(ESGWM) AN EXPERT SYSTEM FOR DATA PREPARATION FOR GROUNDWATER MODELLING

I. HSOUNI SEKKOURI and **D. OUAZAR**

Hydrological Analysis system laboratory
Department of Civil Engineering, Ecole Mohammadia d'Ingenieurs
Av. Ibn Sina, BP. 765 RABAT-AGDAL, MOROCCO
Email : ilhame@hotmail.com

SUMMARY

ESGWM is an Expert System (ES) that serves as a decision-making tool for the choice of an adequate model and the estimation of parameters needed for Groundwater modelling and in particular saltwater intrusion. The parameters include all the input data required for site characterization and aquifer parameters i.e. the hydraulic conductivity, storage coefficient, porosity etc. An important aspect of ESGWM is its ability to generate parameters from various techniques including pumping test, slug test as well as various soil classification system and conventional kriging. A set of rules based on literature and human expertise are made to build a knowledge base to help the user defining, acquiring and estimating the required parameters. The (ES) includes a user interface, databases, GIS, parameter estimation tools and a kriging method.

INTRODUCTION

Modelling systems is a complex multi-disciplinary task requiring adequate approaches and techniques to tackling management and control water resources problems. The lacking parameters/and or coefficients for model calibration leads to the incorporation of heuristic engineering knowledge, which shows efficiency in ensuring a feasible set of suitable parameters necessary for groundwater modelling. An expert system was developed that serves as a decision-making tool for the choice of an adequate model and for the estimation of parameters needed to operate the groundwater model for the to-called sharp model. The expert system helps to define, acquire and estimate required parameters. Integration of geographic information system (GIS) with the expert system enhances the design and calibration procedures of groundwater modelling. GIS is designed to manage, analyse and display all types of spatial data. This capability makes GIS a powerful tool in conducting ground water assessments and preparing data to be treated in the (ES). GIS maintains the spatial location of wells, borings, etc., and provides tools to relate the well or boring to data contained in an external relational database. GIS also provides advanced tools for spatial analysis of the related data. In addition, GIS provides sophisticated map-generation capabilities, useful in communicating results of data analysis. Integration of aquifer tests is one of the best ways of determining physicals properties of water-bearing layers, pumping test, slug test as well as other techniques are given to help the user of the (ES) to estimate adequate data for groundwater modelling. Interpolation of representative values of the required parameters, such as hydraulic conductivity, storage coefficient, etc. is applied by using kriging method.

RELATED WORK ON GROUNDWATER EXPERT SYSTEMS

One of the significant successes of applied artificial intelligence has been the development of new computer assisted systems known as experts or knowledge-based systems. Accordingly, in this study both terms are used interchangeably. Expert systems consist of the applied and experimental aspects of AI science. AI is defined as "the study of how to make computers do things which at the moment people do better" (Rich and knight, 1990). People and computers are the two main factors that are incorporated in this definition. The human part of the definition concerns the expertise while the machine part concerns knowledge transfer. Expert systems contain the same factors (human and machine resources) mentioned above. Accordingly, they are considered as the practical modelling of the findings of the AI science.

Many basic texts in AI provide different definitions for expert systems (e.g., Friederich, et al., 1989; Rich, et al., 1991; Fieschi, 1990; Jackson, 1986). Among these definitions is the definition given by Bowerman and Glover, 1988. They defined an expert system as: " a system of software or combined software and hardware capable of competently executing a specific task usually performed by a human. Expert systems are highly specialized computer systems capable of stimulating that element of a human specialist's knowledge and reasoning that can be formulated into knowledge chunks characterized by a set of facts and heuristic rules." There are currently several expert systems specifically focused towards solving groundwater -related problems that have been successfully developed, are currently under development or have been proposed. Generally these expert systems can be divided into five main groups based on the groundwater issues to which they provide support; i.e. regulatory support, site assessment and remediation, groundwater contamination modelling and water resources (A.S.Crowe and all, (1992), Fedra, K. (1995), Fedra, K. and Winkelbauer, (2002)).

It is noted that there is no such (ES) for preparation data for Groundwater modelling except a prototype developed for USGS modular groundwater model (Gerard Lenon, and all, 1989).

(ESGWM) AN EXPERT SYSTEM FOR GROUNDWATER MODELLING

Deterministic groundwater simulation models impose large requirements for data to define all of the parameters at all of the nodes of a grid. To determine uniquely the parameter distribution for a field problem, so much expensive field-testing would be required that it is seldom feasible either economically or technically. Owing to the high cost of aquifer test which leads to the scarce of adequate data to describe the hydrogeological process, and the need of experts on groundwater modelling to interpret hydrogeological features of groundwater systems and providing advices to the related problem, one needs to develop an efficient tool which can mimic the manner and methodology of a hydrogeological expert in preparing adequate input data set for a model. The (ES) will help to manage data from all type of resources: GIS, MN topographic map collection, Resource reports, copies of ground-water and environmental curriculum, Graphing and data analyses programs (well logs, aquifer characteristics from pumping tests, groundwater quality and quantity, surface-water quality and quantity, digitised files. etc.) for a successful simulation process.

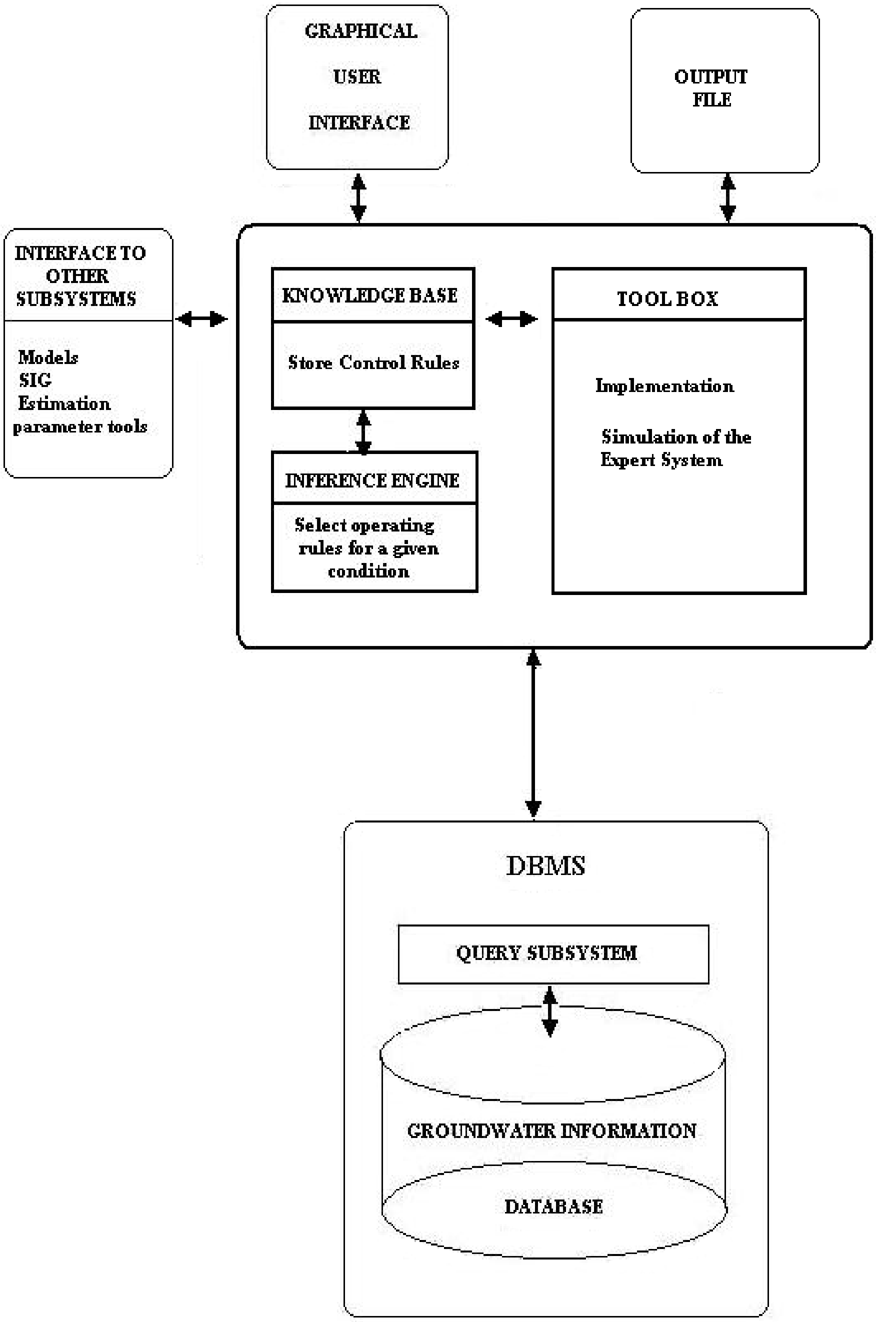


Figure 1 *Architecture of ESGWM*

The (ES) was developed according to the major concepts known in AI fields for developing standard expert systems.

The following list is summarizing the steps that were followed to develop the system:

- Identification of the problem
- Knowledge abstraction and representation
- User Interface
- Database component
- Algorithmic structure and component analysis program
- Knowledge base component
- Inference mechanism for knowledge processing and Modification

Identification of the problem

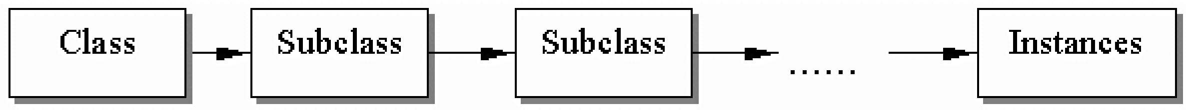
Groundwater modelling requires knowledge and expertise acquired from the applications of aquifer systems over many years. Most of the information is empirical and heuristic. For an accurate prediction of the future behaviour which means the choice of an enhanced Model and for an input data set preparation for ground water models which is an extremely time consuming task; an expert system have been developed, it includes:

- Steps to choose adequate model.
- Interface with a geographic information system (GIS) for the management of spatial data and the preparation of parameters by using background maps. The GIS uses both vector data and satellite imagery;
- A set of data bases, e.g. on soil type, porosity and hydraulic conductivity parameters with a graphical illustration;
- A knowledge base with parameters, rules, background information and guidelines and instructions for the user;
- The inference engine, that guides the user through a preparation data set for a studied case in a simple menu driven dialogue;
- Recommend field measurements when necessary;
- Provide graphical displays including contour and perspective views parameter distributions,
- and a Summary Report generator, that summarizes and prepare the data input set, providing an input file for the model.
- Through the rules of the expert system, external models, programs, spreadsheet, databases and GIS can be invoked as part of the inference procedure. Models can be used to treat a ground water flow problem, a transport flow or saltwater intrusion problem; in this case Sharp a salt water intrusion model was used to simulate a cross section area;

Knowledge abstraction and representation

The term knowledge in KBES has a different meaning from that of ordinary English. In expert systems, knowledge means the information a computer needs before the expert system can behave intelligently. It needs to be abstracted from the knowledge source and represented in unique ways that a computer can manipulate efficiently. There are two dominant ways supported by most expert system shells to represent knowledge. The first one is a rule-based representation. This method uses IF condition THEN action statements to represent knowledge. When the condition in IF part is satisfied or matched, that rule will be fired and the action specified by the THEN part is then triggered.

The action may affect the outside world by causing text to be printed, directing program control such as testing and firing other rules, or instructing the system to reach a conclusion by adding a new fact to the knowledge base. This method is especially useful when the expert system requires intensive reasoning for solving a problem. The second knowledge representation method is frame-based. It uses a network of classes and instances (also called nodes or frames) connected by relations and organized into a hierarchical structure. Each node represents a concept that may be described by attributes and/or values associated with the node. The topmost nodes represent general concepts and the lower nodes represent more specific instances of those concepts. Frame-based representation is able to clearly document information about the domain in a natural way and modularise the information, permitting relative easy system expansion and maintenance. This method is also fully supported by the power of object-oriented programming languages such as information encapsulation and inheritance. Kappa-PC, the selected expert system development environment, supports both methods of knowledge representation. The nature of groundwater modelling systems makes frame-based representation and rule based representation efficient and insightful. In Kappa-PC environment, taxonomic process follows as:



In the application of groundwater modelling, there are two main tasks, the first one is the choice of the model and the second one is the preparation of data for the model.

The topmost class is labelled as Root, which is classified into Model subclass and watershed subclass.

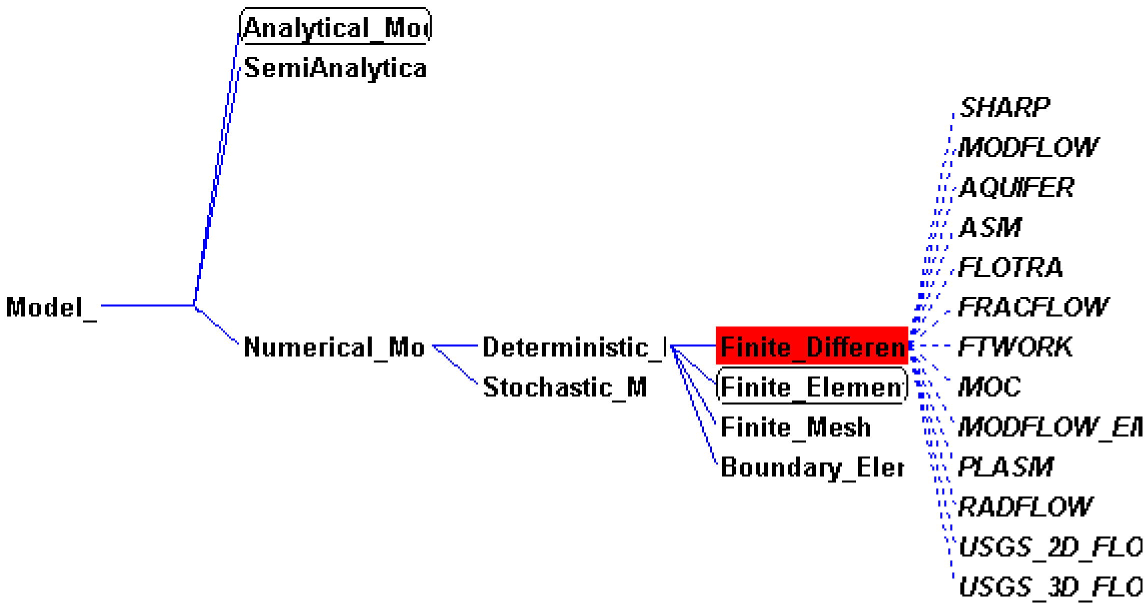


Figure 2 *Hierarchical architecture of model Class.*

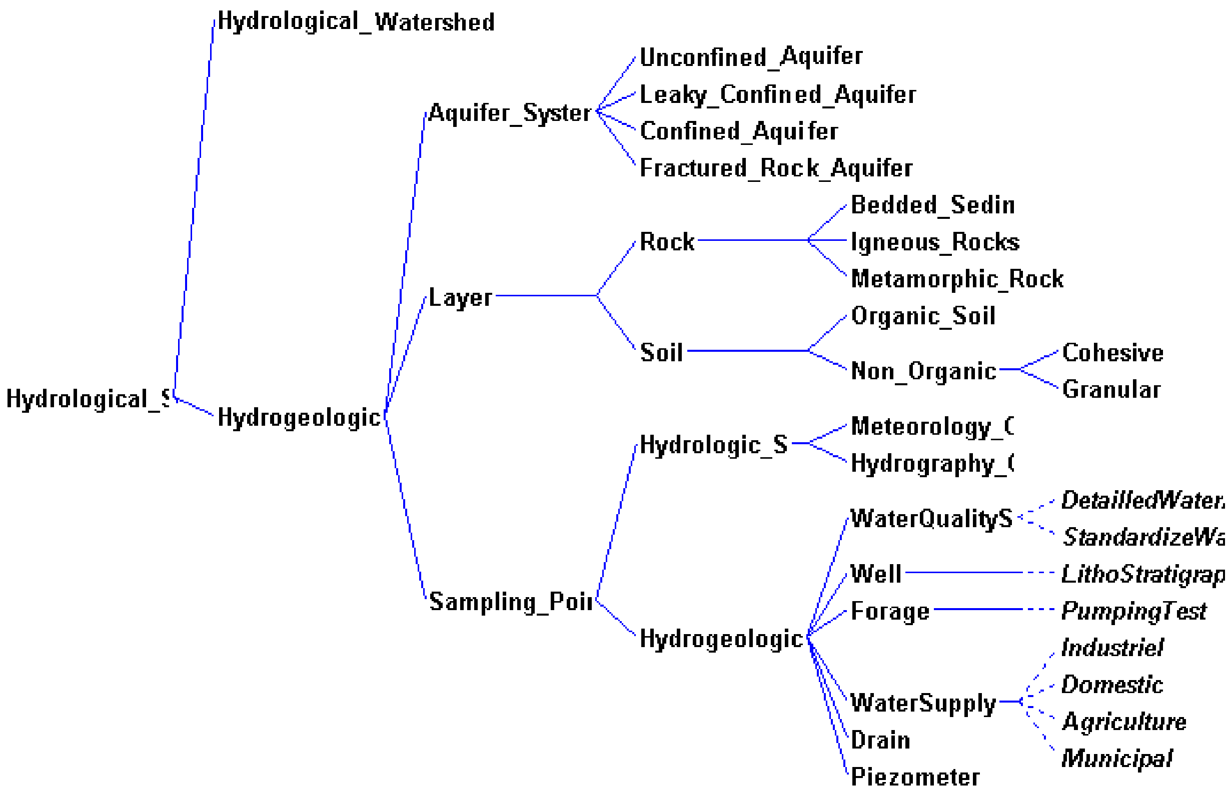


Figure 3 *Hierarchical architecture of Hydrogeological Basin Class.*

The model, which has a very broad meaning and semantically includes all types of models, is classified into three subclasses: Analytical models, semi-analytical models and numerical models. All of these types represent a class of ”Model” that have some common attributes and components. The watershed subclass is subdivided into two subclasses ”hydrological watershed” and “hydrogeological watershed”. The ”hydrogeological watershed” subclass is component of different types of aquifer such as confined aquifer, phreatic aquifer, and leaky confined. They are treated as abstract component. Each component is instantiated into instances representing possible problems that the parent component may encounter. Figure 2 and 3 show one of the hierarchical architectures for groundwater modelling expert system. Attributes of a frame are represented as a set of slots, which in turn can also have attributes such as VALUE. The allowable values of VALUE can be numerical, Boolean, string or object values. Most of the attributes of the problems encountered by aquifer components have numerical values to indicate and evaluate the parameters needed for the model. A series of actions can take place, as specified beforehand, before and after change of the VALUE or if the VALUE is accessed. The actions are defined by methods and, like the actions in the THEN part of a rule, may affect the outside world, direct program control, or instruct the system to reach a conclusion. Methods are attached to a frame and can be accessed through calls from slots of the same frame. Method is a kind of function manipulating attributes of the frame to which it attached and attributes of other frames as well. In conjunction with slots, the function of methods is very similar to that of rules in rule-based knowledge representation.

User interface

User interface, links the user and the knowledge-based expert system. Generally, user interfaces obtain information that is needed to solve a particular problem by asking the user to answer questions or prompting the user to provide relevant information in preformatted way. The system is designed to be used at different levels of user sophistication. The user interface build in KAPPA, is a menu driven task manager, that allow selection of different modules such as existing programs for evaluating parameters from pumping test or slug test. More sophisticated modules (GIS, kriging program, parameter estimation tools) are currently being integrated into the expert system. An expert uses accesses these program as well as database and spreadsheets directly from the user interface main menu. Less experienced users will access these modules from within the expert system shell itself with careful guidance from the system.

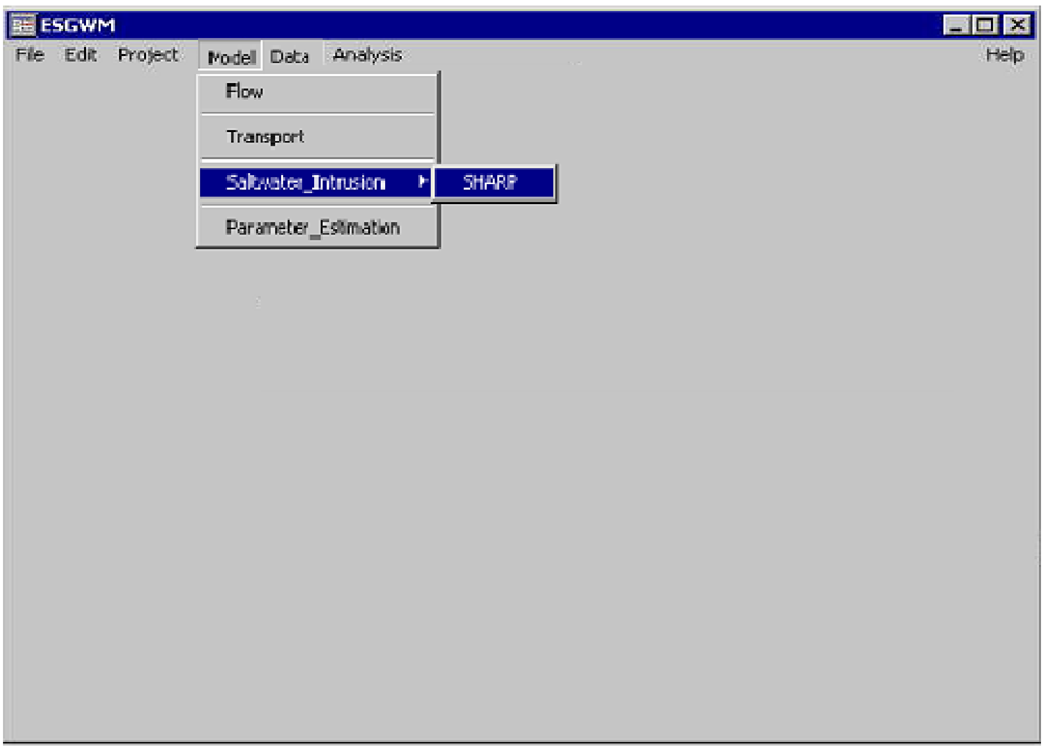


Figure 4 *Example of Expert System Model Submenu.*

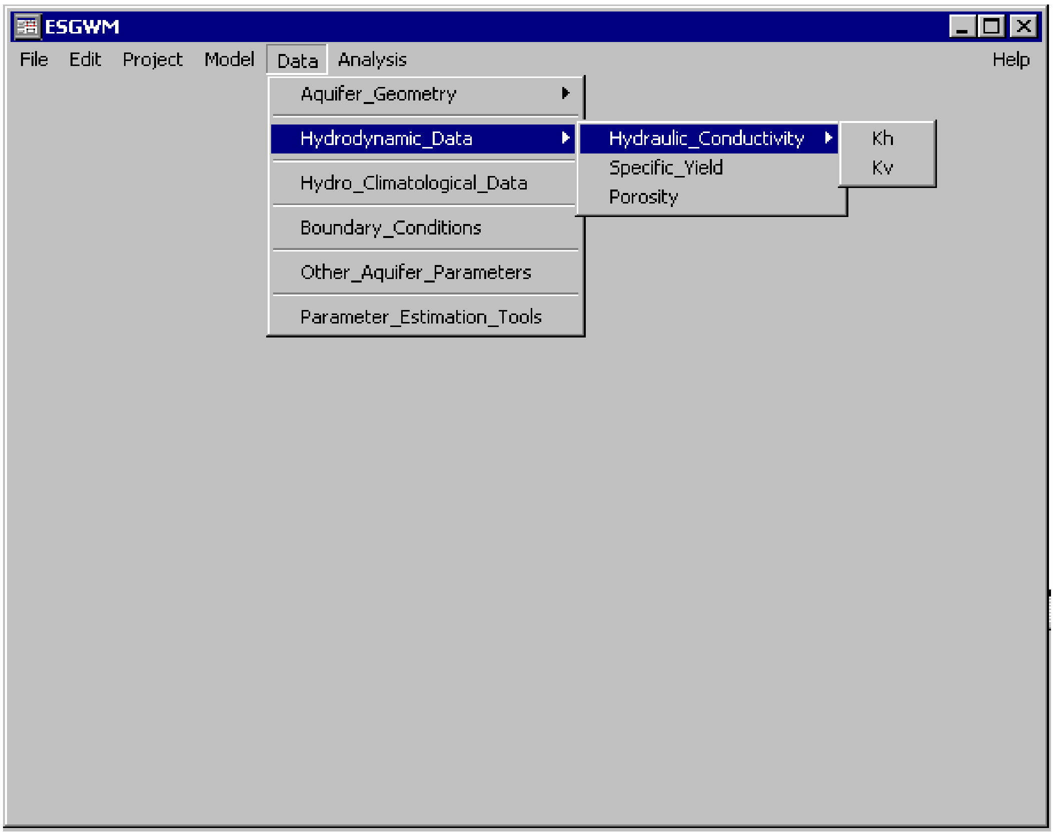


Figure 5 *Example of Expert System Data Submenu.*

ESGWM is organized into four modules (Project, Model, data, Analysis). As the user browses modules, the menus unique to the active module are displayed. The first three items on the top menu bar (File, Edit and Help) are standard items for most Windows applications. These items function the same way in ESGWM as they would in any other Windows application. The remaining menu items (Project, Model, Data, and Analysis) are designed to guide the user through the steps of evaluating and analysing data using ESGWM.

PROJECT – to create a project (to define Aquifer system, well locations and to select a map using GIS). An input data set file submenu is inactive until the choice of the model is complete.

MODEL – used to Identify the model type (Flow, Transport or Saltwater intrusion model), the user is asked to evaluate the hydrogeological environment of the studied area and the (ES) can help the user to choose the adequate model. A submenu of Run model related to each model submenu is inactive until an input data set file is complete.

DATA - used to evaluate data for the used model. As already mentioned, the sharp model is used for the sake of illustration of the methodology.

Input Data file for Sharp model contains:

Number of rows number of columns, number of aquifers, specific gravity of both freshwater and saltwater, viscosity of both freshwater and saltwater, location of observation nodes tracked, hydraulic conductivity of freshwater in x-direction and in y-direction, saltwater and freshwater specific storage, effective porosity, aquifer thickness, elevation of base of aquifer, initial freshwater head, initial interface elevation, substratum, bathymetry, aquitard leakances, (dx, dy), pumping period info, pumping well information and the recharge of the upper unconfined aquifer. The specified parameters can be evaluated in the data submenu.

DATA submenu is organized into six other submenu: A submenu of Aquifer geometry leads to use GIS mapping to generate cross sections, and geologic layers for data conceptual model development, Thickness of aquifer unit, the top and the bottom of the aquifer. The boundary line of the area of interest is also defined by using well records within GIS. A submenu of hydrodynamic data is used to compensate for the lack of hydraulic conductivity distribution information and other aquifer hydraulic parameters. A rule based reasoning leads to the use of many techniques to estimate these values. Both vertical and horizontal hydraulic conductivity can be estimated using a rule based reasoning system to choose between water well record information, aquifer test or the soil database to evaluate the appropriate value of hydraulic conductivity, specific yields, etc. A submenu of hydro-climatologic data: is used to evaluate recharge and discharge values. A submenu of Boundary conditions such as recharge, rivers, or constant heads can be implemented and modified with GIS generated polylines/polygons and attached attributes, the (ES) can help the user to define the appropriate aquifer boundary conditions. Tables In ESGWM interfaces allow the user to manually enter the data line-by-line, or to easily cut and paste data from external spreadsheet applications or ASCII text files. Also An Import data from GIS is stored in Microsoft Access and is used for 2-D or 3-D of raster (grid values) or vector maps (contour maps) of aquifer properties such as hydraulic conductivity. Microsoft Access database is used to store and manage data in a project-oriented data structure by using Kappa interface.

ANALYSIS - is organized into two submenus, a submenu of methods is used to select the appropriate analysis method for data evaluation (methods used to interpret Pumping Tests and Slug Tests); a submenu of Kriging method: GIS can be used for creating maps of hydraulic conductivity and other hydraulic properties through the interpolation of point estimates of parameters. By following these steps, the user interacts with the application via pop-up dialog windows in which he is asked to enter values or to choose from a set of slot value options.

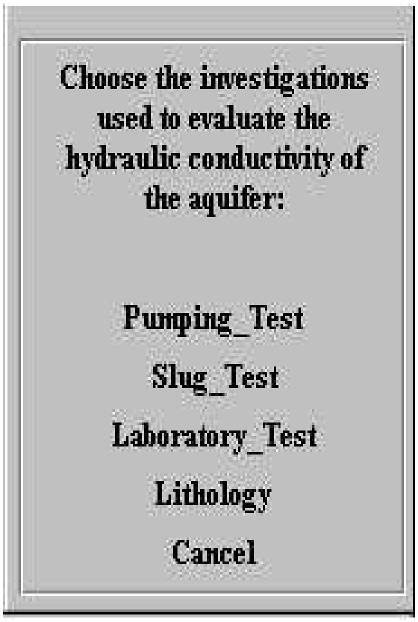


Figure 6 *An example of techniques to evaluate hydraulic conductivity parameter.*

Database component

A database that help to fill gaps in the required input data of the model is presented, An existing set of data bases, e.g. on soil type, porosity and hydraulic conductivity parameters are being screened for possible use. Database made in Mss Access, and related to the expert system, help the user to store, save and manage data. Kappa allows the user to interact with DBMS by using ODBC based database access interface.

Algorithmic structure and component analysis program

The ESGWM leads to choose the model from many existing models and to generate parameters from various techniques. The parameters, generally required implementing a flow model or a salt-water intrusion model (Sharp in this paper) for a realistic site, include three-dimensional characterization of hydraulic parameters. The expert system should be able of evaluating and selecting techniques and relating the user to the GIS, kriging method and parameter estimation model.

Knowledge base component

The knowledge base component provides means for integrating both the data base component and the analysis/ algorithmic component with rules needed for decision-making. Expert rules were either provided by the authors, or derived from published sources. An example of rule is presented for illustration:

```
IF
        AquiferSystem:Medium =PorousMedia And
        AquiferSystem : AquiferType = Both And
        AquiferSystem : FluidPhase = Multiphase And
        Soil : Material = Heterogene And
        Soil : Saturation = Saturated And
        Model:Simulation = SaltWaterIntrusion And
        Model:Dimension = Quasi3D;
THEN
        SetValue(Model:Choice SHARP)
```

Inference mechanism for knowledge processing and modification

ESGWM uses Kappa inference engine to navigate through its knowledge base and solve variable problems during a consultation. In forward chaining, the program begins to look for a path trough the problem by starting at the goal state and seeing how it can be modified to bring it closer to an initial state. This is often true in simulations. There are times when specific information is needed; a more directed type of reasoning becomes appropriate. Backward chaining is the most used, for diagnosis related problems. This type of reasoning was selected for the case of ESGWM.

CONCLUDING REMARKS AND FURTHER DEVELOPMENT

The successful development of the knowledge-based expert system for data preparation for groundwater modelling systems demonstrates that the application of KBES in this domain is promising. Rule based and Frame-based knowledge representation method in conjunction with the power of object-oriented programming enables the knowledge to be abstracted and represented for the computer to manipulate efficiently. The user is able to use the expert system as a decision-making tool to choose a model for treating a problem and then to prepare the data input set by using variable technical methods and estimate model parameters of required. The need of interfacing GIS can be more efficient to manage, analyse and display all types of spatial data. This capability with the integration of parameter evaluation techniques and kriging method makes the ES a powerful tool for the goal assigned.

ACKNOWLEDGEMENTS

The first author would like to acknowledge the sponsorships of the INCO-MED project SWIMED within EU framework.

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