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Expert System for Unit Hydrograph Analysis

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INTRODUCTION

1.1 About Unit Hydrographs

As the unit hydrographs establish a relationship between the excess rainfall and the direct runoff hydrograph, they are of immense value in the study of the hydrology of a catchment. They are of great use in (i) the development of flood hydrographs for extreme rainfall magnitudes for use in the design of hydraulic structures, (ii) extention of flood flow records based on rainfall records and (iii) development of flood forecasting and warning systems based on rainfall.

By definition, unit hydrograph is the direct surface runoff hydrograph resulted at the catchment outlet due to unit(1 mm/1 cm/1 inch) rainfall excess falling uniformly over the catchment in time as well as in space for the specified duration. The unit hydrograph is basically a multiplier which converts the excess rainfall to direct surface runoff. Thus it can be said that the unit hydrograph only deals with the direct surface runoff and excess rainfall. Therefore, the baseflow must be seperated from the streamflow hydrograph and losses must be accounted from the average rainfall hyetograph in order to get the direct surface runoff hydrograph and excess rainfall hyetograph respectively.

1.2 Need of Expert System for Unit Hydrograph Analysis

An Expert System (ES) is a combined human computer system designed to solve particular problems that normally require logical consideration of both facts and heuristics, or rules of thumb, to arrive at a decision. For complex decision problems with a large amount of information and many possible outcomes, expert systems provide efficient solution mechanism. A fundamental ES is made up of a knowledge base and an ES shell (inference engine and user interface). The rule base contains the facts and heuristics specific to the problem being addressed, while the shell contains the generalised system for combining elements of a rule base into a decision.

There are different methodologies for the derivation of unit hydrograph depending upon the data for the gauged catchments. For ungauged catchments, the unit hydrograph can be derived using their physiographic characteristics. CWC has also given some synthetic unit hydrograph relationship for the various sub zones of India. Thus a suitable method should be selected to derive the unit hydrograph of a particular catchment. But this selection is very difficult and requires highly specialised knowledge. An inexperienced engineer or hydrologist is perplexed with the selection of an appropriate method. In this context an expert system would be of great use to aid in the selection of a suitable unit hydrograph derivation method, given the location and data availability of the catchment.

It has been found from the literature review that some Expert Systems have been developed for selection of appropriate model for river flow routing; evapotranspiration estimation and flow measurment in open channels. Some ES have also been developed for the calibration of various available models such as HSPF (modwl for hydrological aspects of a watershed; SRM (snowmelt runoff model) and SWMM (storm water management model). As such there is no expert system for the selection of a suitable model for unit hydrograph derivation.

1.3 About the Expert System UHYDEX

UHYDEX is an expert system developed for the selection of an appropriate model for unit hydrograph derivation of a particular catchment. The system has been developed using the ES development shell EXSYS. It has two separate modules. One for the UH derivation for gauged catchments and the other for the UH derivation of ungauged catchments.

For the gaugedd catchments, the models at present considered for UH derivation are conventional method (with and without baseflow option), Collins method, conventional Nash model, integer Nash model and Clark model. There are many more models available in the literature but as a first attempt, only the above models are selected because their programs are available and these FORTRAN programs are interfaced with the system so that the ES will make the selection of appropriate model for UH derivation and will also derive the UH of that particular catchment.

For the ungauged catchments, the Synders approach and the regional relationships developed by CWC are used.

UNIT HYDROGRAPH DERIVATION

There are different methods for the derivation of unit hydrographs of gauged catchments and ungauged catchments. These are described in the following sections.

2.1 UH Derivation for Gauged Catchments

2.1.1 Conventional Method (With Base Flow Option)

The unit hydrograph from the flood hydrograph recorded from a specific duration individual, isolated storms of fairly uniform intensity distributed evenly over the catchment, is derived using the principle of proportionality. This method is used for the derivation of unit hydrograph from the isolated single period storms. In the programme the constant or non constant base flows supplied by the user are deducted from the discharge hydrograph in order to obtain the ordinates of the direct surface runoff hydrograph. Then the area under the curve is calculated using Simpson's rule and this provides an estimate for the volume of direct surface runoff. The estimate for the volume of direct surface runoff, thus obtained, are divided by the area of the catchment to provide the depth of excess rain. The ordinates of the direct surface runoff hydrograph are divided by the excess rainfall depth to give the ordinates of the unit hydrograph.

2.1.2 Conventional Method (Without Base Flow Option)

In this method the following procedure is followed to derive the unit hydrograph from the direct surface runoff hydrograph of a single period storm.

(i) Determine the volume of excess rainfall in the single unit period (it also equals the volume of the direct surface runoff hydrograph.

(ii) Calculate the proportionality factor (F) dividing the volume of excess rainfall by the unit volume of the unit hydrograph, both in same unit.

(iii) Divide the ordinates of the surface runoff hydrograph by F and this gives the required unit hydrograph ordinates.

This method is used for the derivation of unit hydrograph from the direct surface runoff hydrograph of a single period storm. Here base flow separation option is not included.

2.1.3 Unit Hydrograph Derivation Using Collin's Method

This method is based on a trial and error procedure to derive the unit hydrograph. The method is particularly applicable if the number of blocks of effective rainfall is small and/or if one block contains a large part of the effective rainfall for the storm. The steps involved in the method are as follows :

(i) Make a first estimate of the unit hydrograph. Constant value for unit hydrograph ordinates may be used as a first approximation.

(ii) This first estimate UH is next applied to each effective rainfall block except the largest and the runoff are computed.

(iii) The difference between the actual runoff and the runoff obtained in step (ii) is assumed to be due to the omitted excess rainfall block.

(iv) From this by proportionate adjustment a second estimate UH is obtained and a weighted mean of this and the first estimate is applied in the second step again and so on until the method converges. The weights are the amounts of rainfall in the largest block and the sum of all the others, respectively. Some control may be exercised on the method by smoothing any oscillations which may tend to occur particularly in the later part of the UH as the computation proceeds.

This method calculates the unit hydrograph ordinates using Collin's method.

2.1.4 Unit Hydrograph Using Conventional Nash Model

The instantaneous unit hydrograph may be obtained by routing the instantaneous inflow through a cascade of linear reservoirs with equal storage coefficient. This is the concept of Nash Model. Here the outflow from the first reservoir is considered to be as inflow to the second reservoir and so on. The mathematical equation developed for the T-hour unit hydrograph is given as:

$$U(T,t) = \frac{1}{T}\left[I\left(n,\frac{t}{K}\right) - I\left(n,\frac{t-T}{K}\right) \right]$$

where,

U(T,t) = t^{th} ordinate for the unit hydrograph of duration T hours.
I(n,t/K) = incomplete gamma function of order n at (t/k)
I(n,(t-T)/K) = incomplete gamma function of order n at (t-T)/K
n & K = the parameters of Nash Model

(a) Unit Hydrograph using Given Parameters of Nash Model

This method derives the unit hydrographs corresponding to the different sets of parameter values supplied by the user interactively.

(b) Unit Hydrograph using Conventional Nash Model (Method of Moments)

The following equations are solved to compute the parameters of Nash Model (n and K) using method of moments.

$$nK = {}_1M'_Y - {}_1M'_X$$

$$n(n+1)K^2 + 2nK\, 1M'_X = 2M'_Y - 2M'_X$$

where, $1M'_Y$ and $2M'_Y$ are first and second moment of the direct surface runoff hydrograph about the origin respectively, and $1M'_X$ and $2M'_X$ are first and second moment of the excess rainfall hyetograph respectively.

The first and second moments of direct surface runoff hydrograph and the excess rainfall about the origin are computed using the following equations :

$$1M'_Y = \frac{\sum_{i=1}^{N} \frac{(Y_i - Y_{i+1})}{2} t_i}{\sum_{i=1}^{N} \frac{(Y_i - Y_{i+1})}{2}}$$

$$2M'_Y = \frac{\sum_{i=1}^{N} \frac{(Y_i - Y_{i+1})}{2} (t_i)^2}{\sum_{i=1}^{N} \frac{(Y_i - Y_{i+1})}{2}}$$

$$1M'_X = \frac{\sum_{i=1}^{M} X_i t_i}{\sum_{i=1}^{M} X_i}$$

$$2M'_X = \frac{\sum_{i=1}^{M} X_i t_i^2}{\sum_{i=1}^{M} X_i}$$

where,

- Y_i = ith ordinate of direct surface runoff hydrograph (DRH) in m^3 /s
- N = No. of DRH ordinates
- t_i = Time to the mid point of the ith interval from the origin in hours
- M = No. of rainfall blocks
- X_i = ith block of excess rainfall in mm.

The method "*UH using Nash Model (Method of Moments)*" uses the above procedure to estimate the parameters of Nash Model and the unit hydrograph for the desired duration by Conventional Nash Model.

(c) Unit Hydrograph using Conventional Nash Model (Optimisation)

The parameters of Nash Model n & K may also be estimated using the optmisation procedure. In this package an option has been included to estimate the parameters n & K using Marquerdt Algerithm, which is a non-linear optimisation technique, to minimise the objective function F given as:

$$F = \sum_{i=1}^{N} (Y_i - \hat{Y}_i)^2$$

$$\hat{Y}_i = \sum_{j=1}^{i} X_j \, U_{i-j+1}$$

where,

$\hat{Y}_i$ = ith ordinate of computed direct surface runoff hydrograph in (m^3/S) for an event.

Detailed description about the Marquerdt Algarithm may be found else where.

2.1.5 Unit Hydrograph Derivation Using Integer Nash Model

Integer Nash Model is a simplified form of the conventional Nash Model. It takes the parameter 'n' approximated to the nearest integer and computes the incomplete gamma function using a simplified procedure where the use of Pearson table is fully avoided. The unit hydrograph of T-hour duration is derived using the following equations by this method.

$$U(T,t) = \frac{1}{T} [I(n,y) - I(n,y_1)]$$

where,

$$I(n, y) = 1 - e^{-y \sum_{m=0}^{n-1} \frac{y^m}{m!}}$$

$$I(n, y_1) = 1 - e^{-y_1 \sum_{m=0}^{n-1} \frac{y_1^m}{m!}}$$

$y = t/K$

$y_1 = (t-T)/K$

The integer value of n and modified value of K are obtained preserving the first moment of IUH and checking closeness of the second moment of IUH about the centroid.

This method computes T-hour unit hydrograph using Integer Nash Model.

2.1.6 Unit Hydrograph Derivation Using Clark Model

Clark (1945) suggested that the IUH can be derived by routing the unit inflow in the form of time-area concentration curve, constructed from isochronal map, through a single linear reservoir. The linear reservoir routing is accomplished using the general equation.

$$U_i = C\, I_i + (1 - C)\, U_{i-1}$$

where, C and (1-C) are routing coefficients

U_i is the IUH at the period i,
U_{i-1} is the IUH at the period (i-1), and

$$C = \frac{\Delta t}{R + 0.5\, \Delta t}$$

where, Δt is the computation interval (hours).

The IUH can be converted to a unit hydrograph of unit rainfall duration Δt by simply averaging the two ordinates of IUH spaced an interval Δt apart as follows :

$$UH_i = 0.5\, (U_i + U_{i-1})$$

The IUH can be converted to a unit hydrograph of some unit rainfall duration other than Δt, provided that it is in an exact multiple of Δt by the following equation:

$$UH_i = 1/n\, [\, 0.5\, U_{i-n} + U_{i-n+1} + \ldots\ldots + U_{i-1} + 0.5\, U_i\,]$$

where, UH_i = ordinate at time i of unit hydrograph of duration D-hour and computational interval Δt hours.

$n = D/\Delta t$

(a) Unit Hydrograph using Given Parameters of Clark Model

The method "*UH using Given Parameters of Clark Model*" may provide the unit hydrograph of desired duration corresponding to the parameters supplied by the user interactively.

(b) Unit Hydrograph using Clark Model (Optimisation)

Another option regarding the estimation of Clark Model parameters and corresponding unit hydrograph using optimisation technique is also provided in the package. In this option Marquerdt Algorithm is used to minimise the sum of the squares of the differences between observed and computed direct surface runoff hydrograph ordinates for an event.

2.2 UH Derivation for Ungauged Catchments

2.2.1 Unit Hydrograph Using Snyder's Approach

Snyder's gave some empirical relationships for synthetic UH based on his studies carried out in USA for several catchments in the Appalachian Highlands. Those relationships were originally developed in FPS system.

The relationships in metric unit to be used to derive t_r' - hour unit hydrograph characteristics using this approach are given below :

Time Lag (hrs) or Basin Lag (hrs)

$$t_p = C_t \, (L L_{ca})^{0.30}$$

where,

- t_p = Basin Lag (or time lag) in hours
- L = Length of main stream in Km.
- L_{ca} = distance from outlet to centre of area of catchment along the stream in Km.
- C_t = a coefficient varying from 0.3 to 0.6 for different regions

Peak of UH (cumec)

$$Q_p = (2.78 \, C_p \, CA)/t_p$$

where,

- Q_p = peak of UH in cumec
- CA = catchment area in sq Km
- C_p = a coefficient varying from 0.31 to 0.93

Unit Hydrograph Duration (hrs)

$$t_r = t_p \, / \, 5.5$$

where, t_r = unit hydrograph duration

Modified time lag or basin lag (hrs) (t_r')

Basin lag may be modified for the desired duration of UH, t_r' using the relationship:

$$t_p' = t_p + 0.25\ (t_r' - t_r)$$

Peak of UH for desired duration, t_r'

$$Q_p' = (\ 2.78\ C_p\ CA\ )\ /\ t_p'$$

Width of UH in hour at 50% peak discharge (W_{50})

$$W_{50} = a\ /\ q^{1.08}$$

where, $q = Q_p'\ /\ CA$ & a is a coefficient for the region

Width of UH in hour at 75% peak discharge (W_{75})

$$W_{75} = W_{50}\ /\ b$$

where, b is a coefficient for the region

Base width of UH (t_b)

For large catchments

$$t_b = 3 + 3\ (t_p'/24) \quad \text{(in days)}$$

For small catchments

$$t_b = 5\ (t_p' + t_r'\ /\ 2\ ) \quad \text{(in hours)}$$

The UH peak, basin lag time, W_{50}, W_{75} and t_b are used to define the shape of UH preserving the unit volume equal to one cm.

2.2.2 Unit Hydrograph Derivation Using the Regional Relationships Developed by CWC.

CWC derived the regional unit hydrograph relationships for different sub-zones of India relating to the various unit hydrograph parameters with some prominent physiographic characteristics. The general forms of the relationships are as given below:

$$t_p = a_1\ (LL_{ca}/\sqrt{S})^{b_1}$$

$$q_p = a_2\ (t_p)^{b_2}$$

$$W_{50} = a_3 (q_p)^{b_3}$$

$$W_{75} = a_4 (q_p)^{b_4}$$

$$WR_{50} = a_5 (q_p)^{b_5}$$

$$WR_{75} = a_6 (q_p)^{b_6}$$

$$t_b = a_7 (t_p)^{b_7}$$

where, L & L_{ca} have the same meaning as for the Snyder method;
S is stream slope in metre/kilometre

t_p is time from the centre of unit rainfall duration to the peak of unit hydrograph in hours
q_p is peak discharge of UH in cumec/sq.km.
t_b, W_{50} & W_{75} have the same meaning as given for Snyder's method
WR_{50} is the width of the rising side of UH in hours at ordinate equal to 50% of UH peak, and
WR_{75} is the width of the rising side of UH in hours at ordinate equal to 75% of UH peak.

CHAPTER 3

KNOWLEDGE BASED EXPERT SYSTEMS (KBES)- A BRIEF REVIEW

3.1 KBES-Definition

To define a KBES,- "a knowledge Based Expert System is a program, that simulates the performance of a human expert in a specific narrow domain",KBES are knowledge intensive programs, which are highly interactive and to some extent mimic the decision making and reasoning process of human experts. They can provide advice, answer questions (how?, why?, etc.) and justify their conclusion. The purpose of a KBES is not to replace the experts, but to make their knowledge and experience, more widely available. Typically their are more problems to solve than there are experts available to handle to handle them. The KBES permit others to increase their productivity, improve the quality of their decisions, or simply to solve the problems when experts are not available.

3.2 Major Differences of KBES from Conventional Programs

(A) KBES differ from conventional programs written in C, PASCAL, FORTRAN, COBOL, etc. in the sense that the knowledge of the system is separated from the algorithm which manipulates that knowledge. Just as a database separates data from control, a KBES separates knowledge from control.

(B) Unlike a traditional algorithmic program a KBES allows developers to modify the knowledge of the system without changing the algorithm which control the use of that knowledge.

(C) Whereas a conventional program is algorithmic in nature and requires a complete set of data to produce a unique solution, a KBES is conceptual in nature, can function with an incomplete set of data (facts) and may produce several solutions, each with varying degree of confidence or certainty.

3.3 Anatomy of KBES

KBES typically consists of the following four components as shown in Fig.1

3.3.1 Knowledge Base

The Knowledge Base (KB) contains the systems knowledge i.e. the knowledge specific to the domain of the problem to solved. Knowledge base is a collection of the declarative knowledge such as facts about objects, events and situations and procedural knowledge and procedural knowledge such as information about the course of action. The process of collecting the knowledge about a specific domain is known as knowledge engineering and is the job of knowledge engineer. To facilitate the scanning of knowledge base while making inferences, it is to be condifined into a suitable knowledge representation scheme. The declarative knowledge representation schemes include logic, semantic networks, frames and script. The procedural knowledge representation scheme include production rules As such, the representation of the knowledge base is dependent on the type of implementation of the KBES.

The knowledge base to used in any engineering environment comprises a set of wellestablished scientific principle and also heuristic knowledge developed from experience.

3.3.2 Context

Context is the workspace of current problem constructed by the inference mechanism from the information provided by the user and the knowledge base. It contains facts that reflect the current state of the problem solution. It can be compared with the "short term memory". The context is temporary memory, where a list of facts is built up and unerased at the end of the session. The organisation of the context depends on the nature of the problem domain.

3.3.3 Inference Mechanism

The inference mechanism monitors the executive of the program by using knowledge base to modify the context. In other words, th e main task of the inference mechanism is to compare the facts supplied by the user with the knowledge in the knowledge base and deduce whatever cancelation may logically follow. It is simply a program, which may use several strategies to refer a conclusion. The inference mechanism is provided by the programming environment and contains no domain specific knowledge.

3.3.4 User Interface

The user interface lets user to communicate with the system. It asks questions or presents menu choices for seeking initial information in data base. It deals the intermediate communications and conveys the final conclusion to the user. The user interface is not truly a natural language, instead the information must be formatted and entered in some restricted syntax. The degree of simplicity in interaction determines the way the interfacing software to be written.

The components described above form the kernel of most of the exciting expert systems. In addition there are two modules which are described in any expert system. They are described below.

(i) The Explanation Module

The module provides explanation of the inference used by the KBES. An ideal explation module should be able to handle questions about all relevant aspects of the system's knowledge and actions, it should be easy to use and give answers comprehensively and completely.

(ii) Knowledge Acquisition Module

It serves as an interface between the expert(s) and the KBES. It provides a means for entering knowledge into the knowledge base reusing this knowledge when necessary.

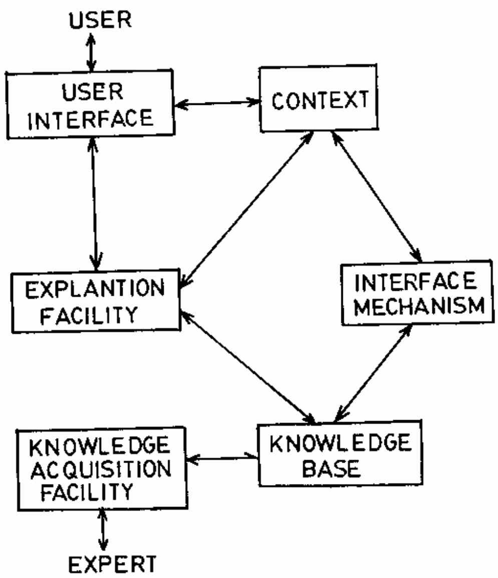

Fig. 1 - Components of Knowledge Based Expert Systems

3.4 Knowledge Base - Representation

There are five different approaches of representing knowledge which are described below:-

3.4.1 Semantic Networks

Semantic network is a collection of objects called nodes and is also known as associative net or propositional net. The nodes are connected together by arcs or links. The links of a semantic network are used to express relationships. Nodes are generally used to express relationships. They are also used to represent physical objects, concepts or situations.

There are no absolute constraints as to how nodes and links are named. Flexibility is a major advantage of this representational scheme. New nodes and links can be defined as needed. Inheritance is another feature of semantic networks. It refers to the ability of one node to inherit characteristics of other nodes that are related to it. There is one more type of inheritance called property inheritance. It means that instances of a class have all properties of more general classes of which they are members.

There are some difficulties with semantic networks. Although they can be very useful in representing knowledge, they have limitations such as lack of link name standards. This makes it difficult to understand what the is really designed for and whether it was designed in a consistent manner. The difficulties also arise in naming of nodes.

Another problem is the combinatorial explosion of searching nodes, especially if the response to a quarry is negative. That is, for a quarry to produce a negative result, many or all of the links in a net may have to be searched. Semantic networks are logically inadequate because they can not define knowledge in the way that logic run.

3.4.2 Object - Attribute - Value Triplets

In this scheme, objects may be physical entities such as beam or a column, or they may be conceptual entities such as propping, gunting, etc. Attributes are general characteristics or properties associated with objects. It is a specialized case of the semantic network approach.

3.4.3 Production Rules

Knowledge, both heuristic and control in a rule based system consists of production rules. Rules are used to represent relationships. The general form for the rules is

RULE # N

IF ((antecedent l)--------------(antecedent N)

THEN ((consequent with certainty Cl)
(consequent with certainty C2)

The IF part is known a premise and the THEN part a conclusion. The rule number is a unique number for identifying the rule. The value of this number does not specify the order of application of the rule. Each rule should present an independent chunk of knowledge.

Rules can be algorithmic or heuristic. Certainty factors indicate the level of confidence in a piece of information. The different types of rules or constraints can be identified in design of structures: domain rules and meta-rules (or rules about the rules). Domain rules consist of well defined constraints give in design specifications. Meta-rules determine the course of design and should be provided by an expert designer.

3.4.4 Frames

Frames provide another method for representing facts and relationships. A frame is a description of an object that contains slots for all the information associated with the object. Slots, like attributes, may store values. Slots, like attributes, may store values. Slots may also contain default values, pointers to other frames, sets off rules, or procedures by which values may be obtained. the procedures may determine the values of slots. In other words,a procedure consists of a set of instructions for mdetermining the value of a slot.

Frame systems are suitable for more complex and richer representation of knowledge.

3.4.5 Logic

There are two most common of representing facts and relationship using logic: propositional logic and predicate logic. These are briefly discussed below.

Propositional logic is a common logic system. Propositions are statements that are either true or false. Propositions that are linked together with connectives, such as AND, OR, NOT, etc., are called compound statements.

There are rules for propogating the truthfulness of statements, depending upon connectiveness. The table called truth table given in Table 1 explain the result of different connnectives.

Table 1 - Truth Table

p	q	p and q	p or q
T	T	T	T
T	F	F	T
F	T	F	T
F	F	F	F

Predicate calculus is an extension of propositional logic. Objects, the elementary objects are adddressed by predicates which are statements about objects. Ordinary connectives can be used to link together predicates into larger expressions.

3.5. Inference Mechanism - Problem Solving Strategies

Inference mechanisms are characterized by the inference and control strategies. These strategies are described in brief below.

3.5.1 Inference

3.5.1.2 Modus Ponens

It is a logical rule that says, as we do without thinking about it, that when A is known to be true and if a rule states, "If A, Then B." it is valid to conclude that B is true. Stated differently, when we discover that the premises of a rule are true we are entitled to believe the conclusions.

3.5.1.3 Reasoning about Uncertainty

Just as consultants and advisors must typically deal with cases for which some information is missing or unknown, an inference engine must be able to handle incomplete information. A detailed discussion on uncertainty follows.

3.5.1.4 Resolution

Resolution is one way to get to discover whether a new fact is valid, given a set of logical statements. In order to show an example of resolution, we need to establish two other logical operations. First it is equivalent to sav "If A, Then B." or "Not(A) or B.". In logic,it is represented by a truth table. Second operation for resolution is that if we have Not(A) or (B) and A or C, then we can resolve these clauses to a singleone: B or C.

3.5.2 Control

3.5.2.1 Backward and Forward Chaining

In backward chaining, the inference engine starts at the goal and works "backward" through the subgoals in an In,. effort to choose an answer. If the possible outcomes A (i.e., the values of the goal attribute) are known, and if they are reasonably small in number, then backward chaining is efficient. If number of possible outcomes is large, the forward chaining strategy is used. In a forward chaining system, premises of the rules are examined to see whether or not they are true, given the information on hand. If so, the conclusions are added to the list of facts known to be true and the system examines the rules again.

Fig.2 shows the process of backward and forward chaining.

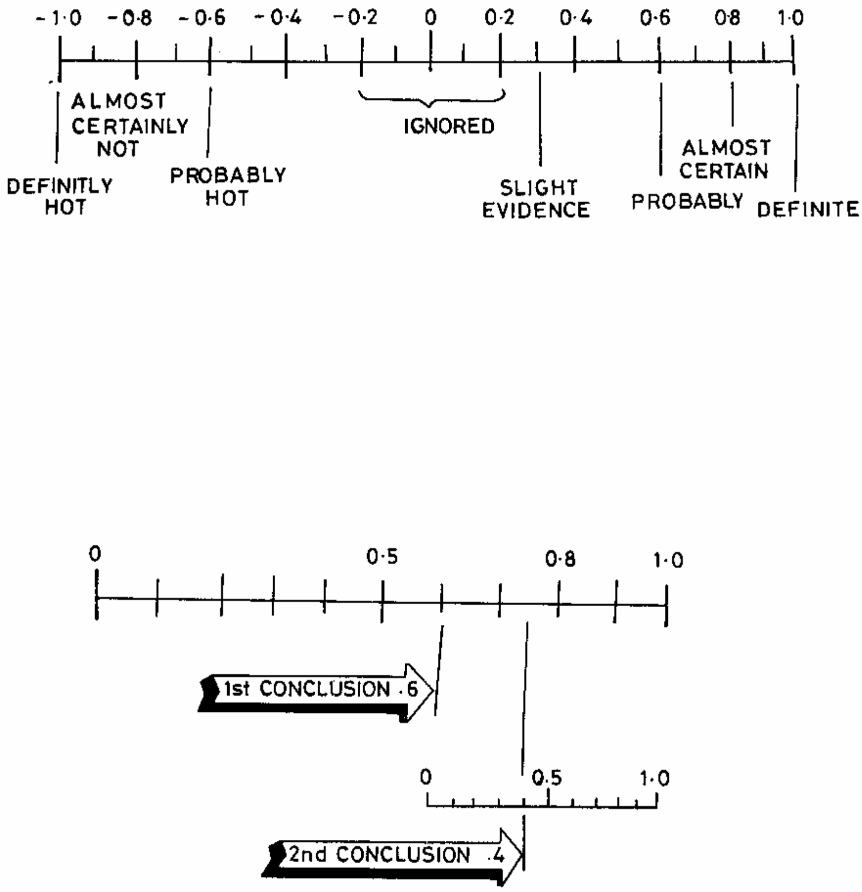

Fig. 2 - Backward and Forward Chaining

3.5.2.2 Depth-first and Breadth-first Search

In depth-first search, the inference mechanism takes every opportunity to produce a subgoal. Searching for detail first is the theme of backward-chaining in a depth-first manner . A breadth-flrst search sweeps across all premises in a rule before digging for greater detail. Breadth-first search will be more efficient if one rule succeeds and the goal attribute's value is obtained.

3.5.2.3 Monotonic and Non Monotonic Reasoning

In monotonic reasoning, all values concluded for an attribute remain true for the duration of the consultation session. In non monotonic reasoning, facts that are true may be retractable.

3.5.2.4 Heuristic Search

Another type of inference drawing is heuristic search which prunes the blind search. A heuristic is a rule of thumb, strategy, trick, simplification, or any other kind of device which drastically limits search for solution in large problem spaces.

There are four heuristic search techniques

* Hill Climbing

* Difference reduction

* Minimax

* Static Evaluation

In hill climbing you compare the difference of present state and goal state, you determine you are moving closer to the goal state or further away. If you are moving away you can backtrack and select a new path.

Difference reduction reduces the distance between the current node and the goal state by setting subgoals.

Minimax is a method of pruning a two player game. Static evaluation - combinatorial explosion is a major problem in a breadth-first, forward chaining search. However if each node is somehow evaluated and the low scoring nodes eliminated, the search space can be dramatically reduced. It should be noted, nevertheless, that heuristic search techniques are not fullproof. They do not guarantee the best solution or even any solution at all.

3.6 Uncertainty

Rules obtained from human experts are sometimes uncertain. Experts describe some rules or facts as"may be", "sometimes", "often", or "not quite certain about the conclusion". You need methods to fhandle these types of probabilistic satatements. Such facilities will clearly

be useful in predicate systems which might produce conclusions like: "the earthworks will be completed by the September"
- probability 0.9

Uncertainty arise from the following form of main sources:

3.6.1 Unreliable Information

This is either due to ill-defined domain concepts or inaccurate data. In addition rule based systems often suffer from weak implications when the expert is unable to establish a conclusion.

3.6.2 Inference With Incomplete Information

When the available information is incomplete, rule based information can not hope to be any better.

3.6.3 Imprecise Descriptive Languages

The numerous ambiguities in natural language are rarely clarified during translation to a formal language. As a result, rules that are not expressed precisely in the formal language can be misinterpreted.

3.6.4 Experts Somtimes Disagree

Combining the views of multiple experts into a consensus knowledge-base is difficult, confusing, and frequently impossible. A rule based system must resolve all conflicting rules before it can develop a consensus knowledge base.

Besides uncertainty with facts, the rules of an expert system may have uncertainty if they are based on heuristics. There are many methods of dealing with uncertainty which are briefly described below.

(A) Fuzzy Logic

Fuzzy logic theory is the most general theory of uncertainty that has been formulated. It has wide applicability because of the extension principle. Fuzzy logic measures the truth of a statement as a number between 0 and 1, and may therefore sometimes very loosely be reffered to as probability. There are fairly standarised methods for combining these truth measures e.g.,

Proposition A is true with value 0.7

Proposition B is true with value 0.5

If we have a rule such as : IF A AND B THEN C

The truth value of C is taken to be the minimum probability of all the antecedents, i.e., 0.5

If the rule states :

IF A OR B THEN C

The truth value of C is taken to be the maximum possibility of all yhe antecedents, i.e., 0.7

There is no justification for taking the maximum of minimum values in every case. It works in the calssical logic case where the truth values are 0.0 and 1.0 and does not usually provoke any objections from users.

(B) Shortliffe Type Certainty Factors

This type of certainty factors have been used in the shell MYCIN. This system allows the knowledge base author to attach a certainty factor in the range of -1 to +1 to the rule. The confidence value for a premise A, for example, is 0.6 and later concluded again as 0.4. When the first conclusion is made, A is entered into active memory with the confidence 0.6. Later, when the second conclusion occurs, 0.6 and 0.4 are combined as shown in Fig.3.

There remains a distance of 0.4 between the original certainty 0.6 and a definite conclusion 1.0. This remainder 0.4 is multiplied by the certainty for the new fact 0.4 to generate an additional increment of 0.16. The is added to the original value, resulting in combined 0.76 confidence in A. The order in which information is combined does not matter. Combining 0.6 and 0.5 is the same as combining 0.5 and 0.6 increment.

(C) Bayes Theorem

Inference nets are used by many shells. They can be seen as an alternative to production rules e.g.,

IF A AND B THEN C

becomes

C depends on A and B

However, there is a fundamental difference in the processing of such statements. The production rules does not give a value to C if A or B fail. The inference network statement always leads to a value for C once A and B have been established. A network consists of many such statements and a set of questions about A, B. etc. In this application to inference, the Bayes theorem is used to calulate a modified probability of the result C as the existence of items of evidence A and B is proved or disproved.

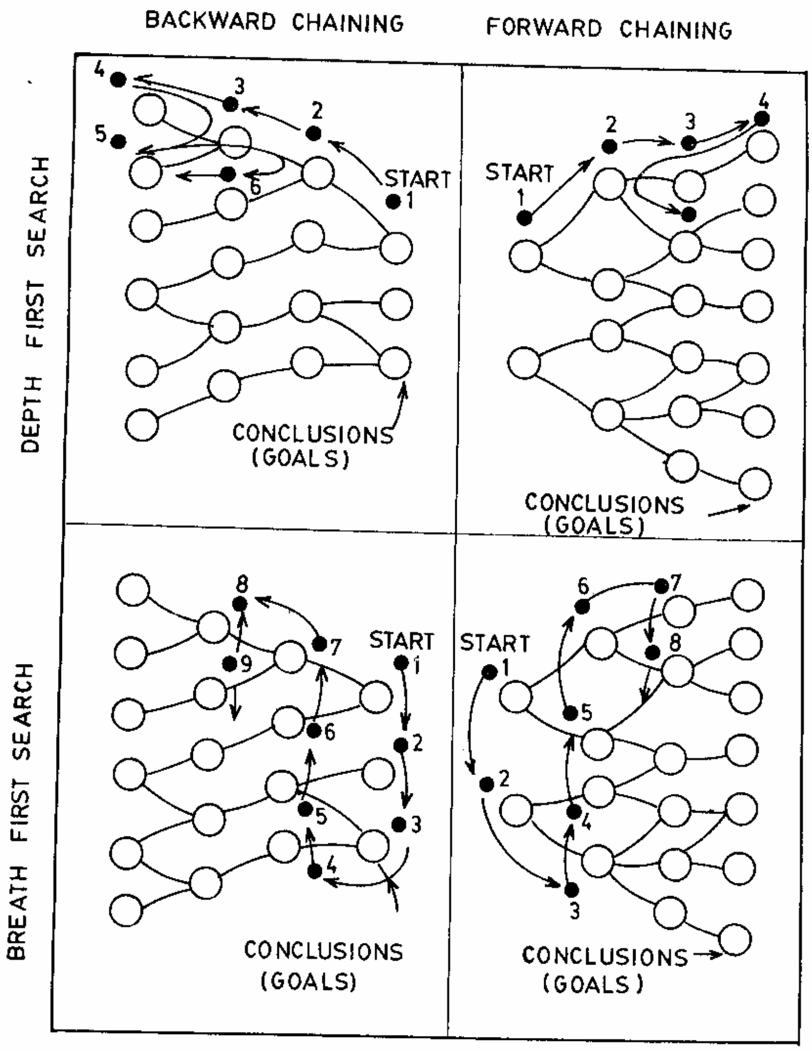

Fig. 3 - Shortliffe Type Certainty Factors

3.7 Expert System Development Tools

A fundamental decision in defining a problem is deciding how best to model it. Sometimes experience is available to aid in choosing the best paradigm. Experience suggests that it is preferable to use a commercial package, if available, rather than writing one from scratch as these tools facilitate the rapid production of a working system and aid the learning process concerning KBES concepts and principles. They allow time to be spent upon mining and organizing knowledge rather than the production of inference from scratch.

The following aspects of expert system development may be helpful in getting a quick aid.

3.7.1 Shell

It is a special purpose utility program designed for certain types of applications in which the user must only supply the knowledge base. The user is therefore not completely free in the way the knowledge is structured. However, a number of facilities that are not available in other tools are available in these shells, in particular the user interface. The shells are usually suitable for a couple of problem domains. Many projects start out with a shell and later switch to another tool. This is a very good approach. With a shell, it is possible to get a good and quick start. The classic example of a shell is the EMYCIN (Empty MYCIN) shell. This shell was made by removing the medical knowledge base of MYCIN expert system.

3.7.2 Programming Languages

Programming languages are translator of commands in a specified syntax. Here, questions of development time, convenience, maintainability, efficiency, and speed determine what language software is written in. The available AI programming languages can be grouped into two catogeries.

3.7.3 General Purpose Programming Languages

General purpose programming languages (e.g. FORTRAN, PASCAL, etc.) do not separate knowledge from the reasoning process. Although an inference mechanism can be built in these languages, it is not standard.

3.7.4 Knowledge Representation Languages

The knowledge representation languages (e.g. PROLOG,OPS5,etc.) offer less freedom to the user than normal programming languages. The largest disadvantage of these languages is the fixed control strategy. It is impossible to choose a control strategy depending on the problem. Also, the methods to represent knowledge are less advanced. Since these languages can easily be extended they allow the users to build constructs tailored to their specific needs. They can even easily build a new control strategy.

3.7.5 Environments

The environments have only recently become available. They are nothing but a language plus associated utility programs to facilitate the development, debugging and delivery of application programs. Utility programs may include text and graphics editors, debuggers, file management and even code generators. Cross assemblers may also be provided to port the developed code to different paradigms such as forward and backward chaining in one application. These environments are very flexible but the many ways in which it is possible to structure knowledge also bring the disadvatage that an engineer might not be able to choose the right one. Also, there is a considerable learning curve. The reward is truly general environment. Although these environments are expensive, they allow the users to start and end with the same tool.

The environments are generally more advanced than the shells, and shells are more advanced than the representation languages. The representation languages offer a programming environment, but such an environment differs from an expert system development environment.

Table 2 gives a comprehensive list of some existing expert system development tools with their salient features.

3.8 Limitations of Expert Systems

Expert systems have 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 coordination 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 performace 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 effect 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 systema can also be used in conjunction with the conventional programs to take advantage of both.

TABLE-2 : EXPERT SYSTEM DEVELOPMENT TOOLS

Name	Language	Knowledge Representation	Inference Mechanism	User Interface	Explanation Facility	Graphics	Probability	Hand Craft	User Sophistication	Machines	Vendor
ART (Automated Reasoning Tool)	LISP C	Hybrid 'Tool Kit' with Frames, goals and production rules	Forward and backward chaining, pattern matching and logic programming	Excellent graphics icon editor	Excellent graphics browser	Excellent includes animation	User defined certainty factors	Very flexible tool-kit for customizing	Powerful system integrating frames, rules and goals. Development tool requires experienced AI programmes	Symbolics, suns VAX, LISP machine IBM-PC/AT TI explorer	Inference Corporation 5300 West Century Blvd Los Angeles CA 90045
KEE (Knowledge Engineering Environment)	LISP	Object oriented frames with multiple inheritence production rules	Forward and backward chaining, provides a truth maintenance system	Strong for rules, representation and inference	Excellent graphical and highly interactive	Excellent object & icon oriented	User defined certainty factors	Flexible environment	A flexible and power ful environment to assist experienced programmers in construction expert systems	Xerox, Lambda, Suns, Symbolics, IBM-PC/AT, TI Explorer, VAX, HP	Intelli Corp 1975 El Camino Real West Mountain Review CA 94040
KES 2	LISP-C	Production rules, Baysian hypothesis and test	Abductive reasoning	Line oriented	Explanation, help, justify and 'WHY'	Windows & menus or dialog	Certainly factors, symbolic probability (both user and expert confidence) -1 to +1 (True)	May be embedded in other program	Knowledge enrineer may select one of three KR schemes for building user frienly ES	Cyber 180, Xerox, Apollo, Sun, IBM-PC	Software Arch. Engg. Inc. 1600 Wilson Blvd. Arlington, VA 22209
Knowledge Craft	Common LISP CRL +OP55/Prolog	Frame based with inheritance and procedural attachment. Integrated production system	Rule based forward chaining and logic programming in prolog.	Knowledge base, frame ;and rule editors, OPS and prolog. work bench	Graphics oriented trace facility	Excellent window oriented		With OPSS & prolog integration	Offers experienced programmers a choice of control strategies and knowledge representation techniques	VAX, TI Explorer, Symbolics, Suns, HP9320, Apollo	Carnegic Group Inc 650 Commerce Court Pittsburgh PA15219
S.I	LISP LISP-C; C-Ada	Rule based, frame based, procedure oriented	Procedural programming is done by control strategies	Knowledge base editor	English text, help and explanation	Menu and Mouse driven	Certainty factors	Through links to UNIX system languages	Shell for computer professionals to develop and deliver efficient ES for diagnosis, design and planning	AT & T, Micro VAX, Sun, Apollo, VAX, Xerox, Symbolics IBM Mainframes	Teknowledge Inc 1850 Embarcadero Road Pali Alto CA 94303
DUCK	NISP Franz LISP, Common LISP	Logic programming in a LISP environment		Varies among LISP environments	First order predicate calculus	Through LISP environment	Must program	Through LISP environment	Experienced AI programmers have four modes: logic rule-based, non-monotonic reasoning, and deduction.	Lambda, VAXs TI Explorer, Xerox, Apollo, Symbolics	Smart Systems Technology 7700 Leasburg Pike Falls Church, VA 22043
LOOPS	INTERLISP-D	Rule, access, object & procedure oriented program ming		Excellent graphics oriented	Not evident since this is a research tool	Original xerox star inspired windows	Not evident since this is a research tool	Very flexible tool	Powerful knowledge engineering language to assist experienced AI programmers in developing ES	Xerox 1100 series	Xerox AI Systems 250N, Halstead St. Box 7018 Pasadena CA 91109
OPS5 and OPS 83	C and Expe LISP	Rule based, OPS83 adds imperative programming	Forward chaining	Varies among several dialects	Must program. It is more a language than a shell	Uses mouse, windows and menu	Must program	General knowledge presentation and control structure	Widely used knowledge engg. providing	Machintosh, Apollo, IBM-PC, VAX, Micro VAX,	Artelligence, Inc. 14902 Preston Rd, Suite 212 Dallas,

									experienced programmers a good environment for building ES	Xerox	Tx 74240
M.1	Prolog -C	Production rule system	Backward chaining limited forward chaining	May use regular word proceddor	Custom text (how and why)	Windows for tracing and debugging	Certainty factors 100 (true) to -100 (False)	Restricted rule based tool	Knowledge based rules written in English like language. Helpless experienced programmers write ES	IBM-PC	Teknowledge Inc. 1850 Embarcadero Road Palo Alto, CA 94303
Personal Consultant Series	PC Scheme (LISP)	Production rule with frames, meta rules and mapping	Forward chaining	Pull down menus with integrated graphics	How & Why and Review	Incorporates captured pictures	Certainty factors 100 (True) to -100 (False)	Can link to external programs	Less experienced programmers can use this EMYCIN like shell for writing ES upto 2000 rules	TI Business Pro, IBM-PC/AT	Texas Instruments Box 809063 Dept DEE02 Dallas, Tx 75380-9063
Super-Expert	Forth for PC version. Pascal for Mac version	Infers decision tree rules from examples with supportical structure	Both (depending upon the user's choice)	Standard spread-sheet, read ahead	Help available shows logic tables used	Spreadsheet screens	Not indicated	Rigid spread-sheet format	Domain experts and less experienced AI programmers may enter examples from which system infers rules	IBM-PC, Machintosh	Softsync Inc. 162 Madison Avenue New York NY 10016
ESP-Advisor	Prolog-2, knowledge base in KRL	Logic based KRL knowledge representation language		Menu driven screen, 'text animation'	User intera cts through scripts plus help	Good use of colour graphics	Must program in prolog	Very good through prolog link	Power and flexibility of KRL, requires some programming experience, easy for small scale systems	IBM-PC/XT/AT Data General/One VAX, Micro VAX II	Expert Systems International 1700 Walnut Street Philadelphia PA 19103
EXSYS	C (can link to external programs)	If-the-else production rules, math capabilities	Backward chaining	Menu driven full screen, text edition	User controlled runtime report generator	Colour coded text	Several types including threshold	Fairly rigid rule format	Very easy to use with excellent totorials, user interface and 5000 rule capacity	IBM-PC, VAX NEC 9801 Machintosh	EXSYS Inc. PO Box 75158 Sta. 14 Albuquerque NM 87194
TIMM	FORTRAN	Frame like, multi-dimensional state space rules in ferred from user examples		Query based dialog to build rules, system checks consistency	Identifies all rules used in consultation	Menu-driven text screen only	Certainty values. Reliability (0-100)	Fairly rigid example Format	Easy to use Sheel with good dialog to guide domain experts in linking system into decesion networks (embeddable)	IBM-PC, Prime, VAX 11/780, Zenith, IBM Mainframes	General Research Corp. 7655 Old Spring Hose Rd, Mclean, VA 221202
GURU	C	Production rules with natural language interface	Backward chaining (default mode) control can be specified at the outset with CONSULT command	Windows oriented NL interface	Recites notes on rules upon 'Why' or 'How' request	Menu driven Windows	Variety of certainty factors O (unknown) to 100 (True)	System development tool	Powerful ES shell integrated with database, word processing, etc. complexity requires experts only	IBM-PC, VAX 11-780, IBM Mainframes	Micro database systems Inc. P.O. Box 248 Lafayette, IN 47902
Extran	FORTRAN	Hierarchies of decision tree rules	Algorithm that converts matrix into an efficient decision tree	Built-in interative editor	Responds to 'why' and 'how' quiries	Interface to suntools windows		Standard rule format	Good development and operation environment, but requires	IBM MVS/TSO VAX VM S and Unix workstations	ITL knowledge link 36 George House Glasgow G12AD UK

									knowledge engineer to program		
CLIPS (C language integrated production systems)	C	Rules written in LISP like syntax (if-then-else, while) (procedural programming)	Forward chaining control strategy	General development interface	Capabilities like cross referencing of relations, style checking and semantic error checking	Graphical development interface	High probability	Can link to external programs	Development interfaced that support pull-down menus, an, integrated editor, and multiple windows	IBM-PC, Machintosh-II, Sun, Apollo, H.P., DEC 3100 RISC, M/CB, DEC VAXs ,	NASA's technology distribution organisation, COSMIC
ART-IM	C	Frames	Forward chaining	Built in editor, dialog boxes debug menu				Integration with external programs	Overlapping windows and pull-down menus. Reference manual contains some tutorial information and examples helpful to new users	IBM Mainframes, IBM PC/ATs, DEC VAXs	
LEVEL 5	Pascal	Facts and Rules Expressed in LEVEL 5 production rule language (PRL) good math capabilities	Backward chaining, forward chaining and mixed mode	Text editor and knowledge base compiler	Prepares customized reports. Also line of reasoning reports and answers to 'what-if'	Color display	Confidence factors range between 0-100	Fairly			
INSIGHT 2	Pascal	Production Rules if AND NOT OR then ELSE	Backward chaining	Menu driven text editor. May use regular word processor to enter rules	User controlled runtime report generator	Through external graphics programs. The external graphics editor has to be accessed using Turbo PASCAL (e.g. Halo Graphics) Allows colour display.	Association of confidence with each rule in the form of probability. Also supports user confidence	Can call external programs written Turbo PASCAL	Provides adequate instruction for users just learning to develop a small system. Manual is very well organised suited for small ES.	IBM-PC	Level five research 503 Fifth Avenue Indialantic FL 32903
VP EXPERT	C	Production rules and induction. Good math capabilities	Backward chaining. Limited forward chaining	Menu driven internal text editor. External word processor may also be used. Windoes can be opened during consultation	intelligent Help to consult with users when they have trouble using the tool. User can ask 'what-if' questions after a consultation.	Color graphic depiction	Supports both, i.e. Expert confidence and user confidence	Can read or write directly to dBASE II & III, Lotus 1-2-3, VP-INFO and VP-Planner	Easy to use for the beginners very well organised manual. Good for small ES.	IBM-PC	Paper back software Inc. 2830 Ninth Street Berkeley, CA 94710
NEXPERT	LISP C- Pascal & Assembly language	Simple rule based	User either strategy as appropriate	Editor integrated in the tool. Pull-down manus for editing and use of mouse for attribute selection. Windows show the activity of the system.	Rule-network uses graphics to show the links between the rules in the KB. Users can ask 'How' & 'Why' questions	Graphics can be added easily by a single command written in a rule to display a picture created in Mac Paint or digitized thunderscan. (Diagrams very details but black	Not built-in. Can be programmed through external programs.	Through Macintosh 'Desk Accessories' environment	Offers experienced programmers a choice of control strategies. Requires learning to create a KB. Documentation poor.	Machintosh	Neuron Data 444 High Street Palo Alto, CA 94301

						and white)					
GOLDWORKS	GCLISP	Frames and production rules	Forward chaining , Backward chaining and a combination	Menu and LISP level interface. Pop up menus, command lines, multiple windows and scrollable screens	Not indicated	Not indicated		dBASE Lotus 1-2-3 DOS-CALL and C	Non-programmers are provided with a menu driven interface to create frames, rules, and objects for the knowledge base; users familiar with USP can use a top level developer interface.	IBM-PC ,	Gold Hill Computers Inc. Cambridge, MA
LEVELS OBJECT		Hybid knowledge representation (objects, databases, rules, demons, rules, methods, hypertext, pattern matching, agendas) Good math capabilities	Forward chaining , Backward chaining and mixed mode	Graphical user interface. Point-and- pick technology for creating and editing objects, rules/demons, displays, agendas and databases. CASE facilities for visual programming.	Knowledge tree graphically diagrams KB and its logical relationships. Historical reports log lines or reasoning and session activities. Session monitor shows runtime activities of the inference engines.	Support for animation and hypertext	Support confidence calculations.	Interfaces to dBASE, Lotus, Focus Hold, SQL Server and ASCII files, Assembler, C, COBOL, Fortran, and Pascal programs can be activated from rules, demons, or methods.	Experienced programmers can handle very complex problems with this tool. Documentation very well defined.	IBM-PC/AT	Information Builders Inc. 1250 Broadway, New York NY 10001

CHAPTER 4

EXISTING EXPERT SYSTEMS IN SURFACE WATER ANALYSIS AND MODELLING

There are many Expert systems developed in the field of hydrology. Some of the expert systems developed in the field of surface water hydrology and modelling have been reviewed and described below:

4.1 ES For Daily Drought Severity

This ES evaluates basin-wide daily drought severity level based on certain rules. five indicators, i.e., streamflow, precipitation, temperature, groundwater and lake elevation are used to build the knowledge base of the system. If streamflow is in a certain drought severity level, e.g. 70%, 80%, 90% or 95%, and at least one of the four other indicators has reached the same or higher severity level as that of streamflow, then the streamflow drought severity level will be selected as the basin wide drought severity level. Next, if streamflow is in a certain drought severity level and at least one of the other four indicators has reached or exceeded a 70% severity, but has not reached or exceeded the same severity as that of streamflow, then a 70% drought severity level will be selected as the basin wide drought severity level. If streamflow is not in any drought severity level, but at least two other indicators are, then 70% severity level will be selected as the basin wide drought severity level. Facts of historic drought characteristics of truncation levels, mean durations, and mean conditional probabilities from selected gaging stations are stored in the working memory. The author has shown through the test results that the system can effectively detect the occurence of a historic drought (Chang et al 1995).

4.2 ES For Flow Routing In a River Network

This ES helps user in the selection of an appropriate mathematical model to solve the problem of flow routing on a specially appointed river network. The way for manipulation of the selected model and whether or not the inter basin rainfall-runoff should be considered are also integrated into the system. VP-Expert has been employed as the shell of this ES. The expert system has been tested on the Changtan watershed, north Guangdong province of China (Zhang and Chau 1995).

4.3 ETES

ETES is a front end expert system for the selection of a suitable evapotranspiration estimation method, given the location, data availability and climatic conditions (South Indian climatic conditions). Ten meteorological stations located in different climatic regions and thirteen ET estimation methods have been considered in this ES. Like a human consultant, the system asks the user for detailed information regarding the details of the project site such as location, season, climatic zone and data availability. It then makes a recommendation based on this information and the system;s own knowledge of such correction factors for converting the resulting ET values to those of methods that result in accurate estimation (Mohan and Arumugam 1995).

4.4 ES For Urban Drainage Modelling

It is a tool kit which provides guidance, instruction and support for training on aspects of network modelling in urban drainage design and simulation models commonly used in Europe. The tool kit comprises four interrelated, interactive components: an expert system, a data preparation and model execution tool, a document browsing facility, and a term bank. The results of the work are illustrated with the aid of snapshots of the system in use (Griffin, Bauwens and Ahmad 1994).

4.5 DELAQUA

DELQUA is an ES that provides assistance in the control of water quality of lakes and reservoirs. An ES shell NEXPERT has been used for its implementation while the hypertext system toolbook has been used to develop the user interface which consists of three levels: (1) an object oriented geographic interface with maps of the country, region and catchment area of waters under consideration, (2) an intelligent front end to support the handling of the simulation model SALMO and the historical database HIDA. and (3) a user interface to consult knowledge bases of three water quality problems (eutrofication, algal blooms and pathogens). The deterministic model SALMO, empirical models of the Vollenweider-type and a fuzzy model are accessible from the knowledge bases for eutrofication and algal blooms (Recknagel et al 1994).

4.6 ES For Fluvial Hydrodynamics

This expert system assists hydraulic engineers to solve the unsteady open channel flow in river networks. A methodology of combining numerical analysis software into an expert system is presented. The verification, validation, application, and future development of this system are also presented (chau and Yang 1993).

4.7 ES For The Biological Monitoring Of River Pollution

This expert system does river pollution monitoring using bilogical data. Data input consists of list of the macroinvertebrates found in the samples taken from the river bed. These are translated into water quality terms using multi-hypothesis Bayesian inference. A probabilty based screening procedure checks the data for any anomalies which might distort the conclusions, and offers the user the oppurtunity to remove them. The system has been implemented on a PC using a rule/frame based ES shell, Leonardo. Performance tests have indicated that this system provides a more consistent means of classifying river water quality than other indices (Walley, Boyd and Hawkes 1992).

4.8 Expert Geographic Information System For Texas Water Planning

This system comprises an expert system that embodies the logical rules and expertise of water resources planning as well as geographic information system that stores and analyses spatially distributed data. Normal water demand forecasts and water supply data along with approriate analysis routines are used in this planning tool, which attempts to follow the logic of current methods and permit plans to be updated and alternatives to be analyzed more rapidly. The system was applied to analyze an existing water supply system for the corpus

Christi, Texas area. Given annual yields for the reservoirs, water demand forecasts, and institutional requirements, the expert GIS calculated potential water supply deficits or excesses in the region over a 50-year planning horizon, and suggested efficient and cost effective alternatives for developing additional water supplies in the event that deficits occur. The method is suitable for expansion to solve much larger and more complex problems (McKinney, Maidment and Tanriverdi 1993).

4.9 Decision Support System For Drought Characterization and Management

This expert system is an effective tool for drought forecasting and management. In this system the critical data are the forecasted streamflow and the forecasted system demand for the coming week. Several different model structures were investigated for use in forecasting both streamflow and system demand. For the streamflow forecasts a probabilistic model structure was developed. Historical data derived from the Kentucky river basin were used to test the resulting decision support system (Ormsbee and Jain 1992). .

4.10 Linking of Expert Systems with Numerical Models

The rule based expert sytem for environmental impact assessment of water resources development projects, named MEXSES was studied to create a link with external models so that MEXSES can use the computational power of mathematical models during the inference process. The information in MEXSES on which the impact assessment is based, is stored in the systems knowledge base in the form of production rules. The expert systems inference engine interprets the information in the knowledge base and generates a conclusion about the impact of the problem under considertion. Besides MEXSES, a model specific program was created to interface the two other programs. The main result of the integeration of other model in the hybrid rule base is that the established link really works; it is possible to invoke a numerical model from the MEXSES and to use the model results in the reasoning process. The user is provided with a powerful modelling and problem solving environment which offers the features of rule based qualitative reasoning as well as the computer power of numerical models. (Nieuwkamer and Winkelbauer 1992).

4.11 SIRAH

Sirah is a software environment for advanced knowledge based models for flood management. An expert system has been developed for flood management support in spain, which uses knowledge based on physical behaviour understanding of flows along a basin and expert personal judgements. Sirah provides as main capabilities: (1) traditional knowledge representation capacity by rules and frames to be used for the ad-hoc knowledge required in every specific case for problem identification and control and civil defence decision recommendations; (2) a library of generic task modules according to the propasals of Chandrashekharan for qualitative modelling of the professional knowledge about behaviour of different physical elements involvedin the response of a watershed; (3) a control specification structure for the process of search of possible short term future scenarios; (4) a set of basic procedures for user interface, knowledge acquisition and inference. The system employs basic simulation tasks and scenario generation tasks to solve the simulation problems related to the different physical components. a model may be defined to be processed inside this architecture by specification of the concept of a basin in qualitative terms and the criteria for reasoning in the search for possible scenarios for problem identification. The SIRAH environment is a case of a possible new generation of artificial intelligence tools oriented towards professional engineering (Alonso, Cuena and Reig).

4.12 Knowledge Based system for SWMM Runoff Component Calibration

A knowledge based system for the runoff block of widely used stormwater management model (SWMM) was developed for SWMM users. The expert system developed for the knowledge based storm water manegement model (KBSWMM): (1) discriminates between the precipitation errors as measured by the given objective functions; (2) selects the appropriate parameter.to reduce the errors to within a user specified tolerence value; and (3) adjusts the error tolerance value if necessary. The automation and the methodical approach of KBSwmm in performing the calibration not only require less time and experience of user, but also may achieve in some cases, better results than the traditional approach to calibrate SWMM. The user is constantly informed with the assignment of new values to the selected parameters and may decide to overwrite the recommendations if necessary. at the nd of the calibration process, KBSWMM also provides a transcript file that summarizes the results, parameters selected new values assigned to them, measures taken, and others obtained throughout the calibration process. KBSWMM has been applied specifically to the upper Buket Timah basin in Singapore, and includes knowledge specific to that catchment (Liong, Chang and Lum, 1991).

4.13 Object Oriented Hydrological Modelling

Hydrological studies for water management systems very often imply the use of hydrological modelling concepts for their design as well as for their management and their environmental assessment. Potentially the various existing models can be applied, but they need some compromise between their flexibility and their possibility of utilization. Object oriented modelling proposes an alternative. It gives the possibility of treating each catchment component separately with a chosen existing model, in combination with the new tools for numerical geographical information systems. An expert system guides this choice and assists the user in his task, according to his objectives, and to the data and methods available (Musy, Meylan and Adebnego, 1989)

4.14 EXSRM, an Expert System for Snowmelt Runoff Model (SRM)

This is an expert system to assist unfamiliar users to set up and operate a complex model for simulating snowmelt runoff. The system encodes the procedures that experienced hydrologists use to set up input data, select parameters, and adjust these values when initial simulations do not match measured data. the expert system is built around an exieting FORTRAN model which is not changed and does not need to be reprogrammed into a different computer language. Parts of the expert system can be implemented as they are completed without affecting the model operation. Since the FORTRAN code itself is not changed, historic inputs and parameter estimations can be mixed with the inputs and parameters developed by the expert system (Martinec, Rango and Engman, 1989).

4.15 Knowledge Based Expert System for Flood Frequecy Analysis

Single station flood frequency analysis is an important element in hydrotechnical planning and design. In Canada, no single statistical distribution has been specified for floods: hence, the conventional approach is to select a distribution based on its fit to the observed sample. This selection is not straightforward owing to typically short record lengths and attendent sampling error, magnified influence of apparent outliers and limited evidence of two populations. Nevertheless, experienced analysts confidently select a distribution for a station based only on a few heuristics. A knowledge based expert system has been developed to emulate these expert heuristics. It can perform data analyses, suggest an appropriate distribution, detect outliers, and provide means to justify a design flood on physical grounds. If the sample is too small to give reliable quantile estimates, the system performs a Bayesian analysis to combine regional information with station specific data. The system was calibrated and tested for 52 stations across Canada. Its performance was evaluated by comparing the distributions selected by experts with those given by the developed system. The results indicated that the system can perform at an expert level in the task of selecting distributions (Watt and Chow, 1990).

4.16 Expert System for Selection of a Suitable Method for Flow Measurment in Open Channels.

The expert system aids the user in the selection of a suitable method for flow measurement in open channels. two aspects of selection are considered: physical characteristics of the gauging site and available equipment and/or structures at the gauging site. The system has been designed for the potential use in environment Canada Two systems, namely, SFM and STR were developed as potential modules for incorporation into an intelligent decision support system (IDSS) considered for supporting the operation of the existing network of gaging stations operated by Environment Canada. The results indicate that for well-defined problems like surface flow measurment method selection, expert system technology may be used to improve the operation, provide rational solutions and provide a useful training tool (Simonoviv 1990).

4.17 Expert System for Calibrating SWMM

Using expert system technology, an interactive user suport framework has been developed to automate the calibration of the runoff block of the SWMM model. It acts as a front end to assist the user in the initial estimation of the parameter values and in building the SWMM input files. It interprets the simulation results, production rules are employed to help the user decide what parameters need to be adjusted. some heuristics have ben developed to evaluate the new pwrwmeter values. The combination of simulation techniques and expert system methodologies facilitates the use of sophisticated models such as SWMM (Baffaut, Bernabdallan, Wood Delleur and Houck, 1987; Baffaut and Delleur, 1989 & 1990).

CHAPTER 5

DEVELOPMENT OF EXPERT SYSTEM UHYDEX

The system (UHYDEX), an expert system for unit hydrograph analysis has been developed for the selection of an appropriate model for unit hydrograph derivation for a given catchment depending upon the location and data availability of the catchment.

The Knowledge base of the system contails rules for the selection of appropriate model for UH derivation. The selection is made depending upon the data availability of the catchment, type of project, location of the catchment etc. Once the selection is made, the system conveys to the user about the most suitable model for the given catchment and gives the user the guidelines to prepare a data file for UH derivation and finally derives the unit hydrograph for the given catchment.

The knowledge base of the system has been implemented through the shell, EXSYS. The knowledge base contains IF-THE-ELSE rules and FORTRAN programs.

The developmental aspects of the knowledge base and the program details of the FORTRAN programs are discussed in the subsequent sections.

5.1 Choice of Expert System Shell

The shell EXSYS was selected because of the following technical considerations:

* The expert system to be developed was a diagnostic one requiring the knowledge representation in the form of IF-THEN production rules, and EXSYS supports such a representation. Hence, by using EXSYS, only the knowledge base was to be developed and thus saved the time of development of the inference engine and the user interface.
* Exsys supports uncertainty which is required for the rules that based on an expert's experience..
* EXSYS enables to call in external programs and write subroutines in any other programming language. Thus, EXSYS expert systems can directly recieve data from automatic testing equipment, data bases, some spread sheets and dedicated programs.
* EXSYS also enables to use graphics developed using external graphics programs.

5.2 Some Important Features of EXSYS

5.2.1 Minimum System Requirements

The minimum system requirements are an IBM PC, AT or compatible with 256K RAM, one single sided disk drive and DOS 2.0 or higher. The full available memory can be used. EXSYS can create about 700 rules per 64K of memory over 192K. That is about 5000 rules in a PC with 640K. Expert systems can be run in less memory then is required for their development.

5.2.2 Running Expert Systems

EXSYS knowledge bases can be run by anyone with essentially no training other than how to start the program. However, EXSYS offers many options when requesting information about what the computer is doing and why.
All knowledge base files for EXSYS are kept in two parts : one with a .RUL filename extension and one with a .TXT filename extension. Both files must be on the same disk (or RAM disk) for the program to work.

To run EXSYS place the work disk, in drive A and turn the computer on or press the Ctrl, Alt and Del keys together. If the computer is already on the screen displays the DOS prompt A>. Then type EXSYS |filename| or in this case UHYDEX, without extension. If just EXSYS is entered without a filename, the program will display the title and ask the user for a filename.

Once an acceptable filename and the knowledge base files have been loaded, the computer wishes instructions on how to run EXSYS. If the user has not run the program in a while, he may wish to refresh himself on the program in a while, he may wish to refresh himself on the program and presses (Y). If he does not wish the program to display instruction he presses (N) or just the (ENTER) key.

5.2.3 Recovering Data

The computer will then ask if the user wants to recover data from a previous run stored on the disk. The EXSYS runtime program lets the user store the data he has entered up to that point, leave the program and be able to return to that point at a later time. If the data thus stored is to be recovered then (Y) is pressed. The user will then be asked for the filename of the file holding the stored input data. The program will read in the data and, after displaying the starting title screens, return to where the user left off. If he does not wish to recover stored data he presses (ENTER) or (N).

5.2.4 EXSYS Displays

The computer displays the subject of the knowledge base and the author. Any key may be pressed. The program may display information explaining the knowledge base the user will be running. This display is an option selectable by the knowledge base author.

The program asks if the user wishes to have the rules displayed as the program determines them to be true. The default value will have been selected by the knowledge base author and will be displayed. The program runs faster if it does not have to display the rules; however, the rules show the user how the program is progressing and may help to educate the user. Regardless of the user's selection he will still be able to see the rules through the use of the "WHY" command or when the final selection of choices has been made.

5.2.5 Interacting with EXSYS

The computer will start asking questions relevant to the subject area of the knowledge base. This is how the program obtains the data needed to make a decision. There are two types of questions the user may be asked : multiple choice and numeric value.

Multiple choice questions will display a statement ending in a verb, followed by a numbered list of possible completions of the sentence. The number or numbers of the choices is/are entered for the user's selection and (ENTER) is pressed. If more than one number is chosen, the numbers are separated by a comma or with a space. If numbers outside the range of the list are entered, the computer will remark the question and not get past the question until it is answered.

The computer will continue asking questions till it has obtained enough information to determine that all the IF conditions in a rule are true. If the computer determines that any of the IF conditions in a rule are false, it will reject the rule and go to the next appropriate rule.

The other type of information the user may be asked for is a numeric value. There will be an explanation of what information the program needs and a space to enter the value. A numeric value including a decimal point may be typed and (ENTER) pressed.

5.2.6 Rules

Rules are the representation of the knowledge of the expert system. A rule is one or more statements in the IF part followed by one or more statements in the THEN part with a note, if necessary, to highlight some key point. The statements are plain English sentences or algebraic expressions and are just the sort of questions the computer has been asking the user. There may also be "choices" in the THEN part. Choices are the possible solutions to the problem the expert system was written for. Choices are indicated by a text statement followed by "-Probability=" and either 0, 1 or a ratio. A well written rule should be easy to read.

There are three main systems available in EXSYS for assigning the probability value. Only one system can be used in a given knowledge base.

0-1 System

If the value following the "Probability =" is a 0 or a 1 the user is in this system. A value of 0 means absolutely no and eliminates the possible solution from futher consideration. A value of 1 is euivalent to absolutely yes and selects that solution for inclusion in the final list of solutions. There is no real probability in this system; only yes or no.

0-10 System

If the value following the "Probability = " is a ratio where the denominator is 10, you are in this system (e.g. Probability = 3/10). This is the most generally useful system and the one most often encountered. In this system 0/10 is equivalent to absolutely no and locks the value at 0/10 regardless of any other value the choice may have received. A value of 0/10 eliminates the choice from further consideration. A value of 10/10 is equivalent to "absolutely yes" and also locks the value for the choice at 10/10 regardless of any other values the choice may have received. Values of 1 to 9 represent degrees of certainty ranging from "very probably no" to "very probably yes". The values from 1 to 9 DO NOT lock the value and are averaged to give the final value for a choice.

0-100 System

If the ratio following "Probability = " has a denominator of 100 you are in the 0-100 system. In this system values of 0 to 100 can be assigned but the values of 0 and 100 DO NOT lock the value. The final value can be computed as an average of the probabilities or can be combined as dependent or independent probabilities. The author of the knowledge base will have selected the approapriate method of combining values.

5.2.7 Using "WHY"

If the user wonders why the program needs to know the information it is requesting, the user can ask it by typing WHY, instead of making a selection from the list of values, and press the (ENTER) key. The program will respond by displaying the rule it is trying to determine the validity of.

5.2.8 Saving Data with "QUIT"

The user has the option of storing the data he has input into the program, exiting the program, and being able to return to the same point later. This can be useful if the user needs to look up information needed by the program or if he must leave the program but does not want to lose the data he has already input. He can select to store the data by entering QUIT in response to any of the computer's requests for data. The program will then ask for the name of the file to store the data in. A filename upto 8 characters but not the name of the knowledge base is entered. If a file already exists, with the name chosen, it will be erased and replaced with the new data. The user will then be asked if he wishes to return to the program or exit to DOS. The data input may also be stored by pressing (Q) when the sorted list of choices is displayed.

5.2.9 Display of the Conclusions

The program will continue asking questions until it has considered all of the possibilities the person who wrote the knowledge base put in and it will then display its results. Just prior to the display of the results, the program may display the information interpreting the meaning of the values assigned to the choices. The inclusion of this explanation is an option available to the knowledge base author. The choices will then be displayed arranged in order by final value. The most likely first, next most likely second, etc. Only choices that received a final value greater than 0 will be displayed. The user may also find other statements or calculated values displayed. These will be displayed as a statement or a statement followed by a numeric value.

5.2.10 Asking How a Conclusion was Reached

The user can ask the computer how it arrived at its final value for a specific choice or why a statement is displayed. If the line number for any choice or statement is entered, the computer will respond by displaying all of the rules it used to determine the value of that choice or statement. The user again has all of the options in requesting more information about each of the rules as discussed above.

5.2.11 Changing and Rerunning the Data

EXSYS provides a very easy way to test and analyse the effect the user's input had on the final list of choices. He can change one or more of his answers, while holding the remainder constant, rerun the data and see what effect the changes have on the final outcome. The current value for the choices can be saved for comparison with the new values.

To change the data (C) is pressed. The user will be asked if he wishes to save the current values for comparison with the new ones he will be calculating. The program will then display a list of all of the information he provided by answering questions. The number of the statement he wants changed is entered and the program will reask that question. The question is answered with the new values that he wishes to try. The computer will return to the display of all of the information that the user told it. Statements are continued to be changed until the data is the way he wants it, then he presses (R) to rerun the data. If, due to the changes, the program now needs more information it will ask for it. The rules will not be displayed during the rerun. The program will then display the new list of choices. if the user opts to have the previous values saved for comparison, they will be displayed in parenthesis.

The ability to change and rerun the data allows expert system models to be built and tested and to see if an answer that the user was not sure of is vital to the final outcome, or really has little effect.

5.2.12 Storing the Results

The user can store the input provided to reach the conclusions by pressing (Q). This is the same as using the QUIT option when entering data. The data input will be stored in a disk file and the user will be able to return directly to this point. This is particularly useful if the user wants to experiment with the "change and rerun" command.

5.2.13 Printing the Results

The user may wish to save a printed copy of the results of the run. To do this he presses (P). He will then be asked if he wishes to have the data he told the computer also printed. If he presses (Y) he will have both the final sorted list of choices printed along with all of the data he provided the computer in answer to its questions.

5.2.14 Exiting the Program

When the user has finished examining the choices he presses the (D) key. He will then be given the option of running the program again with either the same or a different knowledge base file.

5.2.15 Directing EXSYS Output to a File

It is possible to direct the output from the runtime program, EXSYS.EXE, to a disk file. When this option is used, the program will automatically write the results of the run to the disk file, along with the data input by the user, and exit to DOS. This allows EXSYS to be combined in a series of operations controlled by a batch file. Potentially, with all data needed bv EXSYS can be provided by an external program, EXSYS can be used to analyse the data and write it to a disk and another program could be read and use the EXSYS results.

5.3 FORTRAN Programs for Unit Hydrograph Derivation

5.3.1 UH for Gauged Catchments

There are six different methods for unit hydrograph derivation.

The first two methods are used to derive the unit hydrograph from single-period, individual and isolated storms. The only difference is that the first option requires the discharge hydrograph as input and permits the user to supply the constant or non constant baseflow values which are deducted from the discharge hydrograph in order to get the direct surface runoff hydrograph. Then the area under the direct surface runoff hydrograph is computed in the first option using Simpson's rule. The runoff volume in depth unit is obtained for further computations. While the runoff volume (in depth unit) and direct surface runoff hydrograph ordinates are input to the second option.

Third to sixth methods are used for the derivation of unit hydrograph using Collin's method, Conventional Nash Model, Integer Nash Model and Clark Model respectively.

5.2.1.1 Conventional Method (With Base Flow Option)

This method computes the unit hydrograph of a specified duration from the direct surface runoff hydrograph obtained by separating the base flow (constant or non constant), supplied by the user, from the discharge hydrograph of an isolated event.

The values of input variables given in Table 3 are required to be supplied in free format through a data file :

The main output of this method shall include :

(i) Volume of excess rainfall from hydrograph separating the constant base flow or non-constant base flow.
(ii) Unit hydrograph ordinates.

Table 3: Input Variables for Conventional Method (With Baseflow Option)

REC. NO.	INPUT LISTS	DESCRIPTION
1	N	No. of observations
2	(A1(I),I=0,N-1)	Vector containing the values of the discharge hydrograph ordinates (m^3/sec)
3	HR	Data interval in hours
4	AR	Catchment area (sq. mtrs.)
5	NOPT	An integer constant which provides options for baseflow, constant or non constant base flow, to the user. NOPT=1 for constant baseflow NOPT=2 for non-constant baseflow.
6	CB	Constant baseflow (m^3/sec)
7	(CBN(I),I=0,N-1)	Vector containing non-constant base flow values (m^3/sec)

5.3.1.2 Conventional Method (Without Base Flow Option)

This method provides an estimate for the unit hydrograph from the direct surface runoff of an isolated single period storm event.

The values of the input variables given in Table 4 are required to be supplied in free format through a data file.

The main output from this method shall be D-hour unit hydrograph derived from an isolated single period storm event of D-hour duration.

Table 4: Input Variables for Conventional Method (Without Baseflow Option)

REC. NO.	INPUT LISTS	DESCRIPTION
1	D	Duration of Unit hydrograph (hours)
2	VOL	Unit volume of UH (mm)
3	DLT	Computation interval (hours)
4	EXE	Excess rainfall block (mm)
5	NRUN	No. of Direct surface runoff ordinates
6	(DSRO(I),I=1,NRUN)	Vector of direct surface runoff hydrograph ordinates (m^3/sec)

5.3.1.3 Unit Hydrograph Using Collin's Method

This method may be used to derive the unit hydrograph of desired duration and unit volume from multi-period storm using Collin's Method. The duration of unit hydrograph (in hours) must be same as the computational interval (in hours).

The values of the following input variables (Table 5) shall be required in sequence through an input file in free format:

The main output file of this method shall be D hour unit hydrograph of VOL unit volume at DLT hour computational interval.

The duration of unit hydrograph shall be same as the computational interval.

5.3.1.4 Unit Hydrograph Using Conventional Nash Model (Method of Moments)

This option is used for the derivation of unit hydrograph using conventional Nash model from the direct surface runoff hydrograph and excess rainfall hyetograph of an event using the method of moments.

The values of the input variables given in Table 6 are required to be supplied in free format through a file:

Table 5: Input Variables for Collin's Method

REC NO.	INPUT LISTS	DESCRIPTION
1	CA	Catchment area (sq.km)
2	DLT	Computation interval (hours)
3	D	Duration of unit hydrograph (hours)
4	VOL	Unit volume (mm)
5	NRUN	No. of DRH ordinates
6	(DSRO(I),I=1,NRAIN)	Vector of DRH ordinates(m^3/sec)
7	NRAIN	No. of Excess rainfall blocks

Table 6: Input Variables for Conventional Nash Model (Method of Moments)

REC. NO	INPUT LISTS	DESCRIPTION
1	CA	Catchment area (sq.km)
2	DLT	Computational interval (hours)
3	D	Duration of unit hydrograph (hours)
4	VOL	Unit Volume of UH (mm)
5	NRUN	No. of DRH ordinates
6	(DSRO(I),I=1,NRUN)	Vector of direct surface runoff ordinates (m^3/sec)
7	NRAIN	No. of excess rainfall blocks
8	(EXE(I),I=1,NRAIN)	Vector of exces rainfall hyetograph ordinates (mm)

The main output from this method shall be :

(i) First and second moment of excess rainfall hyetograph about the origin.
(ii) First and second moments of direct surface runoff hydrograph about the origin.

(iii) Estimated parameter values, n and K.
(iv) First moment of IUH about the origin (nK) and second moment of IUH about the centroid (nK^2).
(v) Instantaneous unit hydrograph (IUH).
(vi) D- hour and VOL mm unit hydrograph (cumec).

5.3.1.5 Unit Hydrograph Using Conventional Nash Model (Optimisation)

In this option Marquardt Algorithm of non-linear optimisation is used to derive the parameters of conventional Nash Model and corresponding unit hydrograph from the direct surface runoff hydrograph and excess rainfall hyetograph of an event. Table 7 gives the input parameters.

Table 7: Input variables for Conventional Nash Model (Optimisation)

REC. NO	INPUT LISTS	DESCRIPTION
1	CA	Catchment area (sq.km)
2	DLT	Computational interval (hours)
3	D	Duration of unit hydrograph (hours)
4	NRAIN	No. of excess rainfall blocks
5	(EXE(I),I=1,NRAIN)	Vector of excess rainfall hyetograph ordinates (mm)
6	NRUN	No. of DRH ordinates
7	(Y(I),I=1,NRUN)	Vector of direct surface runoff ordinates (m^3/sec)
8	KK	No. of parameters to be optimised
9	(B(J),J=1,KK)	Initial values of the parameters
10	(BMIN(J),J=1,KK)	Minimum values which the parameters may take during optimisation
11	(BMAX(J),J=1,KK)	Maximum values which the parameters may take during optimisation

The main output from this method shall be the optimum values of Nash Model parameters and D-hour 1 mm volume unit hydrograph. In addition to these, the computed direct surface runoff hydrograph ordinates and model efficiency are also obtained as output of this option.

5.3.1.6 Unit Hydrograph Using Given parameters of Conventional Nash Model

This option is used to derive the unit hydrograph from the direct surface runoff hydrograph and excess rainfall hyetograph of an event using the parameters of Nash model supplied by the user interactively.

The values of the input variables given in Table 8 are required to be supplied in free format through a file.

Table 8: Input Variables for Given Parameters of Nash Model

REC. NO	INPUT LISTS	DESCRIPTION
1	CA	Catchment area (sq.km)
2	DLT	Computational interval (hours)
3	D	Duration of unit hydrograph (hours)
4	VOL	Unit volume of UH (mm)
5	NUH	No. of unit hydrograph ordinates

The values of the parameters n & K are required to be supplied by the user during the execution of this option in response of the following :

Please supply the value of N :
Please supply the value of K :

There is a provision in this method to supply different sets of parameter values and to derive unit hydrograph corresponding to each set of parameter values. In this regard the user has to supply either 'Y' or 'y' in response to the following :

Do you want to supply other set of parameter values :

The main output from this method shall be the D-hour 1 mm volume unit hydrograph corresponding to each set of parameter values.

5.3.1.7 Unit Hydrograph Using Integer Nash Model

This method is used for the derivation of unit hydrograph using Integer Nash Model.

The values of the same input variables as described for conventional Nash model are required to be supplied in free format through a file. In addition to this integer value of the parameter 'n' is to be supplied through terminal in interactive mode at the time of running the programme as follows:

(i) The following matter will be displayed over the VDU during the execution of the programme.

ACTUAL VALUE OF N=X
ACTUAL VALUE OF K(HRS)=Y
FIRST MOMENT OF IUH(HRS)=A
SECOND MOMENT OF IUH ABOUT THE CENTROID (HRS^2)=B
SUPPLY INTEGER VALUE OF N :

(ii) The cursor will wait for an input as an integer value of N to be supplied by the user in free format. At step (1), X, Y, A and B are real constants computed by the programme.

(iii) Once the required input are supplied, the modified values of parameter K, first and second moment of IUH will be displayed over the VDU as :

MODIFIED VALUE OF K=C'

FIRST MOMENT OF IUH(HRS)=A'

SECOND MOMENT OF IUH ABOUT THE CENTROID (HRS^2)=B'

where A', B' and C' are the real constants.

(iv) Further, the cursor will wait after displaying the matter given below :

DO YOU WANT TO TRY WITH OTHER INTEGER VALUE OF N
:

(v) Now user may supply either 'Y' or 'N' depending upon his requirement. If the response is 'Y' then the control will be transferred to the statement asking for another integer value of parameter 'n' as follows and step (ii) onward will be repeated :

SUPPLY INTEGER VALUE OF N :

Otherwise, the execution will stop.

The main output shall consists of D hour and VOL mm unit hydrograph for different trial values of n as integer.

5.3.1.8 Unit Hydrograph using Clark Model (Optimisation)

This option of the package may be used to derive the optimum parameters of Clark model from the direct surface runoff hydrograph and the excess rainfall hyetograph of an event using Marquardt Algorithm.

The values of different variables required to be supplied in free format through a file are described below in Table 9.

The main output from this method shall be the optimum values of Clark Model parameters and DUH-hour 1 mm volume unit hydrograph.

Table 9: Input variables for Clark Model (Optimisation)

REC NO.	INPUT LISTS	DESCRIPTION
1	nt,dlt,tcfic,duh	nt - No of ordinates of time area diagram at dlt hour interval dlt - Computational interval (hrs) tcfic - Any fictitious value of T_c duh - Duration of unit hydrograph (hrs)
2	(cumfica(i),i=1,nt)	A vector containing ordinates of time area diagram (Sq Km)
3	NRAIN	No. of excess rainfall blocks
4	(EXE(I),I=1,NRAIN)	Vector of excess rainfall hyetograph ordinates (mm).
5	NRUN	No. of DRH ordinates
6	(ODSRO(I),I=1,NRUN)	Vector of direct surface runoff hydrograph ordinates (m^3/sec)
7	KK	No. of parameters to be optimised
8	(B(J),J=1,KK)	Initial values of the parameters
9	(BMIN(J),J=1,KK)	Minimum values which the parameters may take during optimisation
10	(BMAX(J),J=1,KK)	Maximum values which the parameters may take during optimisation

5.3.1.9 Unit Hydrograph Using Given Parameters of Clark Model

This option may be used to derive unit hydrograph of desired duration and unit volume using Clark model. The input file shall consist of the values of the input variables given in Table 10 in free format:

Table 10: Input variables for Given Parameters of Clark Model

REC NO.	INPUT LISTS	DESCRIPTION
1	CA	Catchment area (Sq Km)
2	DLT	Computational interval (hours)
3	D	Duration of unit hydrograph (hours)
4	NDUH	No. of unit hydrograph ordinates
5	VOL	Unit Volume of UH (mm)
6	NT	No. of ordinates of time area diagram
7	(TAREA(I),I=1,NT)	Vector of time-area diagram ordinates (Km^2)

Clark model parameters T_c and R may be supplied by the user interactively.

The values of the model parameters TC and R and the computational interval DLT may be changed by the user through the terminal in interactive mode as given below and the unit hydrograph may be derived accordingly for each trial run:

(i) Matter displayed during the execution:

SUPPLY VALUE OF TC :
SUPPLY VALUE OF R :

DO YOU WANT TO REVISE TC FOR TRIAL NO. N1 (Y/N):

Here N1 is an integer constant displayed on the terminal and 'Y' or 'N' has to be supplied by the user through the terminal. If the user response is Y the following information are required to be supplied interactively otherwise the control will be transferred to step (ii).

SUPPLY VALUE OF TC : A

Here A is a real constant to be supplied by the user to revise the value of Tc for the next trial run.

(ii) DO YOU WANT TO REVISE THE COMPUTATIONAL INTERVAL FOR TRIAL NO. N2 (Y/N) :

Here N2 is an integer constant displayed on the terminal screen in I3 format. Either 'Y' or 'N' is supplied by the user through terminal. If user has supplied 'Y' then the control will be transferred to the write statement which displays the following :

SUPPLY REVISED VALUE OF COMPUT.INTERVAL :

Now the cursor will wait for the revised value of computational interval. Once this is supplied the computation will proceed to step (iii).
However, if user has supplied 'N', then the control will be transferred to step (iii) without asking for the value of revised computational interval.

(iii) DO YOU WANT TO REVISE R. FOR TRIAL NO N3 (Y/N) :

Here N3 is an integer constant which represents the trial no. and displays on the terminal in I3 format. Either 'Y' OR 'N' is supplied through terminal by the user depending upon the requirement. If user want to revise the value of R in the next trial, then 'Y' may be supplied in response of the above quarry and the revised value of R may be supplied in response of the quarry made as below:

SUPPLY VALUE OF R : B

Here B is a real constant which represents the revised value of R.

From here the control will be transferred to an appropriate statement in the programme to compute the unit hydrograph using revised parameters in case user has supplied 'Y' in response to any one of the quarries listed above. Moreover, the above quarries will be repeated again for the next trial. If the user response in all the quarries made is 'N' then the control will be transferred to the stop statement and execution will be over.

The main output file shall be D- hour unit hydrograph at DLT hour interval corresponding to TC and R values.

5.3.2 UH Derivation for Ungauged Catchments

In this sub-category there are two different options for unit hydrograph derivation.

The first option derives unit hydrograph for a catchment using Snyder's approach while second option is used to derive the unit hydrograph for ungauged catchments using the regional unit hydrograph relationships developed by CWC for the respective regions.

5.3.2.1 Unit hydrograph Using Snyder's Method

This option of the package may be used to derive unit hydrograph for ungauged catchments using Snyder's approach. Various input variables required to be supplied in free format are described in Table 11.

The main output shall be the important characteristics of DUH-hr unit hydrograph for ungauged catchment. These include the peak of Uh (cumec), time lag (hrs.), width of unit hydrograph at 50% of UH peak (W_{50}) (hrs.), width of unit hydrograph at 75% of UH peak (W_{75}) (hrs.) and base width of unit hydrograph (hrs.). The user may draw the shape of the unit hydrograph using these characteristics after preserving the unit volume equal to one cm by trial and error.

Table 11: Input variables for Snyder's Method

REC. NO.	INPUT LIST	DESCRIPTION
1.	Ca, al, alc, duh	Ca - Catchment area (sq Km) al - Length of main stream (Km) alc - Distance from outlet to centre of area of catchment along the stream (Km) duh- Duration of Unit hydrograph (hrs)
2.	Ct, Cp, a, b	Ct - a coefficient used in the relationship for lag. It normally varies from 0.3 to 0.6 for different regions. Cp - a coefficient used in the relationship of peak. It normally varies from 0.31 to 0.93. a - a coefficient used in the relationship of W_{50}. b - a coefficient used in the relationship of W_{75}.

5.3.2.2 Unit Hydrograph Using CWC Method

This option of the package may be used to derive the unit hydrograph with unit volume 1cm for an ungauged catchment using the regional unit hydrograph relationships developed by CWC for the respective region. The input variables given in Table 12 are required to be supplied in free format .

The main output of this method shall be the important characteristics of UH such as peak (m^3

/s), time to peak (hrs), width of UH at 50% of UH peak (W_{50}) (hrs), width of UH at 75% of UH peak (W_{75}) (hrs), width of rising side of UH at 50% of UH peak (WR_{50}) (hrs), width of rising side of UH at 75% of UH peak (WR_{75}) (hrs) and base width of unit hydrograph (hrs) for an ungauged catchment of the region. User may develop duh-hour unit hydrograph with the help of these characteristics preserving the shape of UH for 1cm unit volume.

Table 12: Input variables for CWC Method

REC. NO.	INPUT LISTS	DESCRIPTION
1.	Ca, al, alc, s, duh	Ca - Catchment area(sq Km) al - length of main stream (Km) alc - distance from outlet to centre of area of catchment along the main stream (Km). S - Slope of main stream (m/Km) duh - duration of unit hydrograph for which regional UH relationships are developed.
2.	a_1 , b_1	Regional coefficients in the relationship: $t_p = a_1 (al*alc/\sqrt{S})**b_1$
3.	a_2 , b_2	regional coefficients in the relationship : $q_p = a_2(t_p)**b_2$ where, q_p (cumec/sq Km) =QP/Ca
4.	a_3 , b_3	regional coefficients in the relationship $W_{50} = a_3(q_p)**b_3$
5.	a_4 , b_4	regional coefficients in the relationship $W_{75} = a_4(q_p)**b_4$
6.	a_5 , b_5	regional coefficients in the relationship $WR_{50} = a_5(q_p)**b_5$
7.	a_6 , b_6	regional coefficients in the relationship $WR_{75} = a_6(q_p)**b_6$
8.	a_7 , b_7	regional coefficients in the relationship $t_b = a_7(t_p)**b_7$

5.4 Coding of the Expert System UHYDEX

Figure 5 shows the general structure of the Expert System UHYDEX. The knowlwdge base contains the rules for appropriate model selection and the various models in respective FORTRAN programs. The inference engine and the user interface are separate from the knowledge base and they are provided by the shell EXSYS. Thus, the knowledge base can be updated at any later stage without disturbing the whole program.

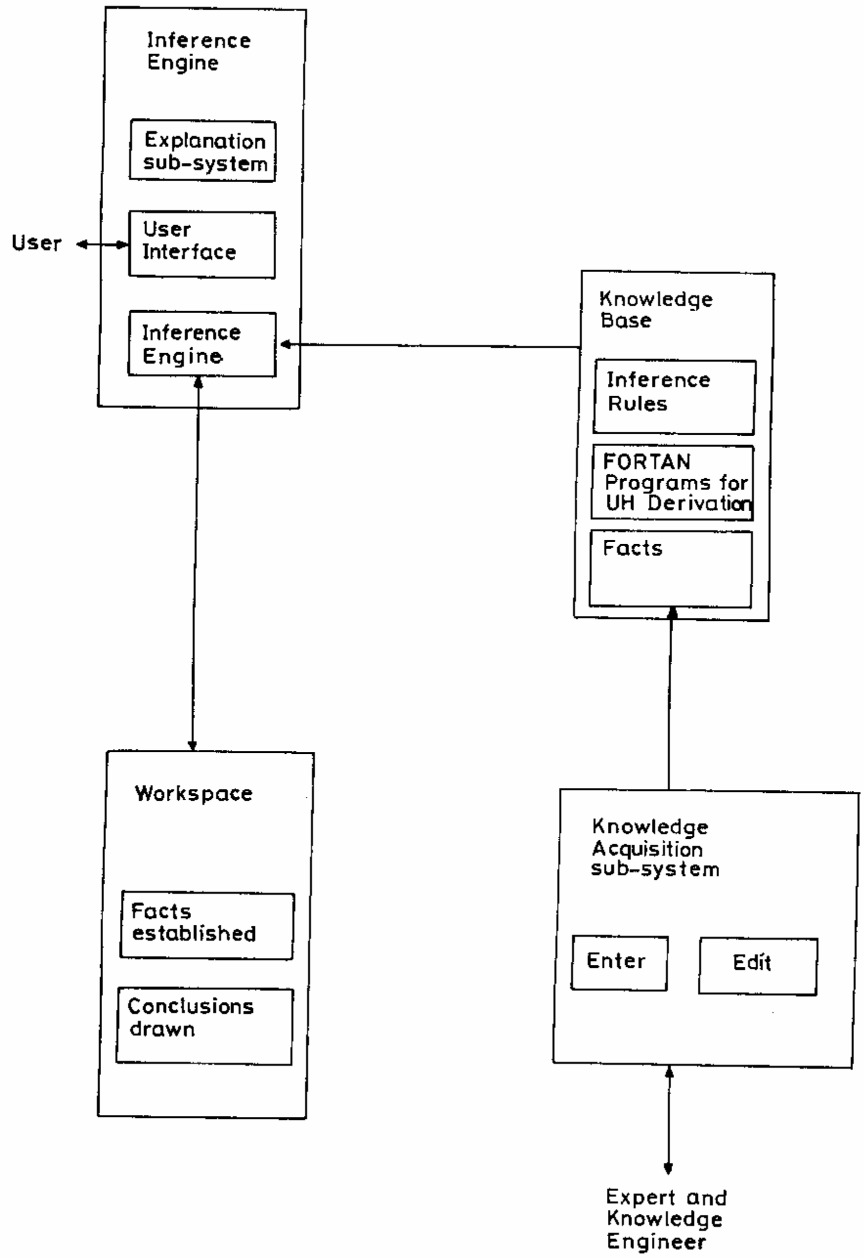

Fig.4 - General Structure of UHYDEX

CHAPTER 6

CONCLUSIONS AND SCOPE OF FUTURE WORK

6.1 Conclusions

The literature review on expert systems in surface water analysis and modelling has revealed the potential of application of expert system for unit hydrograph analysis.

A prototype expert System has been developed for the selection of the most appropriate model for unit hyrograph derivation of a given catchment. The system has been developed on an experimental basis and its domain is limited to seven models for gauged catchments and two models for the ungauged catchments. The sytem first identifies the most approriate unit hydrograph model for the given catchment depending upon the availability of data, importance of the project, location of the catchment etc, and then guides the user to prepare the input data for the selected model and then runs the model to derive the unit hydrograph for the given catchment. the expert system has been implemented through an expert sytem development shell, EXSYS and runs on personnel computers.

The present work involved the following -

(1) Extensive literature survey has been carried out on expert systems in surface water analysis and modelling.

(2) Based upon the literature review and experience of some experts in this field, rules have been formulated for the selection of most appropriate unit hydrograph derivation model.

(3) The knowledge about the domain has been divided into two modules, one for the gauged catchments and the other for the ungauged catchments.

(4) In module 1, model selection for gauged catchments is done. The models incorporated in this module are conventional method (with and without baseflow options), Collin's method, conventional Nash model, integer Nash model and Clark model. Depending upon the users response about availability for the catchment, importance of project etc, the system selects the most suitable model, guides the user for preparation of a input data file and with the prepared input data file, runs the selected model to derive the unit hydrograph.

(5) In module 2,model selection for ungauged catchments is done. In this module, the Snyder's method and the regional relationships developed by CWC have been incorporated. Depending upon the users response regarding location of the catchment, the system picks up the regional relationships of that particular region and derives the unit hydrograph.

(6) The knowledge base has been implemented through the expert system shell, EXSYS. The knowledge is in the form of production rules and there are some FORTRAN programs in each module. The interfacing between the rules and the FORTRAN programs has been done through the shell, EXSYS.

(7) The expert system has been provided with knowledge acquisition facility through the shell. This facility would help in updating the knowledge base periodically as one gains experience with practical problems and proven solutions.

(8) The expert system, UHYDEX, has been tested through variuos case studies and its performance is found to be satisfactory.

Eventhough the proposed expert system is running satisfactorily, yet it suffers from the following drawbacks:

(1) Very few models for unit hydrograph derivation have been incorporated in the expert system at present because of the availability of their FORTRAN programs. Whereas in the literature many more models have been cited which could also be incorporated in the system after developing their FORTRAN programs.
(2) At present, certainty factors have not been attached with the rules of the knowledge base. Therefore, all the models are given equal weightage.
(3) Also there is no provision for the user to attach some confidence value (certainty factor) with his answer, i.e., the system does not incorporate user confidence. This is a limitation of the shell.

6.2 Scope of Future Extensions

The following suggestions are made for thefuture extensions -

(1) The domain of the system could be extended to other models also.
(2) Some graphics programs for the detailing of the derived unit hydrograph could be developed and interfaced with the existing expert system.
(3) Certainty factors could be incorporated in order to improve the degree of expertise of the existing expert system.
(4) A shell other than EXSYS, which supports the 'Users Confidence' also could be adopted for the system development.

Expert Systems are an emerging technology, but one that may, in years to come, revolutionalise professional activities in the field of surface water analysis and modelling. The results obtained with the prototype version of UHYDEX presented in this report are most encouraging, and suggest that with the extensions in the system as discussed above, UHYDEX could become a useful tool for the field engineers and hydrologists.

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