Intelligent Decision Support and Reservoir Management and Operations

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Abstract: Reservoir management and operations are very complex activities in the field of water resources engineering. During the last two decades, a number of systems analysis techniques, particularly optimization and simulation, have been adopted for reservoir planning, design and operations. Recently, the area of knowledge-based engineering (expert systems) has emerged as a potential technique for incorporating human expertise and some degree of intelligent judgement into decision-supporting software. This paper presents the potential benefits of this technology in the area of reservoir management and operations. The presentation is illustrated with an example of an engineering expert system for reservoir analysis that is currently in development.

Introduction

Reservoirs are probably the most important elements of complex water resource systems. They are used for spatial and temporal redistribution of water quantity and quality. Also, reservoirs may change water's ability to generate hydropower. They are designed for flood control and for such conservation purposes as water supply (municipal, industrial, and irrigation), navigation, recreation, low-flow augmentation, and hydroelectric power. According to Yeh (1985), the most important advance made in the field of water resources engineering is the development and adoption of systems analysis techniques for the planning, design, and management of complex water resources systems. Many successful applications of optimization techniques have been made in reservoir studies. Some professional discussions indicate that a gap still exists between theory and application. One of the major complaints of water specialists is that their experience and understanding of the system is not properly incorporated into the models. Among the different problems encountered are that: (1) Two groups of specialists are involved in model creation (system analysts-modelers and water resources specialists); (2) the models are not tested on a variety of different physical situations often leaving the operators helpless; and (3) the interchange of knowledge between modelers and water specialists is often transient.

These facts have resulted in a number of publicized failures of the application of system analysis in the field (Hobbs et al. 1989; Office of Tech. 1982; Rogers and Barthelemy 1986; Wunderlich and Giles 1981). Reservoir management and operations is a complex task with uncertainty involved in the scientific aspects of the problem and judgmental elements involved in the sociopolitical aspects. Therefore, there is no ultimate objective way to find a best solution.

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Knowledge-based engineering or expert systems (ES) is a way to successfully build human expertise and some degree of intelligent judgment into decision-supporting software through artificial intelligence (AI) techniques. The concept of expert systems incorporates the water system expert as a key element in a modeling study (Labadie and Sullivan 1986). It has not yet been established how important are the improvements that expert systems can offer, but some practical experience has already been documented (Nagy et al. 1989; Raban 1989; Palmer and Holms 1988). A very careful evaluation that will quantify the effects in terms of monetary savings is in progress at the United States Bureau of Reclamation (J. D. Christopher, U.S. Bureau of Reclamation, personal communication, 1988).

Knowledge-based engineering is concerned with the representation of knowledge and with symbolic reasoning (Rich 1983; Winston 1984). There are a number of definitions of expert systems (Harmon and King 1985; Hayes-Roth et al. 1983; Waterman 1986), but the writers have derived one appropriate for the field of water resources: A water resources expert system is a computer application that assists in solving complicated water resources problems by incorporating engineering knowledge, principles of systems analysis, experience, intuition, and engineering judgement into the solution procedure.

Knowledge-based systems were brought to the attention of water resources civil engineers almost a decade ago (Kostem and Maher 1986; Maher 1987; SIR 1981). As indicated in Palmer and Tull (1987), such applications are suggested as appropriate and natural, since the discipline of water resources engineering contains numerous procedures developed from theory, actual practice, and "rules of thumb."

The emphasis of the present paper is on the demonstration of the benefits of knowledge-based system technology for reservoir management and operations. After a short review of water resources expert systems, the original concept for applying this technology will be presented. A discussion of reservoir problems and the possible benefits of the application of knowledge-based technology will follow. Finally, a description of the REZES (pilot intelligent decision support system for reservoir analysis) and a description of the experience gained to date will be presented.

Expert Systems in Water Resources

This section summarizes expert systems currently being developed in water resources engineering. It complements a recent survey article (Ortolano and Steinemann 1987) on new expert systems in environmental engineering and is only one element of the much more comprehensive review of Simonovic and Barlishen (1987). Most of the systems included present work in progress; many of the systems are not documented in the literature.

Table 1 lists characteristics of 13 knowledge-based systems. The main purpose of each system is summarized in the following.

HYDRO

HYDRO is an expert system designed to aid in determining appropriate numerical values for various parameters that describe the physical characteristics of a watershed. The values computed by HYDRO serve as input to the Hydrocomp HSPF simulation program for evaluating various hydrolog-

TABLE 1. Characteristics of Existing Expert Systems

Name (1)	Domain (2)	Software (3)	Hardware (4)	User (5)	Knowledge structure (6)	Contact (7)
HYDRO	Evaluation of parameters for HSPF model	INTERLISP	Mainframe	Hydrocomp Inc. U.S. Geological Survey	BNF	
FLOOD ADVISOR	Flow estimation		VAX	n/a	FRAMES	S.O. Russell, University of British Columbia
RAISON	Acid rain analysis	C	Micro	National Water Research Inst.	FRAMES	National Water Resources Inst., Burlington
HYSIZE	Hydroelectric site location	FORTRAN	VAX	Tudor Engrg. Co.	RULES	Tudor Engrg. Co., San Francisco
EXSRM	Calibration of SRM model	ART	Symbolics 3670	U.S. Agricultural Research Service	RULES	U.S. Agricultural Research Service
WATQUAS	Water quality assessment	C	VAX	Ontario Ministry of Environment	RULES	T. E. Unny, University of Waterloo
SISES	Site selection	PASCAL	Micro	n/a	n/a	RFT Associates
ARIANE	Hydro operation planning	Unknown shell	Mainframe	Hydro-Quebec	RULES	M. Hanscom, IREQ, Quebec
RRA	Administration of reclamation reform act	PC+	Micro	U.S. Bureau of Reclamation	RULES and FRAMES	K. Strzepek, University of Colorado
DMWW	Water wells design	PC+	Micro	U.S. Bureau of Reclamation	RULES and FRAMES	K. Strzepek, University of Colorado
WMS	Drought management	INSIGHT 2+	Micro	Seattle Water Department	RULES	R. Palmer, University of Washington
ESSEM	Flow measurement	PROLOG	Micro	Environment Canada, Water Res. Branch	RULES	P. Pelletier, Environment Canada
JOE	Operation of generating station	GEPSE	Micro	Manitoba Hydro	RULES	R. Raban, Manfitoba Hydro

ical aspects of the region of interest. The HYDRO system is intended to provide advice comparable to that of an expert hydrologist in selecting parameter values characteristic of the watershed under consideration. The domain-independent design of its general reasoning system permits HYDRO to be applied to numerical reasoning tasks in domains other than hydrology (SRI 1981).

FLOOD ADVISOR

Flood advisor is a computer-based consultant whose goal is to provide interactive advice about flow estimation under five generalized situations: (1) When a long period of streamflow record is available at or in the vicinity of the location of interest; (2) when a long period of record is available on the stream of interest, but the recording station is located some distance upstream or downstream of the location of interest; (3) when a short streamflow record is available on the stream of interest; (4) when no records are available on the stream of interest, but records are available for nearby streams in the region of interest; and (5) when no streamflow records are available for the region. FLOOD ADVISOR is designed to provide advice for each case (Fayegh 1983).

RAISON

RAISON is a system developed for the analysis of acid rain data. RAISON is designed to examine the relationships between the terrain sensitivity index, which assesses susceptibility to acid deposition according to geologic and soil factors, and the resultant aquatic chemistry (Swayne and Fraser 1986).

HYSIZE

HYSIZE and its simple modification HYSTOR are systems for determining the optimum layout for a particular hydroelectric site. HYSIZE is designed for run-of-river type projects and HYSTOR for sites with reservoir storage. The systems are able to rank alternatives in order of economic priorities and to test the sensitivity of assumed variables, such as fish release (Dotan and Willer 1986).

EXSRM

EXSRM is a system designed to provide assistance in estimating the parameters of a snowmelt-runoff model (SRM). SRM is a simulation model for daily streamflow forecast in a mountain river basin. It requires satellite data on snow cover, daily temperature, and precipitation, as well as other parameters that are not directly measurable, e.g., degree-day factor, lapse rate, runoff coefficient, recession coefficient, and time lag. EXSRM is designed to provide the expertise necessary for estimating the appropriate values for these parameters (Engman et al. 1986).

WATQUAS

WATQUAS is an expert system for extracting knowledge from a large quantity of available historical water quality data and interpreting it in a useful form. Interpretation is a very ill-defined procedure and resists modeling using numerical methods. WATQUAS is a prorotype system that provides: (1) A user-friendly interface to water quality data; (2) an interpretation of historical data; and (3) a planning tool based on expert water quality assessment (Allen 1986).

SISES

SISES is an expert system used for decision making about site selection for specific uses. SISES is designed to provide the expertise of decision-makers without making any a priori assumptions about their preferences, background, or identity. This system gives advice concerning the first phase of site selection, i.e., selecting a number of sites from the available alternatives prior to further evaluation in the second phase (Findikaki 1986).

ARIANE

ARIANE is an intelligent decision-support tool in development at Hydro-Quebec. It is intended to provide a user's guide to the multiannual operation-planning process. It will monitor: (1) Systematic updating and validation of data; (2) intermodel data consistency; (3) the use of heuristic knowledge; and (4) the calling sequence of interdependent mathematical models (M. Hanscom, Hydro-Quebec, personal communication, 1987).

RRA

RRA is an expert system for the administration of the acreage-limitation provision of the Reclamation Reform Act of 1982. The RRA expert system is designed for the U.S. Bureau of Reclamation to ease the workload in the Acreage Limitation Division by providing a mechanism by which the agency personnel or landholders themselves can determine the status of the landholder, as well as the number of acres on which subsidized reclamation water can be received (K. Strzepek, University of Colorado, personal communication, 1987).

DMWW

DMWW is an expert system for designing a municipal water well (DMWW). The system was designed for the Groundwater and Drainage Branch of the U.S. Bureau of Reclamation. The main design objectives were: (1) To create a tool to assist the bureau personnel in the design of water wells (municipal wells, water storage wells, observation wells, and dewatering wells); (2) to capture the bureau expertise in an area of specialization that would be hard to replace; and (3) to develop an expert system that is contained within a PC environment, which allows easy access to the program by bureau field personnel (K. Strzepek, University of Colorado, personal communication, 1987).

WMS

WMS is an expert system designed to evaluate and display information on drought-management planning. A linear programming model is used to generate optimal operating policies as a function of numerous past drought experience. These policies are incorporated into an expert system, and the user is required to identify the degree to which the current drought situation is similar to past events. The system is designed to be operated by the Seattle Water Department system managers to aid them in the complex decisions required to initiate water-use restrictions (Palmer and Tull 1987).

ESSEM

ESSEM is an expert system prototype for the selection of a suitable method for flow measurement in open channels. ESSEM is designed to help select

the optimal flow measurement method for a particular streamflow gaging station, considering a number of factors such as the capital available, the size of the river, the range of flow, ice condition, etc. The system takes into account the uncertainty involved in streamflow measurement (P. Pelletier, Environment Canada, personal communication, 1987).

JOE

JOE is an expert system designed to aid in operations of the Jenpeg generating station in Manitoba, Canada. Manitoba Hydro's Jenpeg generating station is located near the outlet of Lake Winnipeg into the Nelson River system. During the freeze-up period, Jenpeg is often presented with problems caused by ice blocking the trash racks and cooling water intakes. The operation of Jenpeg during the freeze-up period is very complex, involving many judgement calls. JOE is designed to provide the expertise of the Manitoba Hydro staff in operating the Jenpeg station during the freeze-up period (Maxfield 1987).

The review of the presented material and the numerous personal communications of the first writer with researchers in the field leads to the following conclusions:

1. Even though knowledge-based systems were brought to the attention of civil engineers about ten years ago (SRI 1981), all the work that is going on in water resources engineering is in its initial phase. A number of successful pilot systems clearly indicate the potential benefits of this emerging technology in water resources.
2. Almost all of the mentioned research projects are single-problem oriented. This conclusion was expected, since the variety of problems, techniques used for their solution, and different levels of complexity precludes the development of a general expert system approach for water resources engineering.
3. All the reported applications are single programming-tool oriented. In most cases, the high cost of the commercial tools and/or a lack of the knowledge necessary to create the tools has prevented adequate testing of the chosen programming tool for a particular application. Considering the wide choice of available tools, the question of assessing the effectiveness of a particular tool for a particular application becomes very important. A recent publication from RAND Corporation (1988) specifies some criteria for proper tool assessment.
4. The initial application of the new technology is showing a positive reaction between potential users and experts involved in the development of knowledge-based systems. The experts are becoming the key elements in any expert system development. Recent personal experience of the first writer (Nagy et al. 1989; Raban 1989) in working with specialists from Manitoba Hydro clearly indicate that experts are becoming more supportive of expert system technology and more interested in transferring their experties. Experience documented by Palmer and Holmes (1988) with the Seattle Water Department and communication with the U.S. Bureau of Reclamation also show a positive reaction of users and experts in the field. Inexperienced users are becoming exposed to powerful training tools. Due to a downward trend in most government funding, many agencies are facing an "expertise crisis" (experienced engineers are retiring and new hirees need time to gain valuable experience) that may be partially alleviated by the application of this new technology.
5. All the water resources applications of expert systems presented demon-

strate multiple benefits that will be discussed in the following section.

6. Through the initial efforts to bring expert system technology into water resources engineering, a better understanding of new technology has been developed by engineers in the field.

7. All the applications indicate a high involvement of engineers in understanding and using expert system tools.

8. The assessment of different tools for different engineering problems is essential (Firdman 1987; Ludvigsen et al. 1986; Maher 1987; Ortolano and Perman 1987).

9. The investigation of knowledge structure and representation is of great importance for successful application of the knowledge-based system technology (Williamson 1987).

The benefits of knowledge-based technology with regard to water resources engineering illustrated in the presented applications are in: (1) Expertise transfer; (2) saving the expert time; (3) helping inexperienced users in gaining experience; (4) providing better understanding of engineering problems; (5) helping in the process of problem formulation and solution; and (6) a better interpretation of solution results.

From the research conclusion and practical results, knowledge-based technology is apparently taking an important place in water resources engineering. The role of quantitative analysis, optimization, judgment, and computers in engineering planning, design, and operations can be expanded by adopting some of the notions of knowledge-based engineering.

Engineering Expert System Approach

The approach that is used in the research presented in this paper is different from classical knowledge engineering (KE) procedures. Standard KE involves communication between the expert and a knowledge engineer (a new profession emerging from AI) in creating a knowledge base (one of the basic components of ES, wherein the knowledge about a particular domain, or problem, is stored). It is considered the major design procedure for building an ES. In the engineering expert system approach (EES) currently used at the University of Manitoba, as shown in Fig. 1, the knowledge engineer is replaced with an engineer in the field of interest (domain) who has additional knowledge about ES techniques. Unique expertise in the engineering field is thus combined with knowledge about ES technology in an efficient manner. After the recent Engineering Foundation meeting in Santa Barbara, California, it appears that similar approach to EES is widely accepted within the different subdisciplines of civil engineering. In contrast to traditional ES research, where the focus is on general procedures and frameworks, in this approach, the research concentrates on the application and development of ES technology as it directly relates to the specific engineering field appropriate to the particular problem environment.

The EES approach is embedded in the intelligent decision-support concept shown in Fig. 2. This concept links together four basic elements of general engineering planning, decision, and operations procedures: engineering expertise; a systems approach; computer graphics; and expert systems. As such, this concept becomes very similar to the hybrid model-based decision-support approach (Fedra et al. 1986). The concept envisions engineers as the

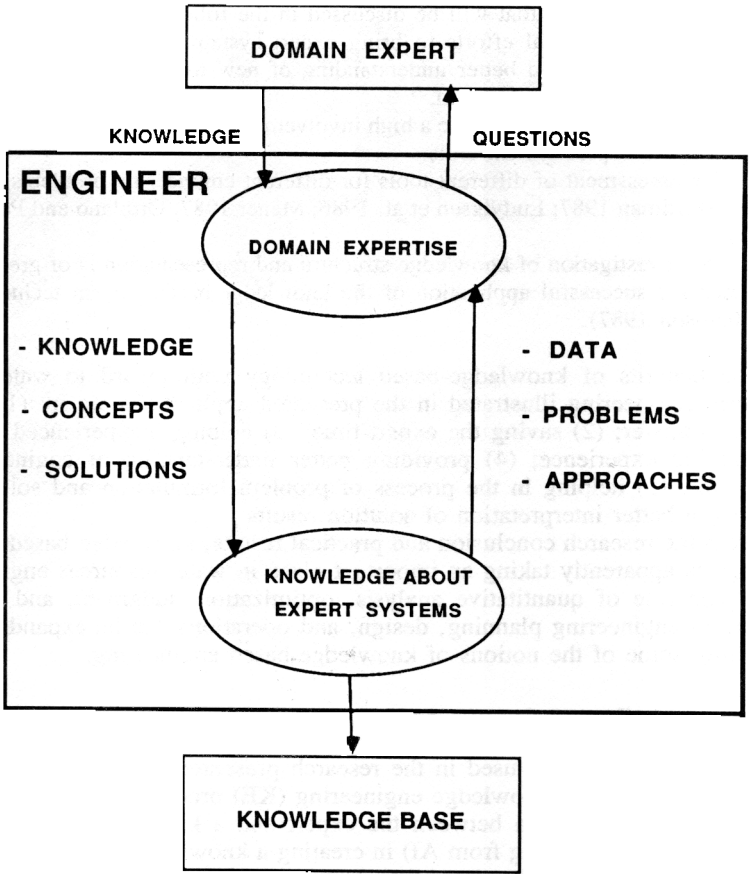

FIG. 1. General Engineering Expert Systems Approach

potential users of the software system as well as the decision and policy makers. In this environment, the computer is seen as a link and translator between the expert and the decision maker, between science and policy. Therefore, the computer is not only a tool for analysis, but a vehicle for communication, training, and experimentation. The major strength of this concept is that the products are application- and problem-oriented rather than methodology-oriented. In this way, AI technology through EES is combined with more classical techniques of engineering analysis, data processing, and systems analysis.

There are numerous engineering applications where the addition of heuristics (small knowledge bases) to an existing set of models may considerably extend the program's power and usefulness and at the same time make it much simpler to use.

Reservoirs and New Technology

Most modern reservoirs are multipurpose in nature. Storage is allocated

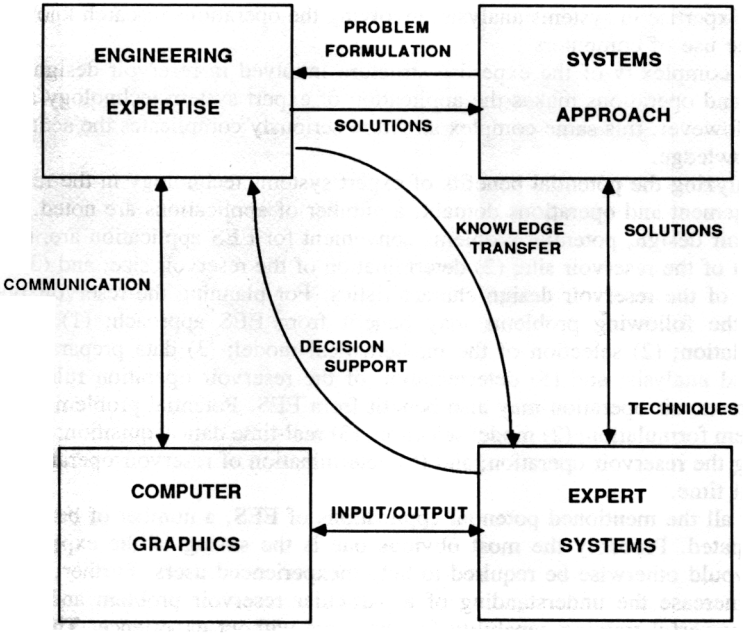

FIG. 2. Intelligent Decision Support Concept

for a number of functional uses. These uses are often incompatible and as such require that compromises be made. The storage of water for various functional uses requires either a surface or an underground reservoir to provide needed capacity. Records of historical streamflows or synthetic records are used to determine inflows to surface reservoirs, and the operating rules for the reservoirs are used to set the releases based on estimated demands.

A major purpose of a reservoir is to stabilize (regulate) the flow of the intercepted river. This is accomplished by permitting impoundment of water during periods of high flow so that these flows can be saved for later release during the lower flow periods. Operation studies are conducted to determine the capacity of a proposed reservoir, or to determine the reservoir operating rules. Real-time reservoir operation concerns the optimal operation of an existing reservoir system.

Mathematical programming methods (optimization and simulation) are used to solve the three reservoir problems usually addressed in the literature as: (1) Reservoir sizing; (2) reservoir planning; and (3) real-time reservoir operation.

Expertise involved in reservoir design, planning, and operations may be classified in three categories:

1. Engineering expertise, involving a wide range of experts in such fields as hydrology, hydraulics, structural design, engineering economics, and geotechniques.
2. Modeling expertise necessary for problem formulation, definition of goals, determination of objectives, and evaluation of constraints.

3. Expertise in systems analysis, involving the operations research knowledge and the use of computers.

The complexity of the expertise structure involved in reservoir design, planning, and operations makes the application of expert system technology appealing. However, this same complex structure seriously complicates the acquisition of knowledge.

Analyzing the potential benefits of expert systems technology in the reservoir management and operations domain, a number of applications are noted. In the reservoir design, potential problems convenient for EES application are: (1) Selection of the reservoir site; (2) determination of the reservoir size; and (3) evaluation of the reservoir design characteristics. For planning the reservoir operation, the following problems may benefit from EES approach: (1) Problem formulation; (2) selection of the mathematical model; (3) data preparation; (4) demand analysis; and (5) determination of the reservoir operation rules. Real-time reservoir operation may also benefit from EES. Potential problems are: (1) Problem formulation; (2) model selection; (3) real-time data acquisition; (4) monitoring the reservoir operation; and (5) determination of reservoir operation rules in real time.

For all the mentioned potential applications of EES, a number of benefits are anticipated. Probably the most obvious one is the saving of the expert's time that would otherwise be required to help inexperienced users. Further, the EES may increase the understanding of a particular reservoir problem and provide very powerful training capability for the users without experience. The special structure of EES (knowledge base, inference engine, working memory, and user interface) is very helpful in problem formalization and solution. EES and computer graphics will make a considerable difference in the interpretation of solution results. Using all the benefits of the EES approach may help in dealing with complex reservoir problems involving uncertainty, multireservoir systems, and multipurpose reservoir use.

Intelligent Decision Support System for Reservoir Analysis—REZES

Computers are widely used in the field of optimal decision making for reservoir design, planning, and operations to carry out the complex numerical calculations involved. REZES is designed to illustrate how the role of mathematical modeling and computers can be expanded by adopting some of the notions of knowledge engineering. The system formulates the reservoir mathematical problem from a pseudo-English description into canonical algebraic expressions. It then recognizes the formulation and selects an appropriate algorithm for their solution. After the selection, the system assists in running the selected model and interpreting the final results. Similar attempts were made by Rogers and Barthelemy (1986) and Balachandran and Gero (1987) in using expert system technology for choosing the best general-purpose optimization program and multicriteria optimization methodology, respectively.

This section of the paper will provide only general information about the REZES system. A detailed presentation is given in Savic and Simonovic (1988). The reservoir analysis is divided into three major phases: (1) Problem formulation and model selection; (2) data preparation and computation; and (3) interpretation and evaluation of results.

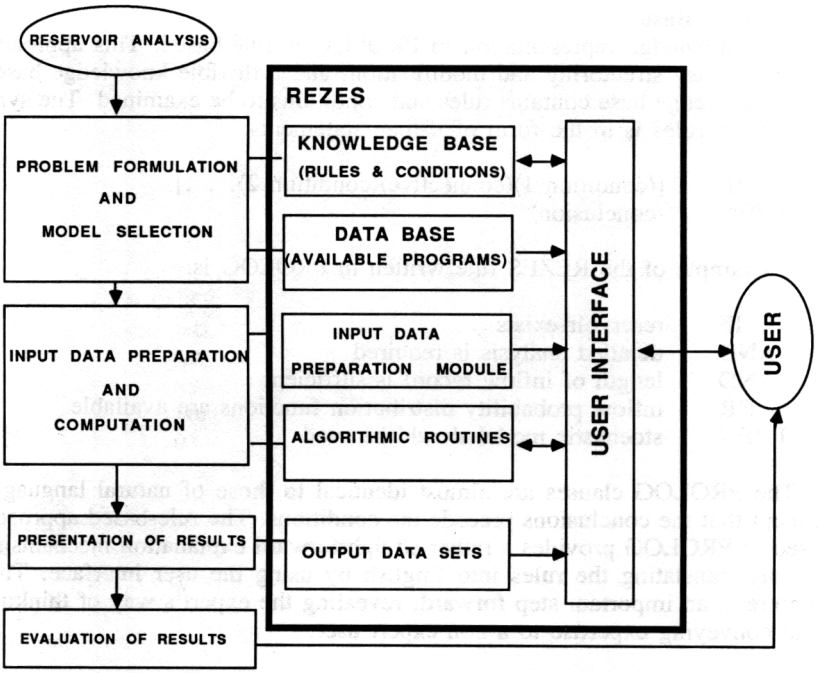

FIG. 3. REZES Architecture

REZES is an interactive, menu-driven consultation program designed as an advisory tool for reservoir analysis. For the initial phase of the development, REZES is used to examine several important advantages of knowledge-based technology over the classical procedural approach for water resources engineering. The most important issues studied are: (1) Capabilities of the PROLOG language for symbolic and numerical computation; (2) communication of systems written in PROLOG with programs written in one of the conventional programming languages; and (3) the frequency and interactive nature of the REZES use.

The major components of the REZES system are the user interface, the knowledge base, the program library, the input data preparation module, the algorithmic routines, and the output data presentation module. A schematic presentation of REZES architecture is shown in Fig. 3.

User Interface

Communication between the user and the REZES knowledge base is maintained through the user interface. This enables the user to provide REZES with necessary information about the problem being analyzed and allows REZES to explain to the user the reasoning employed in problem formulation. In using this component, the user answers questions posed by the system. The system uses the answers to build a formulation for the problem, to select the appropriate model, and to prepare necessary data for solving the problem.

Knowledge Base

The knowledge representation in PROLOG is rule-based. This approach provides easy structuring and modification, and a flexible knowledge base. The knowledge base contains rules and conditions to be examined. The syntax of the rules is in the form of if-then statements:

```
  IF    [⟨condition 1⟩⟨connective⟩⟨condition 2⟩.    ]
THEN    ⟨conclusion⟩
```

One example of the REZES rule written in PROLOG is:

```
  IF    reservoir exists
 AND    detailed analysis is required
 AND    length of inflow record is sufficient
  OR    inflow probability distribution functions are available
THEN    stochastic model should be used
```

The PROLOG clauses are almost identical to those of natural language, except that the conclusions precede the conditions. The rule-based approach used in PROLOG provides a rather straightforward explanation mechanism, simply translating the rules into English by using the user interface. This feature is an important step forward, revealing the expert's way of thinking and conveying expertise to a non-expert user.

Program Library

At the present level of development, five reservoir models are included in REZES:

1. RESER, a deterministic simulation-optimization model for sizing a multipurpose reservoir storage.
2. ILP, an iterative linear programming model for planning the monthly reservoir hydropower production over the year.
3. CCCP, a multipurpose reservoir chance-constrained model for planning the monthly reservoir operation over the year.
4. RPORC, a stochastic reliability programming model for planning the monthly operation of multipurpose reservoir.
5. PROFEXY, a real-time multipurpose reservoir operation model with a daily time step.

Input Data Preparation Module

In order to run the mathematical model selected from the program library, REZES provides advice on preparation and interactive data input. This part of the task is carried out through the data input and preparation module. This module provides an explanation, examples, and the correct format for each input variable.

Algorithmic Routines

At this development level, REZES contains five models used for reservoir analysis. One for the reservoir design problem, three for the planning of reservoir operation, and one for real-time reservoir operation. All the models are written in FORTRAN and have a comprehensive structure.

```
REZES
Welcome to REZES - a prototype Intelligent Decision Support System for Reservoir Analysis

                                                  Consultation
                                                  Load Knowledge
Good advice for a new user:                       Save Knowledge
   - Choose the option 'Help Information' in order List Knowledge
     to obtain information about the starting     Erase Knowledge
     procedure.                                   Edit Knowledge
                                                  Help Information
                                                  DOS Shell
                                                  Exit REZES

Select option with arrow key
```

```
REZES
Is it true that reservoir is existing: no
Is it true that the historical record of inflows is available: yes
Is it true that the length of the record is more than 30 years: yes
Is it true that the inflow time step is a month: yes
Is it true that you require a preliminary analysis: yes
Is it true that you know physical characteristics of the reservoir (min/max) storages: no
Is it true that you know reservoir target releases li.e. demands): yes
Is it true that you have a power production as a demand: no
EXPLANATION OF THE REASONING
It may be concluded that: your model is RESER
By using rule number 19

Rule 19: your model is RESER
if not reservoir is existing
and the historical record of inflows is available
and the length of the record is more than 30 years
and not you have a power production as a demand

F2: Go to line   F3: Search   S-F10: Resize Window   F10:End
```

FIG. 4. First and Second Screens for Presentation of REZES

RESER

RESER, a program for sizing the multipurpose reservoir, is a simulation-optimization model. Using the inflow sequences (historical in deterministic mode or generated in implicit stochastic mode) and the water requirements from the reservoir, RESER determines the size of conservation storage that satisfies four reliability and vulnerability criteria (Simonovic 1985).

ILP

ILP, the iterative linear programming algorithm, maximizes the value of the hydroenergy generated and the expected future returns represented by water left in storage at the end of the planning period (Gryger and Stedinger 1985; Savic 1987).

CCCP

CCCP uses a two-step algorithm for solving the stochastic multipurpose single-reservoir planning problem (Simonovic 1979). First, the chance constraints are transformed into their deterministic equivalents. The linear programming model is then used to find the optimal release policy.

RPORC

RPORC is a stochastic reservoir-planning algorithm based on the reli-

```
REZES
INPUT DATA PREPARATION
You are going to prepare input data for further computation.

RESER needs two input files in order to proceed with computation.

File #1 contains: - historical sequence of monthly reservoir inflows, or
                  - sequence of synthetic (generated) inflows

File #1

Inflows during each year should be stored in one line of the file.

Check the example below, and press F10 after.
EXAMPLE INPUT FILE #1
12.5 10.0 5.7 1.2 4.4 4.6 6.5 0.1 0.2 2.4 11.9 12.7 1.1 ---> year #1

3.4 8.7 12.3 11.5 4.3 7.8 23.4 7.3 13.5 14.4 17.4 15.8 ---> year #2
                                                          .
                                                          .
                                                          .
        month #3                  month #12
      month #2
    month #1
F2: Go to line  F3: Search  S-F10: Resize window  F10: End
```

FIG. 5. Third Screen for Presentation of REZES

ability programming method (Simonovic and Marino 1980). A three-level algorithm is used for the solution of this problem. The first two levels use a multidimensional search for choosing reliability values associated with different constraints. The third level uses a gradient-projection optimization algorithm for optimization of the reservoir releases.

PROFEXY

PROFEXY is the algorithm for real-time multipurpose single-reservoir operation. The methodology used is based on combining three algorithms within a single computer package: (1) A forecasting algorithm (Kalman filter); (2) a real-time reservoir model (linear programming); and (3) a multiobjective programming algorithm (compromise programming). The modeling procedure explicitly utilizes the trade-off between forecast reliability and the penalties associated with deviations from the target values for the reservoir operation (Simonovic and Burn 1989).

Output Data Presentation Module

The REZES system is capable of presenting the output results for the user's evaluation.

Figs. 4–7 show one example of a REZES session that illustrates some of the examined capabilities. Only five screens are selected for the presentation of REZES. The use of REZES starts with the first screen (Fig. 4), which offers the menu. From the menu content, it is possible to select one of the three major groups of action: (1) Knowledge-base development (menu options: Save Knowledge, List Knowledge, Erase Knowledge, and Edit

```
REZES
File # 2 contains numerical data required by RESER

We are now going to create file under the name RES. DAT
Be sure that floppy disc is still in Drive A:

Specify initial reservoir volume (m3/sec)
(e.g. if you want to start the search from S=1 million cub meters that is 0.37 m3/sec)
    -->    0.37

Specify search step - increase in storage (m3/sec)
- execution time and accuracy depend on this term
    -->    0.37

Specify how full reservoir is at start of simulation (%)
(e.g. if you want to start the simulation with 50% of total storage simply type in 0.5)
    -->    0.5

Specify number of years with inflow data (years)
- number of lines with inflows in the file INFLOW DAT
    -->   35

Specify twelve values for mean monthly evaporation loss (m3/sec/ha)
- every value followed by comma or space, (e.g. 0.0012,0.0023,0.0017,...)
--> .001  .0012  .0012  .0013  .0013  .0017  .0018  .0018  .0015  .0013  .001  .001

Specify twelve values for mean monthly infiltration loss (m3/sec)
- every value followed by comma or space, (e.g.  0.02,0.03,0.18,...)
--> .01  .01  .01  .02  .02  .02  .02  .01  .01  .01

Specify twelve values for mean water demand (m3/sec)
- every value followed by comma or space, (e.g. 1.12,1.4,0.87,...)
--> 1.4  1.4  1.4  1.5  1.5  1.6  1.6  1.6  1.5  1.5  1.4  1.4

Etc.
```

FIG. 6. Fourth Screen for Presentation of REZES

Knowledge); (2) consultation (menu options: Load Knowledge, Consultation, and Help Information); and (3) finishing use of REZES (menu options: DOS Shell and Exit REZES). The second screen (lower half of Fig. 4) has been extracted from the consultation mode. It illustrates typical questions asked during the consultation. The questions are posed to extract the information from the user that will be used in formulating the reservoir problem. As can be seen, all the questions are related to the physical facts of the problem. All the terms used are defined in the Help option. From the information provided, the system makes conclusions regarding the problem the user is faced with (planning, management, or design) and which model, from the available program library, is the most convenient for solving this problem. REZES is able to explain the reasoning process by tracking back the rules used for providing the final recommendation. This capability of the system is very useful in training and controlling the REZES reasoning, or logic.

Figs. 5 and 6 show the second component of the REZES system. When the problem has been formulated and a model selected, the system provides advice as to how to prepare the input data. A full description of input data is provided and supported with the example input file subscreen. Following the REZES instructions, the user is able to prepare the input data required

REZES

Output results are stored in the file RES. OUT look below

Consultation

Load Knowledge
Save Knowledge
List Knowledge
Erase Knowledge
Edit Knowledge
Help Information
DOS Shell
Exit REZES

OUTPUT FILE

OPTIMAL RESERVOIR VOLUME RESULTS:

RESERVOIR CONSERVATION STORAGE: 47.2 MCM
RELIABILITY OF WATER SUPPLY: COMPUTED - 0.977
REQUIRED - 0.90

SIMULATION RESULTS - YEAR #1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
VOLUME(MCM)	25.3	28.2	35.1	42.0	41.2	47.2	40.1	32.4	35.5	37.2	32.0	30.5
SPILL(MCM)	0.0	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0

...

FIG. 7. Fifth Screen for Presentation of REZES

for running the selected model. The selected model shown is RESER (simulation-optimization model for sizing a single multipurpose reservoir). The third screen (Fig. 5) contains initial advice for preparing file 1. This file should contain the inflow sequence. The fourth screen (Fig. 6) contains instructions on how to prepare file 2, containing all other data required by RESER.

After finishing the preparation and checking the input data, REZES automatically executes the program by returning to DOS and activating the executable version of the selected model. When the execution is finished, the REZES menu appears again on the screen, providing the user with the output results. As the fifth screen (Fig. 7) shows, the user is presented with all the output results and a proper explanation.

This screen is the end of the present version of REZES. The next phase for the REZES system, currently in progress, is concentrated on developing a more flexible questioning apparatus and the incorporation of four more models into the program library: the reservoir yield model by Loucks et al. (1981); a deterministic planning model based on the dynamic programming algorithm; a stochastic planning model that utilizes the stochastic dynamic programming algorithm; and the balancing-rule real-time operation model of Houck (1981). Further, work is planned to examine the potential benefits of computer graphics in presenting the results within the output data presentation module. Further expansion of REZES will be performed by a PC + development tool.

Conclusions

This paper introduces the possible use of expert systems for reservoir management and operations. A detailed review of water resources expert systems provided the basis for the discussion. The pilot expert system REZES, in development at the University of Manitoba, was used as an example.

Based on the water resources expert systems review, the following major conclusions have been reached: (1) Expert systems have been developed and should be applied to water resources engineering; (2) first reactions between the experts and users are positive; (3) further development is necessary; and (4) the present level of research is focusing on the development and application of ES technology as it directly relates to the specific engineering field appropriate to the particular problem environment.

A second contribution of this paper is in the presentation of the REZES pilot expert system, designed for reservoir management and operations (Savic and Simonovic 1988). Using REZES as an example, a wide range of potential benefits from the application of EES in reservoir management and operations has been identified. REZES was created by experts in the field of reservoir modeling. Potential users of mathematical models have initiated the design of this system. The system has been created to help users in: (1) Problem formulation and model selection; (2) input data preparation and computation; (3) presentation of results; and (4) evaluation of results. The system is still under development; a verification phase is planned for the near future.

In addition to creating REZES for water resources engineers, two more research objectives are considered: (1) To investigate different ways to create expert systems; and (2) to gain some experience in structuring and representing knowledge from the water resources field. The example presented in the paper is programmed in PROLOG with the classic rule-based knowledge base structure. A new version of the REZES has been developed using a PC + expert system shell, with the knowledge base created using the frame and rule structure. A comparative assessment of both approaches will be presented in a future paper.

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Appendix. References

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