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An advanced monitoring system for the management and protection of groundwater resources

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ABSTRACT

In this paper, we describe a new monitoring system designed to support control and management of public drinking-water supply areas. It performs automated measurements of groundwater physical parameters and well discharges and automated analyses to control water quality. The system is able to provide an early warning of pollution events and to simulate contaminants transport. Field data are transmitted to the system control unit, located in the water authority building. Management strategies and remedial alternatives may be evaluated through the numerical models of groundwater flow and solute transport implemented in the control unit. At present time, a prototype of this system is under installation in a public drinking- water supply area close to Empoli (central Italy), in cooperation with Publiser, the local water authority.

INTRODUCTION

The system design and development is carried out in the frame of the Eureka Envinet-ATAC project EU540, involving one danish, one norwegian and four italian companies. The EU540 project goal is the 'Feasibility demonstration, development and realization of advanced hardware/software integrated systems to manage atmospheric and aqueous environments on local and regional areas' (Elisei [1]).

The EU540 project is constituted by a network of five different local monitoring stations, called Local Intelligent Nodes (LIN), plus one mobile air quality monitoring station, called Mobile Intelligent Node (MIN), and one central node (CIN), which elaborates local data collected by nodes into regional models (Fig.1). The five LINs are designed for real time monitoring of air quality in industrial (LIN-1) and urban residential areas (LIN-2), of sea water quality (LIN-3), of on-shore metereological parameters (LIN-4) and groundwater resources (LIN-5). Furthermore, the LIN stations perform the control and forecast of contamination processes at local scale.

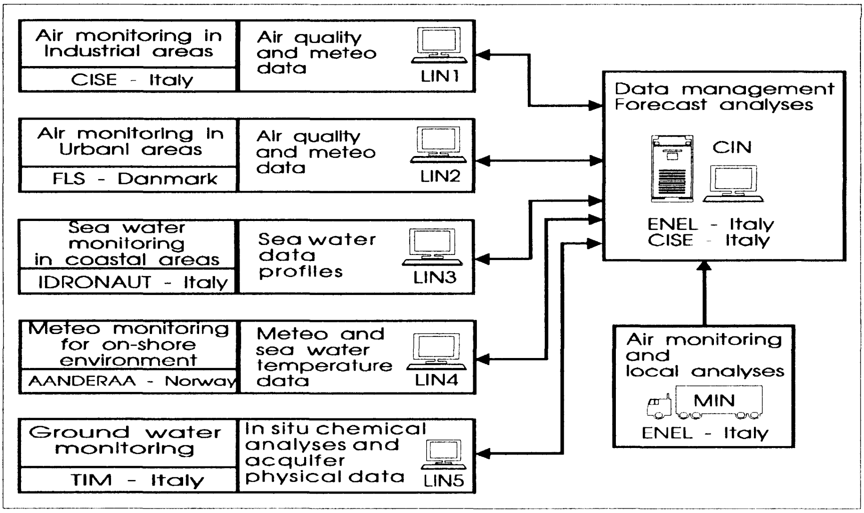

Fig. 1 Configuration and partecipants to EU540 project

The most important performances introduced on the EU540 design are: the development of advanced sensors; the availability of environmental data in real time, integrated with mathematical models; the exchange of data between locals and central node, and vice versa, used to run simulation at local or regional scale of water or air contamination events.

THE DESIGN OF GROUNDWATER MONITORING STATION LIN5.

The LIN5 station is a stand alone system designed for the monitoring and management of groundwater resources. It can also be used for other applications such as the monitoring of surface water bodies or the control of waste disposal facilities. At present, the LIN5 prototype functions are designed for the continuos control of groundwater supply areas.

The most important technological features of the prototype design are its modular set-up, the competitive cost-effective equipments performances and the low-cost operating conditions. The system design is shown in Fig. 2. Its main components are: (a) field instruments, water sampling and analysis devices; (b) one automated apparatus for the devices management, acquisition and transmission of data; (c) one control unit. The user functions implemented in the control unit are shown in Fig.3.

The two first components are set up close to the withdrawal area and include: (a) a set of piezometric, temperature and electric conductivity sensors, plus pumps and flowmeters within the observational and production wells; (b) an "in situ" equipment to measure the concentration of

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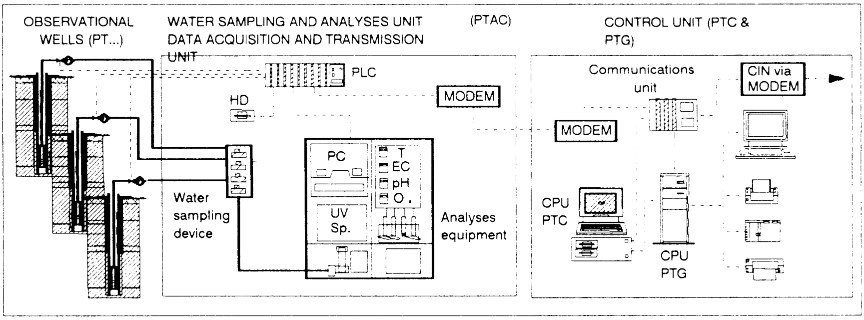

Fig. 2 Design of the LIN5 Node

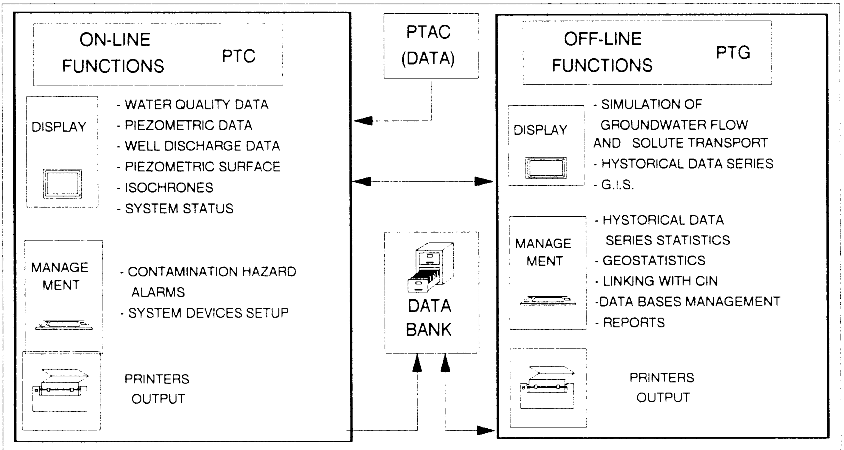

Fig. 3 User functions of LIN5 prototype.

contaminants (nitrates, total organic carbon, phenol and hexavalent crome), physico-chemical (pH, redox potential, dissolved oxigen, turbidity) and physical (temperature, electrical conductivity) parameters of groundwater samples; (c) a Programmable Logic Controller. The "in situ" analytical equipment uses an innovative U.V. spectroscopy technology, developed by the Laboratoire de Chimie et Ingegnerie de l'Environnement of the Savoie University (Thomas and Gallot [2])

The on-line control unit functions (see Fig.3) manage the analyses equipment and the water sampling device (see Fig.2), display the data and warn of contamination hazard, evaluating analitycal data and other parameters trends. Remedial alternatives or water resources exploitation can be planned through the numerical models of groundwater flow, particle tracking and solute transport implemented in the off-line functions of the control unit (see Fig. 3).

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THE INSTALLATION OF THE CONTROL SYSTEM PROTOTYPE AT EMPOLI (CENTRAL ITALY)

The prototype of the LIN5 node is going to be installed, in cooperation with the local water authority, in a drinking-water supply area located in the eastern side of the Empoli plain (central Italy), shown in Fig. 4, where is important the detection of contamination processes as soon as possible.

All the plain water resources are under the control of the local water authority, in order to achieve the best cost-effective management of these resources. At present time, the estimated pumpage from acquifer is 9,000,000 m^3 per year, with a water distribution network of 750 km, for 45,000 users. Most of the water supplied is withdrawn from the alluvial acquifer by 80 wells from 30 to 60 m deep.

Hydrogeology of Empoli plain.

The plain is part of the alluvial valley of the Arno river, north, east and south bounded by hills of Pliocene-age marine deposits (see Fig.4). The geological bedrock of the plain of Empoli consists of Pliocene-age marine deposits overlain by recent Quaternary-age continental alluvium. The older deposits consist of clay and silt. Recent alluvium is from 30 to 40 meter thick in the middle of the plain. These deposits are higly to medium permeable, but facies of low permeability exist and form confining layers. Recharge to the alluvial acquifer system comes from rain (from 80 to 125 mm per year, net infiltration), loss from ephemeral streams and lateral flows from the hills.

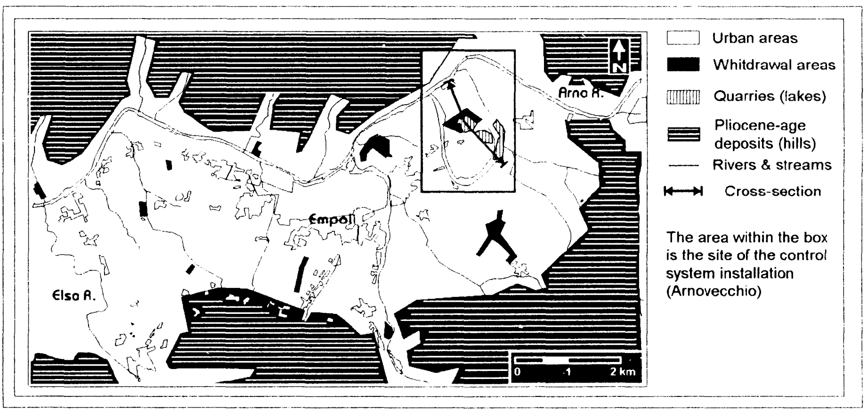

Fig. 4 The plain of Empoli

The site of installation.

The system is going to be installed in the new whitdrawal area of Arnovecchio (box in Fig.4). A cross-section of Arnovecchio is shown in Fig.5. The monitoring network design is shown in Fig. 6.

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In this area, nine wells pump about 1,500,000 m^3 per year. The risk of groundwater contamination is associated with the widespread pollution from agricolture, loss from sewer systems, and aquifer exposure (lakes D, A and C) due to gravel excavation.

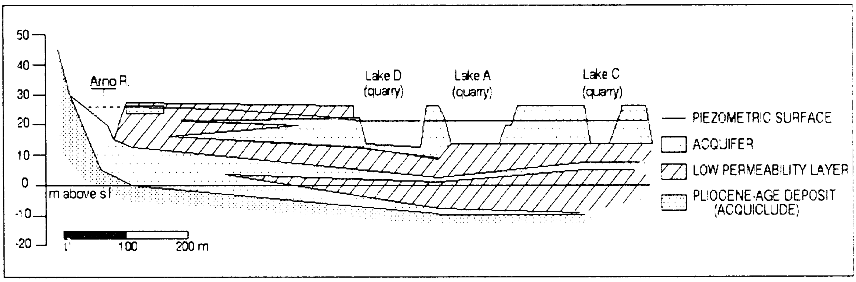

Fig. 5 Cross-section of Arnovecchio

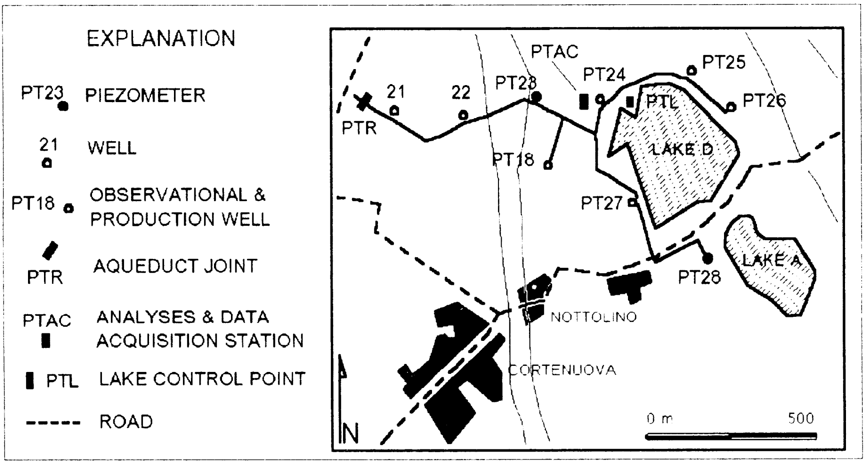

Fig. 6 The control system configuration in Arnovecchio

MODELING APPROACH.

Two-dimensional transient models of the Empoli plain and Arnovecchio area are under construction by means of the U.S. Geological Survey groundwater flow model MODFLOW (Mc Donald and Harbaugh [3]), U.S. Geological Survey particle tracking model MODPATH (Pollock [4]) and solute transport model MT3D (Zheng [5]).

A telescopic mesh refinement method (Ward ed al. [6]) will be used to reach the required level of detail in the Arnovecchio area. The large problem

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domain (Empoli plain) is bounded by the alluvial aquifer physical boundaries. Its solution will define the smaller Arnovecchio model boundaries. Results shown in this paper are related to the first steps of the flow model development.

Boundary conditions and model grid.

The model grid is 120 columns by 70 rows, each grid cell misuring 100 m on each side. The geometry of the acquifer of the Empoli plain has been approximated using one confined acquifer with average hydraulic conductivity, thus in the vertical dimension the grid is one layer deep. The boundary conditions for the model are related as close as possible to natural hydrogeologic boundaries (see Fig.4). The northern and western boundaries of the model follow the Arno and the Elsa River , which define a specified-head boundary. The southern and the eastern boundaries are delineated by the contact with the impermeable Pliocene-age clay deposits, thus defining in general one no-flow boundary. Model grid and boundary conditions are shown in Fig. 7.

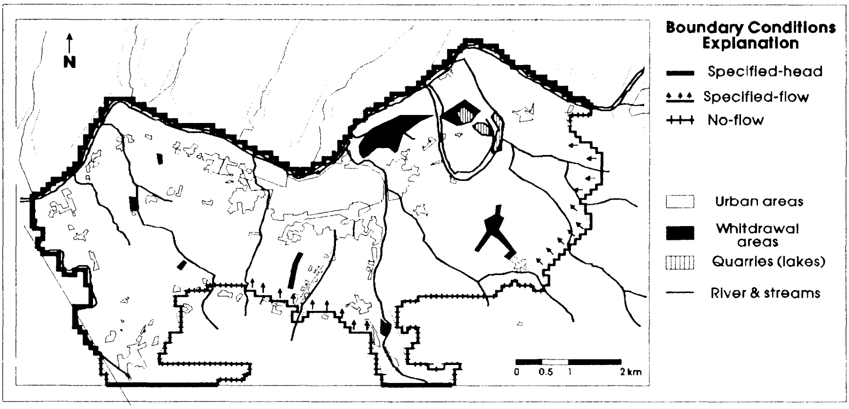

Fig. 7 Model boundary conditions

Estimation of acquifer parameters.

Layers thickness were obtained from known well stratigraphies and vertical electrical sounding. Some measurements of horizontal hydraulic conductivity were obtained from pump tests in observational wells. In general, equivalent horizontal hydraulic conductivity values were estimated using a weighted aritmetic mean between the hydraulic conductivity of each litologic units (Phillips and Belitz [7]), on the basis of ranges of hydraulic conductivities versus litology found in the literature (e.g. Fetter [8], pp. 80). Estimations of hydraulic conductivity and thickness of confined acquifer were obtained interpolating data by kriging methodology (de Marsily [9]). The results are shown in Fig.8.

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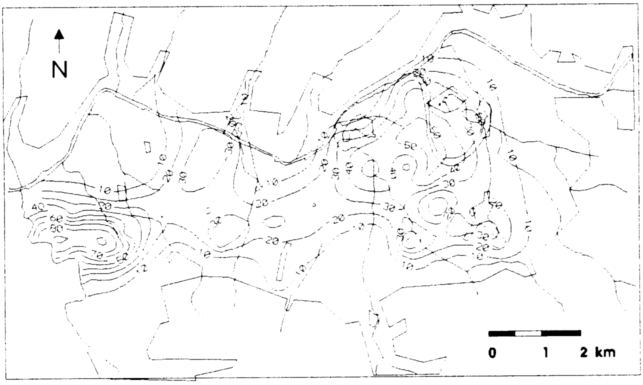
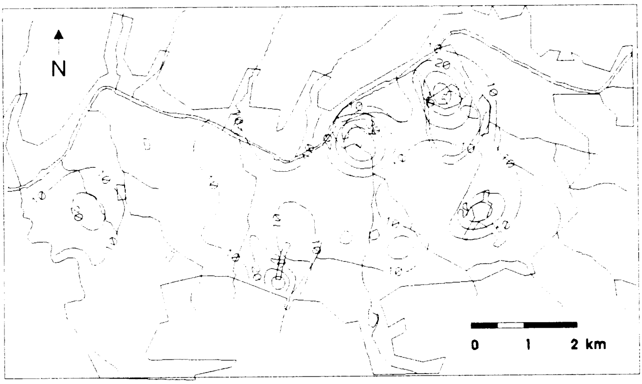


(a) THICKNESS (In m) OF THE CONFINED ACQUIFER



(b) HORIZONTAL HYDRAULIC CONDUCTIVITY (In 10^{-4} m/s)

Fig. 8 Estimation of the acquifer parameters

SUMMARY AND CONCLUSIONS.

The groundwater monitoring system described in this paper constitutes a new approach to groundwater control and management.

The design of the control system foresees the application of sensors and automated analyses equipment, coupled with the use of mathematical model to simulate groundwater flow and solute transport in the area under control.

This system, when applied to public drinking-water supply areas, warns the hazard of groundwater contamination. It provides to responsible personnel a system aid for the management of groundwater supply, and for the evaluation of remedial alternatives of groundwater contamination, according to estimated groundwater balance and travel time of contaminants.

The system functions test will be useful to evaluate the opportunity to use this kind of facility for the risk assessment in the management of groundwater resources

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