ARDx - A Fuzzy Expert System for ARD Site Remediation

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ABSTRACT

This paper details development of an expert system using fuzzy techniques to design remediation techniques for sites contaminated by Acid-Rock-Drainage. The fuzzy system is able to deal with missing, inaccurate, or heuristic data and still make useful design decisions.

Fuzzy sets are defined using a functional relationship between the degree of belief in a certain qualitative concept and one or more quantitative variables. Rules were developed during interviews with a chosen expert in the field. Using user input site data and characterization, the association of the degree of belief in a concept with that of other concepts come together within these rules to a produce a decision or conclusion.

The development of a fuzzy expert system for ARD is a benefit since it produces a standardized adaptable approach to the problem and provides quick advice to a user looking for a preliminary but detailed analysis.

The work done to this point includes a fuzzy controller, separate control modules for treatment options, cost analysis, and interactive hypertext documents. The controller and control modules work together in an attempt to follow the decision-making process as it chooses an appropriate treatment option for a site with possible or existing ARD. The hypertext documents are set up as user help-resources to provide system output information and to use as a training tool on treatment options for ARD or as a diagnostic tool on the possibility of implementing a treatment system.

BACKGROUND

Acid Rock Drainage (ARD) is contaminated acidic drainage from the spontaneous weathering and oxidation of pyrite and other sulfide minerals [1]. Weathering conditions increase the solubility of heavy metals, radionuclides, sulfate, and acidity; and reduce the pH of the drainage. ARD impacts on watershed characteristics and creates adverse effects in the surrounding ecosystem.

The problem exists in coal as well as metal mines. Once exposed, waste rock and/or tailings dams may continue to generate such acidity and pollution for decades and perhaps, centuries. It is imperative that prediction and prevention be used as a primary method to deal with and control ARD at virtually all mine sites. However, in active or abandoned mine sites where the problem already exists, and as a supplement to preventative measures in new mines; treatment of the contaminated drainage is necessary [2]. This can add appreciably to the on-going operating costs of a mine.

Expertise in the field of ARD is often controversial as fundamental knowledge is lacking, expertise are scarce, and new knowledge is continually being sought and applied. Prediction of weather conditions, surface and ground-water flows, chemistry of reactions in the waste piles and dissolution kinetics are all fraught with significant errors. Data to assess and deal with ARD problems are often missing and so heuristic judgements play an important role in decision-making. A fuzzy system is able to handle and manipulate missing, inaccurate, or heuristic data. [3] A fuzzy expert system thrives on these conditions.

The development of a fuzzy expert system for ARD is of benefit since it produces a standardized adaptable approach to the problem, provides quick advice to a user and is equipped for training and teaching.

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ARDX COMPONENTS

In its entirety, the ARDX system is designed to handle ARD problems ranging from prediction, through to prevention and monitoring for treatment. The scope of the project to date deals with decision-making tactics for prevention and treatment at a mine site in one of three mine stages: planning, operating, or closure. The components of the system come together through a knowledge base and inference engine by using rules and fuzzy concepts; and with an explainer engine providing reasoning, explanations and answers to user questions. Figure 1 shows the components of the ARDX system. The knowledge base is itself made up of a main system module (ARDX "main") and numerous sub-modules.

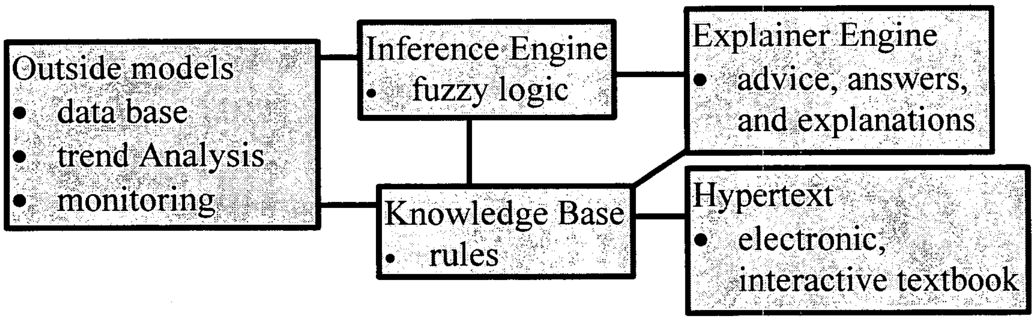

Fig. 1. Basic ARDX configuration flow-chart.

ARDX "main" interacts with the sub-modules and drives the system. It communicates with the user by asking for site specific data input; moves through the appropriate sub-modules; assesses whether an appropriate recommendation has been found; and cycles through again or exits the system as required. Forms pop up when called upon for data input, and hypertext files are used for system output. ARDX "main" decides the final recommended treatment options for the site by assessing the cost of treatment with the probability of success for each treatment option.

DEVELOPMENT PROCEDURE

Development of an expert system requires:

- a clear definition of the problem and domain of the system
- knowledge acquisition
- system development (programming steps)
- testing and verification of the system.

DEFINING THE PROBLEM AND DOMAIN

The first step often poses the most obstacles. In this case the domain of the system was designed to include all treatment possibilities. However, during knowledge acquisition, it became clear that the chosen domain was extremely large. Rather than change the chosen domain of the system, it was decided to focus on two aspects, an overall structure to the decision-making process (developed through ARDX "main") and a more detailed evaluation of separate treatment options (sub-modules). In this way a working system could be developed while separate modules containing further treatment options were added, revised or discarded as seen fit. ARDX "main" has become the seed for development of a larger and more complete system. Figure 2 shows the basic ARDX flow-chart that has become instrumental in organizing and developing the system.

Essentially, the system examines all appropriate methods in terms of their ability to deal with the potential or existing problem. Once a particular method or methods have been evaluated, the system looks for combinations of methods that may improve the solution further. When these have been assessed, the cost of each option is calculated and the recommendations of the least-costly, most-effective options are presented to the user.

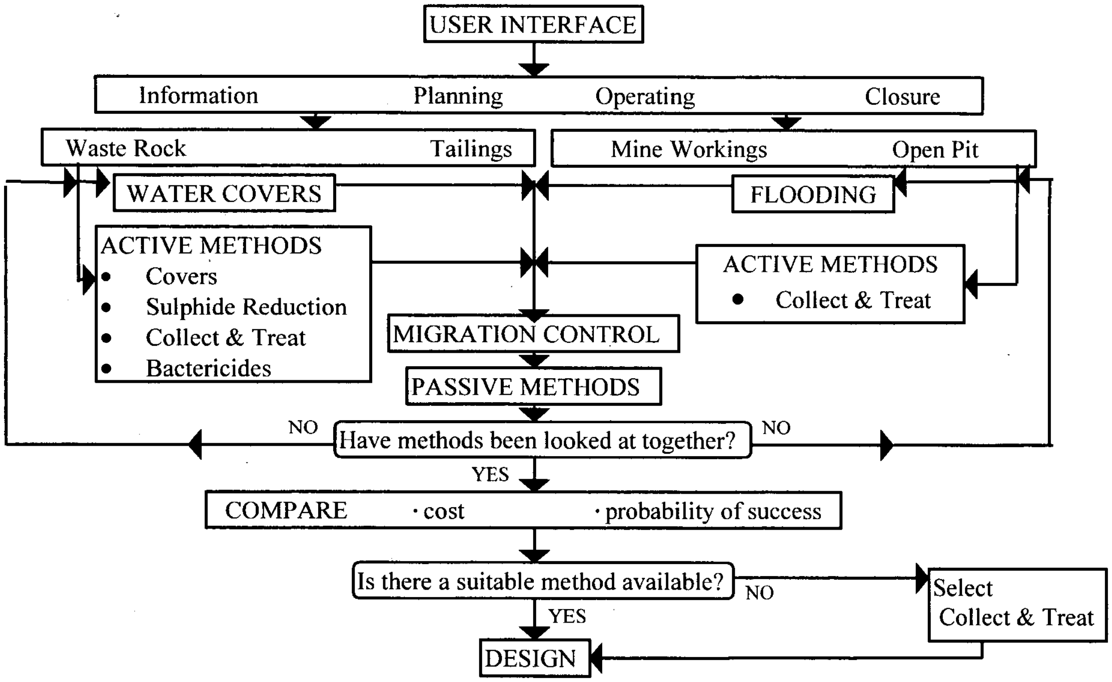

Fig. 2. Basic ARDX Flowsheet.

KNOWLEDGE ACQUISITION

Initially the knowledge acquisition phase included choosing and interviewing the expert as well as extensive literature searches on the topic of ARD treatment. Through interviews with the expert, the framework of the system was established. Expertise was taken from numerous and, sometimes, contradictive published papers on the subject. The challenge of building an expert system for ARD would appear to be in defining rules in a field where many decisions are presently being made by trial and error. Case studies were used to attempt to mimic the actual decision-making process followed by the expert. Acquiring expertise is an ongoing process as the system is developed and expanded.

DEVELOPMENT OF THE SYSTEM

ARDX operates within the COMDALE/X environment. Information is represented using keyword triplets; a method which assigns an attribute and value to each object. Data in a keyword triplet can be stored as strings, floating point numbers, dates, logical fuzzy variables, etc. [4].

The user interface consists of pop up FORMS, text boxes and hypertext documents. Through "forms", data consisting of drainage characteristics and site specifics are input by the user and stored as keyword triplets. The system will communicate with the user in the event of any inconsistency in the input data via text boxes. Once a conclusion has been reached, the output is displayed in a hypertext document.

The first step in successfully developing ARDX "main" was to write a set of preliminary rules to call upon the sub-modules. Output from the sub-modules are based on the concept of "high", "medium", and/or "low" assigned to the probability of successful mitigation or prevention and the capital cost (according to the amount of money available for the project) of the treatment option. Information from each sub-module can be used as inputs to other sub-modules as the system moves through the modules again to review the option of using combinations of the different treatment systems.

Development of the sub-modules is ongoing as new ones are continually being added. The "ACTIVE METHODS" module is itself (like ARDX "main") a smaller driving module that calls upon the various active treatment sub-modules. This secondary smaller driving module was necessary because of the large number of options available. Outputs to each module (probability of success) and the cost (calculated separately), are compared through Fuzzy Associative Memory (FAM) maps and given a Degree of Belief (DoB) in the treatment option.

The "COVERS" sub-module was developed first. This module is part of the extended "ACTIVE METHODS" sub-module and decides on the probability of a cover to be used as an active treatment option. Inputs of site details and characteristics are placed into fuzzy sets. Through these fuzzy sets, inputs are assigned a membership value in a set and a Degree of Belief (DoB) in the concept "low", "medium", and/or "high" [4] [5]. Figure 3 shows the FAM map elements that comprise the "COVERS" module.

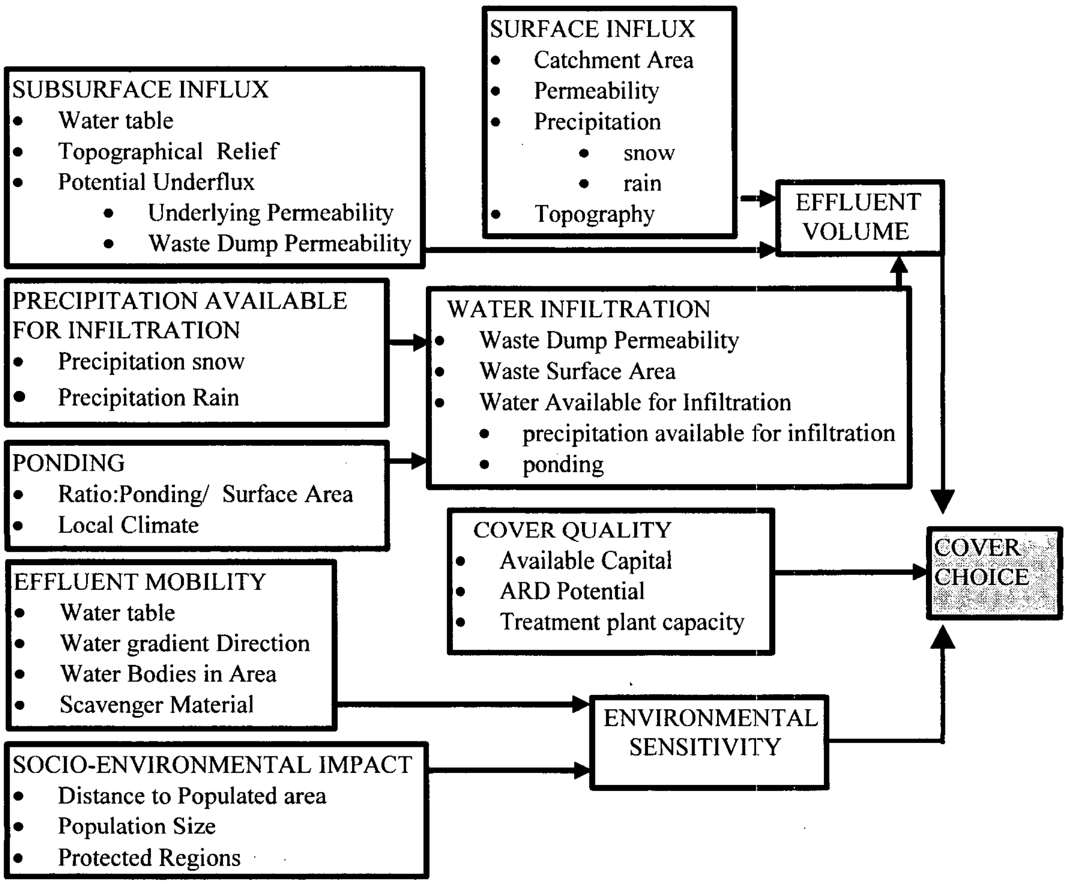

Fig. 3. "COVERS" Module Flowchart

A FAM map is a means to depict rules that combine to determine a degree of belief in a concept from a number of variables [5]. The FAM maps are created through interviews with the expert. They are used within the "COVERS" module to assess input information and decide upon an appropriate cover choice. The FAM map used to acquire a degree of belief in environmental sensitivity from two variables that are themselves determined through other FAM maps is shown in Figure 4. Certainty Factors (CF) of the concepts "sensitive", "slightly sensitive", and "resistant" need not add up to 100 as there may be an overlap in the belief in each concept and can be assigned as indicated within the FAM map.

ENVIRONMENTAL SENSITIVITY FAM		Socio-Environmental Impact		
		L	M	H
Effluent Mobility	H	s = 30 ss = 70 r = 10	s = 70 ss = 40 r = 0	s = 100 ss = 0 r = 0
	M	s = 0 ss = 50 r = 60	s = 20 ss= 90 r = 10	s = 60 ss = 50 r = 0
	L	s = 0 ss = 0 r = 100	s = 0 ss = 40 r = 70	s = 30 ss = 70 r = 10

Fig. 4. FAM map for Environmental Sensitivity of a site.
(ss = slightly sensitive, s = sensitive, r = resistant)

As the number of variables necessary to decide on a concept increases, the size and complexity of the FAM maps also increase resulting in large multi-dimensional maps of the decision-making process. However, by using a two-dimensional FAM map approach as shown above, this complexity can be separated into unique modules which are easy to understand and develop in consultation with the expert.

A separate cost module has been developed and is accessible by all modules as necessary. Calculated costs for an option can be used as inputs to modules. Costs for each remediation option are calculated using unit prices [6] and site-specific information. To account for future cost variability; the module updates all information according to the Marshall & Swift (M&S) index values [7]. The module is able to store input M&S values for future reference and calculations.

The economic evaluation of an treatment option is broken down into capital cost, maintenance and inspection costs; and operating costs due to continued effluent treatment and sludge disposal. The net present value of all on-going maintenance and operating costs are calculated from a user-defined rate of return value (defaulted to 3.5 if unavailable).

Defuzzification is performed using a weighted-average approach for the concepts "no" (an unacceptable treatment option), "no unless" (an acceptable option at a high cost, use if no other is available), "ok" (acceptable option), "good" (acceptable and low-cost), and "very good" (most cost effective) for each treatment option. This becomes the final degree of belief (DoB) in each treatment option recommended.

The output hypertext display provides a list of recommended treatment options, the probability of success and the cost demanded by each option. The user is able to "click" through the document for justification of each recommended treatment option and for information on the decision-making process; and has access to justification of the decision making process within the individual sub-modules.

TESTING

Testing the ARDX system is currently incomplete. Actual mining cases that have used or are using treatment options similar to those investigated by ARDX will be adopted to test the system. It is intended to apply both successful and unsuccessful cases for a comparison of chosen treatment options, their success, and treatment options decided upon by ARDX.

The "COVERS" sub-module has undergone preliminary testing using Samatosum mine data [8]. The data was input by the expert. The resulting output for probable cover treatment options corresponded to one of the options being considered for the mine.

CONCLUSION

Development of a Fuzzy Expert System on the design of ARD remediation plans has been successful. The system has the following benefits:

- a comprehensive, logical organization of the design methodologies has been developed
- a consistent design philosophy can be generated by use of this system
- a training tool has been created to assist in the transfer of ARD technology to the industry
- economic and effective procedures to use for a wide variety of site problems are available

Future expansion of this system will include ARD predictions based on expertise derived from case studies of existing sites. These predictions will be used as inputs to the existing system

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