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AN INTEGRATED TOOL FOR AN APPROPRIATE GROUNDWATER RESOURCE MANAGEMENT

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Introduction

The knowledge of different water bodies and of their physical characteristics is very important for a correct use of water resources, relating to the different water uses (drinking, agricultural, industrial and municipal) and to the decision that a planner must take for matching the needs.

The pollution control represents one of the main aspects for developing an optimal management strategy of water resources and, therefore, it requires a deep and accurate knowledge of the amount of water body and of its relationships with the physical and anthropogenic environment (Lee S.I., Kitadinis P.K., 1996). Presently, human activities cause relevant changes on water cycle, such as existing resource depauperation and water quality worsening.

In the last years the commonly used landscape analyses techniques have pointed out the importance of the method by which the analysis is carried out, paying attention on the logical operations that composed the decisional and procedural processes.

The case study suggests an integrated approach for preventing groundwater pollution, including the following set of problems:

- quality and quantity characterization of the aquifer, with respect to its vulnerability, both intrinsic and related to the anthropogenic land-use;
- water management related to water use for various purposes (irrigation, industry, civil) and to water treated discarded in different water bodies.

The contribution of this paper is a tool addressed to operating technicians and administrative of public offices who plan and manage water resources.

The tool links an algorithmic-type approach and a heuristic system. In particular, the DSS is defined and implemented to provide a complete definition of the aquifer natural structure (Fedra K., 1994), that is based on the application of deterministic parametric model (Leone A., 1995) which has been implemented and integrated taking in to account the agricultural impact.

The Expert System analyses the location of groundwater disposal and pumping wells relating to control on discharge and withdrawals (La Salle A. J., Medsker L.R, 1991). The ES prototype, though connected to law and bureaucratic aspects, has an inference engine that consider the technical experience of the different experts. Due to the complexity and to the multi-disciplinary of environmental aspects, the decisional process is hardly influenced by the integration of the "formal" knowledge, public agencies, with the "informal" knowledge, personal opinions, intuitions, and experiences.

The purpose of this paper is to realize an integrated tool for ground-water management in order to protect ground-water quality and to evaluate ground-water quantity. The main goal of this tool is to provide an efficient and sustainable management of water resources taking into account the local in force regulations. The tool links a Decision Support System (DSS) (Arrivo et al., 1999) and an Expert System (ES) (Borri et al., 1999).

Description of integrated tool

A Decision Support System (DSS) is useful tool to (Negahban. B. et al. 1993):

- synthesize knowledge from large data sets;
- deal with integration, summarization and abstraction as well as ratios, trends and allocations;
- compare data-based generalizations with model-based assumptions and reconciling them when they're different;
- consider creative thinking and monitoring of those creative ideas that were implemented;
- use all types of data wisely;
- understand how derived data was calculated;
- introduce continuously learning, and modifying goals and working assumptions based on data-driven models and experience.

In addition DSS contains also typical functions of the GIS (Geographical Information System) such as (Fraisse et al.,1996):

- a good representation of the environment through which water flows and of the spatial distribution of the characteristics;
- assistance in studying the movement of water and its constituents in the hydrologic cycle;
- an excellent illustration to the spatial variation of a landscape units property by means of related database and cell grid structure in which the area is partitioned into regular grid cells (raster) or using a set of points, lines and polygons (vector).

An expert System (ES) is a computer program that contains a base knowledge, algorithms and rules that infer new facts from knowledge and from incoming data.

It's constituted by:

- a set of rules (if, then, else statements) and knowledge;
- an inference engine;
- a graphical user interface.

ES utilizes human expertise to solve problems, to find solutions limited by encoded knowledge, and is able to explain and justify conclusions and to add intelligence to existing control systems (Borri D., 1994).

According to Simon (1958), on Expert System operates in real conditions and takes into accounts:

- badly defined ambiguous problems;
- incomplete information about the alternatives;
- incomplete information about the kind of the problem;
- incomplete information about the consequences of the assumed alternatives;
- incomplete information about the range and the nature of the values, the preferences, the interests;
- limited time, limited abilities, limited resources.

The relations with various knowledges of experts, and consequently the uncertainties and ambiguities, carry to various modalities of knowledge and then manage with various types of knowledge, classified as (La Salle and Medsker, 1991):

- ambiguous knowledge: the ambiguity comes from the uncertainty inherent into some areas of the cognitive dominion;
- distributed knowledge: some fields of knowledge can be considered like "regional", that is the knowledge is distributed among few experts because of the remarkable importance of field;
- knowledge disjoined: the knowledge can compose in others fields, than eventually they could integrate between them;
- critical knowledge: the redundant or the overlap of the experts knowledge is necessary in order to confirm integrity of expert system;
- contrasting knowledge: the experts can not be agreements each other therefore the conflicts can regard ideologies or different points of view (Barbanente A., et al., 1998);
- synergic knowledge: some applications demand that the disjoined knowledge has to be linked to resolve and/or to supply support for complex problems.

Land use planners and water resource managers can use this DSS-ES as one of available tools to assess the effects of current land use, to simulate future development alternatives, and to describe pollution management practices on valuable water resources, specifically for arid and semiarid regions.

Because variables and assumptions are easily modified, DSS-ES can be used to study the effects of many different scenarios. By evaluating both land use point and nonpoint control options (Petersen. G. J et al., 1991), the DSS-ES can address the adoption of land use policies, and plan the strategy to effectively reduce inputs on water resources.

The ES provides indications at punctual level whereas the DSS gives indications at regional scale. The interface between DSS and ES is an important part of the tool; in fact some elements such as physical and environmental information (e.g., land surface slope, topographical aspect, channel length, land use, and soil and geological properties) are attributed interactively by the DSS and are considered fundamental elements by the ES.

The integration between the two approaches assures the validity in the various parts and combines the "formal" information, identified and formalized from institutions, with the "informal" information, personal judgements, personal intuitions, presentiments, personal experiences (Maciocco, 1993) as shown in Table 1.

Tab.1. Relations between knowledge, rules and choices in the DSS, ES and DSS-ES systems

	GIS	DSS	ES	DSS-ES
KNOWLEDGE	structured	semi-structured	unstructured	structured unstructured
RULES	no rules	semi-structured	structured	structured
CHOICE	assisted	supported	oriented	supported oriented

Prototype

The DSS runs under ARC/INFO (ESRI, 1991) and integrates all kinds of information and applications with a geographic component into one, manageable system (Medsker L., Tan M., Turban E., 1995). DSS and GIS organize, manage, and distribute geographic information selected from various databases while maintaining data integrity and focusing on project direction (McKinney D.C., Loucks D.P., 1992).

The considered DSS stores input data, generates new data, and retrieves additional new data as example pollutant loadings, as a function of spatial data and associated attributes, and displays spatial distributions of pollutant loadings in a given watershed. A very useful analysis that is facilitated by DSS allows analyst to visualize the spatial distribution of loading of a considered pollutant throughout the entire watershed. This display allows one to use the DSS to rapidly determine the relative contributions from different classes of sources during a given period.

The integration in the DSS between model and GIS has been carried out in different ways: from a very simple case in which GIS is used to prepare the model input and analyze its results, to a fully developed way in which the GIS incorporates the model itself. In this paper GIS (ARC/INFO) has been used to overlie some thematic maps representing different model parameters in the whole study area.

ES has been realised with Resolver© software (Multilogic, 1998), a shell for personal computer with inferential engine of backward chaining type with a friendly interface useful to save time and human resources.

The developed ES is constituted by two sections. The first one allows to consider laws and bureaucratic aspects, while a second part is devoted to implement more qualitative and heuristic aspects that involve the protection and the safeguard of the water body.

This shell supplies many instruments for the representation of the knowledge with the possibility to quickly manage more interconnected sections: objectives, questions, variables, trees, rules, validation (Donatelli M., 1994).

The definition of the objectives, to which the system must aim (15 goals have been inserted), represents the first phase of the implementation of the ES.

Subsequently the formulation of the questions (98 questions), necessary to the construction of the tree diagrams, outlines the reasoning of the experts (trees), and the definition of the rules of the type if... then... else (rules).

Such a subdivision has been revealed of remarkable aid for the appropriate management of the system. The ES has been tested in all parts using the validation section (validation) and verifying the closing of all the connections that are used in the input rules.

Resolver, moreover, concurs to the visualization of the used rules, and gets the opportunity to make questions on the covered way and to furnishes explanations on the final result (Conte, 1994).

In the ES the uncertainty has been managed using the fuzzy logic. In every decisional process there are various types of uncertainty and imprecision, each of which demands one specific instrument to be dealt with and represented. The probability theory, in fact, reproduces the stochastic nature of the decisional analysis, but it is not able to measure the imprecision or the uncertainty due to the schematization of the phenomena.

In these types of uncertainty it has been opportune for the new system to resort to fuzzy logic. The nature of these various types of data is given by the imprecision of the information that is introduced to every stage of the environmental process: in scientifical and technical literature fuzzy logic has been applied only in limited section (Zimmerman, 1985). Generally in the decision making fuzzy three main type of imprecision can be identified:

- fuzziness, when there are some difficulties to obtain precise concepts for attributes, criteria, characteristics;

- incompleteness, when data are insufficient;
- validity illusion, this type of imprecision has had to discover the outputs mistaken like the selection of alternatives that do not satisfy the criteria set up.

The developed integration between DSS and ES (Fig.1) allows to provide local decision makers a watershed management tool that can be used to accomplish the following items:

- compare the change in potential pollution and pollutant loading under different development scenarios and anthropic activities;
- estimate the reduction in nutrient loading with implementation of wastewater management practices;
- increase public awareness of nonpoint pollution sources and management solutions through the use of DSS-ES output products;
- good representation of the environment characteristics;
- assistance in studying hydrologic cycle and its constituents.

Finally the prototype, obtaining the integration of a DSS and an ES, includes:

familiar and friendly user interface;

- geographic information system (ARC/INFO);
- relational database management system;
- process decision support system and expert system linkages;
- input and graphics output linkage assistance tools.

A case study under investigation

The study area (approximately 70 km^2) is the Municipality of Bisceglie, a small town located in the southern part of Italy. In this area, as the whole southern Italy, water resources are limited with respect to the demand of farmers. Farmers have proved to have a great entrepreneurial capacity in converting their activities from extensive to intensive agriculture, through the introduction of irrigation.

The study area is characterized by a coastal semiconfined aquifer (Limoni et al., 1993) and groundwater flows almost perpendicularly to the coastline; the dept of the aquifer increases from the coast towards the inland in comparison with the sea level (Lopez et al., 1996).

The main land use is agricultural; moreover other potentially pollutant activities exist. Among these particularly relevant are 14 olive oil mills, located in the North East of the study area.

An analytical survey of groundwater performed in June 1992, allowed to define the pollution of the aquifer (M. Maggiore et al., 1999). The study has clearly demonstrated that: (a) the main stream flowing into the Lama is the treated effluent discharged from the Corato's Municipal wastewater treatment plant, (b) nitrate ions occur into the Lama mainly because of rain-washings of $N\text{-}NO_3$ fertilized agricultural soils bordering the Lama, (c) connections between the Lama and the underlying groundwater exist, (d) the percentage of the infiltration is about 20% to 30%, (e) compared with those measured in the Lama, the concentrations of TOC, $N\text{-}NH_4$ and $N\text{-}NO_3$ result: lower for TOC (it can be adsorbed or biodegraded in the top-soil zone or diluted in the aquifer); about zero for $N\text{-}NH_4$ (it can be biologically transformed into $N\text{-}NO_3$ and/or chemically retained by some components of top- and/or sub-soil zone); greater for $N\text{-}NO_3$ (it can be formed during the partial nitrification of the $N\text{-}NH_4$ occurring in the Lama and/or due to a diffused background of nitrate ions occurring into local groundwater because of the extensive local agricultural practices involving nitrogen based fertilizers), (f) contaminants occurring into the Lama reach the underlying aquifer within less than one week because of several fractures characterizing the local karst area, (g) agricultural soils surrounding the Lama resulted significantly contaminated by halogenated organics formed during the disinfection of the Corato's municipal wastewater because of occasional overflows and/or seasonal use of the water flowing through the Lama for irrigation purposes.

The application of the system has been carried out to obtain an optimal location of wells which pump up water to support different activities. The procedure includes the following phases:

1. location of the site in which the drill of the well is proposed;
2. automatic compilation of a database containing information expressed in the DSS thematic cartographies;
3. automatic imputation of the territorial information in ES;
4. imputation of the unstructured information in the ES;
5. run of the ES;
6. control of the choices and of environmental compatibility of these choices;
7. in case of incompatibility of the choice site, completely automatic examination of the surrounding pixels using an iterative algorithm until the new choice is a compatible one.

In the studied case (i.e., the optimal location of a pumping well) the tool considers a series of parameters and land characteristics (tab.2) associated to an expert knowledge. This knowledge is organized using logical procedures in a semantic network and is represented by rules of the ES.

All these data, as reported in table 2, have been assessed in the DSS and several maps of the zone have been drawn. The point information produced by the DSS is the input for the run of the ES.

Presently, the considered integrated tool is being used to asses the areas in which will be preferable to drill wells, after a certain number of iterations. The choices of the system are also being verified and confirmed by the opinion of reference experts.

Tab.2. The main considered parameters

TOPOGRAPHY	Slopes, exposure, coefficient and density of water-drainage;
COVER VEGETABLE	Land use, theoretical polluting load (pesticides, fertilizers,etc.), zones of preferential outflow;
CLIMATOLOGY	Historical series of precipitations and average temperatures; evapotranspiration; evaporation, effective precipitations (active recharges + runoff)
PEDOLOGY	Type, thickness, texture, mineralogical composition, porosity, permeability, specific retention, chemical-physics soils characteristic
HYDROLOGY	Superficial run off
HYDROGEOLOGY A) UNSATURATED B) SATURATE	A) Water table depth; lithology; structure; porosity; vertical permeability; filtration; fractures indexes; recharges; B) Lithology, structure, permeability, horizontal and vertical effective porosity, groundwater delay, hydraulic gradient, storage coefficient, dispersion, topology of aquifer (confined, semiconfined); interconnections with other aquifer or superficial water bodies; mean flow direction; position of the hydrogeological-watersheds; effective velocity of flow
USE OF WATERS	Location of the wells; cone depressions; systems of recharge
CHEMISTRY POLLUTION	A) Physical and chemical waters parameters, groundwater quality. B) Identification of the polluting zones, concentrations, density, solubility, viscosity, ions exchange, biodegradability, mobility
ANTHROPHIC INFLUENCE	Location of the town, industrial and agricultural impacts, point and diffuse source pollution

Conclusions

In conventional approaches to environmental decision making, each of the processes is performed individually (e.g., fate and transport, risk analysis, cost/benefit, etc.) and often it does not permit an easy evaluation of alternative scenarios or remedial approaches. Environmental DSS-ES overcomes this problem by incorporating several data, models and unstructured information to perform an integrated assessment.

The developed tool puts together a DSS, an ES and a user friendly interface links DSS and ES. The tool is a system that permit to decision makers and analysts to evaluate environmental information and to manage practises for preventing groundwater contamination. The integration of the DSS with the ES allows to link unstructured technical aspects with juridical, social and economic aspects.

Key attributes of the system include the capability to:

- manage uncertainty in the decisional processes for water resources protection;
- quantify uncertainties in relation to the construction of wells, discharge, etc. and/or remedial actions (e.g., pump and treat performance);
- provide recommendations on the implementation of monitoring well network;
- provide visual feedback for the location of the most suitable site of different activities.

The tool is based on process model algorithms and on heuristic approach to assess the potential contaminant migration and operations research methods. The output of the tool provides guideline or key decision analysis needs (e.g., recommended location of wells). The DSS-ES methodology is an improvement of conventional groundwater modeling analysis approaches, because of the following features: 1) allows the user to simulate the different scenarios; 2) quantifies uncertainties through the use of stochastic simulation techniques; 3) evaluates hydraulic conductivity information and spatial variability using of geostatistical routines; 4) provides guideline on monitoring well network (rather than using expert judgment).

The DSS-ES is being tested in the Municipality of Bisceglie with the purpose to asses, inside an established area, the optimal site in which a pumping well should be drilled. The obtained results are being verified on site and compared with the opinion of quoted experts.

The results seem to link all the aspects involving water management and they can represent a useful tool for supporting, consulting and learning technical.

Bibliography

Arrivo A., Uricchio V.F., Borri D. (1999), "Un sistema di supporto alla decisione per la tutela da inquinamento delle falde idriche", Input 99, Proceedings della conferenza nazionale su informatica e pianificazione urbana e territoriale, Venezia, Italia 9-11 giugno 1999.

Barbanente A., Borri D., Concilio G., Macchi S., Scandurra E. (1998), "Dealing with Environmental Conflicts in Evaluation", in Lichfield N., Barbanente A., Borri D., Khakee A., Prat A. (eds.), Evaluation in Planning, Facing the Challenge of Complexity, Kluwer

Borri D. (1994) Artificial Intelligence and Planning Knowledge, in Borri D. (ed.), Artificial For Spatial Planning, Kluwer Academic Publishers, Dordrecht.

Borri D., Di Cillo E., Vurro M. (1999), "La tutela delle risorse idriche nella tutela nella pianificazione territoriale: un sistema di supporto alla decisione", XX Conferenza Italiana di Scienze Regionali – Piacenza, Italia 5-6-7 Ottobre 1999

Charnock T.W., Hedges P.D. and Elgy J. (1996), Linking multiple process level models with GIS. 29-36. IAHS Publ. no. 235.

Conte E. (1994), "La costruzione di Sistemi Esperti diagnostici con l'uso di M1 e di Exsys", in Maciocco G. (ed.) La città, la mente, il piano. Sistemi intelligenti e pianificazione urbana, Franco-Angeli, Milano.

Dlgs 11 maggio 1999, n. 152 (Supplemento ordinario n. 101/L alla Gazzetta ufficiale del 29 maggio 1999, n. 124).

Donatelli M., Ceotto E., Marchetti R., Spallacci P. (1994), "CSYMBA: A PC Based Shell for Cropping Systems Simulation Model Development", Proceedings of the 3rd ESA Congress, Abano-Padova.

Environmental Systems Research Institute – ESRI (1998), ARC/INFO Data Management.

Fedra K. (1994), "GIS and Environmental Modeling", in Goodchild M.F., Parks B.O., Steyaert L.T. (eds.), Environmental Modeling with GIS, Oxford University Press, UK, 35-50.

Fraisse C.W. (1996), "Integration of GIS and GLEAMS for alternative dairy waste management analysis", ASAE Publ. no.942508.

La Salle A. J. and Medsker L.R (1991), "Computerized Conferencing for Knowledge Acquisition from Multiple", Expert, Expert Systems with Application, 3.

Lee S.I., Kitadinis P.K. (1996), "Optimizazion of Monitoring Well Installation Time and Location During Aquifer Decontamination", Water Resources Management, 10, 439-462.

Leone A. (1995), "Uncalibrated Management Models to Assess Agricultural Diffuse Pollution: Their Use in Decision Making", Journal of Environmental Management.

Limoni P.P., Lopez A., Maggiore M., Vurro M. (1993), "Influenza di attività antropiche sulla qualità delle acque sotterranee in un'area costiera dell'acquifero murgiano", relazione presentata al 2° Convegno Internazionale di Geoidrologia, Firenze, 29.11/3.12.

Lopez A., Maggiore M., Masciopinto C., Vurro M. (1996), "Evolution of Ground Water Pollution in a Coastal Aquifer", proceedings 1st International Conference on The Impact of Industry on Groundwater Resources, Cernobbio, Como, 22-24 May.

Maciocco G., (1993) "Sistemi Intelligenti e pianificazione Urbana: Alcune riflessioni", Atti del Seminario Internazionale di Cagliari 10-11 giugno 1993

Maggiore M., Barile G., Dimundo A., Laera G., Lopez A. , Vurro M. (1999), "Role played by a natural channel on groundwater quality in an apulian karst area: a case study", paper presented at the 2° Simposio scientifico sulla "Protezione delle acque sotterranee dall'intrusione marina e dall'inquinamento antropico" Bari, 27 settembre - 1 ottobre.

Mc Kinney D.C., Loucks D.P. (1992), "Network Design for Predicting Groundwater Contamination", Water. Resources. Management, 28 (1), 133-147.

Medsker L., Tan M., Turban E. (1995), "Knowledge acquisition from multiple expert: problem and issue", Expert Systems with Application, 9, 1, 35-40.

Multilogic (1998), Resolver, User manual.

Negahban. B., Fonvo C., Boggess. W., Jones. J., Campbell K., Jones J., Kiker G., Hamouda E., Flaig E., Lai. H. (1993), "A GIS-Based Decision Support System for Regional Environmental Planning", proceedings of the Conference on Application of Advanced Information Technologies: Effective Management of Natural Resources, American Society of Agricultural Engineers (ASAE), Spokane, Washington, 169-178.

Perman C., Ortolano L. (1993), "Testing a Prototype Expert System for Diagnosing Wastewater Treatment Plant Operating Problem", in Wright et al. (eds.), Expert System in Environmental Planning, Springer-Verlag, Berlin, 275-298.

Petersen. G. J., Hamiett. G. N'I. Baumer. D. A. Miller. R. L. Day and J. M. Russo (1991), "Evaluation of Agricultural Nonpoint Pollution Potential in Pennsylvania Using a Geographic Information System", Environmental Resources Research Institute, ER9105.University Park, PA. p. 60.

Simon H. (1958) - Organizations, Wiley & Sons, New York.

Zimmermann H.J. (1985), Fuzzy Set Theory and its applications, Kluwer Academic Publishers, Boston.