PAPER NO. 87-5023

EXPERT POTENTIOMETRIC SURFACE MODIFICATION
FOR
GROUNDWATER CONTAMINANT MANAGEMENT

by

R.L. Ward R.C. Peralta J.R. Brasher

Authors are Res. Asst., Assoc. Prof. and Res. Asst., Agricultural Engineering Department, University of Arkansas, Fayetteville, AR.

For presentation at the 1987 Summer Meeting
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

Baltimore Convention Center
Baltimore, MD.
June 28-July 1, 1987

SUMMARY: An expert system is linked to an previously reported optimization program. The expert system prompts the user for information about a groundwater contamination problem. The expert system determines whether pumping is a suitable containment strategy. If appropriate, it selects several well arrangements to be evaluated by an optimization algorithm.

KEYWORDS: artificial intelligence, aquifer, contamination, expert system, groundwater

ASAE
American
Society
of Agricultural
Engineers

St. Joseph, MI 49085-9659

INTRODUCTION

Pressure to protect groundwater has increased as the public has realized the serious threat posed by groundwater contamination. Remediation or prevention of groundwater contamination is increasingly important for all water users. Inadequate response to contaminant situations may result in unnecessary damage. Excessive response may be unnecessarily expensive. Timely decisions must be made to develop corrective strategies for each particular contamination situation. Needed is the systematic development of tools or methodologies for optimizing remedial actions. This paper describes one such tool-an expert system that includes an optimization algorithm.

Expert systems are computer programs designed to emulate the logic and reasoning processes humans would use to solve a problem in their field of expertise. Interest in expert systems has grown rapidly with the emerging availability of artificial intelligence -based techniques and tools. By emulating human reasoning to combine objective and subjective knowledge, expert systems expand the availability of specialized expertise.

Methods of preventing contaminant spread include construction of artificial barriers to groundwater flow and/or extraction/injection of water from/to the aquifer. Cost of installing and maintaining the different types of artificial barriers varies greatly as does their reliability. Extraction/ injection (E/I) methods have comparatively low installation cost and good reliability, but are commonly used as transitional elements of remedial action efforts. They are less often used as long term solutions.

There are many solutions to contamination problems. Solution selection must be situation-specific and be based on the expertise of the decision maker(s). A method is needed for systematic and efficient evaluation of alternatives and for intelligent strategy selection.

This paper describes an expert system that performs the decision making required to handle groundwater contamination problems. The system queries the user for input of aquifer parameters, contaminant information, time parameters and his confidence in this input. The system outputs a decision that describes the type of solution it feels is best and its confidence in this decision. It also answers questions concerning how the decision was made.

PREVIOUS WORK

Palmer (1985) provides a good overall review of artificial intelligence and expert systems-a rapidly developing field. He describes HYDRO (2) as the most successful application of expert systems to a water resource problem. HYDRO was developed to aid in the calibration of a large hydrologic watershed model. It uses watershed characteristics to calculate initial parameter values. HYDRO calculates the "most likely" values and certainty factors for the parameters. A unique feature permits the user to specify how the certainty factors associated with the parameter estimates are used.

Another example of the application of an expert system to water resources is given by Cuena (1983). Cuena reports the development of an expert system designed to operate flood control dams during emergencies and to plan for best handling of flooding in flood prone areas. The system includes a series of simulation models that predict the hydrologic condition of a watershed. These permit the expert system to provide guidance on operation based upon updated, predicted conditions. The system is driven by a set of physical rules (that describes relations between rainfall, inflow, and flood level) and a set of operation rules (for civil defense and dam operation).

Johnston (1985) presents an expert system for aiding the operation of an activated sludge wastewater treatment facility. Production rules, typically of the "if-then" structure, are used for knowledge representation. Production rules define the paths by which an input into the system can reach a goal state (terminal conclusion). The program requests additional information to resolve inconsistencies. Control strategies are produced and directions for future efforts are presented.

James and Dunn (1985) describe a comprehensive expert system to control city-wide flooding and pollution. The system incorporates the experiences of several experts in model verification, sensitivity analysis, calibration and validation. It provides information on storm intensity, sewer system flows, pollutant concentrations, and status of diversions and storage. It directs excess flows through diversion structures and indicates when to bypass the sewage treatment plant.

Expert system use in agriculture has been proposed and documented by several authors. Huggins, Barrett and Jones (1986) suggest application in decision support, i.e. diagnosing plant and animal disease and developing marketing strategies, and machine intelligence, i.e. developing new sensors and manipulators. Whittaker, Foster and Marke (1986) developed a skeletel expert system called ADAM (Adaptive Assembler for Models) that allows a user to easily custom build models involving conventional equations and human expertise. In a related paper, Thieme and Whittaker (1986) describe several methods of representation and reasoning that are useful for specific types of problems. They discuss two widely used rule paradigms-pattern matching and parameter driven systems. They describe how forward and backward chaining are implemented in each system.

Specific applications of expert systems in agricultural have been shown. Jones, et. al., (1986) developed an expert system from an off-the-shelf software shell to control a greenhouse misting system that allows dynamic implementation of a grower's perceived optimal misting strategy. Kline, et. al., (1986) developed an expert system for sizing and selecting machinery for whole-farm cropping systems. It also integrates a whole-farm management linear program (LP) with the knowledge-based expert system.

An expert system to aid in identifying groundwater pollution sources has been presented by Datta and Peralta (1986). Their paper presents an approach for developing an expert system to aid the identification of locations and magnitudes of a finite number of groundwater pollution sources. A pattern recognition algorithm is used as a secondary knowledge base. The finite sequential recognition algorithm is accessed from within the knowledge base. The expected risk in the pattern classification decision and a heuristic confidence threshold is compared to decide on the acceptability of the source identification.

The purpose of our paper is to describe an expert system that optimizes extraction/injection for groundwater contaminant containment. The first part of the system determines if extraction/injection is the best containment approach for the particular contamination situation. The second part of the system is an optimization program that develops extraction/injection strategies.

METHODOLOGY

Most commercially available expert system shells are based on a single computational model (i.e. production rules, deductive retrieval, etc.). We wanted a system that would combine these. At least part of what constitutes expertise in a particular domain is the ability to select a problem solving strategy which not only works, but is somehow better than the alternatives.

Therefore, a rule-based expert system shell was developed specifically for our use with the Prolog language. Prolog represents facts using an operator followed by arguments (an argument can be thought of as the subject of the sentence). The operator either describes its arguments or defines a relationship between them.

All rule-based systems have three elements-facts, rules and a reasoning strategy. Facts contain knowledge about the states or values of objects that describe the problem. Facts are dynamic because they change as the system executes. Rules contain knowledge about relationships between these facts. They are static. The part of the knowledge system that uses the rules to reason about the problem is contained in a group of inference and control strategies collectively referred to as the inference engine.

Our system is a pattern matching rule based system. In a pattern matching system the postulate is made up of predicate clauses that may contain constants and/or variables. For example, a Prolog predicate clause might be male(fred). This clause would have a truth value of true if the system knew the fact that fred is a male. A Prolog clause may also contain a variable. For example, a clause may be male(?who) where ?who is a variable. This clause can only take on a truth value after the variable has been given a value. If ?who had been assigned the value fred, the truth value of male(?who) is true.

Specifically,our contamination remediation expert system uses production rules (if-then rules) to control the data acquisition phase, uses a forward chaining system for soil/site characterization and uses a backward chaining theorem-prover to handle user interaction.

For example, a forward chaining, pattern matching system starts with a set of facts. All of the rules that can be verified using those facts are fired. The rules that fire add new facts to the knowledge base, causing more rules to be verified and fired. This process continues until either the goal fact (necessary terminal conclusion) has been attained or until there are no more rules that can be applied. When the process stops, the fact set represents all of the implications or effects that may be inferred about the problem.

Our knowledge base is structured into frames to represent the available facts. Frames are powerful knowledge representation structures similar to a matrix in conventional programming. A frame consists of a set of slots related to a specific argument. For instance, a frame called field_7 may have a slot called last_irrigated with a value of july_10.

The core of the expert system is in the inference engine where the determination of the best method of containing a groundwater contaminant plume (so there is no movement of the plume or additional contamination of groundwater) is made. Factors that are considered are type of contaminant, soil and aquifer characteristics, site characteristics and cost.

When building an expert system one must first decide what knowledge the system will contain and how the system will be used. In our system the knowledge domain was purposely kept narrow-it focuses on just one aspect of groundwater contamination. Assuming groundwater is already contaminated the system only needs knowledge for deciding how best to prevent contaminant movement or increased contamination. The system does not try to perform a comprehensive human risk assessment nor does it try to determine the best way to clean up the aquifer. However these are forseeable additions to an enhanced system.

The system is capable of answering "why?" particular input is needed, thus permitting information exchange. Domain information is used by the system in three ways:

1. To aid the user in organizing all needed information to analyze a contamination problem.

2. To use model results to propose the best possible containment strategy for a particular problem.

3. To evaluate the overall confidence in the solution based on subjective and statistical confidence of input parameter estimations and of the user's understanding of model assumptions.

An expert system should avoid alienating the user by treating him as if he knows nothing about the subject area. The general purpose of an expert system is to make decisions, but the degree of decision making should depend on user expertise. This system was designed assuming its user is familiar with the basic terminology and underlying principles of soil charaterization, groundwater flow, and the basic parameters needed to solve the problem.

The user may ask the system "why" in response to any question. The system will respond with a brief and sometimes general explanation of why certain input is important. In some cases the system indicates how data may be used by the model. In appropriate situations, the system will discuss the logic it used up to the point of query.

In order to evaluate a contamination problem, human experts systematically characterize existing soil, site, and pollutant conditions. Modular design allows the expert system to use the same approach. Separate modules perform soil, site, and pollutant characterizations. Each of these three modules contains submodules which check major assumptions, estimate input parameters, access small databases, issue warnings, and offer explanations and advice. Figure 1 is a flow chart showing the following expert system procedure.

The system first explains that it is analyzing three possible containment strategies; slurry trench, sheet piling and pumping. It then explains that the analysis is based on the containment method (any of the three) being one of completely encircling the contaminant plume in the shape of an octagon which would be centered on the assumed point source of the contaminant.

Soil characterization:

The first step in completing a comprehensive site evaluation is to characterize existing soil conditions. The system asks if the user understands the transport model assumption of soil homogeneity. If the user answers "no", "why", or "unknown", the system responds with a brief explanation and will either continue or ask the user if the assumption has been learned. If the user still does not understand, the system will repeat the same explanation. It makes no effort to clarify its explanation.

Without letting the user know, the expert system will lower its overall confidence in the consultation at appropriate times. These include each time the user: 1) does not understand a basic model assumption after the first time he is asked and 2) needs aid in estimating input parameters. Similarly, a human expert would most likely lower confidence in a consultation if his or her client did not demonstrate a basic understanding or provide exact information. The system starts with the smallest individual confidence factor given by the user as he enters required data asked for by the system. The logic behind this is simply that the system can be no more confident in its recommendation than the user is in his least confident piece of data. The system then adjusts this confidence based on user responses as described previously. This overall confidence is used as the confidence limits in the optimization program that follows the expert system (The system's confidence interval ranges from 0% - 100%). In short, the less a user knows about a given situation, the less confidence the system has in its recommendation for containing a contaminant plume.

Once the user understands the homogeneity assumption, the system asks the user for soil parameters. The first questions concern the amount of rock in the soil and the condition of the stratification (interface) between the soil and the bedrock. The answers to these questions determine whether sheet piling or a slurry wall are viable alternatives for plume containment. If "unknown" is given as the answer to either of these questions the system assumes that particular method is a viable alternative (and lowers the overall confidence accordingly). The user is then asked to select a soil type that best describes the soil of the aquifer from a selection table (fig. 2). Using this soil type, the system estimates ranges of effective porosity and hydraulic conductivity from a soil fact database (fig. 3).

The optimization program requires a mean and variance for both transmissivity and effective porosity. The expert system provides this as a posterior probability distribution function (pdf) by specifying a mean and variance. The expert system computes these based on Bayesian theory of prior knowledge of what the pdf should be and, if current information is available, a "likelihood" distribution based on this current information. Bayes theorem states:

posterior pdf = prior pdf * likelihood pdf

Three possible situations exist that the expert system will handle; 1. no field or lab data, 2. Three or less field or lab values for each parameter, 3. four or more values for each parameter.

If no field or lab data is available the posterior pdf used by the optimization program is the prior pdf. The expert system bases its prior mean and standard deviation on the range of values it obtains from the soil fact database. This range of values is assumed to span the mean + 3 standard deviations. With this assumption the system calculates a mean (Xo) and standard deviation (Vo) based on a log-normal pdf for hydraulic conductivity (K) and based on a normal pdf for effective porosity (S).

Field data values for hydraulic conductivity and effective porosity are then requested. If there are 4 or more field data values for these aquifer parameters, the "likelihood" pdf of Bayes theorem is developed by using the mean (X) and standard deviation (V) of the field data values. Subsequently, this is the posterior pdf given to the optimization program.

If there are less than 4 field values for these parameters, the likelihood pdf and prior pdf are multiplied together. (If only 1 value is given for a particular parameter the likelihood standard deviation is assumed the same as the prior standard deviation.) The mathematics of multiplying the likelihood pdf by the prior pdf has been previously derived (Lindley, 1970). The resulting formulas for computing the mean and variance for the optimization program are:

Posterior mean

$$E(K)=\exp[\{1/((\ln(Vo))^{-2} + (\ln(V))^{-2})\}*$$

$$\{(\ln(Vo))^{-2}\ln(Xo) + (\ln(V))^{-2}\ln(X)\}]$$

$$E(S) = [1/(Vo^{-2} + V^{-2})][Vo^{-2}Xo + V^{-2}X] \quad . . . . (1)$$

Posterior variance

$$VAR(K) = [\exp[[\{(\ln(Vo))^{-2} + (\ln(V))^{-2}\}^{-1}]^{1/2}]]^{2}$$

$$VAR(S) = [Vo^{-2} + V^{-2}]^{-1} \quad . . . . (2)$$

Site characterization:

Once soil characterization is accomplished, the system asks questions to characterize the site environment. The system establishes whether the user understands the simplifying assumption of a steady state environment (that all conditions such as precipitation are assumed constant over the entire planning period) and that no other remedial action (such as a clay cap) has been attempted. If he does not, a brief explanation is given.

The system requests the average monthly precipitation in the contaminated area during the planning period. The user must input a value for this parameter since it will not be estimated by the expert system. The user is then asked to describe the study area drainage from a list of drainage classes (fig. 4). Precipitation and drainage inputs are used to provide a safety factor for estimating the farthest extent of the plume at the current time (if this is not known) and the additional distance the plume might travel before a containment strategy is implemented. The system then asks for the average depth to the aquifer, the average saturated thickness of the aquifer and the average hydraulic gradient (all three must have a confidence factor associated with them). These values are used to estimate plume movement and make economic comparisons between strategies.

Contaminant characterization:

The third and final knowledge base module characterizes the contaminant. The system queries whether the user understands the assumption that water is the contaminant carrier and that advection is the major mechanism of contaminant movement. The system asks what the pollutant is. If certain chemical compounds are specified (alcohol, hydrochloric acid, certain hydroxides, etc.) a bentonite slurry wall is eliminated as a possible containment strategy. The user is then asked to give the number of days since the contamination problem began. The user must estimate this period and assign a confidence factor to that estimate (he may give a time when he knows there was no leak; 100% confident). The user is asked to estimate the number of days until the containment strategy must be implemented (with a confidence factor). The farthest extent of the plume at the current time is then requested (assuming a point contaminant source). If unknown, the system will calculate the distance using Darcy's equation and safety factors developed from the precipitation and drainage parameters. If known, the system compares its calculated value with that given by the user. The system issues a warning if the given value differs from the calculated value by more than 40%. Then, using the current extent of the plume, hydraulic gradient and conductivity and the time until the containment strategy will be implemented, the system estimates what the extent of the plume will be at the given future time.

The current expert system assumes that contaminant spillage ceased prior to the current time. Future versions of the system may assume that contaminant is still entering the aquifer. In such case additional pertinent questions might include:

1. What total volume of contaminant has entered the aquifer?

2. Is it still entering the aquifer?

3. At what rate?

These questions, however, are not used at this time. Future versions may use this information to look at different remediation strategies as well.

DECISION ANALYSIS

The final analysis includes economic considerations. By this point the system has eliminated containment methods that are inappropriate (because of irregular stratification, large percent of rock in the soil, too low of a hydraulic conductivity). The system informs the user it is assuming use of suitable containment methods for only a short period of time until the problem can be better analyzed and a suitable long-term remedial action can be planned. Therefore, only capital costs are considered in subsequent analysis.

Capital costs are based primarily on the extent of the plume (in 2 dimensions) and the depth to the bottom of the aquifer. Unit costs used in the analysis are based on federal estimates (Rogoshewski et.al.,1983). Before the economic analysis is performed the user is told that the unit costs are based on 1986 prices. He must input a coefficient to convert these costs to whatever year is applicable. Comparisons are made between slurry walls, sheet piling and pumping (if all three are still viable strategies). These cost estimates are cursory estimates and include simple assumptions of pump spacing and size . If pumping is determined to be the most economical remedy based on capital costs the expert system asks the user within what time period the plume should be stabilized. It then transfers the required data to the optimization program for strategy development. If the resulting calculated optimal pumping values and spacing are quite different from those assumed in the economic analysis another economic analysis of the pumping is suggested by the system.

SYSTEM VALIDATION

A complete validation process is the most important step in building a viable expert system. Unfortunately, it is the most difficult. Ideally, we would like to use documented field contamination problems to compare what the expert system recommends with what was done in the field or with what an "expert" recommended.

So far, we have tested the expert system on a hypothetical situation previously used to test the optimization program (Peralta and Ward, 1986). Following is the expert system run for this hypothetical situation:

```
---------------                                               ---------------

This system will determine, based on input from you about the
contamination problem, the best possible strategy to contain the
contaminant plume.

     This system analyzes three possible containment strategies;
slurry trench, sheet piling and pumping. All three strategies are
based on the assumption that the contaminant is from a point
source and that the containment strategy completely encircles the
```

```
contaminated area in the shape of an octagon which is centered on
the assumed point source of the contaminant.

The following questions are intended to characterize the soil
enviroment.

Do you understand that the system assumes the soil is homogeneous
in the area of contamination?

>> why

The system assumes a homogeneous soil in the area of
contamination. This assumption is important in maintaining a
constant pollutant velocity. If nonhomogeneity exists, the
pollutant will travel at varying velocities. This situation
requires a more sophisticated model than the one incorporated
within this system.

Do you understand that the system assumes the soil is homogeneous
in the area of contamination?

>> yes

What is your estimate of rock in the soil? (Give your answer
followed by a semi-colon and your confidence (in per cent) in the
answer (0-100).

    none

    small

    large

>> small ; 85

What is the condition of the stratification between the soil and
the bedrock?

    very irregular

    slightly irregular

    regular

>> why

If the interface between the soil and bedrock is highly
stratified it would be necessary to key the slurry trench into
the bedrock to provide an impermeable barrier. This causes the
slurry trench to be cost prohibitive and not a viable solution.

>> unknown

It is assumed that a slurry trench can be used as a containment
strategy.
```

```
What soil type best describes the soil of the aquifer? (with a
confidence factor)

       (figure 2 shows on the screen)

>> sandy-loam ; 80

Enter any field or lab values for hydraulic conductivity (m/d).
Each value should be separated by a comma. If no values are
available simply hit return.

>> 20, 30, 40

Enter any field or lab values for effective porosity. Each value
should be separated by a comma. If no values are available simply
hit reurn.

>> 0.2, 0.3, 0.4

Based on the soil type given and the field or lab values given:

 the mean hydraulic conductivity is 26

 with a variance 1.3

 the mean effective porosity is 0.31

 with a variance of 0.002

               ** Soil Characterization Complete **

The following questions are intended to characterize the site
environment.

Do you understand the system assumption that constant
environmental conditions exist (and no other remedial action has
been attempted) throughout the containment period?

>> yes

Estimate the average monthly precipitation (cm/month) at the site
during this time of year? (with a confidence factor)

     0 - 5

     5 - 10

     > 10

>> 5 - 10 ; 90

How would you describe drainage at the site?

     (figure 4 shows on the screen)
```

```
>> somewhat excessive

What is the average depth (m) to the water table? (with a
confidence factor)

>> 35 ; 70

What is the average saturated thickness (m) of the aquifer? (with
a confidence factor)

>> 40 ; 70

What is the average hydraulic gradient (in per cent) of the
potentiometric surface of the aquifer? (with a confidence factor)

>> why

The gradient will be used to calculate the Darcy velocity. The
extent of the plume at the time the containment strategy is
implemented can then be estimated.

>> 0.54 ; 60

                ** Site Characterization Complete **

The following questions are intended to characterize the
contaminant.

Do you understand the system assumption that water is the
contaminant carrier and that advection is the major mechanism of
contaminant movement?

>> no

These are assumptions that greatly simplify the prediction of
plume movement. A more sophisticated model is needed if
mechanical dispersion or molecular diffusion are mechanisms of
contaminant transport.

Do you understand this assumption?

>> yes

Does the contaminant contain any of these compounds (greater than
1%)? (if none hit return)

alcohol   sulfuric acid       calcium hydroxide

hydrochloric  acid    sodium hydroxide    brine (s.g. > 1.2)

>> why

These compounds could possibly increase the permeability of a
bentonite slurry trench by as much as 10 times .
```

```
>> (user hits return)

Estimate the length of time (days) until a containment strategy
can be implemented? (with a confidence factor)

>> 6 ; 90

Do you know the present detectable maximum extent of the plume
(m) from its point source? (with a confidence factor)

>> 70 ; 70

The system estimate for the present extent of the contaminant
plume is 81 m. The system estimate for the future extent of the
plume at containment implementation is 335 m. The 335 m distance
will be used for the economic analysis.

                ** Contaminant Characterization Complete **

The unit costs for the economic comparisons are based on 1986
prices. Enter a coefficient to update these unit costs. (enter
1.00 if 1986 costs are acceptable)

>> 1.00

Each side of the containment octagon will be 274 m in length. The
pumping cost estimate will be based on a pump spacing of 1/4 of
the side length and a 1986 pump cost of $1500.

Please be patient while the system makes an economic comparison
between a slurry trench, sheet piling and pumping.

The system recommends a pumping containment strategy. Its
confidence in this recommendation is 58%.

Do you have any questions about:

1. recommendation

2. confidence value

3. none

Indicate by a number.

>> 2

The system confidence of 58% is based on the user's confidence of
60% in the hydraulic gradient and the user being unsure about
stratification in the bedrock.

Any other questions?

>> 1
```

The pumping capital costs were much smaller than the costs for either the sheet piling or the slurry wall. If this containment strategy is to be used for a great length of time then the operating cost of the pumps should be taken into account.

```
Within what period of time (days) should the contaminant plume be
stabilized?

>> 8

Input to the optimization program will be:

transmissivity    2
     mean - 1200 m /d
     variance - 52

effective porosity
     mean - 0.31
     variance - .002

octagon side length - 274 m

time period to stabilize plume - 8 days

pump spacings - 1/2, 1/4, 1/8 of side length

---------------                                     ---------------
```

This is the end of the expert system analysis of the hypothetical contamination problem. With the given input values the optimization program will determine the most economical pumping scheme to attain as nearly a horizontal gradient as possible within the 8 day time period specified by the user. It will optimize pumping for 3 different well spacings and give results for each.

For the relatively large contaminant plume of the hypothetical problem the pumping capital costs are 30 times less than the capital costs for the other two containment methods. However, costs are more similar in cases of smaller contaminated areas. In addition, if it is anticipated that the containment strategy will be used for any extended period of time the operating costs for the pumping may become an important factor in the decision. This is not, at this time, considered in the expert system but it is an integral part of the optimization program.

CONCLUSION

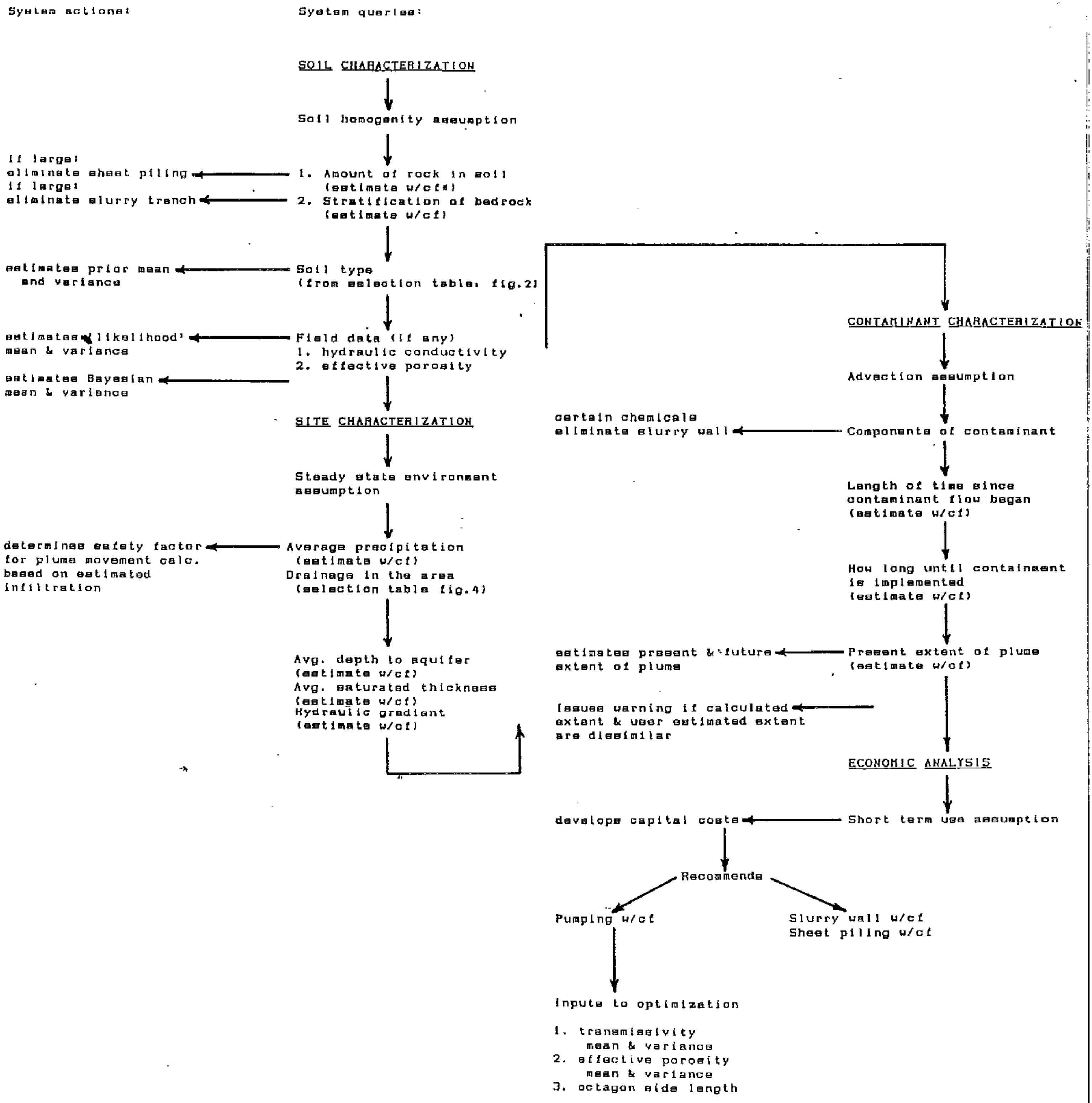
An expert system is developed to provide assistance in assessing how best to contain a contaminant plume in groundwater. The system requests, from the user, pertinent information about the soil characteristics, site characteristics, and the contaminant plume. Based on this information, the system analyzes three containment methods: slurry wall, sheet piling and pumping. The system recommends a containment method and (if pumping is the method chosen) sends required data to an optimization program.

The current expert system compares the three containment methods based on the physical characteristics of the contamination problem and the capital costs of each method. At present the length of time for which the containment method would be used is not considered. Therefore, operating costs for the pumping strategy are not included in the analysis. These operating costs are being added to the analysis to provide a better comparison between the three containment methods.

There are many additions that can be made to provide a more expanded expert system analysis. However, this system does provide a well structured method of analyzing a contamination problem and it develops analytical values for transmissivity, effective porosity and size of containment octagon for the optimization program.

ACKNOWLEDGEMENT

We gratefully acknowledge the financial support and encouragement of the Air Force Engineering and Service Center, Tyndall Air Force Base, Florida, and the Agricultural Engineering Dept., Univ. of Arkansas.



* user must input an estimated answer to the question with a confidence factor (0%-100%) indicating the reliability of his answer.

Figure 1 - Flow chart of expert system

Soil Type	% clay	% sand	% silt
sand	<10%	>90%	>90%
sandy-loam	<20%	>85%	50-70%
sandy-clay	35-55%	60-85%	50-65%
silty-clay	40-60%	20-40%	40-60%
clay	>40%	30-75%	<60%
loam	5-25%	40-60%	75-95%

Figure 2 - Soil type selection table

Soil Type	Hydraulic Conductivity(m/d)	Effective Porosity
sand	.078-571	.13-.40
sandy-loam	.050-250	.16-.46
sandy-clay	.001-1.0	.01-.39
silty-clay	$(.77-600)10^{-3}$	.01-.28
clay	$(1-400)10^{-6}$	.01-.46
loam	.02-16	.01-.46

Figure 3 - Soil fact database

Drainage Class	Observable action
Very poorly drained	Water remains at or on the surface most of the year
Poorly drained	Water remains at or on the surface much of the year
Somewhat poorly drained	Soils are wet for significant portions of the year
Moderately well drained	Soils are seasonably wet (high spring water table)
Well drained	Water readily removed from the soil
Somewhat excessively	Water is rapidly removed from the soil (e.g. uniform drained sands)
Excessively drained	Very rapid removal of water, little or no retention

Figure 4 - Drainage selection table (reference: Ludvigsen, P.J.)

REFERENCES

1. Bear, J., 1979, Hydraulics of Groundwater, McGraw-Hill Book Company.

2. Datta, B., Peralta, R.C., 1986, Expert Pattern Recognition For Pollution Source Identification, Proceedings of ASCE Conference, Water Forum, '86, vol. 1, pp. 195-202.

3. Canter, L. W., Knox, R. C., 1985, Ground Water Pollution Control, Lewis Publishers, Inc..

4. Cuena, J., 1983, The Use of Simulation Models and Human Advice to Build an Expert System for the Defense and Control of River Floods, Proceedings of the Eighth International Conference on Artificial Intellegence, Vol. I, pp. 246-249.

5. Guswa, J.H., Lyman, W.J., 1983, Groundwater Contamination Response Guide, Vol. II, Tyndall AFB, Florida.

6. Huggins, L.F., Barrett, J.R., Jones, D.D., 1986 Expert Systems: Concepts and Opportunities, Agricultural Engineering, Jan./Feb., pp. 21-23.

7. James, W.M., Dunn, A.R., 1985, Integrated Knowledge-based Software for Flood and Water Pollution Management, Computer Applications in Water Resourses, Proceedings of the Specialty Conference of the ASCE, pp. 601-610.

8. Johnston, D.M., 1985, Diagnosis of Wastewater Treatment Processes, Computer Applications in Water Resources, Proceedings of the Specialty Conference of the ASCE, pp. 611-619.

9. Jones, P., Jacobson, B., Jones, J.W., Paramore, J.A., 1986, Real Time Greenhouse Monitoring and Control with an Expert System, presented at ASAE winter meeting, Chicago, Ill..

10. Kline, D.E., Bender, D.A., Van Donge, C.E., McCarl, B.A., Schueller, J.K., 1986 Machinery Selection Using Farm-Level Intelligent Decision Support Systems, presented at ASAE winter meeting, Chicago, Ill..

11. Lindley, D.V., 1970, Baysian Statistics, A Review, Society for Industrial and Applied Mathematics.

12. Ludvigsen, P.J., 1986, Incorporating Expert System Technology to Aid in Characterizing Groundwater Contaminant Potential, presented at the 4th Conference on Computing in Civil Engineering, Boston, Mass..

13. Ludvigsen, P.J., Sims,R.C., Genney, W.J., A Demonstration

Expert System to Aid in Assessing Groundwater Contamination Potential by Organic Chemicals, unpublished.

14. McWhorter, D., Sunada, D.K., 1977, Ground-water Hydrology and Hydraulics, Water Resources Publications.

15. Palmer, R.N., 1985, A Review of Artificial Intelligence, Computer Applications in Water Resources, Proceedings of the Specialty Conference of the ASCE, pp. 591-600.

16. Peralta, R. C., Ward, R. L., 1986, Optimal Piezometric Surface Management for Groundwater Contaminant Control, presented at ASAE winter meeting, Chicago, Ill..

17. Reboh, R., Reiter, J., Gaschnig, J., 1982, Development of a Knowledge-based Interface to a Hydrological Simulation Program, SRI International, Menlo Park, CA, May.

18. Rich, E., 1983, Artificial Intelligence, McGraw-Hill, NY..

19. Rogoshewski,P., Bryson,H.,Wagner, K.,1983, Remedial Action Technology for Waste Disposal Sites, Noyes Data Corp.

20. Terzaghi, K., Peck, R. B., 1967, Soil Mechaniics in Engineering Practice, John Wiley and Sons, Inc..

21. Thieme, R.H., Whittaker, A.D., 1986, Representation and Reasoning Issues in Expert Systems, presented at ASAE winter meeting, Chicago, Ill..

22. Todd, D. K., 1980, Groundwater Hydrology, John Wiley and Sons.

23. Whittaker, A.D., Foster, G.R., Monke, E.J., 1986, A Technique for Intelligent Modeling, presented at the ASAE winter meeting, Chicago, Ill..