Journal of Hydrology, 112 (1990) 237–256
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

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AN EXPERT SYSTEM FOR THE SELECTION OF A SUITABLE METHOD FOR FLOW MEASUREMENT IN OPEN CHANNELS

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(Received February 7, 1989; accepted after revision April 12, 1989)

ABSTRACT

Simonovic, S.P., 1990. An expert system for the selection of a suitable method for flow measurement in open channels. J. Hydrol., 112: 237–256.

The science of stream gaging has evolved through the years, mainly from the experiences and innovations of its practitioners. Stream-gaging procedures are standardized on the national and international level. However, the selection of a suitable method for flow measurement is still a fairly complex process. The knowledge-based system described in the paper is designed to aid the user in the selection process. Two aspects of selection are considered: physical characteristics of the gaging site and available equipment and/or structures at the gaging site. The system has been designed for the potential use in Environment Canada. The paper also discusses the rule-based expert system development tool, VP-Expert. Final conclusion of the research presented in the paper is that the expert system technology may help in the surface flow measurement process. The application seems to be natural, since stream gaging procedures are mainly derived from actual practice and experience.

INTRODUCTION

The hydrometric data collection program in Canada began in 1894 (Fisheries and Environment Canada, 1977). Today the water quantity data are collected at 2700 sites. To help organize and support operating the existing network, an *intelligent decision support system* has been considered (Simonovic, 1989).

The overall accuracy of the record from a gaging station is governed by the physical and hydraulic characteristics of the channel, gage location, equipment accuracy, and techniques used for data processing. There are several methods for measuring river flow, ranging from well established velocity-area, structural and dilution techniques to ultrasonic, electromagnetic and moving boat methods (Herschy, 1978). Major factors affecting the choice of the flow measurement method are: (1) physical characteristics of the gaging site; (2) hydraulic characteristics of the channel; (3) available equipment; (4) available knowledge about the methods available; (5) available structures necessary for certain stream gaging measurements; and (6) required measurement accuracy.

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Expertise in the selection of the most suitable stream gaging procedure is complex, and much of the decision process is based on a combination of field and theoretical experience. However, hydrometric specialists from national agencies, which have the mandate to monitor streams and to determine which gaging method to use, usually use only methods that they know fairly well (Pellitier, 1987). For example, in North America the velocity area method is generally used with the vertical axis current meter, while in Europe with horizontal axis current meter. Also, in Europe, generally fewer verticals (with more observations points per vertical) are used than in Canada. In France use of dilution methods is much more popular. Therefore, the expert system technology has been investigated as the potential tool for advising the inexperienced user in the flow measurement method selection.

Knowledge-based engineering (or expert systems, ES) is a way to successful application of Artificial Intelligence (AI) techniques of building human expertise and some degrees of intelligent judgment into decision supporting software. The application of ES in water resources has been reviewed (Simonovic and Savic, 1989) and the following conclusions reached: (1) Expert systems are present in water resources engineering. Some practical experience has been already documented and the evaluation process is in progress. (2) First reactions between the experts and users are positive. (3) Further development in the field of water resources is necessary. (4) Present level of research is focusing on the development and application of ES technology as it directly relates to the specific engineering field appropriate to the particular problem environment.

In Canada the major responsibility for collecting, processing and distributing the environmental information is given to Environment Canada. In the study (Nordicity Group, 1986) which explored opportunities for the use of AI technologies within the operations of the Canadian government, expert systems have been identified as the most promising AI tools for improving productivity, providing faster and better decision support systems, and improving service to the public.

The paper is divided in two major sections. In the first one, detailed examination of the process for selection of the proper flow gaging method is presented. The second part is discussing the major steps in expert system development with the particular emphasis on the VP-Expert development tool.

METHODS FOR FLOW MEASUREMENT IN OPEN CHANNELS

The expert system for flow measurement contains 27 methods selected from the Handbook published by the International Organization for Standardization (ISO, 1983, 1986).

Velocity–area methods

In simplest words, flow measurement by velocity–area methods involves the

measurement of the area of a river cross-section and the mean velocity of flow through it. Discharge is then computed as the product of the two quantities.

Methods using current meters

The area of cross-section is usually determined by sounding at a number of verticals on the cross-section, together with the measurement of the distance of these verticals from a reference point on the bank. The velocities are determined by current meter observations. These may be vertical axis, cup-type or horizontal axis, propeller type meters both of which provide results of sufficient accuracy when used in the proper way. Various devices, equipment and structures are used to position the meter. The current meter may be mountred on a wading rod (wading method), or on a cable and reel suspension (bridge, cableway, and static boat methods). Velocities may also be determined by floats or by measuring the surface slope when the use of current meters is impractical and where the need for accuracy is not too great.

Moving boat method

This method employs a modification of the conventional current meter measurements in the velocity–area method of determining discharge. In the moving boat method a propeller current meter is fitted to a gaging launch and the latter made to traverse the stream normal to the flow. The object of the method is to measure the velocity at many points across a river more rapidly than is possible using the static boat technique. The principle is based on measuring the magnitude and direction of the component of the velocity resulting from the river current and the movement of the boat across the river.

Ultrasonic method

The ultrasonic technique, known also as the acoustic method, is basically a velocity–area method. The water velocity at a known depth in the river is measured by recording the time it takes for a beam of acoustic pulses to cross the river. Transducers that are capable of sending and receiving acoustic pulses are positioned on either side of the river. They are located so the pulses in one direction travel against the flow, and in the other direction with the flow. The difference between the velocities of the ultrasonic waves is related to the velocity of flowing water at the depth of the transducers. This velocity can be related to the average velocity of flow over the whole cross-section.

Electromagnetic method

The basis for this method is found in the fact that the motion of water flowing in the river cuts the vertical component of the earth's magnetic field and an electromotive force is induced in the water. This force can be sensed by electrodes at each side of the river and is directly proportional to the average velocity of flow in the cross-section.

Measuring structures

A flow measuring structure provides a means of recording discharge at a particular location in a closed conduit or an open channel. It is usually installed with the intention of providing a continuous record of flow variations with time.

Weirs

The discharge at a gaging structure depends on the geometry of the structure and water levels relative to the structure. The geometry of the structure is usually fixed. The relation between head over the crest of the weir and the discharge is established, usually in a laboratory, and applied to field installation. The head over the weir is measured and this value inserted in the proper formula to get a value of discharge. This is the simplest case, where, because the water level downstream of the weir is below some limiting condition (the modular limit), there is a unique relationship between these two quantities. Under these circumstances flow conditions are said to be modular. If the tailwater conditions do affect the flow, the weir is said to be drowned or operating in the nonmodular range. Two independent measurements of upstream and downstream water levels are required to determine the discharge at the structure under these circumstances.

Flumes

The discharge in open channel may be measured by means of a flume, consisting essentially of contractions in the sides and/or bottom of the channel forming a throat. The relationship between the head upstream of the throat of the flume and the discharge is established. Thereafter, the discharge is determined from the measurement of the upstream water level. If the flow is nonmodular, measurements of head both downstream and upstream are necessary.

Free overfalls (end-depth method)

Free overfalls are structures creating abrupt drop in the flow. The measurements of the channel depth at the brink of the drop and the flow area of the channel are required. The discharge is then determined using the proper equation.

Dilution methods

Dilution gauging requires that a whole reach, possibly many kilometers long, satisfies several criteria. The advantage of dilution gauging is that it measures the flow in an absolute way because the discharge is calculated from measurements of volume and time only. There are two basic methods of dilution gauging: the constant-rate injection method and sudden injection method. In the constant-rate injection method (continuous method) a tracer

solution is injected continuously for a period to establish an equilibrium concentration for a finite time at a sampling station downstream. The ratio of the concentrations between the solution injected and the water at the sampling station is a measure of the discharge. In the sudden injection method a quantity of tracer is added to the river, often by simple, steady emptying of a flask of tracer solution. At the sampling station the passage of the entire tracer cloud is monitored to determine the relationship between concentration and time.

Indirect methods

Slope-area method

The cross section of a channel is measured at several sections along a reach which is as straight and as uniform as practicable. The roughness of the channel is estimated after examination of the channel or measurement of the bed features. The discharge is determined by measuring the water level at two or three sections a known distance apart and inserting the slope, width, depth and roughness in an open channel flow equation.

Cubature method

This method is restricted to situations where flow causes a change in water level and the volume of stored water. The water level and surface area of the stored water are measured on two occasions at a known time interval. The mean discharge is obtained by dividing the volume of water stored, or released from storage, by the time interval.

SELECTION OF A SUITABLE METHOD FOR FLOW MEASUREMENT

The choice of method to be used will depend on the characteristics of the site, particularly those affecting the stability and sensitivity of the stage–discharge relation. Other important factors are the type and quality of data required, the manpower and back-up facilities available, the initial capital and future maintenance costs. It is important to note that this expert system is only one module of a much more complex effort (Simonovic, 1989) which will include among other modules an expert system for measurement site location. The work in this direction is currently in progress.

The expert system for flow measurement method selection is using the criteria established by the International Organization for Standardization (ISO) summarized in Table 1. The expert system structure is divided in two major parts. The first system, named SFM, checks all the important physical conditions and required data accuracy. The final recommendation of the first system contains a number of methods applicable for site physical conditions. The second system, named STR, is selecting from the multiple choice of the first system, one method considering the available equipment and availability of measurement structures at the particular site.

Physical characteristics of the site play an important role in selecting a

TABLE 1

Limiting conditions of flow measuring methods (after ISO, 1986)

Method			Criteria						Uncertainty	
No.	Description	Relevant International Standard	Width	Depth	Velocity	Sediment Load	Approach Condition	Time Factor	Minimum Percentage	Comment
1	Velocity-area, by wading	ISO 748	L, M, S	S	S, M	I, R, Y	b, c, d	J, K	±10	A, B
2	Velocity-area, from bridge	ISO 748	M, L	M, L	M, L	I, R, Y	b, c, d	K	±10	A, B, C, D
	Velocity-area, cableway	ISO 748	M, L	M, L	M, L	I, R, Y	b, c, d	K	±10	A, B, C
4	Velocity-area, static boat	ISO 748	M, L	M, L	M, L	I, R, Y	b, c, d	K	±10	A, B, C, E
5	Velocity-area, moving boat	ISO 4369	L	M, L	M, L	I, R, Y	b, c, d	K	±10	A, B, E
			M, L	M, L	M, L, S	I, R, Y	b, c, d	K	±10	F
7	Slope-area	ISO 1070	M, L	M, L	M, L	I, R, Y	b, c, d	K, N	±10	Q
8	Ultrasonic	ISO6416	M, L	M, L	M, L, S	R	b, c, d	G, J, H	±5	
9	Electromagnetic	ISO/TR 9213	M, S	S, M	S, M	I, R, Y	b, d	G, H, J	±5	T
			S, M	S, M	S, M	I, R, Y	c, g, k	K, N	±3	
11	Dilution, chemical, sudden injection	ISO 555/2	S, M	S, M	S, M	I, R, Y	c, g, k	K	±3	
12	Dilution, radioactive tracer, sudden injection	ISO 555/3	S, M	S, M	S, M	I, R, Y	c, g, k	K	±3	
13	Dilution, radioactive tracer, continuous injection	ISO 555/3	S, M	S, M	S, M	I, R, Y	c, g, k	K, N	±3	
14	Cubature	ISO 2425	L, M, S	S, L, M	S, M, L	I, R, Y	f, k	K, H	±10	H
15	Thin-plate weirs, sharp crest, V-notch	ISO 1438/1	S	S	M, S	I	a, b, e, j	J, G	±3	
16	Thin-plate weirs, sharp crest, rectangular, suppressed	ISO 1438/1	S	S	M, S	I	a, b, e, f, j	J, G	±1	
17	Thin-plate weirs, sharp crest, rectangular	ISO 1438/1	S	S	M, S	I	a, b, e, f, j	J, G	±1	
18	Weirs, broad-crested with sharp upstream edge	ISO 3846	M, S	S	M, S	I	a, b, e, h, j	J, G	±5	
19	Weirs, broad-crested with sharp upstream edge	ISO 4374	M, S	S	M, S	I	a, b, e, h, j	J, G	±5	
20	Weirs, triangular profile,	ISO 4360	M, S	S	M, S	I	a, b, e, j	J, G	±5	
21	Weirs, triangular profile, flat-V		M, S	S	M, S	I	a, b, e, j	J, G	±5	
22	Weirs, V-shaped, broad-crested		M, S	S	M, S	I	a, b, i	J, G	±5	
23	Flumes, rectangular	ISO 4359	M, S	S	M, S	I	a, b	J, G	±5	
24	Flumes, trapezoidal	ISO 4359	M, S	S	M, S	I	a, b	J, G	±5	
25	Flumes, U-shaped	ISO 4359	M, S	S	M, S	I	a, b, i	J, G	±5	
26	Free overfalls, rectangular channels (end-depth method)	ISO 3487	M, S	M, S	M, S	I, R, Y	a, b	J, G	±10	
27	Free overfalls, non-rectangular channels (end-depth method)	ISO 4371	M, S	M, S	M, S	I, R, Y	a, b	J, G	±10	

Symbols are defined in the text.

suitable method for flow measurement. According to ISO (1983, 1986) the following criteria are selected: (a) channel width; (b) channel depth; (c) velocity; (d) sediment load; (e) approach condition; and (f) time factor. The set of physical conditions has been expanded with two more criteria: (g) minimum uncertainty; and (h) special conditions. The approach condition and time factor criteria were further divided. The approach condition has been divided in two criteria: (e_1) flow characteristics; and (e_2) channel characteristics. The time factor was divided in two criteria as well: (f_1) measurement time; and (f_2) special time conditions.

All 27 methods presented in Table 1 were characterized by ten criteria. Every criterion has a specific description provided by ISO. Abbreviations used in the following section correspond to Table 1.

Channel width options used are: large (L), medium (M) and narrow (S). Large width corresponds to the width of more than 50 m. Medium is used for the width between 5 and 50 meters, and narrow is used for less than 5 m.

Channel depth is described by: large (L), medium (M) and shallow (S). Large depth is used if it exceeds 5 m. Medium depth corresponds to the depth between 1 and 5 m. Shallow depth is used if less than 1 m.

Velocity options are: high (L), medium (M) and low (S). If velocity exceeds $3\,m\,s^{-1}$ it is considered high. Between 1 and $3\,m\,s^{-1}$ it is considered medium, and if less than $1\,m\,s^{-1}$ low.

Sediment load has been divided into three groups on the qualitative basis: negligible (Y), low (R) and heavy (I). Currently consultations are in progress with the Environment Canada specialists to quantify the description of these three groups.

Flow conditions are described using: subcritical flow (a), flow with no cross-currents (b), turbulent flow (g), and uniform velocity distribution (j).

Channel conditions used are: channel free from vegetation (c), straight channel with uniform cross-section (d), straight channel symmetrical in cross-section (e), channel with vertical walls (f), rectangular channel (h), nearly U-shaped channel (i), and channel free from recess in the banks and depressions in the bed (k).

Time factor used varies between: quick method (J), slow method (K), and very slow method (N). The method is quick if less than 1 h is required for measurement. Slow methods require between 1 and 6 h for measurement, and very slow methods more than 6 h.

Special time requirements are used to distinguish between methods suitable for more frequent discharge measurements (G), and methods suitable for tidal waterways (H).

AN INTRODUCTION TO EXPERT SYSTEMS

Expert systems (ESs) are identified as a way to successful application of AI techniques. Through the application of AI techniques, ESs capture the basic knowledge to assist an individual when dealing with problems of different

complexity (Rolston, 1988). The most powerful characteristic of ESs, making them different from traditional computer applications, is their capability to deal with real-world engineering problems by incorporating engineering judgment and intuition. Therefore, the following definition derived by the author seems appropriate for the field of water resources.

A water resources expert system is a computer application that assists in solving complicated water resources problems by incorporating the engineering knowledge, principles of systems analysis, experience, intuition, and engineering judgment in the solution procedure.

In building an ES, domain (field) knowledge plays an important role. There are many components of the knowledge that is the source of an experts ability to perform (Rolston, 1988): *facts, procedural rules, and heuristic rules.* Therefore, ESs use a collection of the rules and facts to mimic expert behaviour related to problem solving. The simplest way to represent the knowledge is through the use of procedural rules, like in the following example:

IF RIVER-WIDTH > 50 m
AND RIVER-DEPTH < 1 m
THEN METHOD = VELOCITY–AREA

Collection of rules, like one in the presented example, are stored in the *knowledge base.* Knowledge base together with *inference engine* is the heart of an ES. This system is called knowledge storage and generation system. It's function is to store the expert knowledge, to retrieve knowledge from storage, and to infer new knowledge when required. The inference engine is the software that locates (examine) the knowledge and infers new knowledge from the base knowledge. In simple words, the inference engine, is the search strategy that is used to examine the knowledge available (in form of rules) and answers the questions posed by the user. Two basic concepts are used in ES's inference engine: *backward chaining or forward chaining.* Backward chaining is a top-down search procedure. It starts from the desired goals and works backward toward necessary conditions. Forward chaining is a bottom-up search process that starts with known conditions and works toward the desired goal.

Numerous authors present different classifications of knowledge. For example, Hayes-Roth et al. (1983) divide knowledge into public and individual, Rolston (1988) divides knowledge into factual and procedural, and so on. Factual knowledge which corresponds to public knowledge includes facts, theories, and widely available definitions which we may consider static. Procedural knowledge is more individual oriented. It consists of experience, engineering judgment, and intuition providing some knowledge about dynamic action relative to the problem field. The second type of knowledge is of particular value in water resources planning. Modelers are very much concerned with capturing the factual knowledge paying little attention to procedural knowledge (Wunderlich and Giles, 1981; Rogers and Fiering, 1986; Palmer and Holmes, 1988; Hobbs et al., 1989; Simonovic and Savic, 1989).

ES development follows the traditional software development process, em-

phasizing significant differences which are only characteristic for ES. The development procedure includes: problem selection, prototype construction, formalization, implementation, evaluation, and long-term evolution. Each phase has its own characteristics discussed in details in Rolston (1988) and other texts.

Knowledge acquisition has long been recognized as art and a bottleneck in the development of ES (Boose, 1986; Williamson, 1987; Nagy et al., 1989). There are two basic approaches to knowledge acquisition: *the direct approach and the indirect approach.* The first approach involves extracting knowledge from an expert, and the second approach involves case studies to determine variables important to the expert. When the problem domain is water resources planning, getting knowledge becomes a bottleneck. This is due to ill-structure and ill-definition of number of problems within the area of water resources (Nagy et al., 1989). In such a situation it is difficult for any expert to give a detailed explanation of his/her thinking process. The authors personal experience leads to the following approach: the developer should formulate possible rules and then have an expert examine and criticize them.

One of the main reasons for the rapid growth in ES development is the support of a set of powerful development tools (Waterman, 1986; RAND Corporation, 1988). They include *languages for ES development and ES shells.* The general-purpose languages are widely used for ES development, LISP (symbol-manipulation language) being the most widely used and PROLOG (problem-oriented language) gaining popularity. LISP provides many features convenient for symbolic processing. PROLOG is also symbolic, but somewhat more specific than LISP since it has a built-in search mechanism. There is also a growing trend in using more conventional languages for ES development. Several ESs have been developed using FORTRAN, and a large number have been developed using C language. ES shells are packages that aid in the rapid application of ES. They usually provide one, or more, knowledge representation forms (rules, frames, etc.) and inference mechanisms. The value of an ES shell is directly related to the degree to which the problem field characteristics match the characteristics of the shell. For the proper tool selection criteria consult the publication by RAND (1988).

AN EXPERT SYSTEM FOR SELECTION OF FLOW MEASUREMENT METHOD

Why an expert system? Expertise in the selection of the most suitable stream gauging method for a particular site under consideration, is fairly complex, and much of the decision process is based on a combination of field and theoretical experience. Method selection problem is well defined by the International Organization for Standardization. Therefore, it is an excellent candidate for testing the benefits of ES technology. In response to a demand for an increase in the quantity, diversity and reliability of available data, Environment Canada is moving toward establishing an integrated environmental data acquisition network. It is already determined that expert systems technology will

have the major role within this activity. The expert system for selection of a flow measurement method is one module which will become part of the so called intelligent decision support system for surface water quantity data management.

Who and how will use the ES? The ES for a flow measurement method selection has been designed to help hydrometric specialists of Environment Canada. The system can help in three directions: (1) provided physical conditions at the measurement site, the list of methods which may be used is recommended to the user, (2) based on recommended list and additional information about available equipment and structures at the measurement site the system narrows down the list to the best suited method; and (3) for the recommended method, detailed instructions from the database will be provided to help the user in preparing for measurements. This is the operational purpose of the system under consideration. A second use of the system is for planning purposes. The users are Environment Canada specialists responsible for data acquisition management. They can use the system to plan the equipment acquisition and manpower distribution. The system should be executed for all the measurement sites within the region of responsibility. From the system recommendations, the manager can perform planning of equipment and manpower. The third and final use of the system is for training purposes. Using the system and special capabilities of the ES tool used for its design, the training of field personnel can be performed. The system can produce the information on selection procedure that is recommended by International Organization for Standardization as well as detailed information on how to apply a particular method. Note that system knowledge is available in the form of manuals and books. New knowledge is not provided. The ES technology is used to make this knowledge more accessible to the users providing more efficient and accurate service.

ES structure. Flow measurement method selection ES has been designed in specific form using the characteristics of the tool used. The system contains two knowledge bases as shown in Fig. 1. First, knowledge base has been designed to perform the selection of the measurement methods based on the site physical conditions. This knowledge base is named SFM. The second knowledge base (STR) reads the output of the first selection and performs the further selection using the information on available equipment and structures at the measurement site. Second, the knowledge base is connected to the database containing the detailed description of available methods. The system structure is simple and straightforward.

DESCRIPTION OF THE EXPERT SYSTEM DEVELOPMENT

The particular problem requirements are seriously considered in selecting the tool for ES development. The recommendations by RAND (1988) are used. Since the problem is well defined, and the knowledge is available in the form of International Organization for Standardization recommendations, rule-

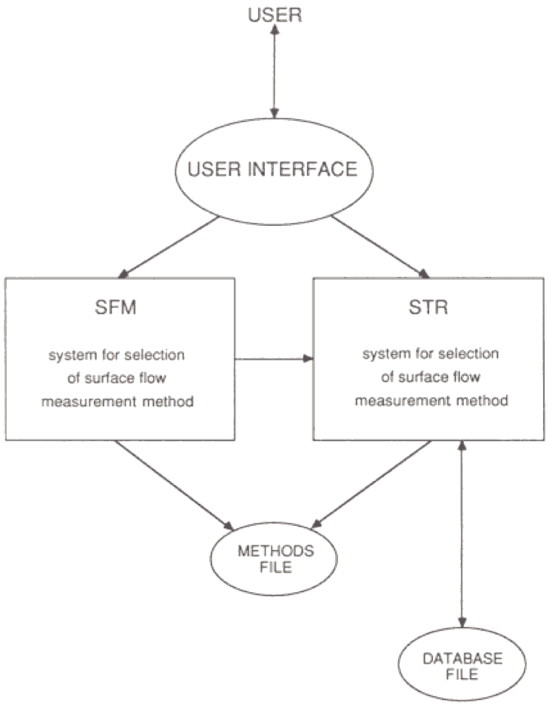

Fig. 1. Expert system structure.

based knowledge representation has been selected. Several other characteristics were required from the development tool such as: good selection capability; support capability and integration capability. It was concluded that the VP-Expert rule-based development tool (Paperback Software, 1987) will be adequate for application.

VP-Expert rule-based development tool

VP-Expert offers a combination of powerful features important for the application field considered in the research documented in this paper. Some of the features include: (1) the ability to exchange data with database files, worksheet files and ASCII text files; (2) an inference engine that uses backward chaining for problem solving; (3) commands that allow VP-Expert to explain its actions during a consultation; (4) confidence factors that let you account for uncertain information; (5) knowledge base chaining which lets you join more knowledge bases together; (6) the ability to record and display graphically the rule-by-rule search pattern; and (7) the ability to execute external DOS programs.

The tool is menu-driven and very friendly. All the instructions are stored in the help menu which may assist directly in the development process. In VP-

Expert the knowledge base file contains three basic elements: (a) the ACTIONS block; (b) rules; and (c) statements. A fourth element, clauses, are contained within the ACTIONS block and rules of the knowledge base.

The ACTIONS block, which consists of the keyword ACTIONS, one or more clauses, and a semicolon, defines the problems goals and the sequence of their solution. Thus, the ACTIONS block tells the inference engine what needs to be found out, and in what order.

Rules, stated as IF/THEN propositions, contain the actual knowledge or expertise. Rules have four basic elements: the name; the premise; the conclusion; and a semicolon at the end.

Statements generally contain information pertinent to the consultation itself. Most of VP-Expert statements assign special characteristics to knowledge base variables. For example, the ASK statement identifies a variable whose value must be assigned by the user during a consultation.

Unlike statements, clauses are not independent in the knowledge base. They always occur as part of the ACTIONS block or the conclusion of a rule.

Special characteristics of VP-Expert relevant to surface flow measurement method selection

The special characteristics of VP-Expert investigated for the application in surface flow measurement method selection include: (a) selection capability; (b) support capability; and (c) integration capability (Simonovic, 1989).

Selection capability. The selection of the most suitable flow measurement methods depends on several factors listed in the section "Selection of a suitable method for flow measurement". This knowledge has been stated in the form of IF/THEN propositions. The FIND clause is used in a VP-Expert knowledge base, to identify variables whose value is needed to successfully complete the consultation. Whenever a FIND clause is executed, inference engine attempts to find a value or values for the given variable. In the SFM knowledge base, variable whose value is to be determined is called METHOD. FIND clause is incorporated in the ACTIONS block of a knowledge base as shown:

```
RUNTIME;
ENDOFF;
ACTIONS
DISPLAY"        Surface Flow .......

CLS
FIND      method
```

Some of the variables in the knowledge base may have multiple options (for example: sediment concentration, width, etc.). Also, the final solution (measurement method) may be multiple. Therefore, it was important to investigate how VP-Expert handles the variables which can be assigned more than one value. The PLURAL statement is used in a knowledge base to define the

variables as "plural", meaning they can be assigned more than one value during a consultation.

A number of questions within the expert system for flow measurement may be answered with different levels of certainty. Therefore, the next important characteristic was the way VP-Expert handles uncertainty. In expert systems created with this tool, numbers referred to as "confidence factors" are used to account for varying levels of certainty. These numbers can be entered into the conclusions of rules in the knowledge base, or entered by the user in response to questions posed by the system. The latter option is used in the expert system for the flow measurement method selection. If the user wants to specify a confidence factor when answering the question, they can press HOME and type a number between 0 and 100 before pressing ENTER to make the choice. If no confidence factor is entered, 100% confidence is assigned to the conclusion value. To find how confidence factors are combined, the reader is advised to use the VP-Expert Manual (Paperback Software, 1987). Note that assigning confidence factors is not the same as assigning probability. The confidence factor is a subjective, not a statistical, value.

During the consultation a user may select such a combination of physical characteristics that the system will not be able to provide the recommendation. Dealing with this specific situation was very important. In the VP-Expert, the keyword UNKNOWN is used to identify variable whose values are not known. Having a keyword UNKNOWN to account for variables with no assigned values allows writing a rule like the following:

```
RULE 28
IF          method = UNKNOWN
THEN        method = not-available;
```

This capability of VP-Expert has been used in a number of cases within the knowledge base.

Support capability. A number of applications of ES technology in water resources rely heavily on the support of external programs for optimization, simulation, regression and other analysis (Simonovic, 1989; Simonovic and Savic, 1989). The VP-Expert capability regarding communication with other programs has been studied. The CALL, BCALL and CCALL clauses let VP-Expert run external programs. This capability was not utilized within the research presented in this paper. Another support aspect was very important in the development of an ES for flow measurement method selection. This one being interaction with database files created using other software packages. There are two ways that these database files can be used by VP-Expert. In the knowledge base described in this paper they are used as information basis. The database files containing descriptions of the measurement methods and instructions for measurements are accessed after the recommendation has been provided indicating which method seems to be best suitable for the particular site. All the information from the database file are then provided to the user.

Integration capability. The modular structure of a number of water resources

problems requires the different knowledge bases to be linked together. In the VP-Expert, the CHAIN, LOADFACTS, and SAVEFACTS clauses link or chain knowledge bases together. In our example, they permit the use of two modules together. The basic steps required in their use are: (a) use SAVEFACTS to save the known values from the current module; (b) issue a CHAIN clause naming a new knowledge base (module). The old knowledge base will be closed and this file will take its place in the current consultation; (c) the LOADFACTS to load the values saved by SAVEFACTS into the new knowledge base. The determination of proper flow measurement method using this VP-Expert option to link two modules: SFM which diagnoses proper flow measurement method/s, and STR which matches the measurement method with the available structure at the particular site. In the first knowledge base the SAVEFACTS and CHAIN clauses are used to save the values assigned to the variables up to this point in the consultation, and load a new knowledge base file STR as shown:

```
SFM.KBS
ACTIONS
FIND          method


SAVEFACTS c:\simon\exp\methods
CHAIN     c:\simon\exp\str;
```

The next sequence shows a section of the new knowledge base file:

```
STR.KBS
EXECUTE;
RUNTIME;
ACTIONS
LOADFACTS c:\simon\exp\methods
```

Note that LOADFACTS is the first clause contained in the second module ACTIONS block. This placement ensures that the saved values be loaded immediately upon execution of the new knowledge base.

USE OF EXPERT SYSTEM FOR FLOW MEASUREMENT METHOD SELECTION

The expert system for flow measurement method selection contains two modules: SFM knowledge base and STR knowledge base. The first knowldge base is examining the physical characteristics of the measurement site. The user has the option to answer all the questions with 100% certainty or to select the level of certainty. The SFM system will examine its knowledge base containing information about 27 methods discussed in the section "Methods for flow measurements in open channels" of the paper. Questioner of the SFM system is based on the criteria discussed in the section "Selection of a suitable method for flow measurement". Based on the information provided the system will come out with the recommendation. The recommendation of the SFM system may have one method, multiple choice of methods or none.

The second knowledge base, STR, is automatically executed after the execution of SFM is finished. The SFM system stores its outcome in the file and the STR system reads them. The questioning within the STR system is directed to gathering the information about measurement structures and equipment available for a particular site. This information is then used in narrowing down the list of methods recommended by the SFM system. If the SFM output contains only one choice, STR finishes with the same choice. If the SFM outcome indicates that no method is available for the particular physical conditions, STR arrives at the same conclusion. Another purpose of the STR knowledge base is to provide the user with the information about selected methods stored in the database files.

The Appendix contains one consultation session with the SFM and STR systems. The system starts with the execution of SFM knowledge base. After a couple of introductory screens, which are used to define the scope of the system, the consultation starts with the question about channel width. Selecting MEDIUM with a certainty factor (CN) of 75%, system proceeds the question about channel depth. Again, MEDIUM is selected with the CN of 90%. The next question is asking for an estimate of the velocity. In the example presented, the estimate is MEDIUM with CN of 60%. Sediment concentration of the next inquiry of the SFM system. Selection is NEGLIGENT with the CN 100%. Flow conditions are estimated to be with NO CROSS CURRENTS with 90%. Channel conditions are CHANNEL FREE FROM VEGETATION with CN 95% and CHANNEL STRAIGHT AND UNIFORM IN CROSS-SECTION with CN 90%. Measurement time is estimated to be SLOW with CN of 100% and MINIMUM MEASUREMENT ERROR is 10% with the CN of 100%. Using all the information provided the system recommend a list of methods: method 6 with CN 84%; method 4 with CN 84%; method 3 with CN 84%; and method 2 with CN 84%.

After the recommendation, the table containing the full method name and ISO number is presented for the user to identify the system collection. This is the end of the consultation with the SFM knowledge base. Since the system uses the integration capability of VP-Expert, the STR knowledge base is automatically executed. Behind the scene the following actions are performed: (a) selected list of methods is saved in the file METHODS; (b) the SFM knowledge base executes the STR knowledge base; (c) the STR knowledge base reads the information from the METHODS file; and (d) STR starts questioning the user.

The first question is used to determine the available equipment. In the example presented CURRENT METER is selected with CN of 100%. Next screen is used to examine the availability of additional equipment. NONE is selected with CN of 100%. Structure availability question follows. BRIDGE is selected with the CN 100%. These answers together with the information provided by SFM are sufficient for the STR system to come with the recommendation for using VELOCITY AREA METHOD FROM BRIDGE with CN of 84%. After the recommendation, the user may request the information about the selected method, available in the database.

CONCLUSIONS

The simple and fairly straightforward example of an ES system has been presented in the paper. The system is developed with the collaboration and interest of the experts in Environment Canada. Verification of the system capabilities will be performed in Environment Canada and potential improvements, expansions and modifications will be identified.

The SFM and STR systems are developed as potential modules for the incorporation into an *intelligent decision support system* (IDSS) considered for supporting the operation of existing network of gauging stations operated by environment Canada (Simonovic, 1989).

The paper has introduced the ES technology and presented one of the tools with the potential for application in IDSS development. A number of very useful capabilities of VP-Expert has been tested in this research. From the results presented it seems that for well-defined problems like surface flow measurement method selection, expert system technology may be used to improve the operation, provide rational solutions and provide a useful training tool.

ACKNOWLEDGEMENTS

In the present form this research has been supported by an operating grant from the Natural Sciences and Engineering Research Council of Canada. This help and cooperation of the experts from Environment Canada (Water Resources Branch, Hydrometric Methods Section) is gratefully acknowledged.

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APPENDIX — EXAMPLE OF CONSULTATION SESSION

SFM

What is the channel width?

if less than 5 m	-narrow
if between 5 and 50 m	-medium
if more than 50 m	-large

narrow [medium] 75 large

SFM

What is the channel width?

if less than 5 m	-narrow
if between 5 and 50 m	-medium
if more than 50 m	-large

narrow [medium] 75 large

SFM

What is the channel depth?

if less than 1 m	-shallow
if between 1 and 5 m	-medium
if more than 5 m	-large

shallow [medium] 90 large

SFM

What is your estimate of the velocity?

if less than 1m/sec	-low
if between 1 and 3m/sec	-medium
if more than 3m/sec	-high

low [medium] 60 high

SFM

How would you estimate the concentration of suspended material?

[negligent] 100 low large

SFM

Describe flow conditions using the following options
(you may use more than one option):

subcritical

[no cross currents] 90

turbulent

uniform

SFM

Describe the channel conditions using the following options
(you may use more than one option):

1. channel free from vegetation
2. straight channel with uniform cross-section
3. straight channel with symmetrical cross-section
4. channel with vertical walls
5. rectangular channel
6. nearly U-shaped channel
7. channel free from recess in the banks and depressions in the bed

[1] 95

[2] 90

3

4

5

6

7

SFM

How much time do you have for measurements?

if less than 1 hour	-quick
if between 1 and 6 hours	-slow
if more than 6 hours	-very slow

quick [slow] 100 very slow

SFM

Using the information you have provided, the recommended method/s is/are:

7 CNF 60

6 CNF 84

4 CNF 84

3 CNF 84

2 CNF 84

Note the selected numbers and check for the full name and ISO classification in the following tables.

Press any key to continue!

#	Name of method	ISO standard
1	Velocity-area by wading	748
2	Velocity-area from bridge	748
3	Velocity-area cableway	748
4	Velocity-area static boat	748
5	Velocity-area moving boat	4369
6	Velocity-area floats	748
7	Slope area	1070
8	Ultrasonic	6416
9	Electromagnetic	TR 9213

Press any key to continue with the table!

STR

Select equipment available for measurement:

current meter 100

ultrasonic meter

electromagnetic meter

none

STR

Type of additional equipment available:

boat

floats

tracers

none 100

STR

Is there a structure available at the measurement site?

bridge cable no

STR

Using the the results of the SFM consultation and information you have provided, the set of SFM recommended methods is reduced and the final recommendation is:

velocity-area from bridge CNF 84

NOTE: If you need detailed information about the method you may continue the consultation.

Press any key to continue!