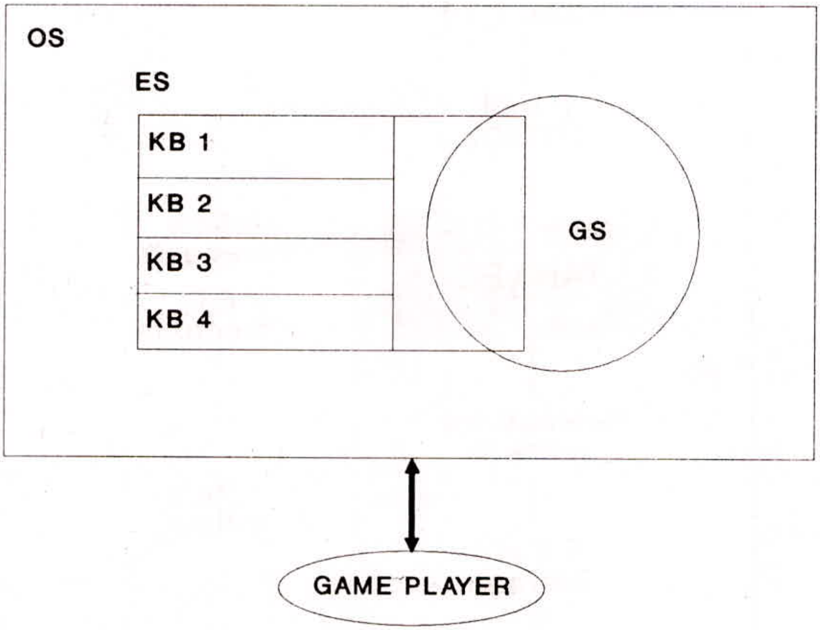


Fig. 4.9 Real-time operation using the hybrid expert system.



OS : MS-DOS
GS : Gaming Simulation in LOTUS 1-2-3
ES : Expert System (IITM RULE)

Fig. 4.10 Co-operative combination of expert system and game model.

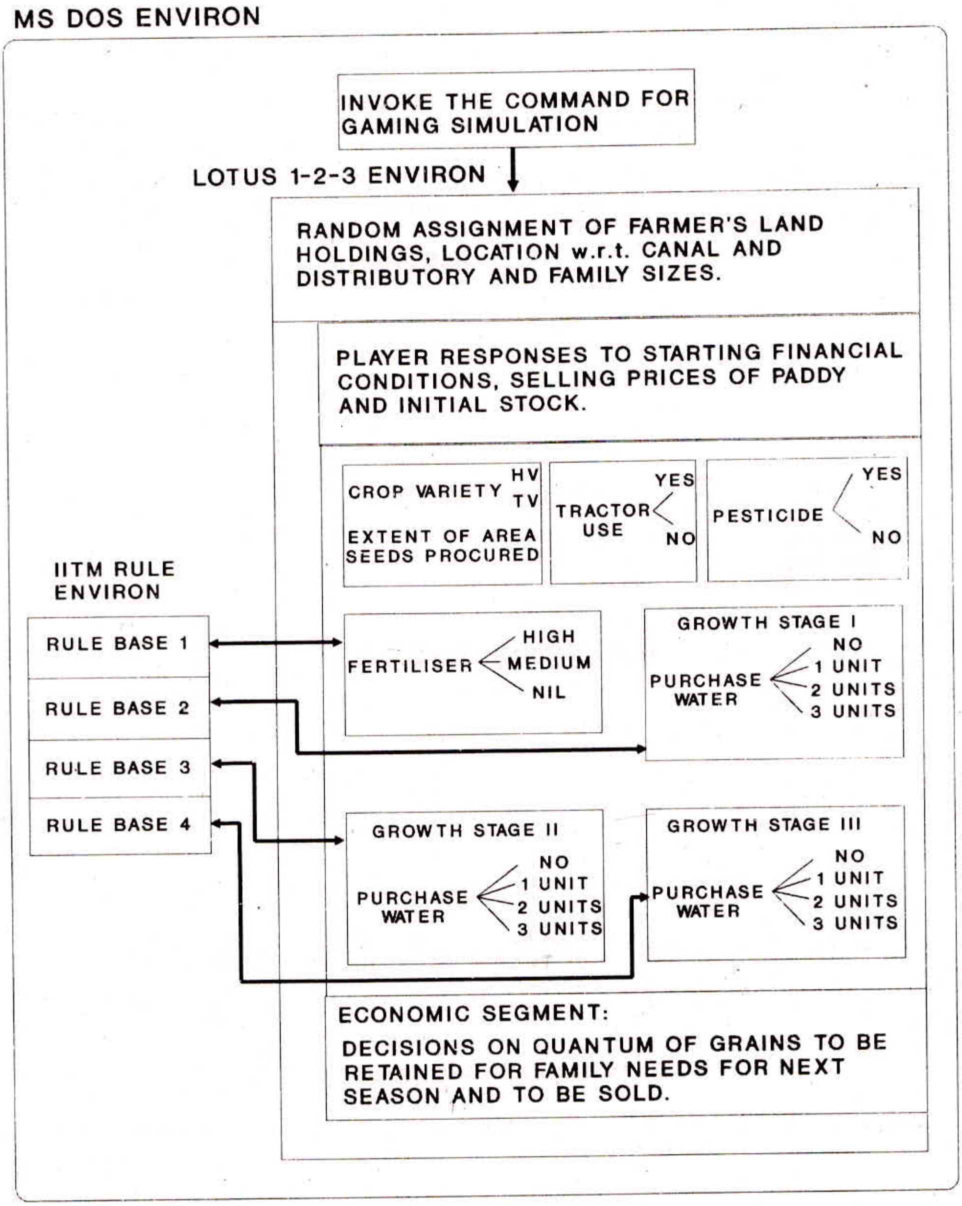


Fig. 4.11 Interactive between the rule bases of the expert system and CASIMBOL program.

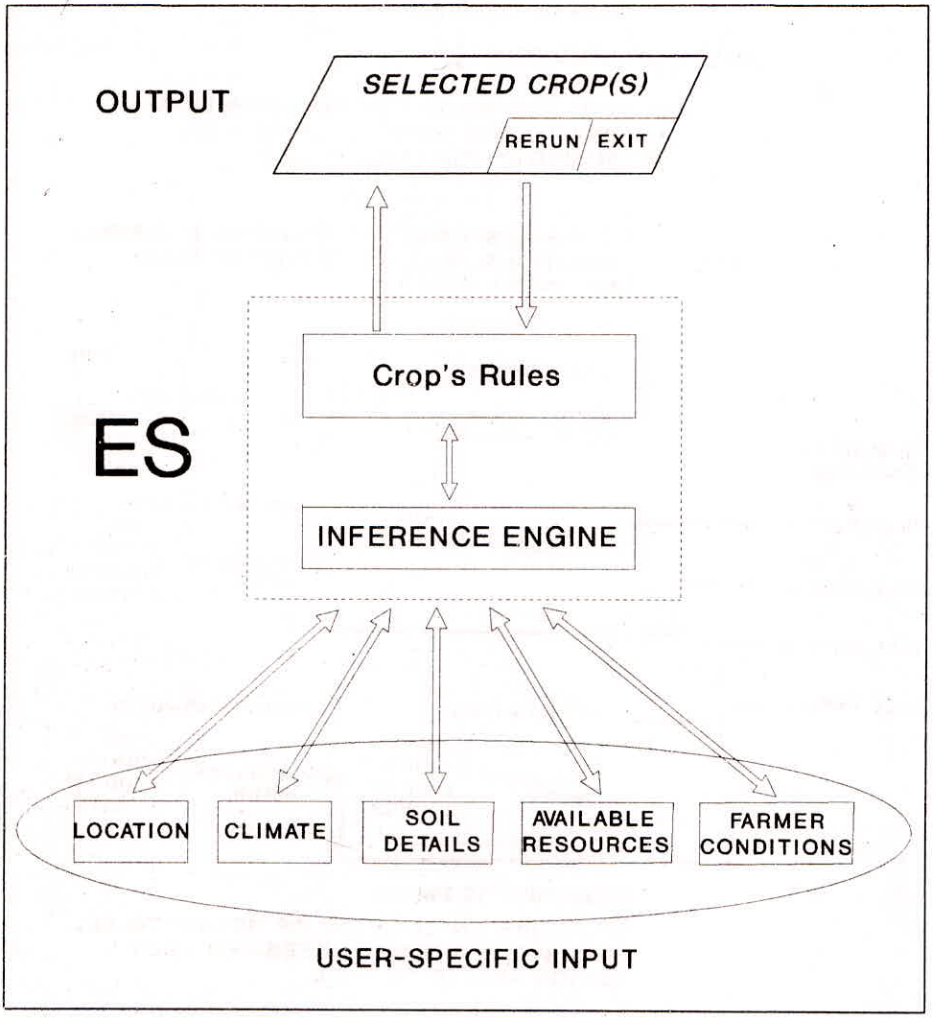


Fig. 4.12 Basic structure of the expert system for crop selection.

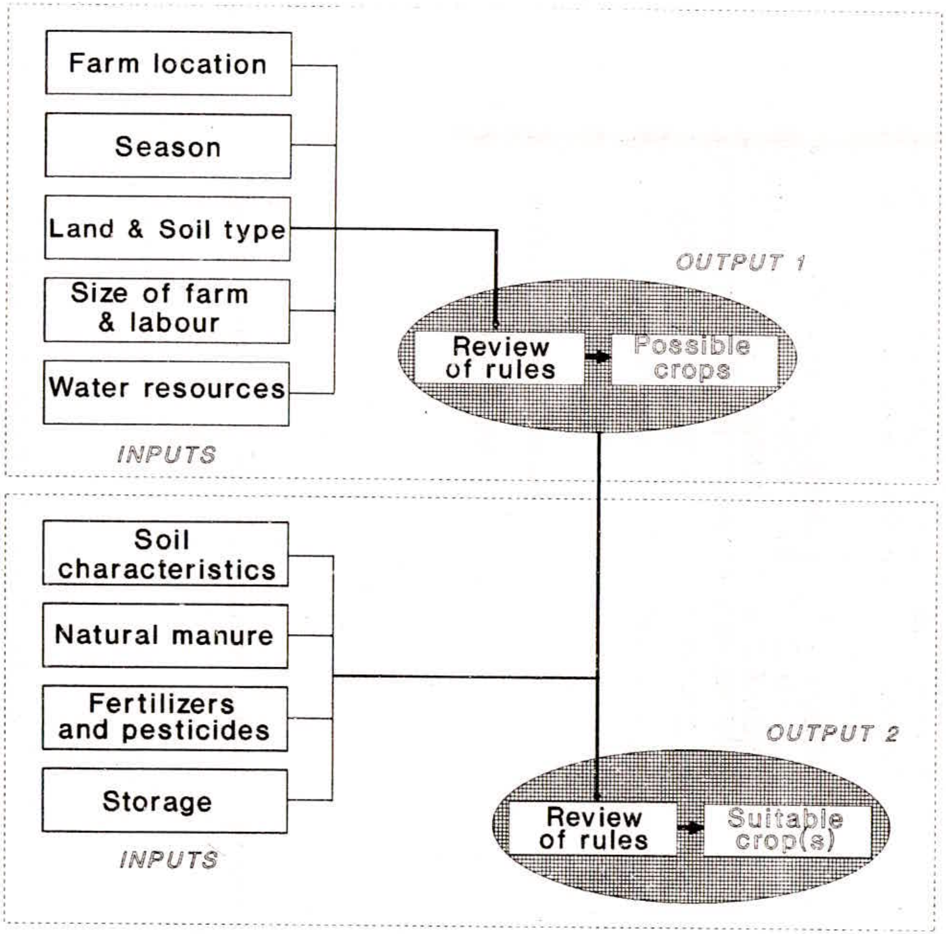


Fig. 4.13 Two levels of crop selection.

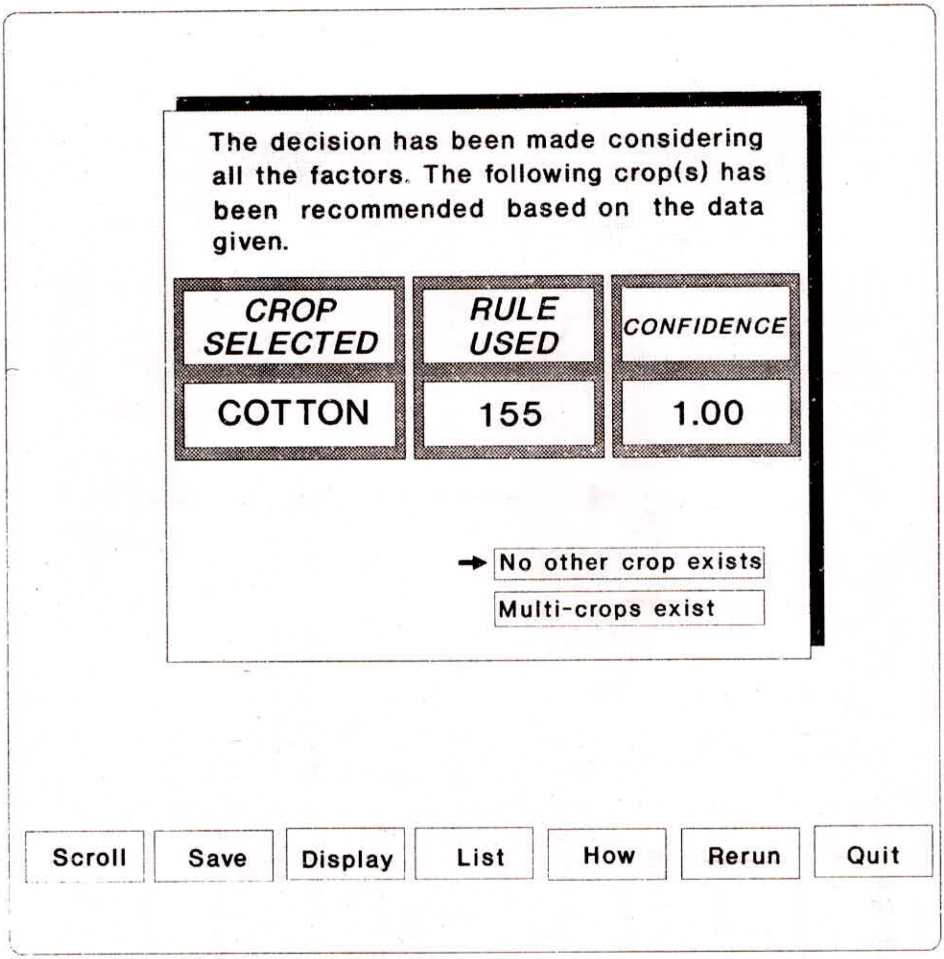


Fig. 4.14 Screen output of CROPES consultation.

CHAPTER 5

CONCLUDING REMARKS

This report presents the development and use of expert systems for water resources management. The important domains for which expert systems have been developed are water resource systems design and planning, reservoir operation, drought management flood control and irrigation management. A summary of the expert systems developed at the Hydraulic and Water Resources Engineering Division of the Department of Civil Engineering, Indian Institute of Technology, Madras, India is briefly provided in the report. The expert systems developed at this division were attempted for the following tasks: flood plain management, crop planning under droughts, optimal reservoir operation, city water supply planning, crop selection, and irrigation water management.

Given the complexity of water resource management, the reliance on experience and experts is obvious. A mere application of systems analysis tools may not aid the system operators satisfactorily without incorporating the experience base. It is found that expert systems are appropriate means of rendering optimization models more useful to the water managers. The other advantages of the application of the ES technique to water resources management are: a saving of the expert's time; increased understanding of the system; reliability of the decisions; and useful training capability for the engineer/ manager.

Based on the experience gained by the authors, it is felt that the ES technique is capable of supporting all aspects of water management. Hence, it is recommended to expand this technique to other domains for which elegant decision tools are not available. Empirical evaluation has been carried out to check the effectiveness of the developed expert systems. It is also important to conduct a practical evaluation by implementing the developed expert systems for decision-making by the water managers. This practical evaluation would be useful to ameliorate the capabilities of an expert system.

It is also suggested that the expert systems can be advantageously made as decision support systems by integrating various numerical models for effective decision-making. It would be of great interest if the expert systems are linked with other modern techniques such as artificial neural networks and geographical information systems.

REFERENCES

Akoundi, K. and M. Karamouz, "A rule based expert System for reservoir operation". *In*: Critical Water Issues and Computer Applications, ASCE, New York, June 1988.

Allen, W.P. (1986). "An expert system for water quality assessment". M.Sc. Thesis, University of Waterloo, Waterloo, Ont., Canada.

Anderson, R.L. and Maass, A. (1974). "A simulation of irrigation systems." Technical Bulletin No. 1431, Dept. of Agri, Economic Research Center, Harvard University, USA.

Antunes, M., Seixas, M., Camara, A. and Pinheirso, M. (1987). "New methods for qualitative simulation of water resources systems." Water Resources Research, 23(11), pp.

Baffaut, C. and Delleur, J.W. (1989). "Expert system for calibrating SWMM". J. Water Resources Planning and Management, ASCE, Vol.115, No.3, pp. 278-298.

Bhatty, M. (1990). "Hybrid expert system and optimization model for multi-purpose reservoir operation." Ph.D Thesis, Dept of Civil Engg., Colorado State University, Ft. Collins, CO, USA.

Brachman, R.J. (1983). "What are expert systems." *In*: Building expert systems. F. Hayes-Roth, W.A. Waterman, and D.B. Lenat, eds. Addison-Wesley Inc., Reading, Mass., pp. 31-57.

Central Water Commission, (1988). Water resources in India. Central Water Commission Pub. No. 30/88, New Delhi, India.

Chakraborthy, A.K. and Roy, P.S. (1979). "Influence of droughts on ecosystems as observed from Landsat". Proc. International Symp. on Hydrological Aspects of Droughts, National Committee for the International Hydrological Programmes, New Delhi, Vol.I, pp. 47-66.

Clarke, N.D., Tan, C.S., and Stone, J.A. (1992). "Expert system for scheduling supplemental irrigation for fruits and vegetable crops in Ontario." Can. Agri. Engg., Vol.34, pp. 27-31.

Clarke, R.T. (1977)." Mathematical models in hydrology". Irrigation and Drainage Paper No. 19, Food and Agricultural Organization of the United Nations, Rome, Italy.

Clarkson, C. and Hartgan, J. (1989). "Expert system approach to water supply management decisions". In: Computer applications in Civil Engg., ASCE, New York.

Cuena, I. (1983). "The use of simulation models and human advice to build an expert system for the defense and control of river floods". Proc. Eight IJCAI, 246-249.

Dotan, R.O. and Willer, D.C. (1986). "Instant hydro forecasting." ASCE Civil Engineering, Vol.56, No.8, pp. 60-63.

Duda, R., Gashnig, J. and Hart, R. (1979). "Model design in the PROSPECTOR consulting system for mineral exploration." *In*: Expert Systems in the Microelectronic Age, D. Michie, (ed.), Edinburg Univ, Press., Edinburg, UK.

Engman, E.T., Rango, A. and Martinec, J. (1986). "EXSRM, an expert system for snowmelt runoff model (SRM). The third scientific assembly of the International Association of Hydrological sciences, Baltimore, MD.

Fayegh, A.D. (1985). "Flood advisor: an expert system for flood estimation.", M.Sc. Thesis, The University of British Columbia, B.C.

Farley, D., Sydor, M., and Brown,G. (1988). "Heuristics and network algorithms for multi-reservoir system regulation", *In*: J. Labadie, et al. (eds.), Computerized decision support systems for water managers, ASCE, New York, June 1988.

Fischer, H. and Schultz, G.A. (1991). "An expert system for real-time operation of a multi-purpose multi-unit reservoir system". Proc. of the Vienna Symp. on Hydrology of Natual and Manmade Lakes, IAHS Publ. No. 206, pp. 151-157.

Findikaki, I.T. (1986). "An expert system for site selection." *In*: Expert systems in Civil Engineering, American Society of Civil Engineers, New York, pp. 57-61.

Floris, V., Simons, D., and Simons, R. (1988). "Development of an expert system for Mark Twain reservoir operation". *In*: Computerized decision support system for water managers, ASCE, New York, June 1988.

Gashing, J., Reboh, R. and Reiter, J. (1981). "Development of a knowledge-based expert system for water resource problems". Final Report, Project 1619, SRI International, Menlo Park, CA.

Goforth, G. and Macvicer, T. (1988). "An operations adviser for regional water management". *In*: Critical Water Issues and Computer Applications, ASCE, New York, June 1988.

Haie, N. and Irwin, R.W. (1988). "Diagnostic expert systems for land drainage decisions." Irrigation and Drainage Systems, Vol.2, No.2, pp. 139-146.

HEC-2 (1981). Water surface profiles User's Manual. Hydrological Engineering Centre, US Army Corps of Engineers, Davis, California.

Hershauer, J., Karim. A., Owens, H., and Philipakis, A. (1989). "A field observation study of an expert system prototype development." Information and Management, Vol.17, pp. 107-116.

INSIGHT (1985). INSIGHT 2: User's Manual. Level five Research Inc., Indialantic, Fla., USA.

Kumar, R. and Pathak, S.K. (1989). "Optimal crop planning for a region in India by conjunctive use of surface and ground water." Water Resources Development, Vol.5, No.2, pp. 99-105.

Labadie, J.W. and Sullivan, C.H. (1986). "Computerised decision support systems for water managers, Journal of Water Resources Planning and Management, ASCE, Vol.112, No.3, pp. 299-307.

Lemmon, H.E. (1986). "COMAX: An expert system for cotton crop management." Science, Vol.233, pp. 29-33.

LEVEL 5 (1990). LEVEL 5 object User's guide. Information Builders Inc., New York.

Loucks, D.P., Kindler, J. and Fedra, K. (1985). "Interactive water resources modelling and model use: An overview". Water Resources Research, Vol.21, No.2, pp. 95-102.

Loucks, D.P., Stedinger, J.R., and Haith, D.A. (1981). "Water resources systems planning and analysis". Prentice-hall, Inc., Englewood Cliffs, New Jersey.

Martin, M., ed. (1985). "Expert systems 85". *Proc.* Fifth Technical Conf. of the British Computers Society, Cambridge Univ. Press, Cambridge, UK.

McDermott, J. (1981). "R1: The formative years". Artifical Intelligence, Vol.2, No.2, pp. 10-50.

Mistry, J.F. (1992). "Water budgeting in irrigation management." Journal of Indian Water Resources Society, Vol.12, No. 3/4, pp. 138-143.

Mohan, S. and Rangacharya, N.C.V. (1988). "Drought identification using streamflow". Proc. International Seminar on Hydrology of Extremes, New United Publ., New Delhi, pp. 343-357.

Nagy, A., Barlishen, K., Burn, D.H. and Simonovic, S.P. (1989). "Toward an expert system for improving the operations planning in Manitoba Hydro." Water Resources Planning and Management, Proc. 16th Annual Conf., Edited by S.C. Harris, Amer. Soc. of Civil Engineers, New York, pp. 477-481.

Nakamura, R. and Tsukiyama, H. (1992). "Analysis by an expert system of initial irrigation canal renovation project planning". Water Resources Management, Vol.6, pp. 223-233.

Nebendahl, D. (1988). "Expert systems: Introduction to technology and applications". John Wiley & Sons Ltd., London, UK.

Nodal Centre on Expert Systems. (1990). IITM RULE User's Manual, Dept. of Computer Science & Engg., Indian Inst. of Technology, Madras.

Oswald, O. (1990). "An expert system for the diagnosis of tank irrigated systems: a feasibility study." Ph.D. Thesis, Anna Univ., Madras, India.

Palanisami, K. and Easter, K.W. (1983). Tanks of south India: A potential for future expan-sion in irrigation. Economic Report ER83-4, Dept. of Agri. and Applied Economics, University of Minnesota, St. Paul, USA.

Palmer, R.N. and Holmes, K.J. (1988). "Operational guidance during droughts: expert system approach." Journal of Water Resources Planning and Management, ASCE, Vol.1, No.4, pp. 284-297.

Palmer, R.N. and Tull, R.M. (1988). "Expert system for drought management planning". Journal of Computing in Civil Engg., ASCE, Vol.1, No.4, pp. 284-297.

Paperback Software (1987). VP-EXPERT: Rule-based expert system development tool. Paperback Software Inc., Berkeley, Calif., 218 pp.

Plant, R.E., Horrocks, R.D., Grimes, D.W. and Zelinski, L.J. (1992). "CALEX/Cotton: an integrated expert system application for irrigation Scheduling." Trans. of the ASAE, Vol.35, No.6, pp. 1833-1838.

Prasad, R. (1979). "Rainwater harvesting in India and Middle East". UNEP Report, Dept. of Civil Engg., Indian Institute of Science, Bangalore.

Raban, R.R. (1989). "Jenpeg Operations expert system (JOE)." Water Resources Planning and Management, *In*: Proc. 16th Annual Conf. Edited by S.C. Harris, Amer. Soc. of Civil Engineers, New York, pp. 473-477.

Roukani,S. and Kangari, R. (1987). "Expert systems in water resources." *In*: Water for the future: Hydrology in Perspective, IAHS Publ. No.164, pp. 457-462.

Russell, S.O. (1989). "The design process-insights from expert system development." *In*: Proc. Fourth Canadian Seminar on Systems Theory for the Civil Engineer. Department of Civil Engg., The Univ. of Manitoba, Winnipeg, pp. 2-8.

Savic, D. and Simonovic, S.P. (1988). "A pilot intelligent decision support system for reservoir analysis". *In*: Computerized decision support systems for water managers, ASCE, New York, June 1988.

Shortliffe, E.H. (1976). "Computer-based medical consultations: MYCIN." American Elsevier.

Simonovic, S.P. (1990). "An expert system for the selection of a suitable method for flow measurement in open channels." Journal of Hydrology, Vol.112, pp. 237-256.

Simonovic, S.P. (1991). "Knowledge-based systems and operational hydrology". Canadian Journal of Civil Engg., Vol.8, pp. 1-11.

Srinivasan, R., Engel, B.A., and Paudyal, G.N. (1991). "Expert system for irrigation management (ESIM)." Agricultural Systems, Vol.36, pp. 297-314.

Swayne, D.A. and Fraser, A.S. (1986). "Development of an expert system/intelligent interface for acid rain analysis." Microcomputers in Civil Engineering, Vol.1, pp. 181-185.

Vedula, S. and Mohan, S. (1990). "Real-time multi-purpose reservoir operation: A case study." Hydrological Sciences Journal, Vol.35, No.4, pp. 447-462.

Waterman, D.A. (1986). "A guide to expert systems". Reading, Mass., Addison-Wesley Publ. Co., Inc.

Yakowitz, S. (1982). "Dynamic programming applications in water resources." Water Resources Research, Vol.4, pp. 673-696.

Yeh, W.W.G. (1985). "Reservoir management and operation models: A state-of-the-art review." Water Resource Research, Vol.21, No.12, pp. 1797-1818.

PUBLICATIONS

1. Mohan, S. and Arumugam, N (1992). An Expert System for Flood Plan Management Proc. Int. Symp on Environmental Hydraulics, Honkong, Vol. II, 1521-1526.
2. Raman, H., Mohan, S. and Bhaskaran, M. (1992). An Expert System for Water Supply Management. Proc. Int. Conf. on Hydraulic Research Vol. I, A153-A166.
3. Elango, K., Honert, R. Nagaraju Kumar, C. Suresh, V. (1992). Based Management Game for Irrigated Farming. Microcomputers in Civil Engineering, Eserver Schiences Pub. Ltd., 7(3), 243-256.
4. Mohan, S. and Arumugam, N. (1992). An expert system for irrigated crop management. In: Proc. of the Int. Conf. on Hydraulic Engg. Software - HYDROSOFT'92, held at Valencia, Spain, Computational Mechanics Pub., Inc., pp. 481-491.
5. Raman, H., and Sunil Kumar, N. (1993). Expert System for Reservoir Operation Jalvigyam Sameksha (Hydrology Review), Indian National Committee on Hydrology, Roorkee, 8(1), 63-77.
6. Raman, H., Mohan, S. and Bhaskaran, M. (1993). Decision Support System for Water Supply Management, Proc. Int. Symp. on Engineering Hydrology, Sanfransisco, California, 1060-1065.
7. Mohan, S. and Arumugam, N. (1994) CROPES. A rule based expert system for crop selection in India. Trans. ASCE, 34(4), 1355-1363.
8. Mohan, S. and Arumugam, N. (1994). A hybrid expert system for reservoir operation. Proc. Int. Symp. on Water Resources Planning in a Changing World Univ. of Karlruhe, Germany, pp. II92-II106.
9. Raman, H., Mohan, S. and Sethuraj, G. (1994). A Knowledge based decision support system for water distribution management. Proc. XIth Int. Conf. on Application of Artificial Intelligence in Engineering. Southampton, Boston, 157-163.

10. Mohan, S. and Arumugam, N. (1995). A hybrid expert system for operation of a small surface storage system. In: Proc. of the Int. IAHS Symposium in Modelling and Management of Basin-scale sustainable water resource systems, held at Univ. of Colorado, Boulder, USA, July 3-14, 1995, pp. 241-246.

11. Raman, H., Mohan, S., and Sunilkumar, N. (1995). Development of expert system for flood management. Journal of Institution of Engineers (india), Accepted.

12. Mohan, S. (1995). A knowledge-based expert system for operation of reservoir during droughts. Proc. National Seminar on Natural Hazards Mitigation, 5-8, Dec., 1995, Bangalore.

CONSTITUTION OF INDIAN NATIONAL COMMITTEE ON HYDROLOGY

i.	Chairman Central Water Commission, New Delhi	Chairman
ii.	Director National Institute of Hydrology, Roorkee	Executive Member
iii.	Dy. Director-General Geological Survey of India, Calcutta	Member
iv.	Chairman Central Ground Water Board, Faridabad	Member
v.	Dy. Director-General India Meteorological Department, New Delhi	Member
vi.	A Senior Scientist National Remote Sensing Agency, Hyderabad	Member
vii.	Member (D&R) Central Water Commission, New Delhi	Member
viii.	Director Research, Designs & Standards Organization, Lucknow	Member
ix.	Additional Director Indian Institute of Tropical Meteorology, Pune	Member
x	Director Central Designs Organization, Gujarat, Gandhinagar	Member
xi.	Chief Engineer (Design) Irrigation Department, U.P. Roorkee	Member
xii.	Director Central Designs Organization, West Bengal, Calcutta	Member
xiii.	Director BODHI, MP, Bhopal	Member
xiv.	Chief Engineer & Director Water Resources Development Organization, Karnataka Bangalore	Member
xv.	Chief Engineer Central Designs Organization, Maharashtra, Nasik	Member
xvi.	Dr. B.V. Rao Indian Institute of Technology, Mumbai	Member
xvii.	Dr. T. Prasad Director Centre for Water Resources Studies, Bihar College of Engineering, Patna	Member
xviii.	Dr. N.V. Pandarikanthan Director Centre for Water Resources, Anna University, Chennai	Member
xix.	President Indian Association of Hydrologists, Roorkee	Member
xx.	Director (R&D&SA) Central Water Commission, New Delhi	Member
xxi.	Senior Scientist National Institute of Hydrology, Roorkee	Member Secretary