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DRAINAGE INDEX CALCULATED WITH ARTIFICIAL TRACERS

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Key-words: tracer, karst aquifer, drainage index

1. Introduction

Among the different approaches applied to hydrogeological study of karst aquifers, very interesting results come from tests with artificial tracers.

These tests, as well as test the limits of a hydrogeological karst system, can provide useful information on the operation of an aquifer, especially through the study of the breakthrough curve. The automated acquirers of fluorescence value, allowing you to monitor with extreme detail the arrival of the dye to the spring (Vigna and Fiorucci, 2009).

The hydrogeological characteristics of an aquifer system affect the geometry of the restitution curve. The interpretation of this curve (shape of the curve, times of arrival and the first peak, maximum concentration) can highlight the main types of aquifers in carbonate rocks (circulation in dominant collector, circulation in interconnected drains, dispersive circulation, Vigna, 2007). The ratio between the speed of first arrival and peak (maximum concentration of dye), provides a coefficient (R_v, Lepiller and Modain, 1986), very useful for the characterization of the various aquifers. The single value relative to the speed of the tracer is not representative of the type of movement as heavily affected by the hydrodynamics of the system at the time of the test. Several tests performed in the same system show maximum speeds calculated very different from each other (even of one order of magnitude) depending on whether the tracking is performed in situations of lean or full.

2. Material and Methods

The study of the restitution curve obtained by automatic acquisition systems is very detailed and can be considered as a continuous recording (Gandolfo M., Vigna B. 2005). Its geometry is mainly linked to the type of the aquifer, which can affect whether or not the processes of diffusion and dispersion of the tracer. In a system with dominant drain circulation the dye will suffer reduced processes with an arrival rather concentrated and of short duration. On the contrary the tracer that moves in a dispersive circulation system will undergo a remarkable series of phenomena of dilution in a complex network of discontinuity that characterizes such systems.

The coefficient R_v, ratio of V_{max} (maximum speed on the first arrival of tracer particles) and V_m (speed relative to modal arrival of more concentrated flows), may highlight the different types of circulation systems in carbonate rocks, regardless of the geometry breakthrough curve tracer and hydrodynamic state of the system.

To test the coefficient R_v were performed a series of tests in carbonate aquifers very different but well-known thanks to the numerous hydrogeological investigations and monitoring of electrical conductivity and temperature of the water.

The study involved several karst systems located in Piedmont (Borello spring, Fuse spring, Vene spring, Bossea spring), in Tuscany (Fontanacce springs) and Sardinia (Su Gologone spring) (Banzato, Fiorucci, Vigna, 2011).

3. Results

On the basis of the different tests carried out, even in the same system and in different hydrodynamic conditions, it was obtained the values of R_v reported in Table 1.

Karst system	R_v
Corchia – Fontanacce spring (Uranine)	1.02
Corchia – Fontanacce spring (Tinopal)	1.02
Ciuaiera – Borello spring	1.13
Colme – Fuse spring	1.15
Tumpi sinkhole – Vene spring (standard flow)	1.15
Edera sinkhole – Su Gologone spring	1.23
Tumpi sinkhole – Vene spring (low flow)	1.13
Tumpi sinkhole – Vene spring (high flow)	1.25
Roccia Bianca sinkhole – Bossea spring (high flow)	2.05
Roccia Bianca sinkhole – Bossea spring (low flow)	2.26
Milano – Bossea spring	4.87

Tab.1 – R_v coefficient calculated by dye test

The correlation between the obtained values of R_v and the different aquifer systems examined, referring to the three conceptual models (circulation in dominant collector, circulation in interconnected drains, dispersive circulation) allowed to index the value of R_v index (drainage index) as follows :

- R_v less than 2; dominant collector system
- R_v between 2 and 4,0; interconnected drainage system
- R_v greater than 4,0; dispersive circulation system

The identified drainage index seems to distinguish fairly well the different types of circulation in carbonate rocks, regardless of the hydrodynamic conditions at the time of tracking. The breakthrough curves obtained from tracer tests conducted in situations of low and high flow in different water systems (Vene and Bossea systems) show geometries (see Figure 1) and very different speeds (eg. Vene system: V_{max} = 175 m/h with high flow, V_{max} = 17 m/h with low flow). The R_v index relating to these situations have, however, very similar hydrodynamic values to the demonstration of the reliability of the index (see Table 1).

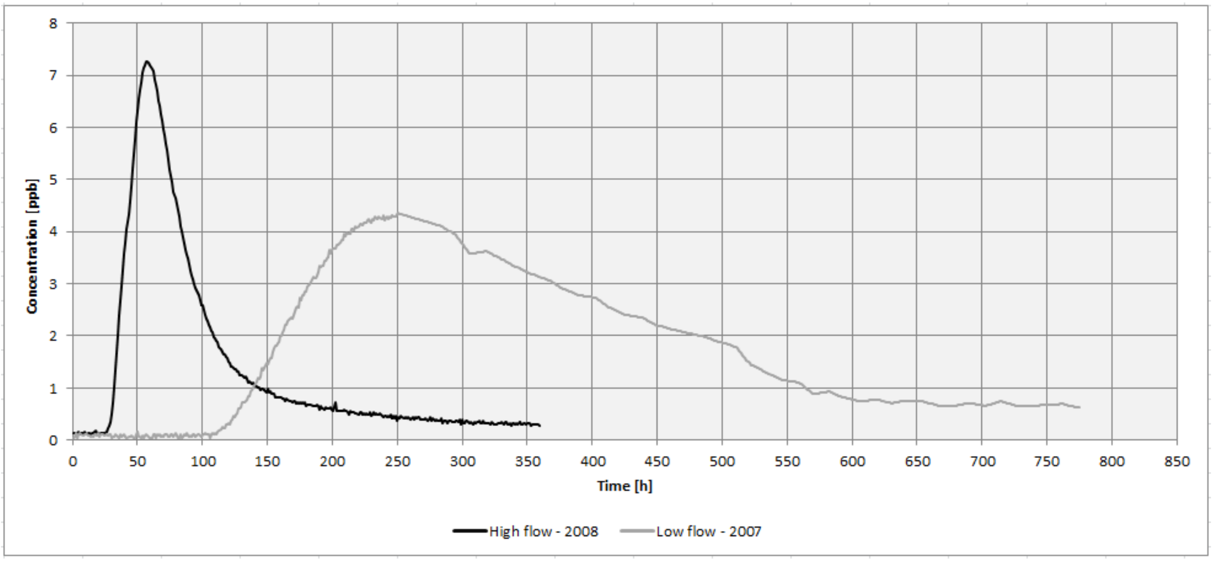

Fig. 1 Comparison between the breakthrough curves of tracings performed at different hydrodynamic conditions in Bossea spring

For additional calibration of this index will require new tests in well-known and monitored aquifer systems and representative of the different ways of water circulation.

4. Conclusions

The identified index, based on the values of R_v in different karst systems examined, seems to be a good indicator of the different types of water circulation set in carbonate rocks. This index, along with monitoring data flow, temperature and electrical conductivity of water, can also provide useful information regarding the vulnerability to pollution of these systems, thus allowing to calculate the area of protection of sources connected to them.

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Borehole flowmeter logging for the accurate design and analysis of tracer test

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Key-words: Tracer Test, flowmeter log, Electromagnetic Borehole flowmeter.

1. Introduction

Borehole flowmeter logs can provide information on direction and discharge of vertical flows and hydraulic conductivities of different aquifer intervals (Moltz et al., 1989; Young and Pearson, 1991). Furthermore, they can give a valid support to the interpretation of environmental data (e.g. electrical conductivity, pH, temperature, dissolved oxygen, Chatelier et al, 2011) into aquifers and along each borehole. Vertical flow data have been considered as fundamental for a correct evaluation of observed changes in borehole environmental data. In fact, without the collected information on vertical flows, these changes could be misleading, compromising the hydrogeological site characterization.

Tracer testing is actually regarded as the most reliable and efficient method of gathering surface and subsurface hydraulic information. This is especially true for karstic and fractured-rock aquifers (Field, 2002) but also in many porous aquifers.

In this work, we outline the importance of flowmeter logging to correctly design and analyze tracer tests for aquifer characterization.

Designing a tracer test without any information on vertical borehole flows can lead to erroneous considerations on tracer arrival and concentration, and thus on calculated hydraulic parameters.

We show the results from two case studies. Both concern complex aquifers, characterized by a chaotic sequence of gypsiferous and marly rocks, where closely spaced boreholes have been drilled to design a remediation project. We performed both natural and forced gradient tracer tests.

2. Material and Methods

The result of a tracer test is closely related to the accuracy in the determination of the tracer concentration in recovered solutions and on the disturbance caused to the hydrologic system. All the tracer tests described below employed a GGUN-FL flow-through fluorometer (Schnegg, 2002, Schnegg and Flynn, 2002, Schnegg, 2003). The GGUN-FL field fluorometer offers an accurate, inexpensive and non-destructive means of automatically monitoring up to three different tracers while removing the effects of turbidity.

For the vertical borehole flow measurements, we adopted an electromagnetic borehole flowmeter (EBF, by Quantum Engineering Corp) with an inner diameter of 2.54 cm able to measure flow rates in the range from 0.04 $l*min^{-1}$ to 40 $l*min^{-1}$ (Young and Pearson, 1991). We performed single-hole flowmeter tests to detect the inflow/outflow zones within the screened section of boreholes.

3. Results

To investigate tracer migration in a complex fractured system (case study 1), a tracing experiment has been carried out using a dye tracer (Na-Fluorescein, Uranine, CAS [2321-07-5]). The test was a forced gradient tracer test and a pulse injection was assumed. Injection point within the injection wellbore was selected by the qualitative analysis of single-hole flowmeter data. So, the tracer solution was injected in correspondence of the previously detected outflow section.

Tracer dilution was observed within the monitoring borehole by two flow-through field fluorometers positioned in correspondence of transmissive fractures detected by flowmeter analysis. Pumping flow rate in the monitoring well was 15 $l*min^{-1}$. However, the key concept in the analysis is that the vertical flow rate along the screen section is not steady. Therefore, as shown in detail in Figure 1a, the EBF was installed above the deepest fluorometer to take into account the flow rate passing through the fluorometer from the inflow point. This flow rate was used for the correct mass balance analysis. We obtained a very high maximum tracer velocity, about 0.03 $m*s^{-1}$, from both fractures.

With the aim to better understand the interconnections between the permeable layers intercepted by three boreholes, a tracer test under natural gradient conditions was also performed (Figure 1b). This test excludes any connection between the injection borehole (IB) and borehole 1, while it confirmed the connections between IB and borehole 2. A maximum tracer velocity of $5.2*10^{-3}$ $m*s^{-1}$ has been computed. The mass recovery of the tracer was estimated around 62%.

4. Conclusions

Single-hole flowmeter tests provide information about the properties of the individual fracture segments surrounding the borehole.

We show that data obtained from flowmeter logging demonstrates their applicability and relevance in tracer test design and interpretation. We present herein a flowmeter test methodology that can be adopted to support cross-hole tracer test design (i.e., optimal position of fluorometers) and the evaluation of tracer tests results.

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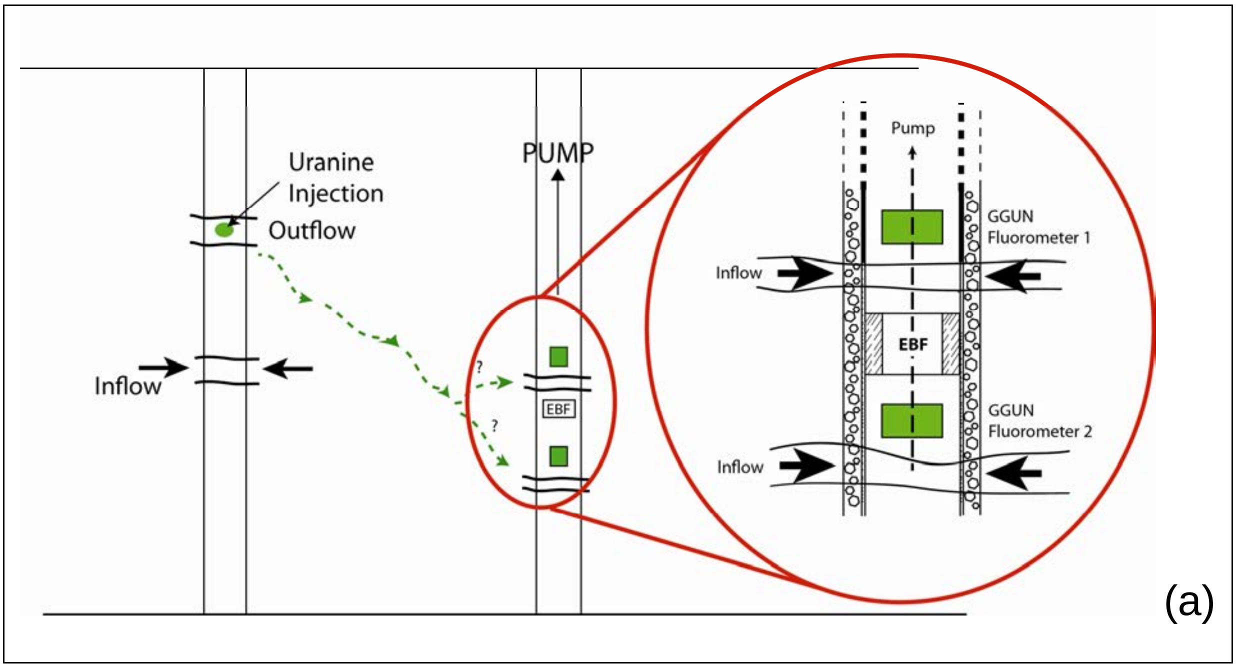

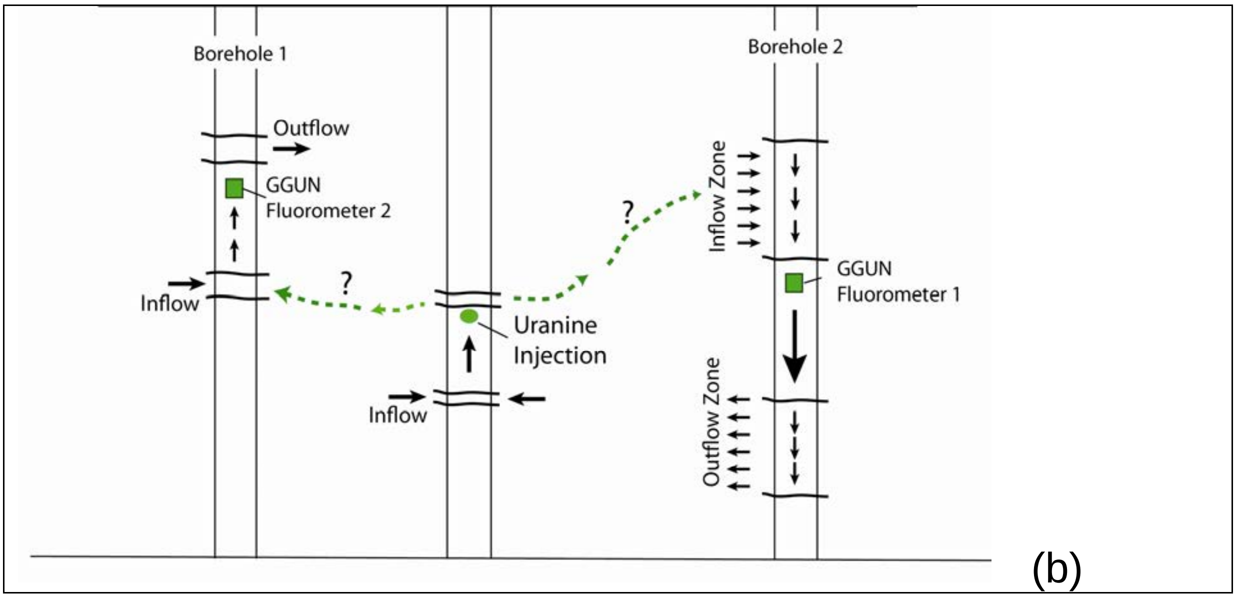

Fig. 1 – Sketch showing the general setting adopted for a forced (a) and ambient (b) gradient tracer test. Tracer injection and recovery were performed at outflow points detected by flowmeter logging. Drawing not to scale.
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UNCONFINED AND CONFINED AQUIFERS CLOSE TO THE PO RIVER IN THE EMILIA-ROMAGNA REGION : GEOLOGICAL SETTING AND GROUNDWATER MONITORING

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Key-words: *Po river, riverbanks, unconfined aquifer, confined aquifer, hydraulic monitoring*

1. Introduction

This work aims to deepen the knowledge related to groundwater in the vicinity of the Po river, considering its relationship with both the river network and the rainfall recharge. Recent geological investigations related to a national program for the seismic study of the Po river embankment allow to confirm the geological model of the area which governs the geometry of the aquifers.

Hydraulic monitoring stations were settled between Reggio Emilia and Ferrara districts, along transversal sections starting from the river axis, crossing the right-hand riverbank and ending few kilometers far away respect to it. One station allows to investigate also in the left-hand side of the river.

Here we present first results related to the area of Reggio Emilia.

The deeper investigated aquifer is composed of a thick upper Pleistocene sandy layer which derives from a high energy fluvial environment, related to the Po river sedimentation during the last glacial period. The bottom level of those Würmian sands can reach a depth of more than 50 m. The more shallow investigated aquifer interests the alternated sediments of fine and coarse Holocene materials for a thickness ranging between 7 to 12 m near the top, deposited by a meandered fluvial system, similar to the present (Bondesan et al. 1974, Servizio Geologico d'Italia - Regione Emilia-Romagna, in press).

The conceptual hydrogeological model consists of two different aquifers (named A0 and A1) of sandy-gravely Pleistocene-Holocene deposits of the regional multilevel aquifer (Regione Emilia-Romagna & ENI-AGIP, 1998, Severi et al. 2002), both in direct hydraulic contact with the main surface waters.

2. Data and Methods

The studied monitoring period starts in april 2011 up to December 2011. Stations consist of piezometers with inside one transducer each, which measures hydraulic pressure, electric conductivity and temperature. Data are collected hourly and sent through a GSM system to a server, so that they can be almost instantaneously checked through the web.

Two kinds of piezometers are installed: type "c" is typically filtered at a 10-50 m depth interval in order to catch the first confined aquifer starting from the topographic surface (A1); type "f" is filtered 2-10 m deep in order to catch the water table (unconfined aquifer – A0). The confined aquifer is investigated at three locations: i) between the Po river and the right embankment, ii) in the external right embankment footstep, iii) about 3 km far away from the right embankment.

The unconfined aquifer is investigated at two locations, beside piezometers "c": i) at the external right embankment footstep, ii) about 3 km far away from the right embankment. The river level is monitored hourly through 4 hydrometers, and by means of hydraulic simulations we have estimations of data in each study section.

In this work we present data related to two sections of the Reggio Emilia area (Figure 1), where data related to a point 2 km in the left-hand side of the Po river are also available (POM_c).

3. Results

Results collected up to now (Fig. 2) show that usually the confined aquifer has a piezometric level about 1-2 m lower respect to the unconfined aquifer, but during significant floods (e.g. the November flood) the situation is inverted. These data confirm previous observations (Regione Emilia-Romagna, 2007).

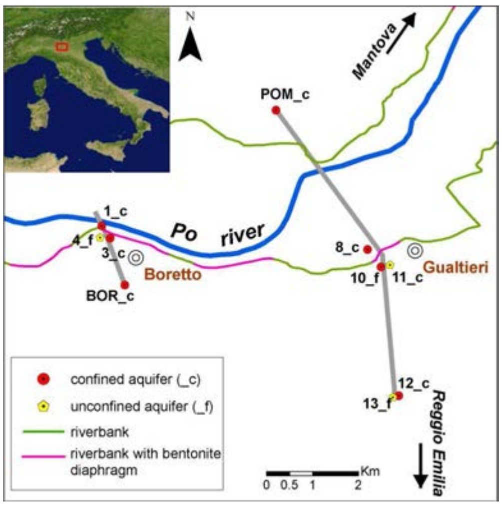

Figure 1 – Geographic setting of the study area.

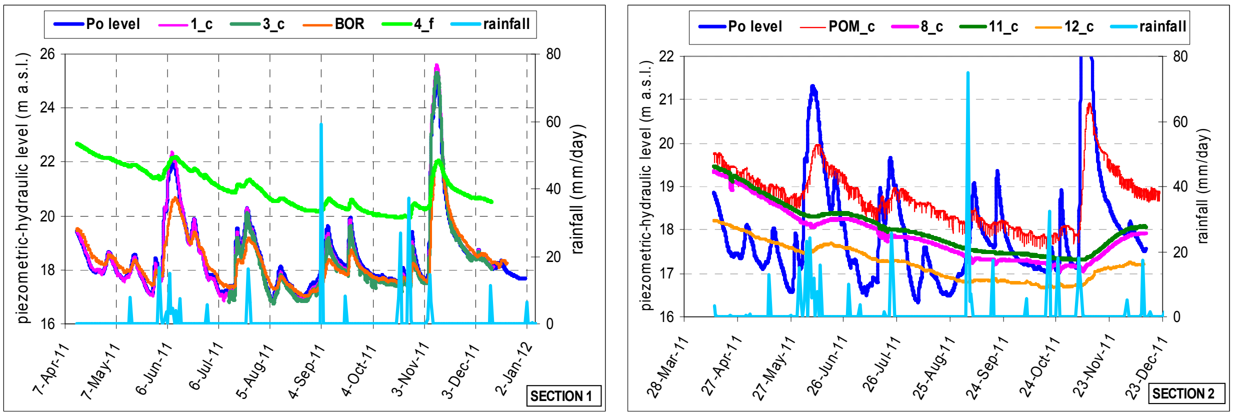

Figure 2 – Monitoring results of piezometric level respect to the Po river level.

The river generally drains the unconfined aquifer, but during floods this relationship is inverted. Even if the unconfined aquifer level is higher respect to the river level most of times, it follows river trend.
Piezometric level of the confined aquifer is influenced by the river as far as a distance of about 2 km from the river itself. Close to the river (some hundreds of meters) piezometric level of the confined aquifer closely match those monitored within the Poriver. Nevertheless, confined aquifer piezometric level can be influenced by local effects, such as riverbank bentonite diaphragm (11_c), coverage litology (8_c), and presence of groundwater wells (POM_c). If the riverbank is protected with bentonite diaphragm, the river influence is strongly reduced both in the unconfined and in the confined aquifer, even if the diaphragm doesn't reach the bottom of the aquifer.
Electric conductivity and water temperature show significant trend for the comprehension of the interaction of aquifers with river and rainfall.
Electric conductivity of confined aquifer strongly decreases in the vicinity of the river during floods: this is an important evidence about river-aquifer mass interaction (Colombani et al, 2007).
In the unconfined aquifer during some heavy rainfall events the electric conductivity rises up instantaneously because of migrating salts at depth.
The temperature of the confined aquifer doesn't feel the effect of floods and seasonal variations, keeping a constant value of about 14.5° C; on the other hand, the unconfined aquifer has a 2°C temperature gradient from spring to autumn. Temperature data confirm if an aquifer is confined or unconfined: as a matter of fact sometimes in deep piezometers (_c) is recorded a typical unconfined temperature trend which is due to sandy sediments above the aquifer that don't completely isolate the system from athmosferic temperature.

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FLOW VELOCITY EVALUATION WITH POINT DILUTION METHOD USING THERMIC AND SALINE TRACERS

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Key-words: hydraulic conductivity, single well point dilution, saline and thermic tracers.

1. Introduction

The knowledge of groundwater flow velocity is important for the quantitative and qualitative management of groundwater resources.
A reliable measurement of this parameter can be obtained through field tests, by applying the point dilution method in a single well (Drost et alii, 1968; Halevy et alii, 1967).
This well known method determines the horizontal Darcy flow velocity (V_f) by marking a particular volume of water of the prospecting borehole with a tracer and subsequently controlling its dilution in time.
The filtration velocity (V_f) in cm day^{-1} can be estimated using the following relationship (1) (Custodio et alii, 2007; Drost et alii, 1968):

$$V_f = -(\pi\gamma/2\alpha r_1 t)\ln C/C_0 \qquad (1)$$

where γ is the correction factor which considers the probe volume (cm^2), α is the correction factor to eliminate the distortion of the groundwater flow lines caused by the presence of the well, r_1 is the well radius (cm), t is time (days) and C and C_0 are the tracer concentration at time t and at start time.
The method can also be used to estimate K values of the aquifer if the hydraulic gradient (i) near the well is known, by using the Darcy's equation, V_f= Ki.
The best techniques for this method are those which provide the use of artificial radioactive tracers like 131I and stable salts like NaCl for marking. In any case considering the serious bureaucratic and economic difficulties concerning the use of radioisotopes , it has been preferred to apply this method by using saline (NaCl) and thermic tracers and by using a conductometric probe and a thermic sensor. This work thus aims to control whether and how the use of water at high temperature as tracer is reliable as well as the limits and potential of the thermic sensor.
The study area is located in the City of Colegno (next to Turin).
From a geological point of view this plain area consisted of gravelly-sandy fluvioglacial deposits (Pleistocene-Holocene) of the Dora Riparia River.
These deposits, which form a wide flat area, are characterized by terraced structures.
Under the fluvioglacial deposits there is a level of polygenic conglomerates with variable degree of cementation (Interglacial Gunz-Mindel).
The series continues with “Villafranchian” layers (alternation of gravelly-sandy and clay-loamy levels) (upper Pliocene-lower Pleistocene).
The shallow aquifer, with the main direction of flow from NW to SE and hydraulic gradient included between 0.007-0.01, was detected over Villafranchian deposits.
Particularly, it is a multi-layered system with a shallow aquifer and various deep confined or semi-confined aquifers.

2. Material and Methods

The point dilution tests were conducted in the shallow aquifer during July and December 2011 using tracers such as NaCl and water at high temperature (Figure 1).
The piezometer chosen for the tests is characterized by a 50 meters deep plastic casing; this has an inner diameter of 100 mm and screened between 37.20 and 49.60 m.
The groundwater level was detected at 36.79 m from ground level.
The tests started with the measurements of electrolytic conductivity and temperature baseline values after a careful calibration of the conductivity probe.
The marking of the water column was performed using the so-called Spanish method (Custodio E. & Llamas M.R, 2007).

This method involved the use of a flexible plastic hose (diameter 1.5 cm) opened and ballasted at the lower end.
The plastic hose is introduced into the piezometer up to its bottom. The amount of water in the hose is calculated on the base of the known water level in the piezometer and the internal section of the hose.
An equal volume of tracer (NaCl or hot water) was prepared and placed into the hose.
This volume replaced the original and the plastic hose is filled with tracer solution; the slow withdrawal of the hose allowed the uniform distribution of the tracer in the aquifer near the piezometer.
After the slow withdrawal the water column was scanned with the probe at different depths.
In detail, measurements were performed every meter at intervals of 15-30 seconds (Figure 2).
The values found, net of the natural base ones, were used to plot the diagrams concentration / temperature vs time and to determine the respective V_f.
In detail the temperature-concentration ratios (C_t/C_0-T_t/T_0) and their time are plotted in semilogarithmic field ($\ln C_t/C_0 - t$), ($\ln T_t/T_0 - t$).
In most cases that relationship was linear, in others was similar to a broken line formed by segments of straight lines.
The slope of linear regression line is proportional to horizontal flow velocity according to equation 1.
Horizontal filtration velocity is computed in each depth step interval as $V_f = m(-\pi\gamma/2\alpha r)$, where m is slope of regression line (Pitrak M., et alii 2007).

3. Results

The values of filtration rate and hydraulic conductivity, calculated with the two detection systems, have small differences.
Horizontal filtration velocity varies on average from 50 to 250 cm day^{-1} while the hydraulic conductivity varies between 10^{-4}-10^{-3} m/s. Values determined using NaCl are average lower than those determined using thermic tracer.

4. Conclusions

The aim of the work was essentially to value the reliability of the single-well methodology in a test area with well known lithostratigraphic and hydrogeologic features through the use of NaCl and thermic tracers.

The results obtained with thermic and saline tracers fit to the type of gravelly sandy-silt aquifer of the tested area confirming the validity of the adopted method for the evaluation of the groundwater flow velocity.

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Figures and Tables

Fig.1 – Saline tracer injection.

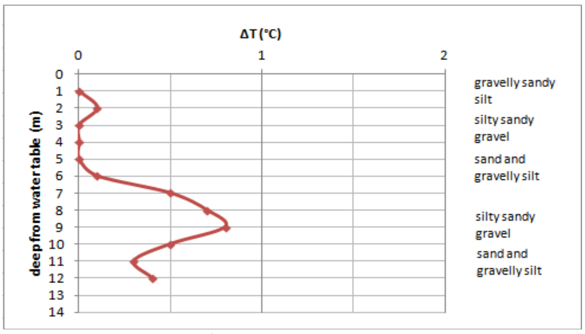

Fig.2 – Variation of the temperature along the water column 30 minutes after the thermic tracer injection.

SPRINGS AS MAIN GROUNDWATER DEPENDENT ECOSYSTEMS

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Key-words: Biodiversity, springs, northern Apennines, diatoms, benthic algae, cyanobacteria, water mites, copepods, ostracods, hydrochemistry, SAL springs.

1. Material and Methods

Springs are peculiar habitats. They are areas were groundwater comes to daylight. Several springs (in particular the perennial ones) show virtually constant water temperature all over the year. Many of the morphological, physical, and chemical characteristics (e.g., hydrological stability) of the spring habitat are determined by the hydrogeological features of the parent aquifer (Van der Kamp 1995). The environmental (physico-chemical) stability of permanent sources can allow the colonization by rare organisms or taxa which are of special interest for biogeographic reasons.

EBERs (Exploring the Biodiversity of Emilia-Romagna springs) is a three-years-lasting (2011-2013) Project fostered and funded by the Geological Service of the Emilia-Romagna Region. Its main goal is an exploratory investigation on the biota of selected springs of the Emilia-Romagna Region. It is characterized by a multidisciplinary approach with the aim of spring-habitat characterization and advancement to disseminate an improved awareness of the role of this resource in the territorial and thematic planning.

The reasons for spring habitat peculiarity and biodiversity richness are complex (e.g., marked heterogeneity of characteristics, complex microhabitat mosaic structure, ecotonal environment – transition from surface to groundwater, and from aquatic to terrestrial habitats). Springs are however imperilled by direct (especially water exploitation and tapping) and indirect anthropogenic impacts.

Sixteen springs were considered for the EBERs Project (Fig.1), selected on the basis of the following criteria:

Location in different types of nature preserves, in particular in Sites of Community (E.U.) Importance;
Occurrence of deep-seated gravitational deformations in slopes (DGPV);
Representativeness of the ecomorphological spring types occurring in the study region: rheocrenic, limnocrenic, helocrenic, hygropetric springs and sources with special physico-chemical characteristics (e.g., SAL - springs associated limestones- springs);
Availability of medium-term data series (temperature, discharges, algae nutrients, trace elements and heavy metals);
Location of the aquifers within the main geo-lithological types of the Emilia-Romagna Apennines;
Location in the different altitudinal belts and with permanent hydraulic regime;
springs in natural or near-natural conditions.

Field work was so far carried out in the summer of 2011. Some physical and chemical variables (pH, conductivity, temperature, redox potential, dissolved oxygen) were measured directly in the field with multi-probes. Water samples were collected for comprehensive chemical analyses (major ions, nutrients including phosphorus fractions, trace elements and heavy metals; Jacopo Gabrieli, IDPA-CNR, University of Venice). As regards the biota, special attention was devoted to the photoautotrophs that were assessed also in the field. In particular the following were collected:

Bryophytes characterizing the springs and its immediate surroundings (Daniel Spitale, Museo delle Scienze, Trento);
Diatom microalgae that can provide useful and interesting information on water quality (Marco Cantonati and Nicola Angeli, Museo delle Scienze, Trento). Detailed analyses were carried out also on the other benthic algae including cyanobacteria that form macroscopic structures and colourings (M. Cantonati, Museo delle Scienze, Trento). A specific part of the study dealt with SAL-springs' algae (Eugen Rott, University of Innsbruck, Austria) in two petrifying springs, the sole spring type indicated as priority habitat by the European Union Habitat Directive (92/43/CEE).

Further, in each spring zoobenthos samples were collected (overall management of invertebrate samples Reinhard Gerecke, University of Tübingen, Germany) to gain information also on the animal component of these environments.

Special attention will be devoted to some groups, such as water mites (R. Gerecke, University of Tübingen), the group that includes the highest number of species exclusive to springs (so-called crenobionts). Microcrustaceans such as ostracods (Giampaolo Rossetti, University of Parma) and copepods (Fabio Stoch, University of l'Aquila) are analysed as well, since they are particularly well suited to evaluate the relations between spring and aquifer.

The contribution of the Emilia Romagna Geological Survey and University of Bologna is aimed at defining the spring geological hydrostructure, and to the classification of groundwater flow system that discharges next to the outcropping area by using a hydrological-exhaustion-based method (Gargini et al., 2008) to identify the drainage basin and to foster the territorial conservation of the capturing structures.

Only an integrated hydrogeological-ecological approach allows to lay the foundations for conservation actions and for the monitoring of springs, understood not as simple points of aquifer-system discharge but as complex GDEs (groundwater dependent ecosystem).

With this contribution our aim is to illustrate the first results of the ongoing analyses on the samples collected in the 16 springs.

Acknowledgements

We are grateful to Raffaele Pignone, Responsible of the Servizio Geologico, who supports EBERs and innovation.

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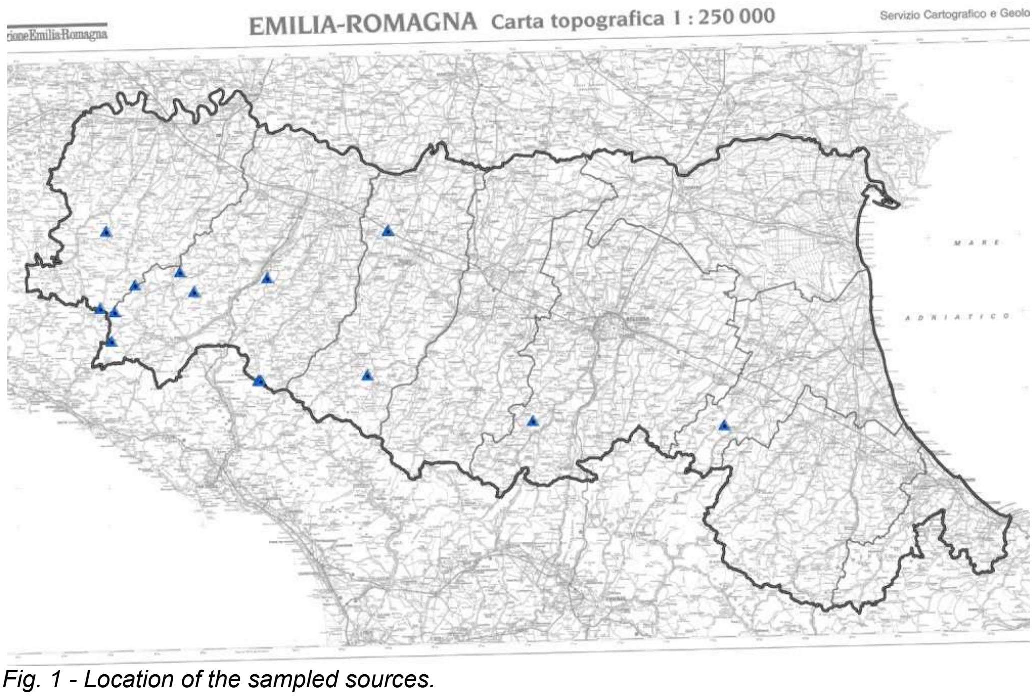

Fig. 1 - Location of the sampled sources.

THE GROUNDWATER DEPENDENT ECOSYSTEM OF SAGITTARIO RIVER, CENTRAL ITALY: RELATIONSHIPS BETWEEN SURFACE/GROUNDWATER AND NITROGEN CYCLE

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Key-words: Groundwater dependent ecosystem, multilayer aquifer, nitrogen isotopes

1. Introduction

This study is led by the need of an improvement of the river basin management, in an area where artificial changes in river dynamic, natural flood risks and the anthropogenic impact, resulting from industrial, zootechnical and agricultural practices, are impacting the fluvial and riparial ecosystem and the related aquifer system.

Whole study activities focus on the Sagittario River, starting from its entrance in the Peligna Valley (Abruzzo, Central Italy), to the confluence with the Aterno River (10 Km). The related alluvial aquifer is represented by a multilayer system, locally separated by low-permeability levels and lenses, having high content in organic matter.

This study had two major goals: to improve the knowledge about the hydrogeological characteristics of the study area, examining the relationship between surface water and groundwater; to assess the distribution and fate of nitrogen both in groundwater and surface water.

This approach allowed an evaluation of environmental impact of both local contamination (dumping ground, sewage system, cattle breeding) and diffused contamination (agricultural farming).

2. Material and Methods

In order to understand the relationship between the Sagittario River and water table, three seasonal discharge surveys were performed using a portable flow meter.

Water samples were collected along the riverbed. 13 springs, 3 wells and 3 new monitoring wells, located close to the River, were investigated during December 2010 and August 2011. Groundwater from monitoring wells was sampled using a packer system at different depths.

Physical and chemical parameters were measured in-situ: Temperature, Eh, pH and electrical conductivity (EC).

Laboratory analyses including major ions, DOC, minor ions, $\delta^{18}O$ and Deuterium, $\delta^{18}O$ and $\delta^{15}N$-NH_4^+, and $\delta^{18}O$ and $\delta^{15}N$-NO_3^{2-} were performed. For chemical analysis 50 mL of water was collected in PVC bottles, filtered, and then acidified with HNO_3. Major ions analyses were carried out by chromatographic technique, minor ions analysis were performed using ICP-MS. For DOC analysis, 25 mL PVC bottles were filled with water pre-filtered through a 0.45 µm Millipore filter directly in the field site and acidified with HCl 2N to pH 2. DOC was analysed using a Dohrmann DC-190 Total Carbon Analyzer. Groundwater and surface water samples (100 ml) for analyses $\delta^{18}O$ and Deuterium of water were kept frozen until analyzed.

According to the $\delta^{15}N$-NH_4^+analysis, a 100 ml sample volume were collected, adjusted to pH 4.5-5 with 20% H_2SO_4 and frozen until analysis. Groundwater and surface water samples were also collected from 1l up to 3l, needed to perform the isotopes analysis for the $\delta^{18}O$ and $\delta^{15}N$-NO_3^{2-}. The samples were stored in PVC bottles and kept frozen until analyzed. Samples were prepared and analysed with the procedure stated by Silva et al. (2000). Isotope analysis was performed at the Environmental Isotope Laboratory, University of Waterloo, using a VG Isogas Prism Series II mass spectrometer. The international standards are atmospheric nitrogen (AIR) for nitrogen isotopes and Vienna Standard Mean Ocean Water (VSMOW) for oxygen and hydrogen isotopes. The analytical error is ±0.5‰ for $\delta^{15}N$ and $\delta^{18}O$ of nitrate, and ±0.1‰ and ±1‰ for $\delta^{18}O$ and Deuterium of water, respectively.

3. Results

Results from discharge measurements indicated the strong relationship between river and water table. Upwelling and downwelling zones have been identified throughout the stream.

The geochemical facies that characterize the water in the study area is *Ca-HCO₃*, with slight variation according to SO_4, Ca, Mg, Na and K content, probably due to different water-rock interactions and seasonal variability.

In the Peligna Valley (Abruzzo, Central Italy), the recharge contribution from the Morrone's carbonate massif (Desiderio et al., 2003) to a deeper groundwater system has been defined by comparing isotope results of $\delta^{18}O$ and $\delta^{2}H$ and chemical tracers.

Two different isotope signals representative of the recharge water have been found in the groundwater samples (Fig.1). A group of waters including the spring SI and the well PC showed the less enriched $\delta^{18}O$ and $\delta^{2}H$ values, indicating recharge from the surrounding carbonate ridges. A second group including groundwater and surface water comes from local and perched springs (SN, SO, SM), including the PB well, showing local recharge effect. Other samples show intermediate isotope signals, indicating a mixing between local and relatively higher altitude recharge. Along the River, a shallow aquifer related to local infiltration is interacting with the surface water, by the hyphoreic system. Deeper groundwater separated by a low-permeability layer shows differences, both in terms of hydrodynamic (confined aquifer) and hydrochemistry (reducing conditions).

Chemical analysis showed how nitrate's distribution varied considerably and ranged from 0,03 N-NO_3 and 22,79 N-NO_3 (mg/l). Groundwater and surface water N-NO_3 values increase linearly with distance from the River bed. On the contrary a decrease in ammonium concentrations with distance from the River bed is observed; its values ranged from 0,10 up to 16,31 mg/l as N-NH_4.

The NO_3-$\delta^{15}N$ values varied from a minimum of 4.72‰ to a maximum of 11.72‰. The $\delta^{15}N$ signal (Fig.2) that represents SO, SM, SL, SH and SD is probably due to nitrogen natural source such as organic matter deposition; lowest values could be attributed to agricultural practices, where synthetic fertilizers are commonly used (Aravena et al., 1993). The $\delta^{15}N$ values of SC, SH, and SN (October survey) could be attributed to manure or septic waste

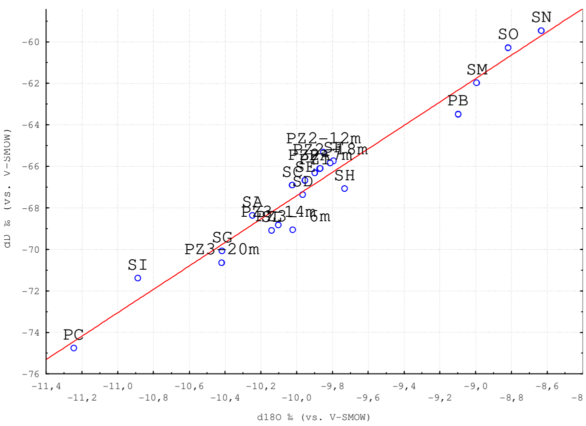

Fig.1- $\delta^{18}O$ and Deuterium plot. S: spring, P: well

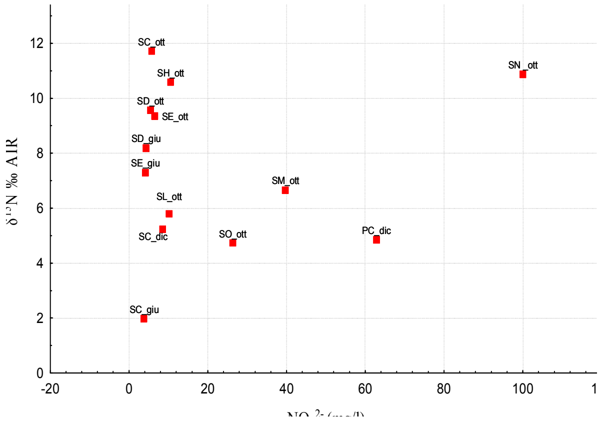

Fig.2- $\delta^{15}N$-NO_3^{2-} and NO_3^{2-} plot. S: spring, P:well

4. Conclusions

The hydrogeological framework includes two different groundwater flow systems in the alluvial deposits, separated by a local aquitard: a shallow aquifer locally fed by local recharge and river losses and a deeper aquifer system fed directly from the carbonate massif that surround the basin.

The strong interaction between groundwater and river represents an additional variable to be considered for future groundwater management strategy, taking into account inputs into groundwater of surface water affected by anthropogenic impact and the role of the hyporheic zone.

Nitrate contamination in the shallow aquifer is negligible, due to hydraulic condition that characterize the unsatured zone: peat and clay deposits determinate anoxic condition, reducing infiltration processes and lead denitrification ones. Local highest nitrate concentrations reflect a punctual contamination due probably to anthropogenic practices that involve synthetic fertilizers and animal waste.

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FLOW AND TRANSPORT IN FRACTURED MEDIA AT DIFFERENT SPATIAL SCALES

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Key-words: non linear flow, laboratory tests, tracer tests

1. Introduction

Fractured aquifers can exhibit complex hydrodynamic flow patterns due to some degree of heterogeneity and anisotropy of the medium; in this context the use of simplified approaches to describe flow and transport can lead to erroneous interpretations of the on-going dynamics and consequently even inefficacy of management interventions adopted.

In real rock fractures, microscopic inertial phenomena can cause an extra macroscopic pressure loss which deviates flow from the linear relationship among pressure drop and flow rate. Moreover, heterogeneity intervenes even in solute transport in that the equation that prescribes a linear relationship between the dispersive mass flux and the concentration gradient is not valid.

Moreover, the spatial organization and the degree of networking of the drainage system is also responsible for the various and also contrasting relationships detected between hydraulic conductivity and the scale of investigation.

In this study the presence of non linear flow and non-Fickian transport has been analyzed at bench in a limestone formation.

Hydraulic and tracer tests on artificially created fractured rock samples have shown evidence of non linearity in flow and tailing in breakthrough curves.

Due to the mentioned scale dependence of the hydrodispersive properties of the medium, the obtained results have been compared to experimental data coming from field tracer tests in the industrial area of Bari that show presence of nonlinear laminar/non-laminar flow regime and concentration profiles that cannot be described by typical advection-dispersion breakthrough curves.

All the carried out realizations show that that the aquifer hydrodynamics depends primarily on heterogeneity and flow analysis predictions based upon a linear relationship such as Darcy's law can lead to inaccuracies up to significant errors in problems such as contaminant transport.

2. Material and Methods

The experiments have been carried out on a block of carbonatic rock of parallelepiped shape (0.60×0.40×0.8 m) recovered from the ‘Calcare di Altamura’ formation (which is located in central part of Apulia region -Southeastern Italy) where the fracture network has been made artificially.

Water inside the block can move through different pathways according to the hydraulic head difference between the upstream tank connected to the inlet port and the downstream tank connected to the outlet port.

The volumes of water passing through different paths across the fractured sample for various hydraulic head differences and breakthrough curves for saline tracer pulse across different pathways have been measured.

A general Darcian-like relationship can be used (Chin et al, 2009) to describe all the mentioned flow regimes and to account for nonlinearities in the relationship between hydraulic head gradient and flow velocity:

$$\vec{v} = -K_{eff}\left(\nabla h\right)\cdot\nabla h$$

K_{eff} [LT-1] is the effective hydraulic conductivity, respectively, and $h = p/\rho g$ [L] is the total hydraulic head. For instance, according to Forchheimer’s law, effective hydraulic conductivity can be written as (Cakmak, 2009):

$$K_{eff} = \frac{2}{a+\sqrt{a^2+4b\left\|\nabla h\right\|}}$$

Where a [TL^{-1}] and b [T^2L^{-2}] are the linear and inertial coefficients respectively in terms of hydraulic head.

As far as solute transport, the well known Advection-Dispersion Equation (ADE):

$$\frac{\partial C}{\partial t}+\nabla\cdot\left(\vec{v}C\right)-\nabla\cdot\left(\mathbf{D}\cdot\nabla C\right)=0$$

often fails to predict observed behavior of solute in the subsurface (Neuman & Tartakovsky, 2009) because in presence of heterogeneity dispersivity values might depend on the spatial and/or temporal scale of observation, investigated by many researchers (Hsieh, 1998). In the present study, the classical advection-dispersion equation –used as a benchmark for comparison in a numerical model– poorly describes the experimental breakthrough curves of the tracer propagation.

3. Results

The above experimental results have shown evidence of non linearity in flow and concentration profiles that cannot be described by conventional solute transport models.

These laboratory tests are coherent with forced pumping well tests carried out in the fractured aquifer at Bari IRSA laboratory (Masciopinto et al., 1997) where a Forchheimer type equation has been used for higher Reynolds numbers to clarify the non-linear regime. The simulated hydraulic heads has been better fitted by considering the presence of non-laminar flow.

Moreover, the Breakthrough curve of the Chlorophyll tracer injection test (Masciopinto et al., 2010) carried out at Bari fractured aquifer has shown an early first arrival and a tail. The model concentrations under laminar conditions show a large deviation from the experimental BTC, while the model concentrations under laminar/non-laminar conditions agree with the experimental data.

4. Conclusions

Critical emerging issues for fractured aquifers are the validity of the Darcian-type “local cubic law” which assumes a linear relationship between flow rate and pressure gradient to accurately describe flow patterns and of the advection-dispersion equation to describe solute transport

In this study a series of controlled laboratory tracer test experiments have been carried out to investigate solute transport under the non-Darcian flow conditions in a fractured formation.

The results clearly evidence that in fractured aquifers, inertial phenomena cause pressure losses which deviates flow from linearity.

The presence of this phenomena cannot be neglected in the study of flow because their effects can produce relevant deviations of the groundwater velocity estimations and, consequently, in the results of simulations of pollutant transport (Masciopinto et al, 2010)

The results are coherent with the theory that non-Darcian flow increases dispersion respect to Darcian flow.

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VULNERABILITY ASSESSMENT BY FUZZY LOGIC IN A COASTAL AQUIFER OF NORTHERN SICILY

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Key-words: Groundwater, Vulnerability, Fuzzy logic, Acquedolci plain, SINTACS method

1. Introduction

The exigency to reduce some uncertainties in parameterization of pollution groundwater vulnerability is very felt, especially in complex aquifers (Ducci, 2010). This paper, considering the well-known SINTACS system (Civita & De Maio, 2000), proposes new approaches to implement the knowledge of hydrogeological complex systems of Northern Sicily. Here, the fuzzy approach can mitigate problems of ambiguity originating from the standard application of contamination vulnerability assessments (Cameron & Peloso, 2005). As an example, fuzzy logic takes into account the natural stochastic variability of vulnerability factors, including background noise levels and eventual errors in sampling and measuring procedures.

2. Material and Methods

In order to attain the proposed goals, Authors have utilized a fuzzy logic routine relevant to the MathLab software (The MathWorks Inc., 2003). This developed evaluation system reaches to emulate the expert knowledge, taking into account empirical and subjective elements, usually neglected, but closer to the human reasoning. In the synoptic scheme of Fig. 1, it is quoted the most commonly applied fuzzy methodology, which is the Mamdani inference engine (Mamdani & Assilian, 1975). Flowchart in Fig. 2 summarizes the whole applied fuzzy logic project, showing the phases followed in this paper up to the evaluation of the results.

3. Results

The calibration of fuzzy logic system forecasts that membership functions, linguistic terms and rules of the inference engine are established (Zadeh, 1965). In this way, it is possible to test (using appropriate MATLAB tools as the Surface View) the dependence between outputs and inputs, eventually modifying them. The rules applied in the Acquedolci area (Fig. 3) represent heuristic data and concepts, expressing with linguistic terms the relations between input and output variables. In this case, the used vulnerability grades are represented by five term sets: *very low, low, medium, high* and *very high,* here referred to a limited number of SINTACS parameters (*Depth to water, Net recharge, Hydraulic conductivity, Slope,* see Fig. 4). Applying the fuzzy logic, a further set of vulnerability maps was elaborated, with the same group of parameters, and Fig. 5 exhibits the product of this elaboration, which is the *Acquedolci fuzzy-logic vulnerability map*. By comparing this map with the previous SICS elaboration, resulted from the standard point-count system procedure, notable differences are clearly shown in the vulnerability classification, as in the inland part of the plain, evidencing weaker zones previously considered less vulnerable.

4. Conclusions

As a matter of fact, fuzzy logic can contribute to overcome certain difficulties in the complex field of contamination risk assessment, where non-linear and multi-dimensional elements are involved and the hydrogeological data themselves are intrinsically vague and uncertain (Woldt *et alii*, 1996). Fuzzy logic advantages in risk contamination assessment can be summarized as follows:

1. capability to perform non-linear models and to treat doubtful and unconvinced data;
2. flexibility in erasing and/or adding rules and in using points and weights in order to assign differentiate importance to variables;
3. conceptual simplicity and good matching with the human way of thinking (Kosko, 1993). The efforts to test fuzzy logic application in the studied area allowed us to better depict the vulnerability conditions of aquifers, closely influenced by deterministic and stochastic phenomena.

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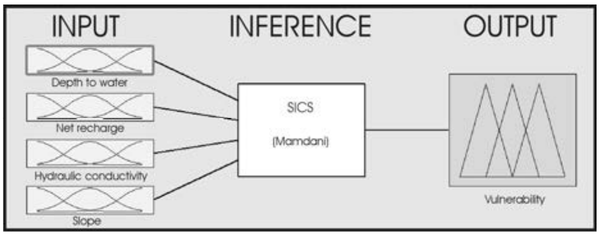

Fig. 1. Synoptic scheme of the fuzzy logic structure referred to the studied system (*Fuzzy Logic Toolbox*). *Mamdani* inference engine is here purposely quoted.

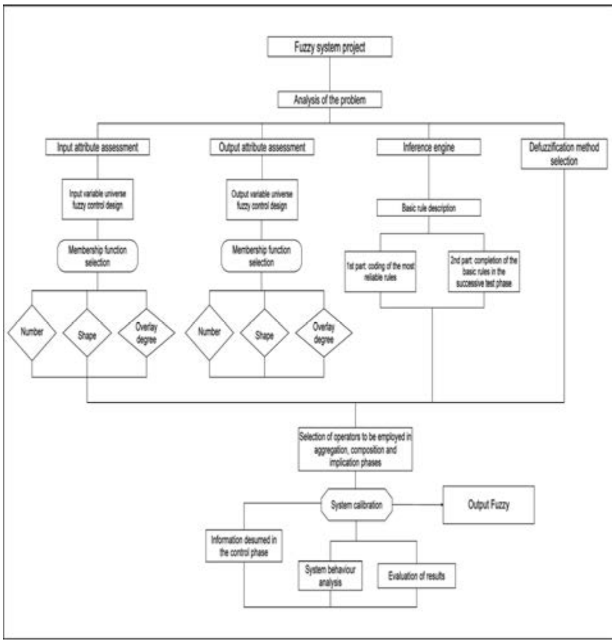

Fig. 2. Flowchart of the fuzzy logic project.

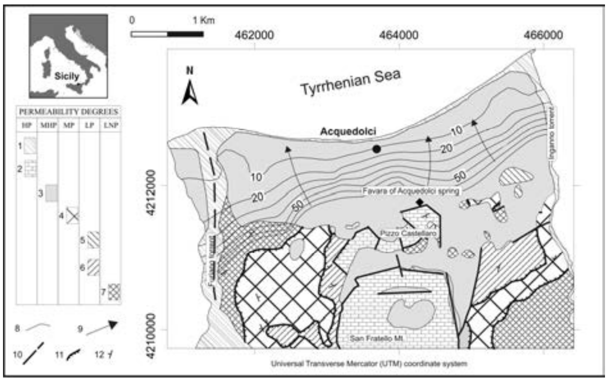

Fig. 3. Hydrogeology of Acquedolci (Northern Sicily). 1: High permeability (*HP*) for porosity (detritus, alluvial deposits); 2: high permeability (*HP*) for fractures and karst (limestones); 3: medium-high permeability (*MHP*) for porosity (fluvial-marine terraces); 4: medium permeability (*MP*) for porosity and fractures (flysch); 5: low permeability (*LP*) for porosity (lacustrine deposits); 6: low permeability (*LP*) for porosity and fractures (marly limestones); 7: low or null permeability (*LNP*) (flysch and metamorphites); 8: groundwater contour lines (m a.s.l.); 9: groundwater drainage axes; 10: faults; 11: thrusts; 12: strikes and dippings.

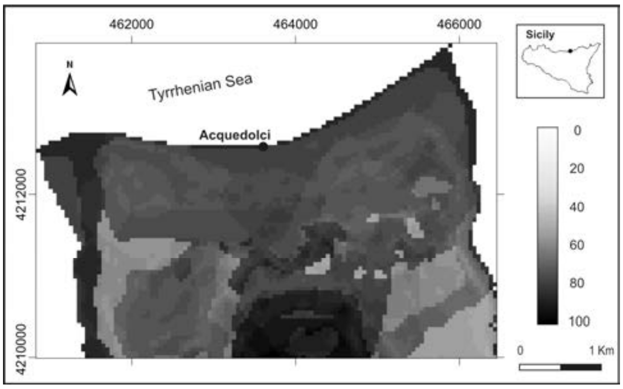

Fig. 4. Pollution vulnerability map of the Acquedolci plain performed by the modified SINTACS method (*SICS release,* relevant to four parameters: *Depth to water, Net recharge, Hydraulic conductivity, Slope).*

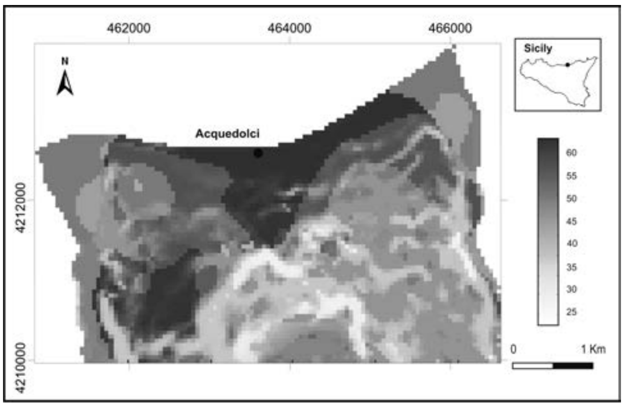

Fig. 5. Fuzzy-logic vulnerability map of the Acquedolci plain (*Release SICS*).

CLIMATIC CHANGE AND WATER RESOURCES IN CENTRAL ITALY: AN UPDATE

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Key-words: water resources, climatic change.

1. Introduction

In the last hundred years the average global atmospheric temperature has risen by about 0.6°C - 1°C (cf. for example Dragoni & Sukhija, 2008; Bates et al., 2008). In southern Europe and the Mediterranean area, this rise is associated with higher frequency and duration of droughts, and a general decrease of average yearly precipitation. This paper regards in particular Central Italy, where the trends detected in instrumental series of precipitation and temperature show that in all the stations with a statistically significant trend there is an increase in mean annual temperature (gradients up to +0.01°C/year) and a decrease in annual precipitation, with linear gradients up to -7 mm/year (De Felice & Dragoni, 1994; Brunetti et al., 2009; Di Matteo et al., 2011; Vergni & Todisco, 2011). Climate change greatly influences the hydrogeological processes regulating both groundwater and surface water availability. Evidence of this influence is represented by the statistically significant negative trends found in the mean annual and monthly yields of some important hydrologic and hydrogeologic systems. Negative effects can also be observed on lake systems, on which climatic changes induce decreases in levels and outlet discharges, amplified by constantly increasing withdrawals.

Within the framework of this general picture, the present work presents some results regarding the impact of the going on climatic trend on two specific systems.

2. Material and Methods

In order to define the possible future climatic scenarios for two hydrogeological systems (Trasimeno Lake and Bagnara spring), long meteorological series of temperature and rainfall, recorded in stations located close to the two systems, were analyzed. The results of statistical analysis have been therefore used to define the climatic scenario for the next 30 years.

A mathematical model was used under the defined scenarios to simulate the future behavior of Bagnara Spring and Trasimeno Lake.

3. Climatic Trends Trends.

For the Bagnara spring the analysis of twelve rainfall series shows that all of the series having a statistically significant trend indicate a decrease in mean annual rainfall, with negative gradients up to 3.43 mm/year. There are no series showing a significant positive rainfall trend. As for temperature the results of statistical analysis of data are more uncertain, since there are stations indicating an increase in temperature and a few stations indicating a decrease. Nevertheless the longer series of Central Italy (Rome and Perugia) indicate a clear increase in mean annual temperature. For these and other stations with a positive temperature trend, the increase in temperature is associated to a decrease in rainfall (i.e. warmer years are associated to dry years), and that the gradients are higher in the last 30 years. The decrease in rainfall is mainly concentrated in the main recharge interval (from October to April), with negative gradients up to 5mm/semester.

4. Bagnara Spring Modeling and Scenarios up the Next 30 Years

Bagnara Spring is located in Umbria-Marche Apennines, at an elevation of 650 m a.s.l., while the average altitude of the calcareous massif feeding the spring has an average elevation of about 1150 m a.s.l. (Cambi and Dragoni, 2000).In order to quantify the possible discharge reduction of Bagnara spring in the next 30 years, a numerical rainfall-discharge model was run under different climatic scenarios. The model is a variation of a series of lumped models that have already been worked out to simulate the rainfall – runoff transformation of some basins in Central Italy (Cambi et al. 2003; De Felice et al. 1993; Dragoni and Valigi 1995, Di Matteo et al. 2011, Dragoni et al, 2011a; Dragoni et al, 2011b). The last version of the model (SPRING-02) was implemented in EXCELL and adapted to the case of aquifers feeding springs and deeper fluxes, i.e. outflows at different altitudes.

The model is characterized by two tanks in series (TANK1 and TANK2) which conceptually represent the soil and the aquifer respectively. TANK1 regulates the production of actual evapotranspiration, surface runoff and aquifer recharge. The model was calibrated and validated, with fairly good results (Nash-Sutcliffe index = 0.83 for the validation). The climatic scenarios were set assuming that rainfall and temperature trends detected in the last 60 years would continue over the next 30. The results of the simulations have shown that the mean annual discharge variation of the spring, with respect to the mean discharge of the 1998-2010 period, should range between – 19% and -25%.

5. The case of Lake Trasimeno

The rainfall-discharge process was simulated also for Lake Trasimeno, a large Lake close to Perugia in Central Italy (Dragoni et al., 2011b). The applied monthly model (LAGO-04) is similar to the model used for Bagnara Spring, but it is made up by 3 TANKS (representing respectively the surface basin, the aquifer feeding the Lake and the Lake). The Trasimeno hydrogeological system is different from Bagnara system: the rainfall over the Lake's watershed is about 50% less then in Bagnara, and the geological setup is made up mainly by recent unconsolidated sediments and flysch formations. After calibration and validation the model was applied to the Lake under different climatic conditions. The results are reported in table 1.

% P	% Sr	% Rch
-5%	-9%	-40%
-10%	-19%	-70%
-20%	-38%	-95%

Tab. 1-*Yearly precipitation decrease (P), Surface runoff (Sr) decrease and aquifer recharge (Rch) decrease for the Trasimeno lake basin.*

6. Final considerations and conclusions

The investigations carried out show that if the climatic trend continues (and this is highly likely) the water resources in Central Italy will be strongly affected. In order to minimize the impact of the climatic changes, the most important hydrogeological systems must be modeled and on such basis future scenarios have to be built, so that appropriate management strategies are prepared. Unfortunately, at present the hydrometeorological data are not as many and of good quality as they should be: it is imperative that a reliable data net for the measurement of these data is established

Acknowledgements

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A MULTIDISCIPLINARY APPROACH TO THE PHYSICAL AND GEOMETRICAL CHARACTERIZATION OF MULTI-LAYERED AQUIFERS

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Key-words: hydrofacies; electrical resistivity, 3D modelling

1. Introduction

Recognition of the framework of complex aquifer systems is a key topic to analyse groundwater conditions and contaminant transport in heterogeneous and anisotropic aquifers. Groundwater models are useful tools for management and protection of water resources, but their predictive function is often constrained by a deficient characterization of hydrogeological parameters at a local scale.
A wide variety of structural, volcanic and depositional processes produce a composite spatial distribution of hydraulic conductivity in alluvial aquifer systems. Groundwater flow and solute transport simulation in similar multilayer systems of several aquifers, aquitards and aquiclude needs a vast amount of observed data (e.g. Ouellon et al., 2008; Hsien-Tsung Lin et al., 2010; Vienken and Dietrich, 2011).
Many tools for the knowledge of lithologic and stratigraphic features and of spatial heterogeneity at different scales are available (de Marsily et al., 2005; Galloway, 2010), but it is essential to improve the hydrofacies models including in situ testing procedures that would better treat the rock strata connectivity and the geometry of aquifers.
With regard to coastal alluvial aquifer system of the Sarno River plain (South Italy), this paper points out a multidisciplinary approach to delineate aquifer/aquitard unit and depict a realistic 3D modelling of the hydrogeological heterogeneity using geological, hydrogeological and geophysical techniques. Namely, due to its composite hydrodynamic conditions and to the high human impact, it has been chosen the sector of this plain located at the river mouth. Accordingly, this paper presents some interesting aspects to quantify the relationship between geophysical parameters and hydrostratigraphic properties of a highly heterogeneous alluvial aquifer system.

2. Material and Methods

Geophysical investigations may be used to complete the hydrogeological features of aquifers (e.g. Crumbling et al., 2003; Rubin and Hubbard, 2005; Drahor et al., 2011). But it is clear that established standard methodologies for the assessment of hydrodynamic parameters are not available.
This paper provides an approach to built the hydrogeological block diagram combining the most common existing data for hydrogeological characterization with a 3D resistivity model.
The sample area stretch for 2.5 km^2 at the Sarno river mouth and its DEM derives from apposite survey data. The focus of the study is the array of existing information which consist of about 14 stratigraphic logs, mainly assembled in the SE sector, and a number of geotechnical characteristics of these alluvial, marine and pyroclastic deposits. The reliable reconstruction of the aquifer model has been carried out involving the hydrogeological survey, the analysis of cartographic records (aerial photo, geologic and topographic maps), and the concept of aquifer analogues (e.g. Miall, 1996; Lunt & Bridge, 2004; Tronicke et al., 2004; Bersezio, 2007).
To constrain the hydrogeological features in the NE sector, a 2D geoelectrical tomography survey along profiles has been conducted, which has permitted a 3D electrical representation of the investigated buried volumes.
With regard to the recognized hydrofacies and the following hydrogeological fence diagram of the framework, the "horizon" approach procedure (e.g. Lemon & Jones, 2003) was applied to develop the 3D modelling of the examined aquifer system.

3. Results and conclusion

The recognized hydrofacies, embodied in figure 1, identify a multilayered aquifer. The hydrostratigraphic scheme points out the distribution of alluvial, marine and volcanic units

and the influence of the variation of the coastal onlap. In the eastern area the groundwater flow is confined and takes place chiefly in the most permeable aquifer, underlying the aquitard corresponding to the volcanic ash layer.
Likewise, the 3D resistivity model shows at comparable depth a layer characterized by resistivity values < 16 Ohm m. In addition, the spatial variability of the resistivity may be related to the hydrostratigraphic architecture and to the heterogeneity and different water content of each hydrofacies.
In conclusion, the stratigraphic and geomorphologic setting of quaternary deposits may be transfer in aquifer analog.
With regard to the geometric properties and the connectivity of hydrofacies, this study provides a hydrogeophisical approach and the potential of geophysical methods to constrain hydrodynamic parameters.

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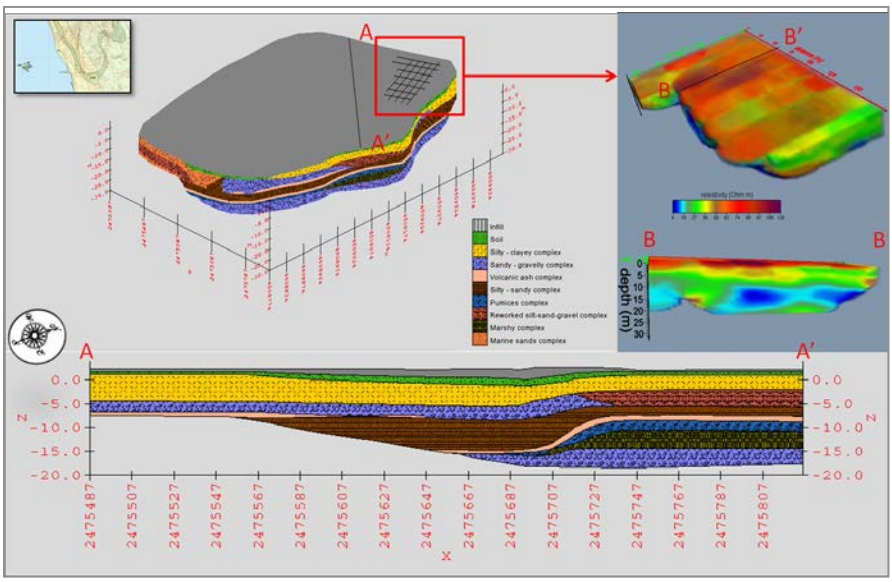

Fig. 1 – Hydrogeological block diagram of the coastal alluvial aquifer system of the Sarno River plain

HYDROGEOLOGICAL ANALYSIS OF LAND SUBSIDENCE IN THE CAMPANIAN PLAIN

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Key-words: land subsidence, SAR interferometry, aquifer system, groundwater pumping

1. Introduction

This paper presents the framework of a research program, theoretical and experimental in nature, issued by a cooperative multidisciplinary group of the Department of Earth Sciences – University of Naples Federico II and of the Institute for Electromagnetic Sensing of the Environment (CNR-IREA) National Research Council in Naples.

The objective is the analysis of land subsidence phenomena that develop in many areas and are related to over-pumping of groundwater resources by means of advanced technologies to measure surface displacements (inSAR techniques).

In the last years many studies showed the great potential of this technique to recognize the hydrodynamic conditions of several strategic regions (Galloway & Hoffmann, 2007).

The correlation between the spatial distribution of the surface displacements and the hydrogeological data enables to identify structural and/or lithostratigraphic features that control the groundwater flow (e.g. Bawden et al., 2001; Buckley et al., 2003; Schmidt & Burgmann, 2003) likewise to point out the influence of the natural or man-induced fluctuations of the water level on the temporal spreading of surface deformations (e.g. Hoffmann et al., 2001, 2003; Colesanti et al., 2003; Ferretti et al., 2004), till to evaluate hydrodynamic parameters such .as the hydraulic conductivity and storage coefficient of aquifer systems (Hoffmann et al., 2001, 2003; Halford et al., 2005).

In particular, the present paper deals with a sample application of the methodology to analyze both at long-term and short-term the subsidence phenomena and with related review of geological, geotechnical and hydrogeological data on the Campanian Plain (South Italy), in two sectors characterized by different spatial and temporal evolution of groundwater hydrodynamic during the reference period of land subsidence.

2. Material and Methods

Land subsidence is sinking of land surface elevations from changes that take place underground.

Several techniques can be used to measure variation of land surface elevation. At the present the approaches for ground deformation analysis based on remote sensing techniques and, in particular, on the Synthetic Aperture Radar (SAR) systems, are among those with a larger spatial coverage capacity and a smaller impact on the environment.

These approaches, referred to as Differential Interferometric SAR (DInSAR) techniques, allow to produce spatially dense deformation maps with centimetric/millimetric accuracy. An effective way to detect and follow the temporal evolution of the investigated deformations is via the generation of time-series; to do this, the information available from each interferometric data pair must be properly related to those included in the other acquisitions via the generation of an appropriate sequence of so called InSAR interferograms (Gabriel et al., 1989).

The Small BAseline Subset (SBAS) algorithm (Berardino et al. 2002, Lanari et al. 2004), developed at IREA CNR in Naples, is a DInSAR technique that implements an appropriate combination of differential interferograms produced from image data pairs characterized by a small orbital separation (baseline); this technique enables to investigate the space-time characteristics of the detected deformations.

By applying the SBAS approach to an ERS-1/ERS-2 and ENVISAT data set of images spanning the time-interval from 1992 until 2006, two sectors of the Campaniana Plain have been investigated.

In order to highligth the temporal characteristics of the detected displacement, deformation time-series on selected areas have been also analyzed.

The approach to assess the causes of observed surface deformations is based on a reliable review of hydrogeological data, combined with

geological, morphological, structural and geotechnical ones.
The effects of groundwater over-pumping are critical and need careful consideration.
It is well known that land subsidence caused by withdrawal of fluids from porous media is attributed to the non recoverable compaction of aquitards. When the reduction in pore-fluid pressure (due to the decline of water table) causes an increase in effective stress to values greater than the preconsolidation stress, the pore structure of vulnerable fine grained horizon in the aquifer-system may undergo significant reorganization. This circumstance produces a permanent reduction of pore volume and subsequent vertical compaction of the intercalated aquitards; as a result vertical displacement of land surface takes place.
Collection, coordination and re-interpretation of exiting data concerning above all with water table levels, well and drilling stratigraphies, hydrogeological and geotechnical field investigations and laboratory tests on undisturbed samples, as well as levelling data and surface deformation observations enables a comprehensive picture of field conditions.
At the same time a refined monitoring network of water table levels is identified.

3. Results and conclusion

Results show that measured surface deformations in the Campanian Plain, during reference period, are related to the stress state changes, caused by water table lowering. The extension and rate of land subsidence phenomena depend on local hydrogeological and lithostratigraphic conditions (water table lowering, thickness and properties of compressible soils).
A double level approach to the subsidence has been issued, focussing the attention both at long-term and short-term. In particular, long-term data are based on the rate of subsidence due to an established water table lowering, while the short term ones are based on the velocity of subsidence phenomena according to temporal evolution of piezometric level.
The treatment of available data shows the effectiveness of the methodology to relate long term subsidence phenomena and water table lowering.
The short-term analysis points out a reliable integrated procedure able to assess the aquifer system storage coefficient.

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HYDROGEOLOGY OF THE "MAIOLICA" AND "SCAGLIA" CARBONATIC AQUIFERS IN THE NORTHEASTERN FLANK OF MT. PAGANUCCIO (FURLO MOUNTAINS, MARCHE, ITALY).

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Key-words: Umbro-Marchesan carbonate aquifers, Na-Cl facies, vertical drainance

1. Introduction

The paper presents the preliminary results of hydrogeological , geophysical and hydrochemical surveys carried out at the M. Paganuccio – S. Anna site (municipality of Fossombrone, Marche Region). The aim of the study is the preliminary assessment of groundwater resources in Umbro-Marchesan carbonate aquifers, followed by direct research of groundwater by deep drillings, as a part of a project intended to supply a mineral water bottling plant.

2. Material and methods

After the acquisitions of basic geologic and hydrogeologic informations, the in situ investigation started with the survey of meso-scale structures and local buried geometries of rock-formations by means of tomographic geoelectrical survey (ERT). Hydrometric and hydrochemical investigation was carried out on existing water springs and streams, in order to reconstruct a scheme of possible groundwater circulation within the aquifers. Preliminary water budget calculations were developed in order to determine the average infiltration of the aquifers (Farina, 2012). The second phase of the survey was to locale and drill boreholes to verify the hypothesis made, and characterize groundwater quality and quantity.

3. Results

The survey showed the particular hydrogeology of the Scaglia aquifer, where a rather shallow water circulation occurs in large rock bodies involved in ancient landslides (Deep Seated Gravitational Slope Deformations) and/or the associated debris overburden. That circuit originate the water springs of the area, most of them in the 1-5 l/sec yeld range. Deeper groundwater occurring in fractured limestones and marls of the Scaglia aquifer (140 m b.g.) shows very high salinity (E.C. of 16.000 uS/cm at 25°C) and a Na-Cl facies. The Maiolica aquifer shows quite limited outcrops in the area and a lower thickness (< 100 m) than the average, due to the "condensed" stratigraphic series of upper Jiurassic-lower Cretacic sequence overlying the carbonate platform of lower Jurassic age (Cecca et al.,1996) Nevertheless Maiolica limestone shows variable fissuration and locally high permeability, supporting a good water productivity in the drilled boreholes (up to a dozen of l/sec or more). The water is of Ca-HCO3 type, (E.C. of 480-500 uS/cm at 25°C) with a relative enrichment in Cl and SO4, compared to the most common hydrochemical features of the Maiolica's spring water (Dramis, 1973).

4.Conclusions

The study showed the particular hydrogeological behaviour of the Scaglia aquifer at the S. Anna site, where high-salinity waters suggest very low rock permeability and the occurrence of structural "traps" in the fore limb of the Furlo anticline. That anomaly, compared to the regional situation, has similarities in the surrounding areas, where salty waters where found both in vertical and horizontal drillings, expecially near the Scaglia Rossa-Scaglia Variegata border. As for the Maiolica aquifer, based on E.C. and piezometric logs during the drilling and water-budget considerations, we suggest that it may receive indirect alimentation both from the Scaglia aquifer, via vertical downward drainance through the marly Marne a Fucoidi aquitard and, expecially, from the Calcare Massiccio regional aquifer, thoroughly outcropping in the near Furlo Gorge; that is made possible by the extended faulting and the little thickness of the Jurassic aquitard (Rosso Ammonitico fmn.). After preliminary pumping tests, a long-term test will be carried out on the Maiolica aquifer and seasonal water sampling and analysis will take place. Isotopical analysis are suggested for a further comprehension of the hydrogeological basin and water cycle in the area. The study carried out is a first contribution to the understanding and subsequent modelling of the deep hydrogeology of the Furlo area. That is necessary for a proper management of the groundwater resources of the area, traditionally exploited by a local mineral water bottling plant.

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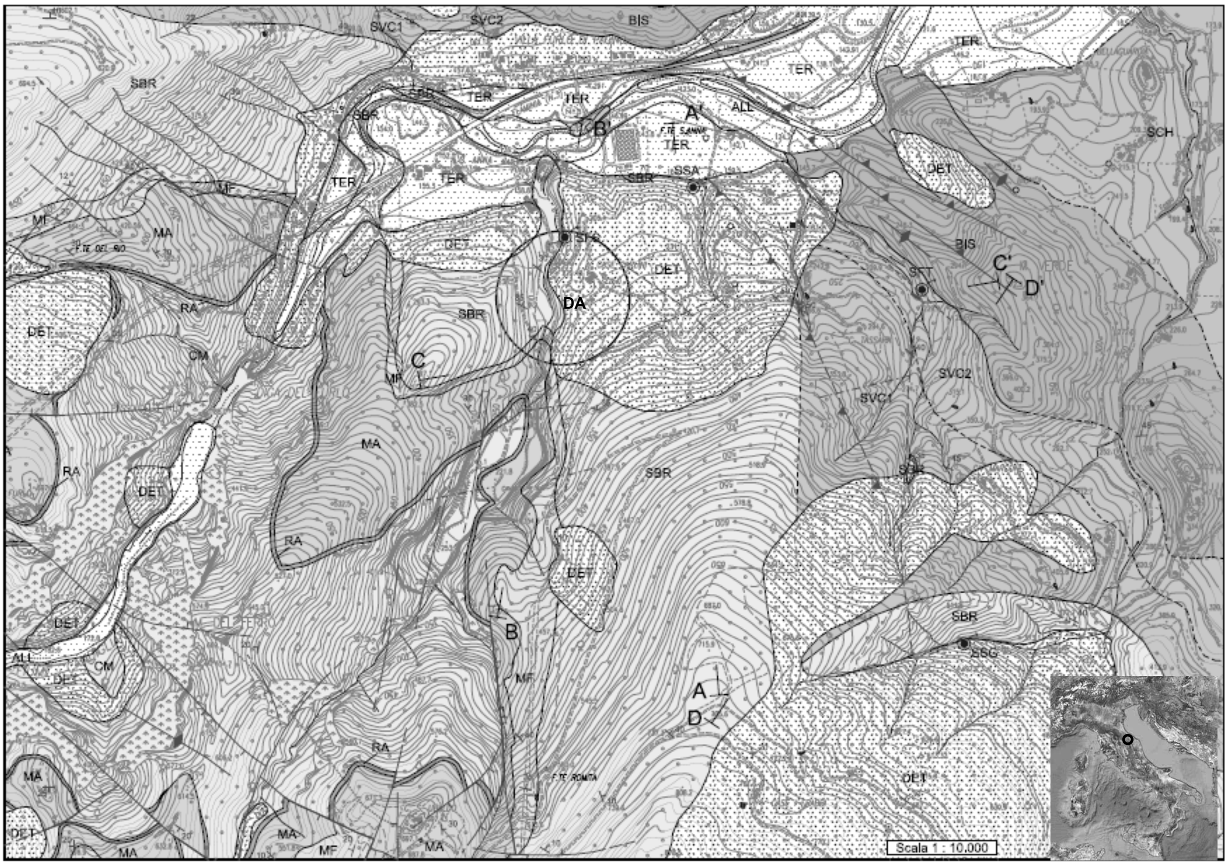

Fig.1 – Hydrogeological map of the S. Anna area (from Cecca et al. ,1996, modified)
AQUIFERS: CM (Calcare Massiccio + Corniola limestones); MA (Maiolica lmst.); SBR (Scaglia Rossa e Bianca lmst + marly lmst.); BIS (Bisciaro marls + lmst.); DET/TER (Slope Debris and Alluvial gravelly deposits)
AQUITARDS: RA (Rosso Ammonitico marls); MF (Marne a Fucoidi marls); SVC1-2 (Scaglia Variegata e Cinerea marls); SCH (Schlier marls and clays).
SS A-T-G: main water springs; DA: Drilling area; A-B-C-D: hydrogeological cross-sections

THE EFFECT OF THE TEMPERATURE INCREASE ON THE AQUIFER RECHARGE PROCESSES

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Key-words: aquifer recharge, evapotranspiration, temperature increase, Campania.

1. Introduction

This study describes results obtained from a simple hydrological analysis carried out on the two hydrogeological catchments, located in Southern Italy: Termnio-Tuoro and Cervialto massif (Civita, 1969; Celico & Civita 1976). Analyses focused on the role that temperature increasing has on aquifer recharge processes, supported by GIS tools.
The topic appears very interesting, as the recent drop of the spring discharge couldn't be explained only by the drop of the rainfall observed in the Campania area (Fiorillo & Guadagno, 2010; 2012).

2. Material and Methods

Based on a resolution of 20x20 m of the digital map of catchments, ground-elevation distribution of each catchment has been computed.
To evaluate the afflux on each catchment, a set of rain gauges has been considered to compute the annual mean distribution of the rainfall. Using GIS tools, a specific rainfall height has been associated to each ground-elevation of catchments.
Based on the thermometer stations available, the relation between annual mean temperature and elevation has been deducted for the entire area. Using GIS tools, a specific temperature value has been associated to each ground-elevation of catchments.
The actual evapotranspiration, E_r, has been computed using the *Turc* formula and the *Thornthwaite* method.
Under GIS environment, the above computed *Afflux grid* and *Temperature grid* have been combined to compute the actual evapotranspiration distribution on catchments.

3. Results

The Cervialto catchment is characterised by higher ground-elevation than the Terminio catchment, indicating an (i) higher amount of snow and (ii) higher thickness of the vadose zone. Both features favour a smoothed response of the spring discharge to rainfall event, as effectively can be observed from the spring hydrograph analyses (Fiorillo, 2009).
The different ground-elevation distribution cause a different distribution of the temperature and afflux on the two catchments. The annual mean rainfall is 2110 mm and 1887 mm for the Cervialto and Terminio-Tuoro catchment, respectively.
The annual mean temperature of the catchment is 8.5 °C and 10.3 °C for the Cervialto and Terminio-Tuoro catchment, respectively.
The mean of the actual evapotranspiration found is 502 mm and 540 mm for the Cervialto and Terminio-Tuoro catchment; this difference depend on the different ground-elevation distribution of the catchments.
The actual evapotranspiration has been also computed using a *Temperature grid* built under hypothesis of temperature higher that the mean of +2 °C and +4C° uniformly over the catchments. Results are shown in Table 1, where an increase +2 °C causes an increase of the actual evapotranspiration of 70 mm for the Cervialto catchment, and of 75 mm for the Terminio-Tuoro catchment.

Table 1. Results of main hydrological parameters of catchments. Er, actual evapotranspiration.

Massif		Mean	Max	Min	σ
CERVIALTO	Elevation (m a.s.l.)	1179	1809	417	241.8
	Afflux (mm/year)	2109.5	2620.8	1529	191.1
	Temperature (°C)	8.5	13.51	4.4	1.36
	Er (mm)	529.1	688.52	409.9	42.68
	$Er_{(+2°C)}$ (mm)	599.0	768.93	455.9	47.13
	$Er_{(+4°C)}$ (mm)	677.7	854.02	529.9	51.58
TERMINIO-TUORO	Elevation (m a.s.l.)	903	1806	340	258.2
	Afflux (mm/year)	1886.8	2547.3	1463.0	194.4
	Temperature (°C)	10.3	14.0	4.4	1.7
	Er (mm)	586.6	702.8	413.2	54.2
	$Er_{(+2°C)}$ (mm)	661.5	782.1	470.1	58.8
	$Er_{(+4°C)}$ (mm)	744.7	865.0	533.7	62.5

4. Conclusions

The recent temperature increase, especially during winter time (Caloiero et al., 2011) appear to have consequence on the discharge of basal karst springs, as it reduces the amount of infiltration useful to recharge the aquifers. Results indicate that an increasing of 1 °C uniformly on both catchments analysed would cause an increase of the actual evapotranspiration of about 35 mm and 38 mm, respectively for the Cervialto and Terminio-Tuoro catchment. Analyses focused on yearly and monthly scale, but more detailed analyses based on daily-scale are in processing.

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HYDRAULIC BEHAVIOR OF KARST AQUIFERS DURING DRY PERIODS

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Key-words: karst aquifer, hydrograph recession, Southern Italy

1. Introduction

Karst aquifers have a fundamental importance for water supply, and large springs are often exploited for commercial and public water supplies (Bakalowicz, 2005; Ford & William, 2007; Goldscheider & Drew, 2007).

During the period of no recharge, spring discharge decreases until the following recharge event, and provides a typical recession limb on the hydrograph. This part of the spring hydrograph is believed to express some fundamental hydraulic and geometric characteristics of aquifers (Schoeller, 1965; Forkasiewicz & Paloc, 1967; Bonacci, 1993; Eisenlohr *et al.*, 1997; Kovacs *et al.* 2005).

Fiorillo (2011) provides a simple hydrogeological model explaining the behavior of the karst aquifer during emptying and also discusses other models that predict the shape of the spring hydrograph in the semilogarithmic plot. On the basis of this model, daily discharge measurements of some karst spring of southern Italy have been analyzed. Data from monitored-water well level inside spring catchments have been also considered.

2. Material and Methods

The model simulates the drainage of a simple cylindrical water-filled tank by different physical laws, and tries to connected the hydraulic behaviour of the tank to actual karst aquifers. The model can be arranged by overlapping several simple tanks with different basal area, A_1 (*composite tank-reservoir*).

Drainage occurs by a tube-hole, with area A_2 an length L, located at the bottom of the tank, and analytical expressions are computed in relation to the geometry of the tank and to the type of tube-hole. The role of the water viscosity decreases if A_2 increases. If the area A_2 is sufficiently wide, the water viscosity can be ignored and drainage occurs in terms of *Torricelli efflux velocity*.

If the area of the tube-hole, A_2, is small, the water viscosity effect cannot be ignored, and drainage can be analysed by the *Poiseuille law*. Filling the tank-connected tube with sand, the drainage can be also modelled using *Darcy's law*.

The above different tank-drainage systems have been called *Torricelli, Poiseuille* and *Darcy reservoir,* respectively.

The characteristic of the *Torricelli reservoir* is the linear decrease of discharge with time; the main consequence of this behaviour is the constant slope of the discharge-time plot at any time and independent of the initial water height, h_o, into *tank-reservoir*.

The *Darcy* and *Poiseuille reservors* present the characteristics of the *Linear reservoir*, where the discharge diminishes exponentially with time and reaches zero for t=∞; in a semilogarithm plot the hydrograph appears as a straight line with a slope angle *arctg(α)*, where α is the recession coefficient.

In the *composite tank-reservoir*, the changing of the size area A_1 causes a variation of the coefficient of recession during drainage. If area increase from $A_1^I \rightarrow A_1^{II}$, the recession coefficient decreases from $\alpha^I \rightarrow \alpha^{II}$ and, independently from the model used (*Torricelli* or *Linear reservoir*), the following relationship can be deduced (Fiorillo, 2011):

$$\frac{\alpha^I}{\alpha^{II}} = \frac{A_1^{II}}{A_1^I} \tag{1}$$

During the drainage, if the water table area of actual karst aquifers, A_c, is constant, the above equation becames for the *Torricelli reservoir* (Fiorillo,2011).

$$\frac{\alpha^I}{\alpha^{II}} = \frac{n_{eff}^{II}}{n_{eff}^I} \tag{2}$$

where the effective porosity, n_{eff}, is computed along the water table level, and $n_{eff}^{II} > n_{eff}^I$

For linear reservoirs (*Darcy* and *Poiseuille reservors*), the equation 2 has to be replaced by:

$$\frac{\alpha^I}{\alpha^{II}} \approx \frac{n_{eff}^{II}}{n_{eff}^I} \tag{3}$$

3. Results

To verify the equation 3, discharge data of some karst springs and monitored-water well level have been compared.

Data come from springs located in southern Italy, and the analyses has been focused on the summer to early-autumn period. Results from three springs are shown in the below figure.

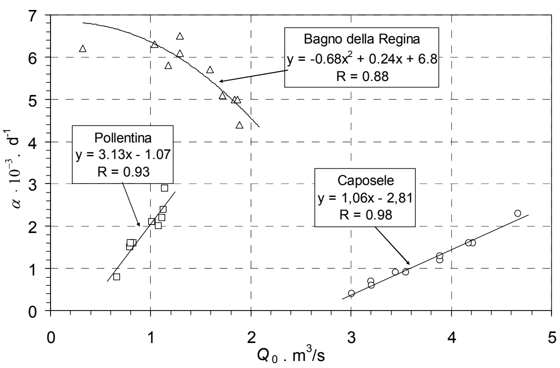

Fig.1 Results for three springs (Caposele, Pollentina and Bagno della Regina) located along the northern sector of the Picentini mountain (Southern Italy): relation between the recession coefficient α and spring discharge at the beginning of the draining, Q_0; years 2000–2009.

The Caposele and Pollentina spring show a linear and positive correlation between α and Q_0; for these springs the recession coefficient is smaller during droughts (low value of Q_0) and higher after wet years (high value of Q_0). On the other hand, the Bagno della Regina spring shows a negative correlation between α and Q_0. In all cases, a single recession coefficient value seems unable to explain all the draining processes of the aquifer.

During the recession periods, the ratio of discharged volume at springs has been connected to the ratio of the effective porosity, allowing to verify the equation 3.

4. Conclusions

The variation in the recession appears to be strongly controlled by the product of the effective porosity (along the water table) and the area occupied by the water table. This product has been called *discharge area*, because it expresses the area of the aquifer filled by free-flowing water along the water table. Both parameters can vary during the emptying process, and they control the shape of the hydrograph on the semilogarithmic plot.

Springs characterized by a decrease of the recession coefficient when Q_0 decreases, as Caposele and Pollentina, generally support the discharge during the long dry period in the Mediterranean areas and can be considered *drought-resistant*.

Springs characterized by an increasing of the recession coefficient when Q_0 decreases, as Bagno della Regina, appear *drought-vulnerable* and their behavior can lead to no spring discharge during prolonged dry period.

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Cost- and time-effective methodology to evaluate aquifer parameters in coastal aquifers

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Key-words: aquifer parameter, permeability, groundwater monitoring, pumping test, straddle packers

1. Introduction

The increasing request of freshwater in coastal areas due to intense anthropization has intensified the research on saltwater intrusion (Barlow and Reichard 2010; Custodio 2010; Post and Abarca 2010). A sustainable groundwater management requires the estimation of some fundamental aquifer parameters (such as hydraulic conductivity) and their variability in order to quantify the magnitude and direction of groundwater fluxes. In case of saltwater intrusion in coastal aquifers also the vertical variability of groundwater quality is fundamental (Netzer et al. 2011) since seawater is characterized by elevated density and viscosity with respect to freshwater and this feature induces density driven flow within the aquifers (Barlow 2003). For these reasons there is the need of cost- and time-effective techniques to define real physical parameters and dynamics of the aquifer.

2. Material and Methods

In this study we present the methodology developed via straddle low pressure packers to characterize simultaneously vertical hydraulic gradients, permeability, and groundwater quality in standard fully penetrating piezometers. The methodology uses two inflatable packers to isolate a window of 0.2 m. The original instrument has been modified by positioning a Levelogger LTC Solinst within the sampling window (Fig. 1). The Levelogger monitors head, temperature and electrical conductivity every 1 second. In line with the packers is connected a centrifuge pump with a flow controller (Fig. 1). The system is set at the desired depth within the piezometer and the packers are inflated by a portable air compressor. Before to start the pumping test, the inflated packers system is left to stand until the piezometric equilibrium, monitored by phreatimeter, is reached. Once the piezometer equilibrium is restored and the point head measurement is recorded, a constant rate pumping test is performed using a flowmeter; or whenever the flux is very low, the outflow rate can be monitored by a litre counter and chronometer. *k* values (m/s) were derived from the equation (Bureau of Reclamation 2001):

$$k = \frac{Q}{C_s r \Delta h}$$

where C_s (-) is the conductivity coefficient for semi-spherical flow in saturated materials through partially penetrating cylindrical test wells and for these condition is equal to 28, r (m) is the radius of the test well, Δh (-) is the head hydraulic gradient between static head and steady state head under pumping condition.

3. Results

The methodology has been applied on several piezometers of the regional monitoring network of the Emilia-Romagna Region (Bonzi et al., 2010). The 2" piezometers are fully screened with a geotextile sock instead of gravel pack, to prevent short-circuits during the pumping tests. The Levelogger LTC records simultaneously the piezometric drawdown induced by pumping and any variations in temperature and electrical conductivity within the aquifer window isolated by the packers. From these data, the equivalent freshwater head and intrinsic permeability values can be derived. During the pumping test the piezometric head can also be monitored by Leveloggers placed above and below the packers; this allows to verify if there is any pressure drop within the piezometer due to a defective isolation of the packers. Finally, groundwater sample can be collected as soon as the pumping test has completed without removing the straddle packer. The use of a Hydrolab flow cell connected to the Hydrolab MS-5 probe (Fig. 1-5) also permits to acquire in situ the other hydrochemical parameters (i.e. dissolved oxygen, pH, and redox potential), which are not recorded by the Levelogger.

The results of pumping test obtained using the packers system have been compared with the intrinsic permeability calculated by pedotransfer formulas. The comparison shows a general agreement along each piezometer profile. Although, the major discrepancies have been found in peat layers, where the grain size characterization is particularly challenging due to the organic nature of these sediments.

4. Conclusions

The proposed methodology is relevant for a detailed characterization of coastal aquifer parameters and flow dynamics.

Application of this integrated method permits to simultaneously perform groundwater sampling, groundwater quality control and aquifer testing. Intrinsic permeability and multilevel equivalent freshwater heads can be easily calculated from acquired data and vertical gradient in the aquifer can be highlighted.

Moreover this technique makes the data available during the monitoring phases and it can be integrated with other techniques of vertical investigations. It is a cost- and time-effective technique that is able to optimize the phase of aquifer characterization with the phase of groundwater monitoring and sampling.

The major issue associated with the presented technique is the hydraulic tightness of the packers that has to be verified before each measure; once that is done, the methodology allows multilevel groundwater sampling in a single monitoring campaign.

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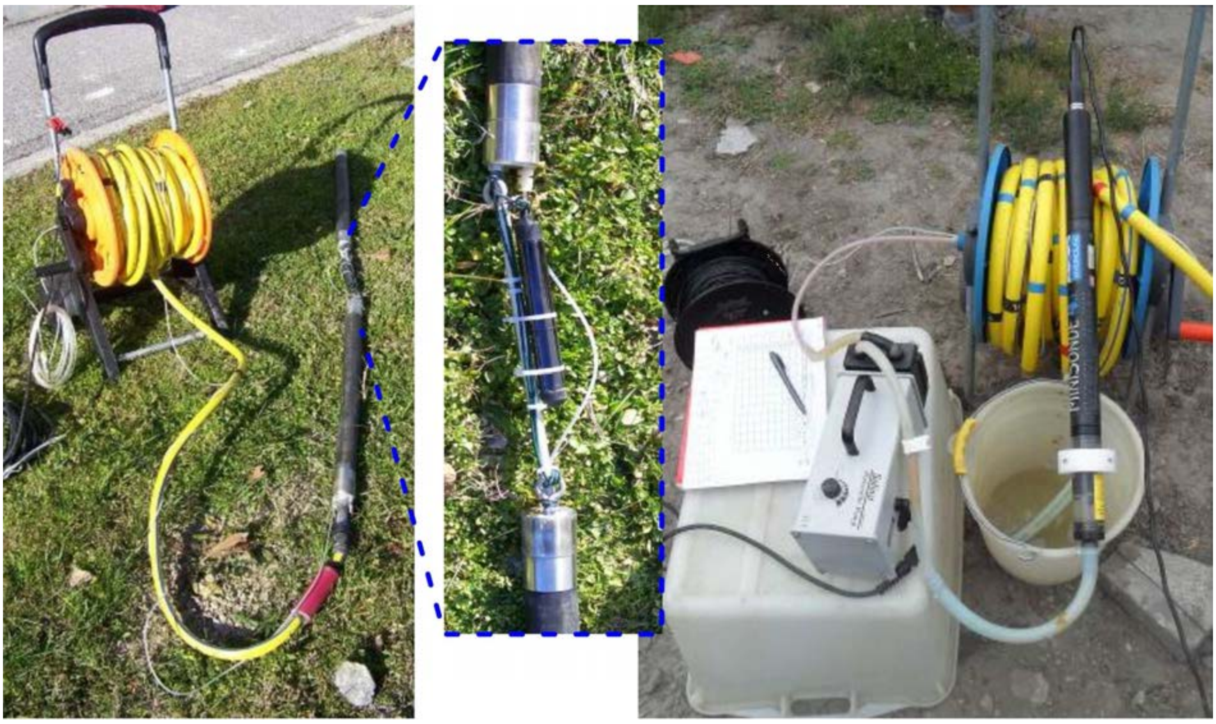

Fig. 1 – on the left the modified straddle packers with Levelogger positioned within the sampling window; in the center a zoom of the sampling window and on the right the Hydrolab flow cell for the monitoring of hydrochemical parameters.

CONCEPTUALIZATION AND PARAMETRIZATION OF A KARST AQUIFER USING LONG TERM MONITORING DATA AND QUANTITATIVE HYDROGEOLOGY: THE ACQUE ALBULE CASE

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Key-words: Hydrothermal systems; Long-term groundwater monitoring; Time series analysis; Deep and shallow groundwater systems relationships

1. Introduction

Hydrogeological characterization of complex hydrothermal karst systems is usually performed by considering hydrogeochemistry (Nalbantçilar and Göçmez, 2005) and physical-chemical characteristics (Liñan Baena et al., 2007). Other studies have adopted a quantitative approach for the analysis of detailed geological settings (Chiocchini et al., 2010; Mazza and La Vigna, 2011) and long-term monitoring activity. In studies using hydrogeochemistry and isotopic and physical-chemical approaches, the analysed water give information about the reservoir lithology, the origin of recharge water (sea water, meteoric water with a range of elevation, juvenile water) and sometimes the temperature of deep water (using geothermometers). In contrast, research activity using quantitative methods focuses primarily on the geological setting definition of the study area and the three-dimensional setting of aquifers through cross-section development with geophysical data, thereby allowing the identification of the recharge areas of the main sources. Moreover, surveying and long-term monitoring activity on the aquifers contribute to the detection of groundwater flow paths, identification of correlations between different reservoirs and evaluation of discharge amounts (Larocque et al., 1998).

Several studies (Giggenbach et al., 1988; Petitta et al., 2010; Carucci et al., 2011) have substantially contributed to the hydrogeochemistry of the Acque Albule basin (AAB - Central Italy), but the quantitative hydrogeology and groundwater flow pattern of this area has not been studied thoroughly. This note is intended to highlight the need for long-term monitoring activity in hydrogeological research, to characterize complex groundwater systems. Regarding the case study presented here, this activity is crucial if the anthropic pressure on groundwater resources significantly affects the natural conditions, which can be understood only by continuous analysis and frequent data collection.

2. Material and Methods

Characterization of the AAB hydrogeological setting was based on field hydrogeological prospecting and long-term monitoring.

For better comprehension of the hydrogeological layout of this complex system, a hydrogeological survey was performed in February 2008. This period was chosen after descriptive statistical analysis of collected monitoring data at that time (about 2006-2007) to survey in a period with minimum average variance of groundwater levels.

Data on the superficial water flow in channels and streams and the groundwater table elevation, electric conductivity and temperature in the wells and piezometers were collected during the survey.

Data registered at the plain monitoring network and at the natural shaft of Pozzo del Merro (PdM) were compared using the fast Fourier transformation (FFT).

3. Results

The system conceptualization consists in two superimposed aquifers, one in the superficial travertine, one in the carbonate bedrock which under the plain results confined by thick marine clay.

The most significant part of this note is the analysis of the long-term hourly monitoring dataset of the AAB monitoring network and of the Pozzo del Merro (PdM), which represents the regional carbonate aquifer. Comparisons between rain and continuous spring outflow data are frequent (Fiorillo and Doglioni, 2010) in the literature about karst systems. The monitoring activity allows for comparisons of groundwater levels variations and frequencies in the wells, piezometers and natural shafts (Bonacci and Roje-Bonacci, 2000; Rahnemaei et al., 2005;). The long-term data of the AAB were selected by periods with no sampling interruptions. The comparison between deep and shallow aquifers shows a similar periodicity, which should confirm relationships between the two levels.

The time difference between the start of a rising event in the Regina Lake (superficial aquifer) and in the PdM is about 42 h, and the distance between them is about 8.5 km. Considering the PdM data series as the piezometer data of the deep groundwater system and the Regina and

Colonnelle Lakes as a level data series registered in a "pumping well" that is pumping the calculated outflow, the deep reservoir transmissivity (T) and storage coefficient (S) can be estimated using the Cooper-Jacob (1946) method. The calculated values of 0.457 m^2 s^{-1} for T and 4.41 10^{-3} for S, which are comparable to other Apennine carbonatic reservoirs. Therefore, because theoretical conditions are not fully respected in this case study, the computed transmissivity and storage coefficient were not considered as absolute values but rather as indicators of the hydraulic properties of the limestone aquifer.

4. Conclusions

The principal outcomes of this study are as follows:

- A groundwater flow conceptual model is proposed for the AAB and characterized by three main hydrostratigraphic units. The limestone bedrock outcrops along the borders of the basin, where it is lowered by normal faults. At the top of the bedrock, Pliocene sandy-clayey marine deposits (UTB auct.) divide a superficial travertine plate and quaternary deposits from the carbonates. The fractured bedrock constitutes (under the plain) a leaky confined aquifer with an order of magnitude of transmissivity preliminarily evaluated as about 0.5 m2 s-1; a second unconfined aquifer is defined by the fractured travertine (transmissivity defined in Petitta et al. (2010) is about 0.2 m2 s-1), which is strongly dewatered by quarry activities (4000 l s-1). Pliocene deposits may be considered as non-continuous aquiclude. The two aquifers are connected at the centre of the plain, where deep hydrothermal water coming from the limestone bedrock flows through the Pliocene deposits into the travertines and mixes with the shallow aquifer. The mixed groundwater in the travertines partially flows from the hydrothermal springs and partially follows the flow path. Because the dewatering was always active, it can be considered as a constant (anthropic) external stress in this system, at least in the last twenty years.
- Geological information together with survey and hydrograph analysis of groundwater levels substantially contribute to this complex groundwater system conceptualization and parametrization. These results confirm the importance of long-term monitoring activity in hydrogeological research. In addition, comparison of levels by statistical analysis could help to understand the relationships between different reservoirs and evaluate the quality of survey data.

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USE OF TRACER TESTS FOR THE ASSESSMENT OF THE RELATIONSHIP BETWEEN SURFACE WATER AND A DRINKING-WATER SPRING (QUINCINETTO, TURIN)

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Key-words: drinking-water spring, surface water, tracer tests, fluorescein

1. Introduction

The Montellina Spring is the main source of drinking-water supply of the City of Quincinetto (Turin). It is characterized by a high discharge, varying on average from 50 to 150 l/s (Sea Consulting & GDP, 2010).

The Renanchio Stream is placed in the right watershed and likely feeding the Montellina Spring (Fig.1). The design of a derivation for an hydroelectric plant from the Renanchio Stream has required the execution of a hydrogeological study. This study allowed an analytical assessment of the hydrogeological relationship existing between the Renanchio Stream and the Montellina Spring.

2. Material and Methods

The Montellina spring is located in the right side of the Dora Baltea Valley. In this area the bedrock consists in the Eclogite Micaschist Complex of the Sesia Lanzo Zone (Compagnoni *et alii*, 1977). It is formed by coarse polimetamorphic micaschist, with gneiss body and basic seams. Locally a Mesozoic cover also develops, represented by quartzite, marble and calcschist.

The bedrock shows a complex structural setting due to the main alpine deformation events. It is affected by striking fracture systems E-W, N-S, NW-SE and NE-SW favoring the landslides.

The bedrock is diffusely covered by glacial deposits referred to both the Dora Baltea Valley and tributary Renanchio Valley glaciers.

The Montellina spring emerges in a landslide body of large elements, near the contact with the underlying glacial sediments. It is also located where the detachment niche crosses a striking NE-SW fracture.

The hydrogeological surveys consisted of:

- measurements of the Renanchio Stream discharge using sodium-cloride (NaCl) tracer tests;
- measures of the overflow of the Montellina Spring employing sodium-cloride (NaCl) tracer tests;
- tracer tests of the Renanchio Stream with fluorescent tracer and its continuous monitoring at the Montellina Spring.

The tests were conducted during 3 measure campaigns between July and November 2011, to verify the results for different discharge of the Renanchio Stream.

In particular the discharge of the Renanchio Stream was evaluated by two tracer tests in two measuring stations (referred as upstream section and downstream section) for each campaign of detection; the tracer tests were carried out by slug injection of a known mass of NaCl in solution into stream.

The losses of the stream in the investigated sector were evaluated on the basis of the difference between the measure of discharge in the upstream section and in downstream section.

The measure of the overflow of the Montellina Spring, that is the surplus water flowing out to superficial network, was evaluated by 3 tracer tests using NaCl. The tracer tests were carried out, by slug injection into the stream created by water surplus of Montellina Spring of a known mass of NaCl.

The estimation of the rate of Renanchio water feeding the Montellina Spring was performed by 3 tracer tests of stream using a fluorescent tracer and its continuous monitoring at the spring. The used tracer is uranine, that showed no effect upon either the genotoxicity or the ecotoxicity tests (Behrens et al., 2001).

The tracer tests were carried out by slug injection of a known amount of fluorescein in solution into the stream in the upstream section. After the injection, the detection and record of fluorescein were started in the water of the Montellina Spring at regular time intervals. The used measuring equipment is a fluorometer, positioned in the spring water.

The rate of the Renanchio Stream feeding the Montellina Spring was calculated by assessing the mass of fluorescein which had reached the spring.

Then the following parameters were evaluated (De Luca *et alii*, 2012):

- amount of water of the Renanchio Stream that feeds the Montellina Spring;
- percentage of water of the Renanchio Stream that arrives to the spring;
- percentage of the discharge of the spring which is derived from the Renanchio Stream discharge.

3. Results

The discharge of the Renanchio Stream varied considerably between July and November 2011, ranging from 133 l/s and 1493 l/s in the upstream section and from 102 l/s and 1104 l/s in the downstream section; also the losses of the stream in the investigated section are different depending on the monitoring campaign, ranging from 31 l/s and 389 l/s.

On the contrary the discharge of the Montellina Spring remained fairly steady between 144 l/s and 181 l/s.

The rate of the Renanchio stream feeding the Montellina Spring, calculated by tracer tests with fluoresceine (Fig. 2), is lower than 19 l/s, both in low water period and in flood period. In details, the surface water moving to the spring ranges between the 1% and 14% of the Renanchio Stream discharge in the upstream section. At last the percentage of the Montellina spring discharge coming from the stream ranges between 8% and 13%.

4. Conclusions

Tracers tests using NaCl and fluorescein allowed to identify and quantify the relashionship between Renanchio Stream and Montellina Spring. Even if there is a large variation of stream discharge and stream losses during the study period, the discharge of spring remains fairly steady.

The quantification of the rate of the Renanchio Stream feeding the Montellina Spring proved that only a small part of stream losses moves to spring. As a consequence, the derivation of Renanchio stream water for hydroelectric use has only a moderate impact on Montellina Spring discharge.

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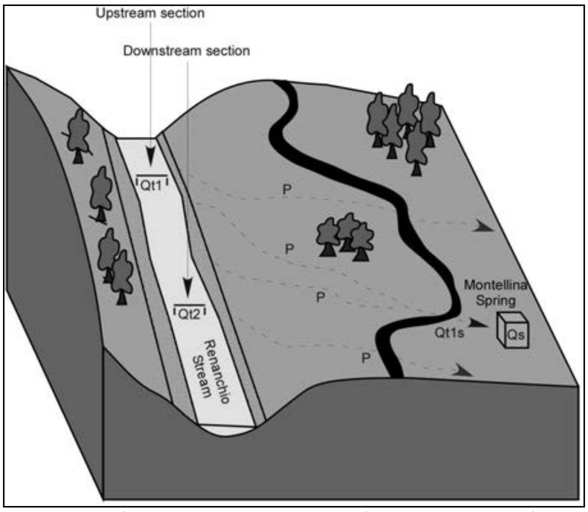

Fig. 1 – Conceptual scheme of study area (Qt1 - discharge of the Renanchio Stream in the upstream section; Qt2 - discharge of the Renanchio Stream in the downstream section; P - losses of the Renanchio Stream; Qs - discharge of the Montellina Spring; Qt1s - rate of the Renanchio Stream feeding the Montellina Spring).

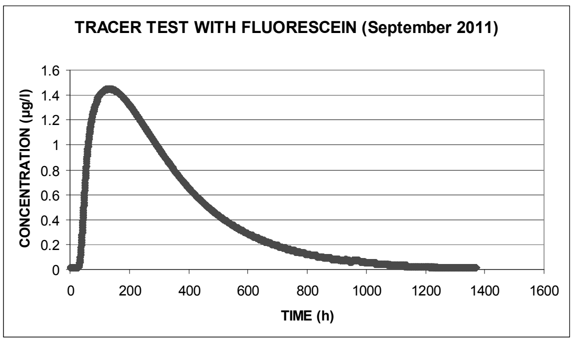

Fig. 2 – Fluorescein concentration in the Montellina Spring during the tracer test in the Renanchio Stream of September 2011.

ANALYSIS OF BOREHOLE DILUTION TESTS BY A NUMERICAL MODELING APPROACH

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Key-words: Borehole dilution test, Venetian plain, Variable-density flow, SEAWAT-2000.

1. Introduction

The borehole dilution test, also called single point dilution test, is a method used to estimate horizontal groundwater velocity in the aquifer surrounding a borehole. In this method, a tracer is introduced and homogeneously distributed into a borehole test section. The tracer is subsequently diluted by the groundwater flow and its decreasing concentration is measured over time. Borehole dilution tests use a variety of tracers, such as radioactive tracers, dyes, brines and deionized water, and have been conducted since 1950^{s} in fractured and porous aquifers (Halevy et al., 1967; Pitrak et al., 2007; Tsang et al., 1990).

The theory, the principles of application and the limitations of the single point dilution technique are well known (Halevy et al., 1967; Drost et al., 1968). Particularly, use of brine, such as a NaCl solution, presents obstacles when using an analytical solution to evaluate the test results, because density contrast would cause unfavorable attenuation of the flow or density movement of water (Pitrak et al., 2007).

To overcome this issue Shafer et al. (2010) have recently proposed to analyze the result of a borehole dilution test, with NaCl brine, using a three dimensional numerical modeling approach with SEAWAT-2000, variable-density flow and transport model (Langevin & Guo, 2006).

The results presented here concern the application of this method in the analysis of three single point dilution tests made in a shallow unconfined aquifer in the middle Venetian plain.

The test-site is located in the “Fontanili” zone, near Villaverla (VI), inside the area of ACEGAS-APS, which is the municipal water supply company of the city of Padua.

The subsoil composition and consequently the hydrogeological features, until up to 10 m bgl, shows high heterogeneity with gravel horizons alternating with sandy, silty and clayey levels. The hydraulic conductivity (K), derived by slug-tests, range over three orders of magnitude (from 2.6E-06 to 3.8E-03 m/s; Ortombina et al., in press).

2. Material and Methods

Three single point dilution tests were done in the GP5 borehole, drilled in the test-site. This piezometer has a depth of 3.96 m bgl, with screens from 0.96 to 3.96 m bgl and a diameter of 50 mm.

The tests were done in different periods and by different procedures. The first test was done in April 2011 using 10 l of saline solution with a NaCl concentration of 12 g/l. The second and the third tests were done respectively in June and in December 2011 using 25 l of saline solution with a NaCl concentration of 9.6 g/l.

Ideally, it would be preferable for the tracer to mix instantaneously within the well volume following release. In practice, this is difficult to achieve and to facilitate the mixing, the saline tracer was injected gradually along the screen. At the end of each injection one or two recording electrical conductivity (EC) sensors were placed in the screened part of the borehole and set to record EC in 10-min intervals for 5 days. In the first test the EC sensor was placed at 2.5 m in depth, while in the second and third tests the EC sensors were placed at 2.3 and 3.1 m from the top of the borehole. An experimental relationship was carried out to convert from EC (mS/cm) to NaCl concentration (mg/l).

A three-dimensional finite difference numerical model was implemented with SEAWAT-2000 in order to reproduce the decrease of NaCl concentration registered during the first test. The model domain is an 18 x 20 m rectangle centered on GP5 borehole and oriented with a 50° inclination from the North direction, according to the mean groundwater flow direction. A high-spatial resolution, non-uniform grid with cell dimension from 3 cm to 30 cm resulted in 102 columns (X-dimension) by 118 rows (Y-dimension). The minimum 3 cm horizontal grid spacing was designed to represent the diameter of the borehole (5 cm) and, separately the 2 cm thick gravel pack surrounding the screen. The vertical discretization is represented by 18 layers of variable thickness and was designed to break the screen interval into segments so that the model results would be directly comparable to the elevation of the EC probe. Four zones of hydraulic conductivity (K_x, K_y and K_z), Specific storage (S_s), Specific yield (S_y) and effective porosity (n_e) were distinguished to represent respectively wellbore, gravel-pack surrounding the screen, upper gravel aquifer (layers 1-8, on average, from 52.38 to 49.97 m a.s.l.) and lower sand aquifer (layer 9-18, from the bottom of the

gravels to 48.61 m a.s.l.). The upgradient and downgradient constant heads (1st type boundary conditions) were established at the north-eastern and south-western sides of the domain to reproduce the hydraulic gradient during the test.
The tracer injection was simulated by modifying the initial concentration on the cells corresponding to the wellbore as a function of the EC recorded at the beginning of the test. The model was implemented in transient mode, with a total simulation time of 5760 min.

3. Results

The Darcy velocity, analytically calculated through a drainage coefficient of 2 (Pitrak et al., 2007), is respectively equal to 5.62E-07 m/s for the first test, 2.59E-07 m/s for the second and 2.63E-07 m/s for the third test. These values are slightly different because the dilution tests were done with hydraulic gradients very similar and low ranging from 0.4% to 0.3%.
With the transient simulation, a very close match of calculated concentrations to observed concentrations, which span the entire history of tracer displacement, was obtained (Fig. 1). The quantitative calibration reaches a good level, expressed by a normalized root mean square (RMS%) of 2.54%. The parameters that produce these results are shown in Tab. 1.

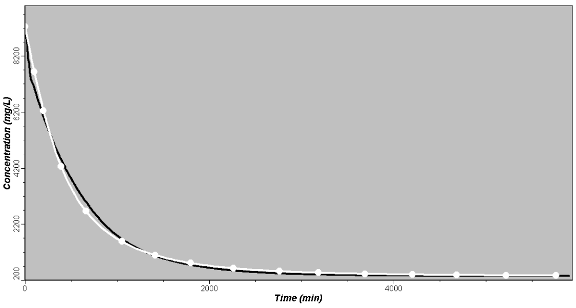

Fig. 1 – Concentrations of NaCl vs. time: observed values (black line) and calculated values (white line and point).

Zones	K_x (m/s)	K_y (m/s)	K_z (m/s)	S_s (1/ft)	S_y&n_e ( )
wellbore	1.00E-02	1.00E-02	1.00E-02	3.05E-06	1
gravel-pack	1.00E-03	1.00E-03	1.00E-03	3.05E-06	0.3
gravel aquifer	9.00E-05	9.00E-05	9.00E-06	3.05E-06	0.14
sand aquifer	1.10E-05	1.10E-05	1.10E-06	3.05E-06	0.09

Tab.1 - Estimated values of Hydraulic conductivity (K_x, K_y e K_z), Specific storage (S_s), Specific yield (S_y) and Effective porosity (n_e).

K were assigned as isotropic properties on the horizontal plane (K_x=K_y) and as anisotropic properties on the vertical plane (K_x/K_z=10), except for the wellbore and gravel-pack zones where K was always isotropic. The Longitudinal dispersivity (α_L) was fixed at 0.07 m on the entire domain, while the ratios of transverse to longitudinal dispersivity (α_T/α_L) and of vertical to longitudinal dispersivity (α_V/α_L) were fixed respectively at 0.1 and to 0.01. During the calibration process, the wellbore parameters were fixed, whereas the gravel-pack and aquifer parameters were allowed to vary. All parameters derived from the calibration process are consistent with other supporting information regarding the aquifer and groundwater flow properties (Ortombina et al., in press).

4. Conclusions

The borehole dilution test with brine is a fairly easy and inexpensive method to estimate horizontal groundwater velocity. The critical component of this test is the density contrast between the brine and the groundwater, which may lead unfavorable attenuation of the flow or density movement of water.
A method different from the traditional approach for analyzing data from borehole dilution tests with brine is the numerical modeling technique. Using a variable-density flow and dissolved transport numerical simulation to reproduce the test results provides a substantially improved estimate of aquifer properties as compared to analytical techniques that provide estimates only of groundwater velocity.

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HYDRAULIC CONDUCTIVITY DISTRIBUTION AND HYDROGEOLOGICAL BEHAVIOUR OF SOME AQUITARDS IN SOUTHERN ITALY

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Key-words: aquitard; carbonate aquifer; marly-clayey-calcareous succession; siliciclastic deposits; southern Italy

1. Introduction

Carbonate aquifers are a primary source of groundwater in southern Italy supplying an average volume of 4.1 x 10^9 m^3 per year (Celico, 1986). Hydrogeologic surveys carried out mainly at regional or catchment scale, suggested that the main springs of these aquifers often occur at the contact with lower permeability siliciclastic deposits or marly-clayey-calcareous successions.

These successions are then considered as aquitards in the actual conceptual model (Celico, 1986). Nevertheless, to date there are no studies at site scale that analyse relationships between carbonate aquifers and their relative aquitards, despite the possibility that these interactions may have a great significance in controlling the effectiveness of groundwater flow schemes and water balances in carbonate aquifers and in defining the potential of these lower permeability rocks as a groundwater source. The hydrogeologic role of other successions made up of sandstones, marls and siltstones have been recently investigated in northern Apennine (Italy). The research demonstrated that the latter does not behave as aquiclude (Gargini et al., 2008; Vincenzi et al., 2009), as reported in previous studies. A few other studies (Eaton & Bradbury, 2003; Eaton et al., 2007) on the hydrogeology of sedimentary rock aquitards demonstrated that flow dynamics can be more complex than previously believed. The new findings have important implications for predicting groundwater flow and for planning and protecting water supplies.

The main goal of this research was to analyse the hydrogeologic role of siliciclastic deposits and marly-clayey-calcareous successions along the northern part of the Matese carbonate massif (southern Italy) through (1) the hydraulic characterization of siliciclastic rocks at a test site, by means of Lugeon tests and (2) the identification of the groundwater flow system discharging at an important spring located within a marly-clayey-calcareous succession at a second test site, by means of isotopic investigations.

The Matese carbonate massif can be defined as a basin-in-series aquifer system (sensu Celico et al., 2006). Several important springs (mean annual discharge up to 4.7 m^3 s^{-1}) are fed by the hydrostructure. The northern side of the carbonate massif is bounded mainly by siliciclastic deposits and marly-clayey-calcareous successions (De Corso et al., 1998). Two test sites were selected within these lower permeability deposits.

2. Material and Methods

At test site 1, the hydraulic conductivity of siliciclastic rocks was calculated using the results coming from several tens of Lugeon tests that were carried out in 20 boreholes. At test site 2, rainwater samples for stable isotope ($\delta^{18}O$) analyses were collected in three rain samplers along the northern slope of the carbonate aquifer, at 1150, 1014, and 635 m asl. The sampling was carried out on a monthly basis from November 2007 to October 2008. During the high-flow period and the low-flow period, water samples for stable isotope ($\delta^{18}O$) analyses were collected (1) at spring SC, (2) at well P1 drilled within the marly-clayey-calcareous rocks, upgradient of the spring, and (3) at well P5 drilled within the same succession, downgradient of the spring. $\delta^{18}O$ was used as environmental tracer to identify the groundwater flow system discharging at spring SC.

3. Results

The results obtained in test site 1 can be summarized as follow:

- The hydraulic conductivity of siliciclastic deposits ranged from 1.1 x 10^{-8} to 2.7 x 10^{-6} m s^{-1}.
- In some boreholes at a depth below 30-35m from the ground the rock mass did not absorb the injected water;
- At a depth shallower than 15m from the ground the hydraulic conductivity was usually higher than 5.2 x 10^{-7} m s^{-1};
- Taking into consideration the hydraulic conductivity values (6.9x10^{-7} to 3.5x10^{-6} m s^{-1}; Celico et al., 2006) calculated in the carbonate protolith, there is no significant contrast in permeability between the different rock types along the boundary in the upper 15 m of siliciclastic deposits

- Such findings show that significant groundwater discharge is allowed from the massif towards the siliciclastic deposits if the hydraulic head in the massif is higher than a threshold depth, which was about 15 m below ground at this site;
- From this depth and deeper, the groundwater discharge abruptly diminishes to become negligible below 25–30 m below ground.

The result obtained at test site 2 can be summarised as follows. Taking into account the isotopic composition of the precipitation and the local $\delta^{18}O$ gradient, the results of isotopic analyses (table 1) depicted the following scenario:

	$\delta^{18}O$ (‰ vs SMOW)		
	P1	**Spring SC**	**P5**
High Flow Period	-7.67	-7.82	-7.27
Low Flow Period	-7.61	-7.87	-7.54

Tab. 1 – Isotopic composition of groundwater and spring water.

- Both the spring SC and well P1 are clearly fed by the carbonate massif, thereby suggesting that a significant groundwater discharge is allowed along the boundary between carbonate rocks and marly-clayey-calcareous deposits;
- Thus, the reverse fault that lies between carbonate and marly-clayey-calcareous deposits does not behave as an aquiclude or aquitard; instead, it appears to partially impede groundwater discharge;
- The shallower and more densely fractured marly-clayey-calcareous sequence does not behave as aquitard and allows the groundwater to flow towards the spring SC;
- The isotopic content of groundwater collected at well P5 is more depleted than the content of rainwater collected within the marly-clayey-calcareous succession; thus, a significant mixing occurs at this site between groundwater flowing from the carbonate massif and local infiltration water; as expected, in low-flow period, the contribution of local infiltration water is lower, as demonstrated by the more depleted $\delta^{18}O$ content in P5.

4. Conclusions

This study demonstrated that siliciclastic deposits and marly-clayey-calcareous successions in the Apennine chain (southern Italy) may allow significant groundwater discharge from carbonate aquifers. Thus, they do not everywhere behave as aquitard, contrary to the previous model (Celico, 1986). Instead, groundwater flows through the upper part of these successions, where stress release fracturing and weathering enhanced rock permeability in the near surface bedrock. In the wider context of the southern Apennine chain, 3 main scenarios can be depicted:

- Scenario A: the hydraulic head in the carbonate aquifer is higher than the bottom of more densely fractured rocks and the thickness of the more densely fractured rock interval is not sufficient to accommodate all inflow; in such a scenario, the groundwater flows in part at a spring and in part through the more densely fractured rocks;
- Scenario B: the hydraulic head in the carbonate aquifer is higher than the bottom of more densely fractured rocks and there is no significant contrast in permeability along the transition between them; in such a scenario, complete groundwater inflow is allowed and springs have not developed along the border of the carbonate massif;
- Scenario C: the hydraulic head in the carbonate aquifer is lower than the bottom of more densely fractured rocks; in such a scenario, no significant groundwater flow is allowed.

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Problems in the application of the environmental isotope to the hydrogeological analysis of high mountain aquifers

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Key-words: isotopes, carbonatic aquifer, karst, hydrogeology

1. Introduction

The subject of this paper is the analysis of problems related to the use of environmental isotopes in central Apennine limestone aquifers (Barbieri et al. 2003; Boni et al. 1986; Conversini and Tazioli 1993; Desiderio et al. 2005; Minissale and Vaselli 2011; Tarragoni 2006; Tazioli et al. 2007). Just using the ^{18}O and ^{2}H, in different zones of Apennine, we noticed that many problems can arise, due to several, often interacting, factors.

In this paper description and analysis of such problems – connected to the generally very complex and not always completely defined hydrogeological setting- are presented. Two different areas have been covered by the investigation: central Marche ridge and Sibillini Mountains in the south-western Umbria and Marche regions. In these areas the aquifers of Calcare Massiccio, Maiolica and Scaglia are generally divided by different aquicludes (Boni et al. 1986; Nanni and Vivalda 2005). Owing to the structural setting of ridges, among the aquifers there is evidence of hydraulic contacts (due to tectonics) which mix different groundwaters. An important role in recharging and circulation of groundwater is played by karstification. For the Massiccio complex, which contains the basal groundwater regional flow, the role of karstification is known, above all because the karst systems are numerous, known and permit inspection.

On the contrary, for the Maiolica and Scaglia complexes, often connected to the basal aquifer, the karst zones are rare and less known, particularly in Scaglia aquifer. So tectonics and karstification lead to hydraulic contacts among different aquifers; this fact makes the identification of hydrogeological basins and the study of groundwater circulation very difficult, especially in the Mt. Sibillini area.

Aquifer recharge in Sibillini Mountains is strongly driven by karstification, characterized by dolines and active sink holes which probably develop either in the Maiolica and the Massiccio complexes. This fact brings to a rapid infiltration of rainwater and snowmelt towards aquifers.

Environmental isotope ^{18}O and ^{2}H were used to better understand groundwater circulation and area recharge in the studied zones. In this way, the local meteoric water lines (LMWL) and isotopic altitude gradient could be derived for the Mt. Sibillini area (highest quote of 2450 m asl) and in central Marche ridge area (highest quote of 1450 m asl).

This paper studies and develops methodologies concerning LMWL and isotopic gradient determination, which are presented with an examination of problems deriving from data interpretation.

2. Material and Methods

In the investigated areas, different sampling methods have been chosen. In the Mt. Sibillini area, characterized by the presence of a snowpack, which remains for a long time, an automatic sampling system, with a heating resistor to avoid freezing of samples, has been installed with periodic sampling of rainwater and snow. In the central Marche ridge a simple system – made by an insulated PVC cylinder, placed in heated rooms and sampled monthly – has been utilized. The measurements have been performed from 2006 to the present years. Isotopic data have been processed calculating for each sampling station the average of the values, weighted with rainfall amount; these weighted values have been related to the altitude of the sampling station. The regression line (obtained with least squares method) has a slope that is the so called isotope/elevation gradient.

3. Results

The obtained results allowed to stress issues concerning isotopic data collection and interpretation, and to make certain considerations about the use of isotopic data in hydrogeology. For example, the analysis of the relationship ^{18}O–^{2}H for the different sampling stations, highlighted that some samples may have been an anomalous behavior.

Such anomalous data might indicate sampling errors, bad storage of samples, or not too accurate analytical determination. The choice of rejecting some data might be made to avoid inexact drawing of the LMWL; this fact involved a loss of quality in the LMWL.

Another issue concerned the necessity of measuring the isotopic content of the snowmelt and melting water, together with the isotopic values of the rain water as well. Melting water constituted, in several cases, the main recharge input of some springs and aquifers. Sampling of such water is very difficult, above all for the presence of slopes between 1500 and 2500 m asl, but even for the presence of karstic plateau and active sink holes which collected and moved such waters up to the aquifers.

Concerning the isotope/elevation gradients, for the Mt. Sibillini area we obtained a value of ^{18}O of -0.161 ‰ / 100 m, close to that obtained in central Marche area (-0.145 ‰ / 100 m). The obtained values are in the range of the gradients indicated by Longinelli and Selmo, 2003; Zuppi et al., 1974; Tazioli et al., 2007; Tarragoni 2006.

Using these values to calculate the elevation of recharge area of springs (located in the studied zones), different problems have been stressed. In the central Marche area the calculated elevation were consistent with the hydrogeological setting; in the Mt. Sibillini area the obtained elevation were generally consistent with the physical setting; the complexity of hydrogeological setting in this area made difficult to interpret the isotopic data. Not always, in fact, was it possible to identify the contribution of several aquifers to the basal flow.

4. Conclusions

Several problems relating to the application of environmental isotopes to hydrogeological studies in the central Adriatic Apennine, are concerned with different aspects connected with the mode of obtaining the isotopic data, or with conceptual aspects related to the complexity of the hydrogeological system.

In this paper the importance of the correct position of the gauging stations and of the sampling methods of the rain waters, snow and especially snow melting waters, is pointed out.

The respect for these factors is essential to reconstruct a valid local rainfall line.

Conceptually, this work highlights the difficult utilization of the environmental isotopes, to define the aquifer recharge zones of high mountains, without an effective geological model. For the central Marche ridge, whose we have a well defined hydrogeological model, the contribution of isotopic analysis to identify the spring recharge areas was decisive, while for the Sibillini mountains this contribution has been more problematic. Therefore, in presence of a very complex geological structural setting, that in turn involves an equal hydrogeological complexity, the support of the environmental isotopes to define the recharge areas of the aquifers and the groundwater circulation might be less decisive. Just on the basis of the different issues emerged and discussed here, in the context of our current studies, we have considered to develop special snow melt samplers and to enhance the monitoring network specially in relation to the different altitude of the acquifer outcrops.

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GROUNDWATER FIELD MEASUREMENTS FOR STREAM SEEPAGE ESTIMATION

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Key-words: stream seepage, numerical modeling, heat transport, artificial recharge

1. Introduction

The water leakage from gravel riverbeds in high plain areas is one of the most important natural factors contributing to groundwater recharge in Veneto region (Northern Italy, *fig. 1-A*).

Along the Brenta river two pilot transversal ramps (permeable check dam) were built in order to reduce the downstream flooding risk and to increase the river dispersion. These engineering works represented an useful opportunity to estimate the hydraulic interaction between the aquifer and the Brenta river. In this area, in fact, the stream seepage reaches very high values (4 – 5 m^3/s km).

The objective of the study is to compare the stream seepage before and after the realization of the artificial ramps, by means of several field investigations and a groundwater monitoring activity carried out since 2007.

To this purpose, groundwater head and temperature data were used as calibration targets for numerical modeling of flow and heat transport.

2. Material and Methods

Boreholes and monitoring wells were drilled to obtain the geotechnical classification of sediments and the hydraulic parametrization of the unconfined aquifer. Automatic probes and level data loggers were also used to monitor temperature and pressure head both in river and in the piezometric network.

The experimental dataset was therefore analyzed to build the site specific conceptual model.

Numerical finite difference (FDM) and finite element (FEM) models were developed to obtain respectively the flow field distribution and the heat transport simulations, concerning mixing processes of shallow water into the aquifer.

In particular a transient two-dimensional groundwater model was realized to determine the equivalent hydraulic conductivity of the streambed.

A specific 3D transport model was finally set up to estimate the river dispersion rate, considering the thermal monitoring time series as calibration target.

3. Results

Field measurements confirmed that the pilot ramps realized in Brenta riverbed have locally increased the stream seepage rates.

After the completion of hydraulics works persistent rises of water table (of about 4 meters) have been detected in near monitoring wells. This condition seems to be stable during a long-term monitoring period which includes all the different phases of the hydrogeological regime.

Thermal datasets proved to be useful to validate the artificial groundwater recharge effectiveness. For example, in monitoring well Pz1, that was at first barely influenced by the stream leakage because of the greater distance from Brenta river (*fig. 1-B*), a marked head and temperature variation was identified after the realization of ramp S1 (*fig. 2*).

The groundwater temperature resulted heavily conditioned by the streambed dispersion, even in furthest monitoring point.

The modeling process considered different saturation conditions of the gravel bed material, and the computed values of hydraulic conductivity well agree with those obtained by borehole field tests.

The computed increase of stream seepage rate connected to artificial recharge in check dam S1, is of about 1 m^3/s.

Heat transport model also showed a significant fitting to the thermal monitoring data, so it was possible to obtain a valid characterization of riverbed leakage in this location. These results suggest the usefulness of thermal data for a reliable interpretation of the river dispersion process.

4. Conclusions

The aim of this study was to provide a quantitative analysis of the complex interaction between a leaking river and unconfined aquifer.

An analytic approach was used during the initial stages of the work to estimate the incremental dispersion rate from stream to aquifer, consequent to the realization of hydraulic works in the riverbed.

The results of numerical modeling confirmed the the hydraulic parameters measured in the field and allowed to estimate the increase of stream discharge connected to the artificial ramps, which is in the range of 1 m^3/s.

Long-term monitoring activities are planned for the next years, in order to assure the actual conditions stability.

Included in a project of compensatory actions, stream seepage estimations support in the next future the development of sustainable waterworks in Brenta river basin.

Aknowledgements

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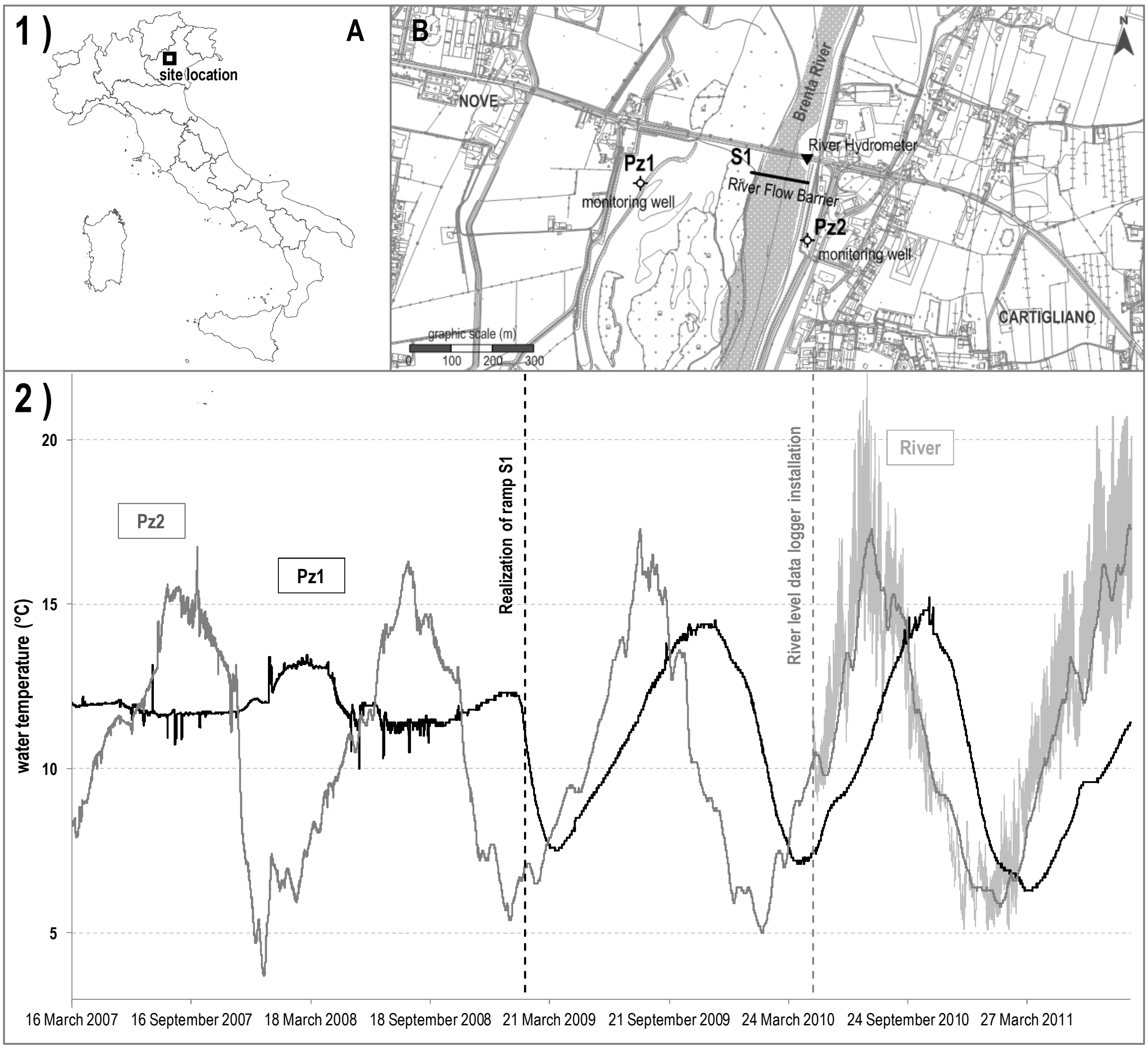

Fig. 1) A - Site location map, B – Monitoring wells, river level data logger and transversal ramp S1 position; 2) Water temperature measured in monitoring wells and in the stream before and after the realization of pilot check dam (permeable river barrier).

THE SNOW MELTING PROCESS

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Key-words: Melting snow, spring flow, monitoring

1. Introduction

The Italian territory is characterized by the presence of large mountainous areas (Alps and Apennines), which houses the main feeding areas of many important springs typically located at the foot of the mountains.
In areas at high altitude, winter and part of the spring precipitation are solid, accumulating large masses of snow that only in the following months, with increasing temperatures, start the melting process providing large amounts of water for the basic charge aquifer (De Walle 2009). In many alpine areas the accumulation and subsequent snow melting have a length of more than eight months, heavily influencing the hydrodynamic spring.
In systems characterized by a high permeability (Vigna et al. 2010, Vigna 2007), the flow rate is small in the winter season, with the exception of mild increments linked to abnormal temperatures due to winds *Fhőn* or Sirocco. In March, the water flow begins to present a progressive increase characterized by very marked daily fluctuations related to changes in solar radiation and night-day temperature of the air. The maximum peak flow is recorded as a result of spring rains, when the liquid contribution is compounded by an additional tax rate related to the snow melting. Flood continues until the summer, when, even in July, mild daily fluctuations of the flow are still observed. In systems characterized by lower permeability, daily changes of water flow are no registered, due to the inertia of the system: the discharge has a progressive increase, reaching the maximum at the end of the spring season, when the contribution of snow melting is added by the rainfall of this period (Banzato et al. 2011). Next the flow decreases very slowly, reaching minimum values just in the winter season. On the multi-year hydrographs, the relationship between the winters, characterized by copious snow and major flooding are strictly evident.
In general to take the values of the precipitation at high altitude are used pluviometers equipped with heater or meters to the snow height, which can measure with good accuracy the volume of inputs. These values can not be correlated with spring discharges, since the snow melting is very late compared to the snowfall. Moreover, the heated pluviographs require, for a proper functioning, the electrical current, that in many mountain areas is not available.

2. Material and Methods

For several years the hydrogeology team of the Politecnico of Torino is testing a new instrument (called "interred snowpluviometer") capable of directly measuring the amount of water due to snow melting (Vigna et al. 2009).
The experimental equipment consists of a calibrated funnel, buried up to level ground, connected through a tube with a rain gauge held in a container buried under the ground level. There is no need artificial heating of the funnel and the acquisition system as being buried is able to work even with air temperatures of many degrees under zero (Fig 1).

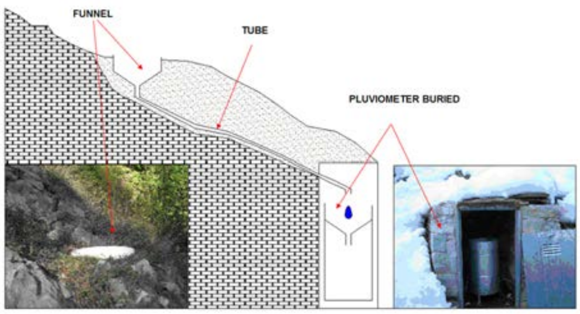

Fig 1 – Interred snowpluviometer sketch

More experimental equipment have been installed at two different test site. The first is located at 400 m asl in an area easily accessible for manual controls. The second to about 800 m asl at the Bossea experimental station, where for over 30 years hydrogeological data are acquired (Banzato et al. 2011). In this second site it has installed more experimental devices, with different exposures to solar radiation. To check the reliability of measurements and comparison with conventional equipment, were also installed other pluviographs nearby.

3. Results

The snow melting, detected with the new equipment, is characterized by hourly values generally quite low with peaks around 20 mm occurring in conjunction with the hottest hours and most solar radiation. In function of daily temperature trend, values may vanish altogether (when air temperatures fall below zero), or reduced to a few millimeters at night. In response to air temperature variations, alternate days with significant contributions to periods in which the snow melting is completely absent (Fig. 2). This process begins in the sunniest and lower altitude side then extending, with the increase in air temperature, to the higher altitude areas with northern exposure. The fusion persists for several weeks or months (depending on local climatic and morphological situation) promoting the process of water infiltration in aquifers with a rather low permeability. On the contrary the rainy, that usually go on short periods with a generally high intensity, causing a water runoff in areas of low permeability, the shares of snow melting are an important, relatively continuous and of long time water contributions for the underground.

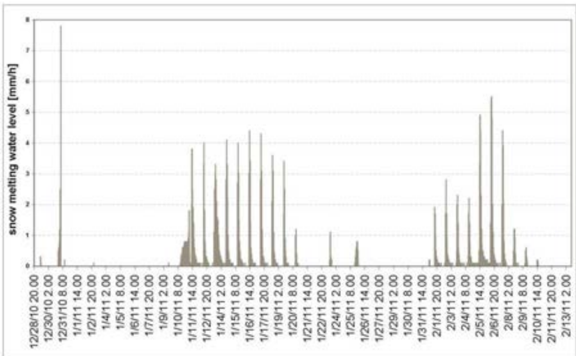

Fig. 2 – Snow melting hourly values in winter 2011 regarded by interred snowpluviometer

4. Conclusions

The comparison between the data, recorded during an entire winter season, from heated snowpluviometers and those detected by the experimental equipment, shows that the total value associated with the snowfall is very similar to the demonstration that the detection system is reliable and that the sublimation phenomena are negligible.

The same comparison shows how the daily values recorded by the two devices are very different even if these data are detected in experimental stations located at low altitude.

In areas at high altitude, the time interval between snowfall (recorded by heated snowpluviometers) and contributions related to the melting process can be up to five months.

Given the obtained achievements, "interred snowpluviometers" are the only instruments available to detect and quantify the process of melting snow levels. These devices have proven effective and affordable, can replace in the mountainous areas the traditional pluviographs

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PARAMETERIZATION OF HARD ROCK AQUIFERS IN THE ROMAGNA SECTOR OF NORTHERN APENNINES), RAVENNA AND FORLI'-CESENA PROVINCES (ITALY)

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Key-words: Marnoso-Arenacea formation, springs, groundwater flow systems, Northern Apennines, hydrologic recession

1. Introduction

In Northern Apennines (Italy) hard rock aquifers prevail on karst and porous aquifers. A big portion of the chain is formed by siliciclastic and calcareous turbidites, arenites and ophiolites. These geological units constitute the most valuable groundwater reservoir of the area.

A plenty of springs discharge from these huge outcrops of hard rock aquifers; these springs originate from a variety of groundwater flow systems (GFS), connected to hydrogeological structures of different complexity and depth.

Some previous studies in different test sites of Northern Apennines (De Nardo et al., 2007; Gargini et al., 2008; Canuti et al., 2009; Piccinini et al., in press) allowed to define a first outline of springs and GFS in these geological units: mean spring flow rate is low (VII-VI class of Meinzer), due to the dominant low-medium permeability of the rock mass; the GFS discharge is mainly stream-focused and represents the basis of surface waters environmental flows. Locally, in proper conditions, bigger springs occur, attaining discharges of 10-20 L/s during low flow conditions and so capable to sustain public water supply of local community.

The here presented investigation has been founded by the Public Agency responsible for watersheds hydrologic budgets (Autorità dei Bacini Regionali Romagnoli, Emilia-Romagna Region) and derives from the need to refine the watersheds hydrologic budgets and from an idea of the Geological, seismic and soil survey.

The study area (Fig. 1) has an extension of about 1800 km^2 and encloses the mountain sector of the following watersheds: Lamone River, Marzeno River, Montone River, Rabbi River, Bidente River and Savio River.

Marnoso Arenacea Formation mainly outcrops in the study area (Fig. 1), except for the south eastern sector where mainly arenitic units outcrop.

2. Material and Methods

An investigation group formed by the authors has planned the hydrogeological characterization and springs/upreach streams monitoring activity on different test sites, in order to evaluate groundwater resources and to rank different GFS in terms of yield, base flow discharge, recession coefficient and hydrochemistry. The aim of the research follows two main goals: the hydrogeological mapping of groundwater resources in Northern Apennines, correlating discharge regime and base flow hydrological behaviour with lithology and geological structure, and the need to get an insight on groundwater balance on the involved watersheds.

Different springs databases have been collected from the Local Water Suppliers, committed with the management of distribution networks, and have been analyzed and compared with the geological framework in order to select a sampling data set.

49 springs have been selected for a monitoring activity developed in the summer 2011, in order to measure the low flow conditions (and contemporarily the basic physico-chemical parameters) and to analyze the recession phase of the spring hydrogram. At two springs a continuous monitoring system has been set up, in order to get a more detailed recession curve.

Concerning the monitoring activity on streams, 24 stream sections have been selected for the measurement of flow rate during the recession phase of summer 2011, by means of an electromagnetic current meter. Each section has been measured from 3 to 4 times in the summer, in order to get the recession coefficient.

The watersheds have been divided in sub-watersheds, for which the "specific hydrogeological productivity Pi" ($L/s*km^2$) and the "coefficient of infiltration CI" has been determined, expressed, respectively, by the base-flow specific discharge (referred to the whole sub-basin) and by the ratio between the direct recharge and total rainfall inside the sub-watershed. Direct recharge for each sub-watershed has been estimated by average

summer discharge and recession coefficient according to the methodology of Gargini et al. (2008).
Rainfall and air temperature occurrence all over the area were defined, as contour lines, either as historical record (1960-2004) or in reference to the hydrological years of investigation; from the raw data potential and actual evapotranspiration have been determined (according Thornthwaite & Mather 1957).

3. Results

The main results obtained from the investigation are: a local improvement of census of springs used for public water supply on the study area; the hydrogeological characterization and parameterization of 49 springs, selected on the area for their importance (in terms of location, geological setting, flow rates, physico-chemical parameters); the characterization of low flow conditions in the main streams of the study area; the hydrogeological classification of the different members of Marnoso Arenacea Formation and mainly arenitic geological units outcropping in the Savio Valley; the hydrogeological productivity of the different sub-watersheds and the consequent aquifers parameterization; the hydrogeological map for the studied area.

4. Conclusions

This study tried to regionalize the information and the conceptual models coming out from the experimental monitoring data.
It allowed to define a regional groundwater conceptual model and, starting from this, to set up an useful instrument for the management of groundwater resources. A derived thematic map suitable for the purposes of the Autorità dei Bacini Regionali Romagnoli will be drawn.

Acknowledgements
The authors wish to acknowledge Autorità dei Bacini Regionali Romagnoli of Emilia-Romagna Region for financing the investigation.

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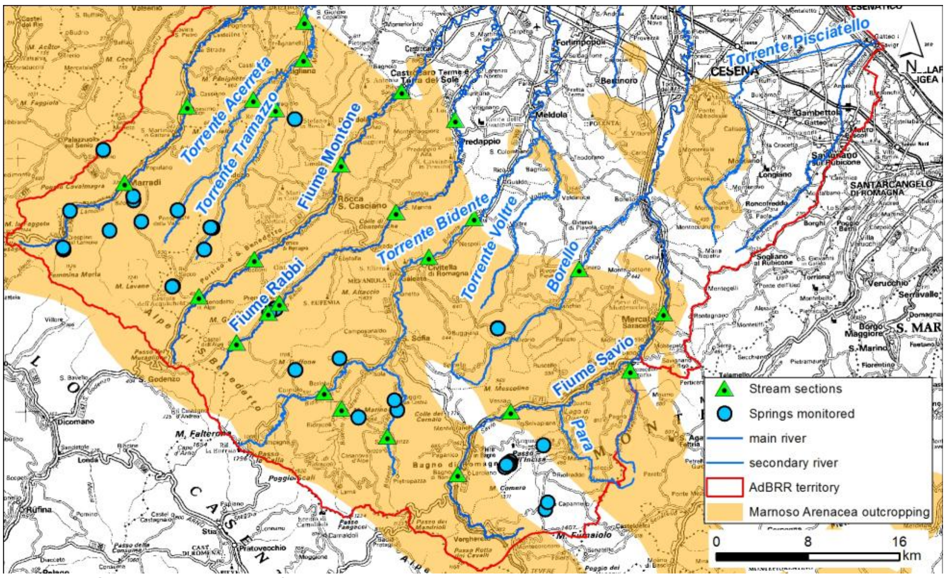

Fig. 1 – Schematic map of the study area (scale 1:500,000)

RESURGENCE BELT DISCHARGE AS ENVIRONMENTAL INDIRECT INDICATOR.

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Key-words: hydrogeological balance, groundwater resources, Friuli Plain

1. Introduction

Groundwater resources in the Friuli Venezia Giulia Region (northeast Italy) are an important natural resource in terms of quantity, quality and ease of supply. This optimal condition, however, allowed an irrational and uncontrolled exploitation that inevitably produced tangible consequences on the quantity and quality of the available water resources.
Seen that in the Friuli Venezia Giulia Plain are present more than 50.000 wells, most of them flowing, a deep study has been realized in order to evaluate the environmental sustainability of the withdrawals. To define the groundwater resources, a 3dimensional reconstruction of the aquifer systems has been realized starting from more than 3.000 stratigraphies (Zini et al., 2011). A campaign of wells identifications started. This permitted to evaluate the amount and distribution of the existing wells and the values of the real discharge. Although, the situation on a global scale, can be considered as not yet alarming, even if there are increasingly frequent reports on water pollution and other indicators of the progressive depletion of groundwater reserves. Since ten years ago, there is a lowering in groundwater levels in the High Plain and a loss of pressure in Low Plain confined aquifers (Cucchi et al., 1999). These phenomena are accompanied by the gradual amplitude range reduction of Resurgence belt, resulting as decrease in the amount of available water to the naturalness of the lowlands. In light of this, it is easy to predict that, unless appropriate measures, the intense human pressure will cause the persistence, if not the increase, of the just described phenomena (Cucchi et al., 2008). On one side, the derived discharge rates in mountain basins are returned to the valley only after the intersection with the Resurgence belt producing a decline in the active recharge of the High Plain. On the other side, well withdrawals dissolve a significant amount of water resources and constitute the most important forced element for the groundwater flow.

2. Material and Methods

By using a purposefully oversimplified conceptual model, the Resurgence belt can be defined a kind of groundwater "overflow" for the regional plain. The studied territory was considered as a "semi-closed box" in which the pouring into the sea and underground interchange with the neighboring aquifers are not relevant and recharging groundwater is mainly due to the dispersion of runoff water, infiltration, rainfall and irrigation practices incident on the High Plain.
In the general computation for the hydrogeological groundwater balance, the recharge from the mountain basins to the High Plain has been evaluated to be 130,5 m^3/sec (R_M), the one from the High Plain to the Resougence belt was 177,9 m^3/sec (R_{AP}) and the one for the Low Plain was 43,7 m^3/sec (R_{BPA}).

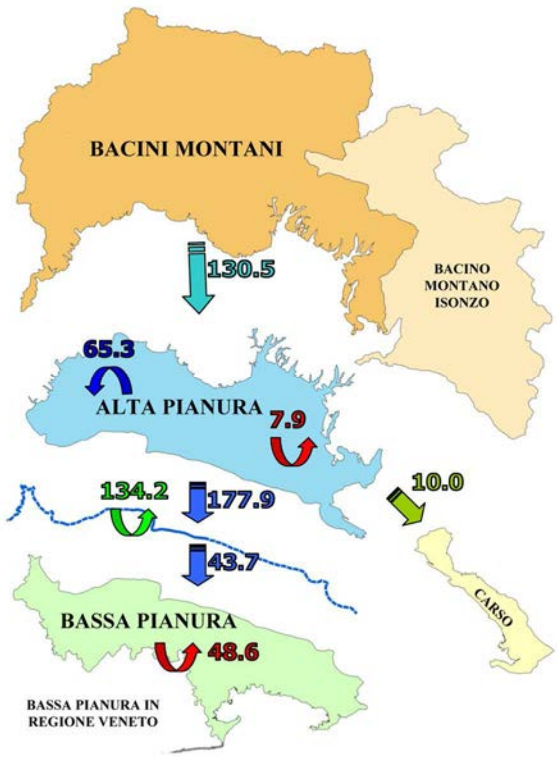

Figure 1: Complete scheme of the hydrogeological groundwater balance for the Friuli Venezia Giulia Region.

At present, in the FVG Region, the total amount of withdrawal reached huge values as 59,3 m^3/s: of which 56,7 m^3/s from the phreatic and artesian aquifers of the Friuli Plain. The total withdrawals for the Plain were estimated in 59,8 m^3/s considering also the right Tagliamento withdrawals located in Veneto Region having a value of 3,1 m^3/s (2,5 m^3/s confined and 0,6 m^3/s unconfined).

4. Conclusions

According to the previous assumptions, the Resurgence belt drains an average quantity of water equal to the active recharge from the High Plain subtracting the magnitude of well withdrawals from the confined aquifer systems in the lowlands. Withdrawal entity, Resurgence belt discharge, phreatic levels in the High Plain and confined aquifers pressure in the Low Plain are closely interdependent and in dynamic balance. According to this schematization, the Resurgence belt discharge is an indicator of the withdrawal magnitude and its sustainability.

Acknowledgements

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GROUNDWATER MONITORING NETWORK IN THE CLASSICAL KARST

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Key-words: karst aquifers modeling, Classical Karst Aquifer, monitoring

1. Introduction

Classical Karst is a large area located between the North-Eastern part of Italy and the South-Western part of Slovenia. The area runs for about 40 km long and 15 km wide in the SE-NW direction and is bounded on the NW by the Isonzo River valley, on North and NE by the Vipava River valley, on East by the Pivka River basin, on South and SE bordered by the Cicarija structure while on West is bounded by the Gulf of Trieste washed by the Adriatic Sea.

The plateau, slightly inclined towards NW, consists of carbonate lithotypes widely involved by karst landforms. The karst lithological characteristics do not allow the establishment of a perennial hydrography surface due to the high rock mass permeability related to the karstification. Rainfall and river waters are immediately swallowed by the karstified bedrock where they create a network of caves that first transfers the water vertically into the rock mass through the vadose zone and secondly collects them in an aquifer characterized by large horizontal or sub-horizontal conduits which transport the water to the springs area.

The main water contribution to the Classical Karst aquifer is well identified in the area where Reka River sinks in Škocjan Cave, in Slovenia; after flowing more then fifty kilometers over impermeable rocks, when the river meets limestones and begins to incise them, it quickly disappears into the caves. From that point it is named Underground Timavo River. The windows opened on the path of underground Timavo River are extremely rare; in Slovenia three deep wells reach large tunnels and rooms flooded by the river (Kacna Abyss, Strsinski dolini Cave and Kanjaduce Cave) while in Italy Timavo River is intercepted by Trebiciano Abyss and Lazzaro Jerko Cave. Few other known cavities are intercepted by groundwater only during the highest floods: these are Claudio Skilan Cave, Massimo Abyss, Gigante Cave, Lindner Cave and Colombi Cave. A deep piezometer reaches the groundwater base level near the limestone-impermeable Flysch contact.

The Mathematics and Geosciences Department of Trieste University (D.M.G.) is monitoring all the water points on the Italian Classical Karst territories since 1995; in cooperation with slovenian partners (Park Škocjanske Jame and ZRC SAZU Center of Postojna). In this way, a complete scene on the Classical Karst aquifer is emerging. Only the collaboration between Italy and Slovenia could lead to a reasoned groundwater monitoring network in order to plan the best transboundary aquifer management and protection in order to study the complex karst hydrodynamics.

2. Material and Methods

The instruments of the monitoring network are Schlumberger Water Services CTD DIVER and Gemini Datalogger. They measure water level (pressure sensor), water temperature, conductivity (four electrode conductivity cell). The sample interval used in our studies is 30 minutes or one hour without stop for 333 days. Instrument dimensions are: diameter 22 mm; length 183 mm; weight 150 grams. Their little dimension and long range allows their installation also in remote zones (i.e. bottom of deep caves).

3. Results

From Škocjan Cave, Underground Timavo River has an hypogean flow to Trebiciano Abyss and Lazzaro Jerko Cave through big conduits. During its course, it probably, overflows in Claudio Skilan Cave during the main floods. It receives also a great amount of rainfall waters coming from the karst plateau through percolation. The main drains transfer Timavo waters to Lindner Cave and then to Timavo Springs. Part of that water is lost through coastal Aurisina Springs in spite of the fact that the impermeable rocks disappear under the sea level. Great conduits are incorporated in a rock matrix at low permeability: it is well represented in Massimo Abyss, Lindner Cave, Gigante Cave. Continuous underground water monitoring has been essential to define the dynamic of waters of the Classical Karst and the water residence time and the relationship between the main drainage and the matrix.

Recently the discover of two new caves reaching with their deepness the underground Timavo flowing water and the realization of some piezometers, permit to re-analyze the monitoring data of the last 15 years and to better understand the behaviour between the main conduits and the matrix.

4. Conclusions

The data analysis highlights the circulation complexity inside the hydrostructure: during the flood the flow is conditioned by the Reka river regime while, during low-water, the circulation is more influenced by the infiltration due to the rainfall and from the Isonzo river contribution. The circuit connecting Škocjan cave with Timavo springs is characterized by a series of large pipes that allow the flood impulse transfer within 1 to 3 days.

The monitoring carried out showed that during the floods the most part of the circuits are under pressure and only a comparative analysis for levels and conductivity permits to correctly evaluate the water transit times. Infact, if the rising water level in the caves is simultaneous due to the increasing hydraulic load upstream, the changes in conductivity are different from site to site and allow to intercept the incoming flooding water and to estimate correctly the propagation water velocity.

Different is the behaviour in the northweaster sector (Merna – Iamiano area) where the circulation is dispersed and lower flows are underlined. The beginning of the floods is often delayed compared to the outfall and it is partially due to the stop up water coming from the Reka – Timavo circuit.

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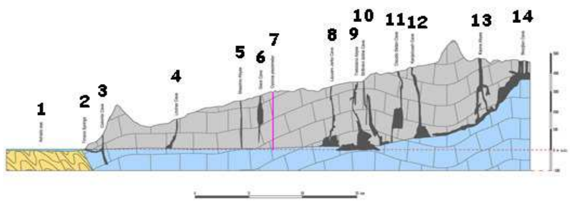

Fig. 1 – Monitoring hypogean stations in the Classical Karst. 1) Adriatic Sea, 2) Timavo Springs, 3) Colombi Cave, 4) Lindner Cave, 5) Massimo Abyss, 6) Giant Cave, 7) piezometer, 8) Lazzaro Jerko Cave, 9) Trebiciano Abyss, 10) Strsinkni doline Cave, 11) Claudio Skilan Cave, 12) Kanjaducah Cave, 13) Kacna Abyss and 12) Škocjan Cave.

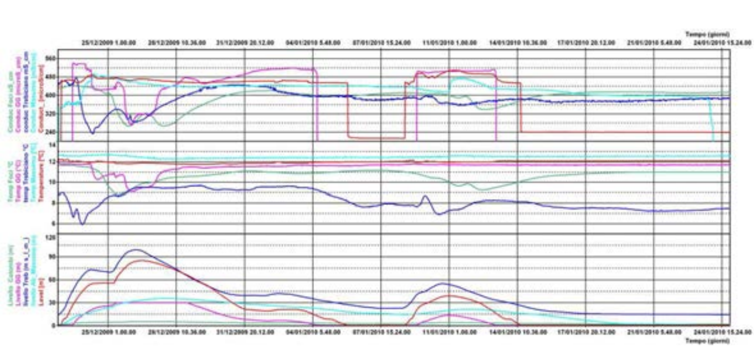

Fig. 2 Conductivity, temperature and water level behaviour for the following monitoring stations Grotta dei Colombi Cave (Timavo spring), Grotta Gigante Cave, Trebiciano Abyss, Massimo Abyss in the period between 25/12/2009 and 24/01/201.

ARSENIC MOBILITY UNDER ANAEROBIC CONDITIONS – A LABORATORY STUDY

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Key-words: arsenic, soil, anaerobic reaction, leachate test

1. Introduction

Arsenic has been recognized as a major contaminant of concern. It has been proven that it is widely distributed in soil and groundwater. Several studies have identified a possible contamination source in the natural mobilization.
There are evidences that the presence of Arsenic in GW may be due to:

- *Fe* mobilization from Iron minerals,
- *As* mobilization from Arsenic minerals.

This study has been undertaken to verify the mobility of *As* under reducing conditions. Geochemistry indicates that under reducing condition *As* is found in a mobile state.
This behaviour is similar to that of Iron and Manganese, which become mobile in their reduced state.

2. Material and Methods

The study was carried out using 4 natural soil samples collected at 1,5 m bgl from two different sedimentary basins (Brenta river: samples 1-2; Piave river: samples 3-4) both placed in the Venetian Plain (Italy). Samples have been analyzed for Arsenic content either with total acid digestion (EPA 3052) and with "environmentally available" extraction (EPA 3050B), a leaching test using demineralized water (PR/SUO-TEC/151-2007) and a modified leaching test with demineralized water and addition of organic substrate (glucose). The modified leaching test was carried out in closed vials (anaerobic conditions) and the redox potential and pH were daily monitored prior to sample analysis.
Soil samples have been analyzed for granulometric distribution, pH, organic carbon content and a XRD analysis was also performed for qualitative basic mineralogy presence.
Microorganisms were not added, all reactions in the anaerobic test related to autochthonous soil bacteria.

3. Results

Table 1 reports main parameters of soil analysis. The four soil samples clearly showed chemical differences between the two basin river deposits. Arsenic content, in fact, varies from 23 to 6 mg/kg. The total acid digestion and the "environmentally available" extraction lead to similar results indicating that the analyzed metals are not associated with silica minerals.
Table 2 reports leachate tests result. The standard leachate test with demineralized water, normally used to calculate the partition coefficient (k_d), brings to a minimal Arsenic content, around 1 μg/l. Iron content instead varies from 110 to 15 μg/l, while Manganese concentration varies from 150 to 57 μg/l.

Soil Sample Analysis

		1		2		3		4	
		A	B	A	B	A	B	A	B
Arsenic (as As)	mg/kg	23	24	26	21	6	6	6	3
Iron (as Fe)	mg/kg	23000	19968	38000	31878	12000	14671	12000	8371
Manganese (as Mn)	mg/kg	350	441	240	231	290	380	240	160
Organic Carbon	%	0,2		0,7		0,2		0,4	
Sand	%	11,4		7,9		3,7		29,7	
Silt	%	61,3		31		59,8		41,7	
Clay	%	27,3		61,1		36,6		28,6	
Total Organic Carbon	%	45		0		59		23	
Active Limestone	%	11		0		13		5	
pH	-	8,5		7,2		7,9		8,1	
Quartz	C	present		present		present		present	
Calcite	C	present		-		-		-	
Clinochlore	C	present		present		-		-	
Muscovite	C	present		present		-		-	
Dolomite	C	present		-		present		present	

A: Total Acid Digestion - EPA 3052 1996+EPA 6020A 1998
B: "Environmentally Available" Extraction - EPA 3050B 1996+EPA 6020A 1998
C: Qualitative XRF Analyses

Tab.1 – Results of chemical analysis on soil samples.

Leachate Tests

		1	2	3	4
Demineralized water test (1 day) PR/SUO-TEC/151-2007					
Arsenic (as As)	mg/l	0,001	0,001	<0,001	<0,001
Iron (as Fe)	mg/l	0,110	0,015	0,051	0,100
Manganese (as Mn)	mg/l	0,082	0,150	0,057	0,070
pH (at the beginning of test)	-	8,7	7,1	8,5	8,7
pH (at the end of test)	-	8,2	5,2	8,4	8,3
Demineralized water test (1 day) PR/SUO-TEC/151-2007_mod					
Arsenic (as As)	mg/l	<0,001	<0,001	<0,001	<0,001
Iron (as Fe)	mg/l	<0,010	<0,010	<0,010	<0,010
Manganese (as Mn)	mg/l	<0,001	0,003	<0,001	<0,001
pH (at the end of test)	-	8,5	7,2	7,9	8,1
Eh (at the end of test)	mV	352	452	360	416
Demineralized water test (10 days) PR/SUO-TEC/151-2007_mod					
Arsenic (as As)	mg/l	<0,001	<0,001	<0,001	<0,001
Iron (as Fe)	mg/l	0,025	0,010	0,010	<0,010
Manganese (as Mn)	mg/l	<0,001	0,065	<0,001	<0,001
pH (at the end of test)	-	7.0	5,7	6,8	7.0
Eh (at the end of test)	mV	372	453	444	434
Anaerobic test (10 days)					
Arsenic (as As)	mg/l	0,140	0,006	0,013	0,013
Iron (as Fe)	mg/l	14	2,5	4.0	45
Manganese (as Mn)	mg/l	3,90	0,26	3,30	6,30
pH (at the end of test)	-	6,23	4,50	6,00	5,90
Eh (at the end of test)	mV	-158	-218	-228	-238

Tab.2 – Results of leachate tests on soil samples.

The leaching process in anaerobic condition, lasted for ten days, led to greater concentrations of *As*, *Fe* and *Mn* in the solution. The pH and Redox conditions were daily monitored after batch opening. The trends of pH and Redox potential give evidence of variations in leachate conditions inside pH/Eh graph, as indicate in Figure 1. As expected, the oxidation of glucose by microorganisms led to anaerobic conditions, characterized by a decrease of pH and redox potential. The results at day 1 are similar to those in the standard test, there are only evidence of less metal concentration in the leachate and this is probably related to the not continuous agitation of the sample. The control batch (without glucose), after ten days, confirmed the expected reactions showing a minimal metal concentration in the leachate, low pH condition (similar to standard test) and high redox potential (anaerobic condition not reached).

As mobilization, under lab experiment conditions, can be related to the iron minerals dissolution with associated presence of Arsenic, or to a direct dissolution of Arsenic mineral species. Both hypotheses can be valid under the method conditions. Several sample parameters (organic content, pH, alkalinity, iron minerals) can modify the results in term of Arsenic content in the leachate, but the general approach is expected to be valid in every site conditions.

4. Conclusions

The lab study confirmed the theoretical redox-reaction for Arsenic species from pure minerals or as substitutes of iron in crystal lattices. The results may explain the origin of *As* contamination in aquifers with natural organic content, and they also may explain the induced *As* contamination in hydrocarbon plumes. Finally the comparison between the standard leachate test with demineralized water and similar leachate tests in anaerobic conditions shows that the *As* mobilization can be very different.

In other terms, calculating the partition coefficient for *As*, *Fe* and *Mn* not only pH condition are important but also the redox state. The use of the latter test (in anaerobic conditions) can also anticipate unexpected worst case conditions in risk analysis calculation.

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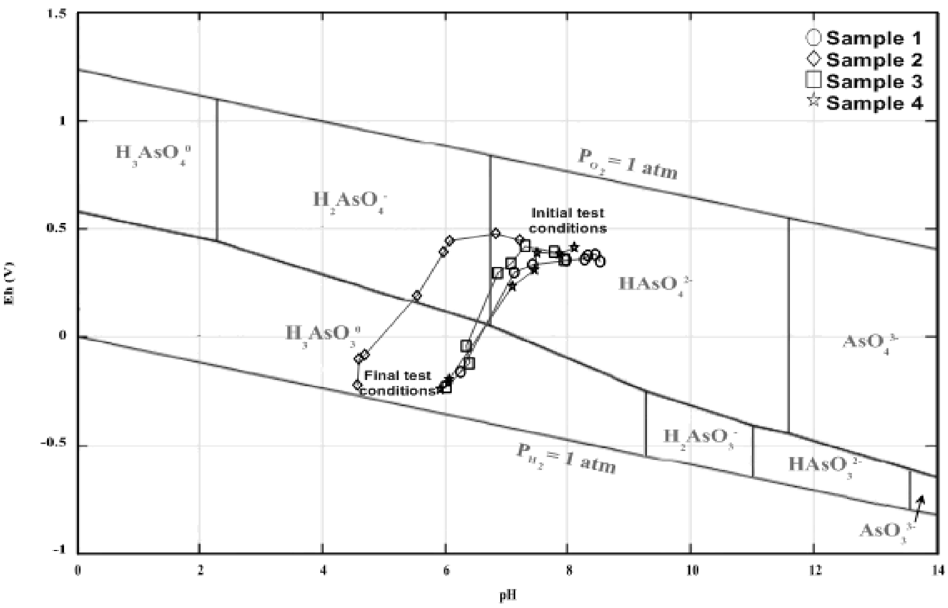

Fig. 1 The sample paths within the diagram pH-Eh for As, subjected to leachate test in anaerobic conditions.

APPLICATION OF THE INTEGRAL PUMPING TEST METHOD IN NORTH-EAST AREA OF MILAN FOR CONTAMINANTS SOURCE IDENTIFICATION

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Key-words: source identification, Integral Pumping Test

1. Introduction

In the northen zone of Milan and all around the northern outskirts of the city there is an extended industrial area. Several contaminant plumes travel in the aquifers from the north into the city, where the groundwater is the resource used by the Milan public water supply system.

The Gorla pumping station is one of the 31 public stations used to provide urban water supply services. This is the pilot area (about 5 ha) that was chosen in the EU FOKS project (1CE026P3) for Integral Pumping Test (IPT) application, because of its exposure to incoming pollutants: Cr VI, Freon141, PCE and TCE.

The Milan groundwater system is a multi-layer alluvial aquifer. The upper unit forms the Traditional Aquifer (TR), an unconfined aquifer with high transmissivity. Moving southward from Gorla station a clay layer separate the TR in a shallow unconfined aquifer (TRa) and a semiconfined aquifer (TRb). The Gorla wells are screaned in TRb that here reach a thickness of 60 m. Due to the complex hydrogeological conditions and the overlapping of different plumes, though in the area for many years groundwater monitoring campaigns are periodically performed, the identification of contaminant sources is always a challenging task. Project goal is to list the most probable sources and reduce the study area for deeper investigation and remediation activities.

2. Material and Methods

The IPT methodology was developed by the EU project INCORE, as a tool for groundwater investigation and source localization in contaminated areas. This methodology consists of a multiple-well pumping test in which the wells are positioned along a control plane downstream of suspected contaminant source zones and perpendicular to the mean groundwater flow direction. During the pumping, concentration time series of target contaminants are measured (Schwarz et al. 1998, Ptak and Teutsch 2000, Schwarz 2002). The method of Integral Pumping Test employs the effect of the increasing capture zone during a pumping test and the multiple contaminant concentration measurements, to estimate the spatial distribution of the contaminants and the total mass flow rate of a contaminant plume in groundwater.

In 2000 the IPT methodology was applied in Milan in a private brownfield (Zanini et al., 2004) drilling 5 new wells to build a proper control plane. Nowadays the methodology was applied by Milano Municipality in reason to test the possibility to minimize the costs and logistical issues through the use of existing public wells. In Milan pilot area two control planes were implemented using Gorla station wells: “IPT set 1” started in May 2010 and lasted about two months; “IPT set 2” was performed in November/December 2011 to improve the results in the eastern part of the pilot area. A numerical flow model was implemented to support the IPT design in order to identify wells capture zones (i.e. the investigated areas) and to evaluate the distribution of the contaminants.

3. Results

Freon141b, it was clearly detected in the west part of the control plane (P18 and P11, Table 1, Figure 1). According to the production history and the analysis of chemicals detected in last 5 years in the municipal groundwater monitoring network, two areas were recognized as sources responsible of Freon141b contamination.

All TCE measured concentration values were lower than 5 μg/l that can be considered a background value in Milan. Therefore TCE contamination could be reasonably considered as a diffuse pollution (mass flow rate 2.14 g/d for 100 m aquifer width).

The main PCE concentration values were found in the west zone of the control plane and P11 showed the highest mass flow rate (20.7 g/d, Table 1). Nevertheless the quite homogeneous PCE concentration distribution along the control plane didn’t allow to clearly detect the plume center line and showed a large plume between P11 and P4. The numerous detected “strips” should indicate that small plumes, originating from many sources, probably overlap each other in different zone.

The highest concentration values of Chromium VI were detected in the eastern part of the control plane between P1 and P5 and the core of the plume was identified in P16. Through numerical particle backtracking analysis, starting from the control plane, 9 brownfield/productive areas were selected as highly potential responsible of the contamination origin.

Tab.1 – IPT results. Mass flow rate, mean and max concentration evaluated through the application of IPT methodology for TCE, PCE, CrVI and Freon 141b.

		IPT set 1							IPT set 2		
		P18	P11	P12	P1	P3	P4	P5	P15	P16	
TCE	Mean Conc [μg/l]	3.2	3.2	2.4	1.8	2.1	2.1	3.3	2.0	2.0	
	Max Conc [μg/l]	3.6	4.2	3.2	2.6	2.4	2.5	4.1	2.0	2.9	Σ
	Mass Flow Rate [g/d]	4.1	**4.6**	2.5	1.5	1.3	1.3	2.3	2.0	1.8	**21.4**
PCE	Mean Conc [μg/l]	9	14.4	13.5	15.6	12.4	11.8	9.7	9.8	10.5	
	Max Conc [μg/l]	14.8	26.7	17.2	20.2	14.1	13.0	11.1	11.0	12.5	Σ
	Mass Flow Rate [g/d]	11.5	**20.7**	13.5	13.1	8.0	7.2	6.7	9.8	9.4	**99.9**
Cr VI	Mean Conc [μg/l]	5.9	6.0	8.0	11.8	16.2	20.4	11.2	15.2	41.0	
	Max Conc [μg/l]	8.9	15.7	14.4	17.6	29.3	40.1	14.6	17.7	84.2	Σ
	Mass Flow Rate [g/d]	7.5	8.6	8.0	9.9	8.1	12.5	7.7	15.3	**36.9**	**114.5**
Freon 141b	Mean Conc [μg/l]	73.2	92.0	57.9	31.7	8.3	-	-	-	-	
	Max Conc [μg/l]	94.3	120.8	74.0	50.5	15.3	-	-	-	-	Σ
	Mass Flow Rate [g/d]	93.5	**133.8**	59.1	26.7	5.4	-	-	-	-	**318.5**

4. Conclusions

The use of existing wells to perform IPT, in order to save costs of drilling, is applicable and reasonable but in awareness of the limits and restrictions deriving from the application to a complex system as a city, characterized by interference with urban activities and needs that may often interfere with pumping time and volume of groundwater subjected to demand.

Although the IPT application could not be rigorous, the interpretation of results gave important information about the distribution of plumes in Gorla zone.

Good results were achieved for the compound that measured the highest concentration values (Freon141b and CrVI), whereas some uncertainties remained for PCE. The IPT results allowed to draw up a ranking list of the activities that have to be performed to study more in detail the contamination. Thanks to this results Municipality of Milan is programming a series of new and well focused investigations to definitively locate the responsible contaminant sources. Meantime inverse osmosis and active carbon plants for pumped water treatment, are maintained active to ensure the proper quality levels of the distributed water.

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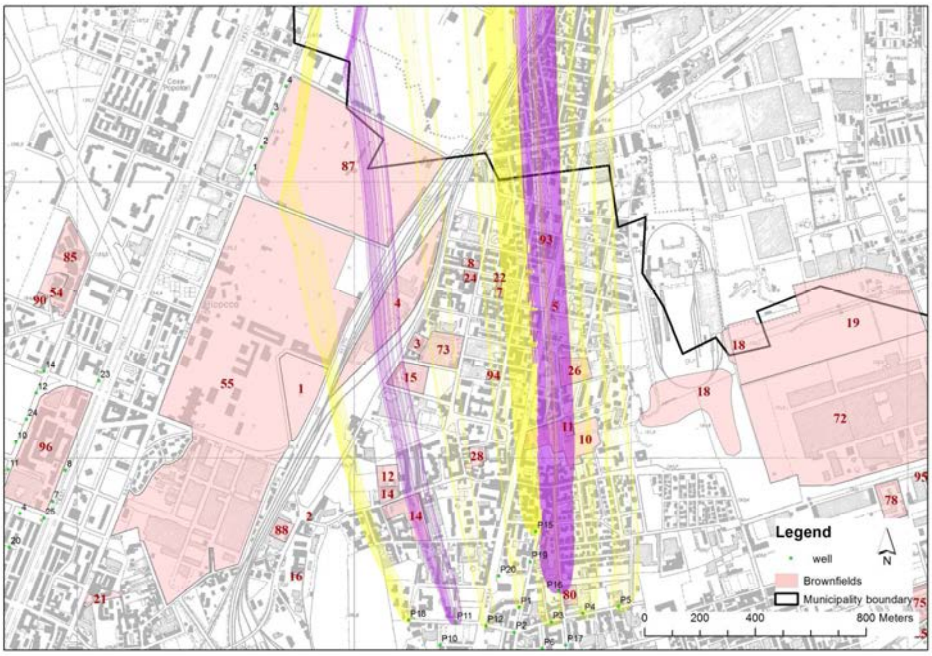

Fig. 1 – Particle backtracking (yellow and violet lines). Violet lines show the particle backtracking for P11 and P16, in which the highest mass flow rates, respectively of Freon 141b and CrVI, were detected. The pink areas are the known brownfields located upstream the pilot area.

APPLICATION AND COMPARISON AMONG THREE METHODOLOGIES TO CALCULATE AQUIFER VULNERABILITY IN A MUNICIPALITY OF VERCELLI PROVINCE (PIEDMONT - ITALY)

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Key-words: hydrogeology, aquifer vulnerability, DRASTIC, GOD, SINTACS

1. Introduction

In this study, three different methods for estimating the vulnerability of an aquifer were compared. The three methods are: the DRASTIC method (Aller et al, 1987), the SINTACS R5 method (Civita and De Maio, 2001) and the GOD method (Foster and Hirata, 1987).
The study area comprises Municipality of Tronzano Vercellese, which has an area of approximately 45 km^2, located in the South - West of the Vercelli Province, in the Piedmont Region.
The area is made up of a thick quaternary deposit succession, laying on Pliocene marine deposits. The surface layers are represented by fluvial and fluvio-glacial deposits, consisting mostly of sandy gravel sediments, intercalated with silty clay.

2. Material and Methods

The methods used to assess vulnerability of aquifer are different, depending on the physiology of the areas, for which they have been studied, the number and amount of available data, the purposes of surveys which have been tested.
From the point of view of typology, these methods can be classified into two basic groups:

- <u>simple scoring systems</u>: they are based assigning to the chosen parameters, a range of score, which is divided suitably depending on the field of variation of the parameter. Among these methods, Foster and Hirata (GOD) is the most widely used, thanks to its easy structure (such as in the basin of Po river).
- <u>scoring and weights systems</u>: each parameter is diminished or enhanced by adjusted a relative coefficient or "weight", which can vary depending on the type of land use or hydro-geological characteristics of aquifer (SINTACS (Civita 1998), DRASTIC (Aller et alii, 1987)).

3. Results

A medium high degree of vulnerability was gotten with the three methods in the study area. In fact, the method GOD assigns a medium degree of vulnerability, while the other two methodologies DRASTIC and SINTACS indicated a high vulnerability degree. Intrinsic factors that determined the vulnerability high degree, are: lithological characteristics of the aquifer, depth of groundwater and hydraulic conductivity.
The shallow aquifer consists mainly of gravel and heterometric sand or gravel, with high permeability. The soils have fine fraction and in particular have a reduced thickness, thereby exerting little protection to the shallow aquifer. As a result of these factors, the hydraulic conductivity values reach about 20 m / d.
Another factor that contributes to increase the degree of vulnerability is depth of water table.
This depth appears to be shallow (usually from 1 to 3 m from the P.C, sometimes between 3 and 5 m) up to coincide with the surface during the period of rice flood fields. In winter depth of water table, stays close to ground level, with oscillations of few meters between maximum and minimum level.

4. Conclusions

Different result was obtained with the method of GOD, other than the other two methods DRASTIC and SINTACS. As a result, the first one is a score method with simple parameters, suitable to be used in large areas (small scale), which show a contrast vulnerability even among neighboring areas. The other two methods are based on weight scoring systems, which takes to examine a wider range of parameters. Therefore they can discriminate with greater detail in small areas (large scale).
Although parametric methods based on weighted scores can get a more precise estimate of the vulnerability result of the area,

they are much more complex and difficult to apply in the areas, where not all the input data are available.

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SINGLE AND DUAL-DOMAIN MODELS FOR THE INTERPRETATION OF NUMERICAL TRANSPORT EXPERIMENTS IN ALLUVIAL SEDIMENTS

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Key-words: alluvial aquifers; heterogeneity; dual-porosity model; dual-permeability model

1. Introduction

Alluvial aquifers are generally very heterogeneous at different scales. In particular, the heterogeneity at fine scale significantly affects the transport of contaminants at the macroscopic scale, that is of interest for the practical applications. For example, the presence of preferential flow paths, which are connected bands of permeable material, causes some particles of solute to travel faster than the rest of the particles, giving rise to early arrivals, tailing and, possibly, double peaks in the breakthrough curves.

The classical approach to the modeling of transport in aquifers is the single-domain approach, which is based on the advective-dispersive equation and considers the heterogeneous porous medium as an equivalent homogeneous volume.

More refined approaches are represented by dual-domain models, that consider the heterogeneous porous medium as a superposition of two domains. In particular, the dual-porosity model assumes that water can flow in one of the two domains (mobile domain) but not in the other (immobile domain) and that the two domains can exchange solute (Rausch et al. 2005). The dual-permeability models (Skopp et al. 1981), instead, assume that both domains are mobile and that, in general, they have different Darcy's velocities and dispersion coefficients; two formulations of such models can be defined depending on whether the two domains are considered as coupled, i.e., they can exchange solute, or uncoupled.

The research here presented aims at comparing the performance of these transport models in describing the results of some numerical experiments of non-reactive transport in blocks of alluvial sediments characterized by different degrees of heterogeneity.

2. Material and Methods

The case study considered in this work is described in Zappa et al. (2006). It consists of three prismatic blocks of alluvial sediments, each with a volume of a few cubic meters, dug at a quarry site into real sediments of the Ticino basin (Northern Italy).

A geostatistical simulation of the blocks was performed in order to obtain the hydraulic conductivity field (Zappa et al. 2006). Some numerical experiments of convective transport of a conservative solute were performed with a particle tracking technique, where the flow field was computed with a flow model for steady state saturated flow (Vassena et al. 2010). These numerical experiments simulate the evolution of a plume of solute that is instantaneously injected through the upstream face of each block, whereas the virtual field data are represented by the arrival times of the particles at the opposite face. From these data, the experimental cumulative breakthrough curves can be computed and fitted with the different transport models.

For the initial and boundary conditions adopted, the single-domain and the uncoupled dual-permeability models admit an analytical solution, as discussed by Baratelli et al. (2011).

The dual-porosity and the coupled dual-permeability models, instead, have been implemented with a Crank-Nicholson finite difference scheme, an upwind technique for the convective term, and a second-order correction to reduce numerical dispersion due to truncation errors (see, e.g., Ataie-Ashtiani et al. 1999).

The calibration of the transport models has been conducted with the Levenberg-Marquardt algorithm, and the number of parameters to be identified ranges from two for the single-domain model to seven for the coupled dual-permeability model.

3. Results

Figure 1 represents the experimental breakthrough curve together with the best fit obtained with the single-domain, dual-porosity, uncoupled and coupled dual-permeability models for the block of sediments in which the presence of preferential flow paths was evidenced by both the sedimentological analysis (Zappa et al. 2006) and the connectivity analysis (Vassena et al. 2010).

Figure 1 shows that the fit of the experimental data obtained with the uncoupled dual-permeability model significantly improves those obtained with the single-domain and the dual-porosity models. Instead, the coupled dual-permeability model gives no significant further improvement.
In particular, Figure 1 shows that the dual-permeability models are able to describe the double peak which is present in the experimental breakthrough curve, as they take into account both the particles of solute that travel fast in the preferential flow paths and the slower particles that travel in the less permeable sediments.
Moreover, the comparison of the different dual-domain approaches indicates that, in order to correctly describe the transport of solutes in this block of sediments, it is necessary that both domains are mobile; on the other hand, the two domains can be considered independent, as the exchange of solute between them is very slow.
In the case of the block of sediments where the presence of connected structures of permeable sediments was less pronounced, instead, the single-domain model can already describe well the experimental data. This means that these blocks, regarding their transport properties, are well represented by an equivalent homogeneous domain.

4. Conclusions
The results showed that, in the case of the blocks of sediments where the presence of preferential flow paths was more evident, the uncoupled dual-permeability model was able to significantly improve the fit of the experimental cumulative breakthrough curve with respect to the single-domain and dual-porosity models. Therefore, the dual-permeability models can be effectively applied not only to fractured rocks or macroporous soils, but also to alluvial aquifers, which are characterized by smaller permeability contrasts.
Moreover, the introduction of the exchange term between the two domains of the dual-permeability model did not lead to a significant further improvement of the fit.
In the case of the block of sediments with less pronounced presence of preferential flow paths, the standard single-domain model was shown to efficiently describe the experimental data.
Therefore, a preliminary analysis of the volume, based on sedimentological, geostatistical and connectivity analysis, is important to decide whether a more complex dual domain approach, which requires more computational effort, is necessary.
An efficient transport modeling of heterogeneous environments characterized by the presence of preferential flow paths is essential in order to avoid the underestimation of the travel times of the particles of solute, which can be a serious issue for practical applications, as the studies of groundwater contamination by pollutants.

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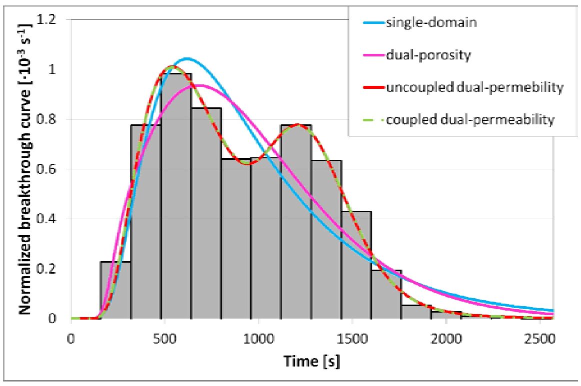

Fig. 1 – Experimental breakthrough curve (histogram) and best fit of the different transport models.

Geostatistics simulation of hydraulic conductivity field applied on groundwater flow and transport modeling in heterogeneous aquifer

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Key-words: geological heterogeneity, geostatistical simulation, mass transfer approach, numerical modeling

1. Introduction

ENEA has been involved in several research projects on environmental restoration and removal of contaminants from groundwater (Maffucci et al, 2009). These activities are focused mainly on the evaluation of technical feasibility and economic sustainability of Emergency actions (MISE) and reclamation of contaminated sites. Modelling of groundwater flow and transport of pollutants is of major importance from the environmental perspective, but it rises a number of related issues, such as a the presence of both strong geological heterogeneities and quantification of mass-transfer phenomena of solutes (Koltermann & Gorelik, 1996). The classical advection-dispersion models based on Fick equation are often inadequate to properly simulate transport processes (Feehley et al, 2000).

In the present study several geostatistical techniques were used for describing and quantifying spatial variations of the hydraulic properties. Results are then applied to several numerical flow and transport models using mathematical approaches. A study area (located in Tuscany - Northern Italy), containing an aquifer contaminated by organic halogen compounds flowing through an alluvial silty sandy sedimentary body, has been chosen to discuss the addressed topic.

2. Material and Methods

The lithostratigraphic model was reconstructed by using a 96 geognostic data set distributed within a test area of 800x600 meters where the contaminated plume was detected from 1991 to 2009. The domain has been discretized with a horizontal grid of 5x5 meters, with 16 layers with a thickness comprised between 0.25 and 1 meter. Geological heterogeneity was classified in 4 separate homogeneous categorical variables. On the base of the observed hydraulic properties within the study area, vertical and horizontal stratigraphic variations are then determined by using different geostatistical simulation methods to both evaluate different probabilistic solutions and possibly reduce uncertainty concerning the structure of the geological model.

S*tructure imitating methods* (Koltermann & Gorelik,1996) and other four different spatial statistic methods have been used*:* Gaussian simulation as the Turning Bands (TB) and the Truncated Plurigaussian (TP); and No Gaussian simulation such as the Sequential Indicator Simulation (SSI) and the Markov Chain (MC). Some of these are based on spatial variography analysis (SSI and TB), others on the transition probability (MC), the most complex ones on both of them (TP). Frequency distribution of data and spatial covariance function are the same for all geostatistical solutions and the simulations were parameterized using the same stratigraphic conceptual model (*imaging reference*).

A synthesis model of the spatial variability is obtained during post-processing by performing a statistical analysis of 50 simulations for each method. The field of hydraulic conductivity is obtained via geostatistical reconstructions of the aquifer through calibration (*process-imitating*) of flow and transport numerical models simulating the contaminated plume. In the present study we used the MODFLOW code (Harbaugh et al, 2000) for the flow and MT3DMS (Zheng & Wang, 1998) code for the transport.

In order to determine the relationships between the reconstructed geostatistical simulations we compared results in terms of scale of analysis and mass transfer phenomena, namely, advection-dispersion component (ADMT), and dual-domain models (DDMT).

3. Results

The solutions provided by the geostatistical models were analysed both in terms of using Experimental Semi Variogram (ESV), and in terms of geometric continuity and connections of geological structures. The different heterogeneity configurations show a low linear spatial correlation with lithofacies overlapping of about 30%. TB and TP models have 50% of nugget effect, and SSI and MC models about 80%. The SSI model simulates the lower spatial continuity of the geologic structures with a 60 meters range, and TP model show the maximum value of 180 meters range. The study shows that the geostatistical models based on the spatial covariance as SSI and TB, (*covariance based*),

may be inadequate for reproducing continuous macrostructures, as they generate very erratic patterns due to the difficulty to simulate the ESV for excessive anisotropy between XY and Z spatial discretisation.
The MC and TP models, which are based on probability transitions (*geologic-based*), allow to both better reconstruct and highlight the interconnections of geological macrostructures, but local heterogeneity at the microscale are not captured. *Geologic-based* methods revealed the difficulties in the transposition from the 1D to 3D chains and the uncertainty to chose the ratio between the size of the structures, between the ratios of length to thickness which strongly influence the reconstruction of geological elements at the reduced scale. TB and SSI transport models show a wide and irregular in shape dispersion plume compare to MG or TP, which is more regular and compact. After a time interval of 40 years, the simulation of the cumulative mass of pollutant sinking out the domain is about 87% for the solutions of DDMT approach and 96% of ADMT's one. Generally, simulating the plume distribution by DDMT models introduces by a large tailing effect compared to those given by ADMT models and a better matching with measured concentrations.
Once applied to the conductivity fields generated by the MC and TP methods, the ADMT model provides solutions with Channel Flow Path plume (CFP) and with an overestimation of time needed for mass contamination transfer. The *Upscaled* DDMT transport model furnishes a partially improved solutions. The transport model solution obtained with the TB conductivity field, which is able to represent both macrostructures and lower scales structures, provides a proper calibrated Preferential Flow Path (PFP) of plume pattern. Furthermore, the latter considers both the diffusion/dispersion and sorption dynamics with apparently no dependency from the modeling approach selected.

4. Conclusions

We presented a field-size case study of a contaminated aquifer characterised by solutes macrodispersion transport in a strongly heterogeneous soil. In particular, we focused on on different geostatistical simulation methods to recostructing the hydraulic conductivity field coupled with two transport modeling approaches. Our results indicate how the choice of geostatistical method for reconstructing the geological structure and hydraulic connection unit network at the different scales is a critical aspect for simulation contaminant transport. As confirmed also by several authors (Feehley et al, 2000), the DDMT approach allows to accomodate the process of mass-diffusion mixing related to scale geometric characteristics of the different structures that generally cannot be properly described by means of the ADMT model. The current study evidences how the DDMT approach may partially compensate the effects of matrix diffusion with no apparent dependency on the heterogeneity *geologic based* models, none of which does really reduce significantly the uncertainty of the solutions. Even when performing model parameter optimization, we do not get a complete compensation of the solution uncertainty that is indeed affected by the geological structure. Finally, we conclude that the choice of the geostatistical model is the key factor that really determines our ability of explicitly accommodate sorption and diffusion phenomena in transport model and that this is much more important than the choice of the modeling approach itself.

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AUTOMATED MULTI PARAMETERS MONITORING AS INDICATOR OF GROUNDWATER INFLOW

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Key-words: Groundwater monitoring, heat, temperature, electrical conductivity, pH, water tracer

1. Introduction

When investigating contaminated sites, unusual phenomena of flow or transport in groundwater can be detected by means of multiparameter probes, either installed permanently inside monitoring wells or used for vertical logging. In this paper a series of cases study are presented, in which chemical and physical anomalies were at first detected using multiparameter measuring data, and have been confirmed afterwards by chemical analysis. The examples in this paper include atypical plant layouts, injection wells, drainage systems, etc.

2. Material and Methods

Groundwater monitoring have been carried out through a set of multiparameter probes, that are able to detect water level, electric conductivity, temperature, dissolved oxygen, oxidation reduction potential and pH. The frequency of data capture acquisition was ranging from 30 seconds (in vertical logging) to 15-60 minutes (in remote monitoring). Early detection of physical anomalies through these instruments has often been validated afterwards by chemical determinations on water samples.

3. Results

Automated multi parameters monitoring in contaminated sites and in particular hydrological contexts, such as lagoons, seaside locations or the proximity of geothermal plants, has shown interesting results concerning water chemistry and the correlation between groundwater and production cycles.

4. Conclusions

The cases study show that monitoring of groundwater parameters such as temperature, electric conductivity, pH, dissolved oxygen and oxidation reduction potential very often allow to detect and determine existing phenomena of flow and transport, at very low expenses.
This procedure is very useful in the identification and selection of those monitoring points particularly fitted for other investigations (for instance through chemical analysis) and, in general, for the optimization of monitoring networks.
In the cases study, monitoring of chemical and physical parameters highlighted some particular hydrological situations related to tidal influence, fluvial drainage, precipitation.
Biodegradation in contaminated groundwater, leakings, water withdrawal and injections were also detected.

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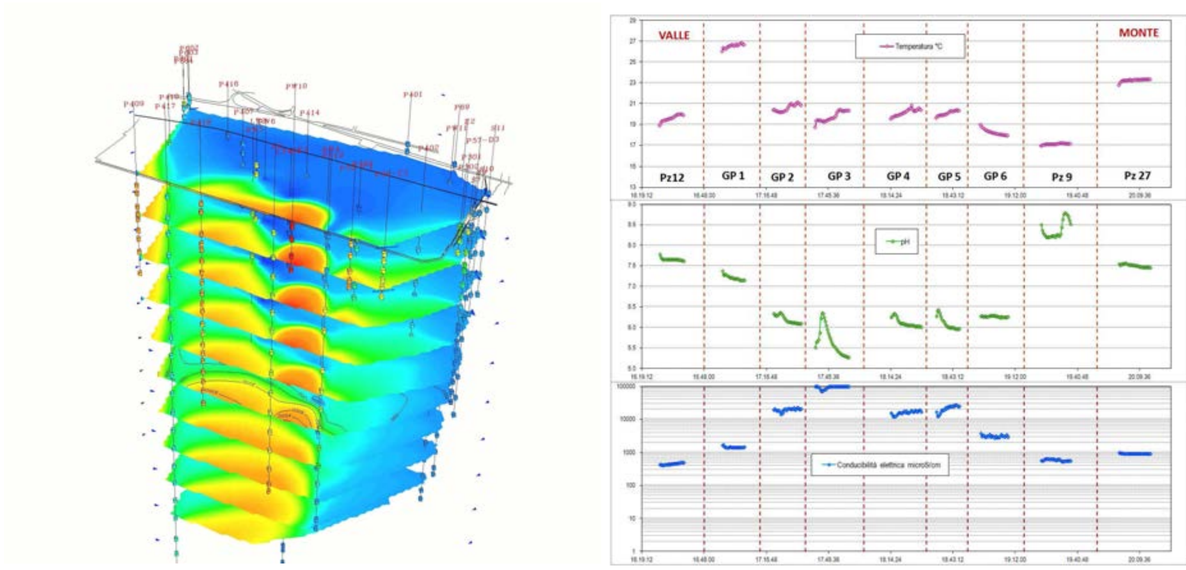

Figure 1 – Figure on the left shows the electric conductivity registered in a contaminated site by the sea, represented by horizontal sections. Data were captured by vertical logging. Figure on the right shows variations of temperature, pH and electric conductivity in a contaminated production site. The monitoring wells in the middle showed the most extreme values of pH and electric conductivity, and were afterwards found to be the most contaminated.

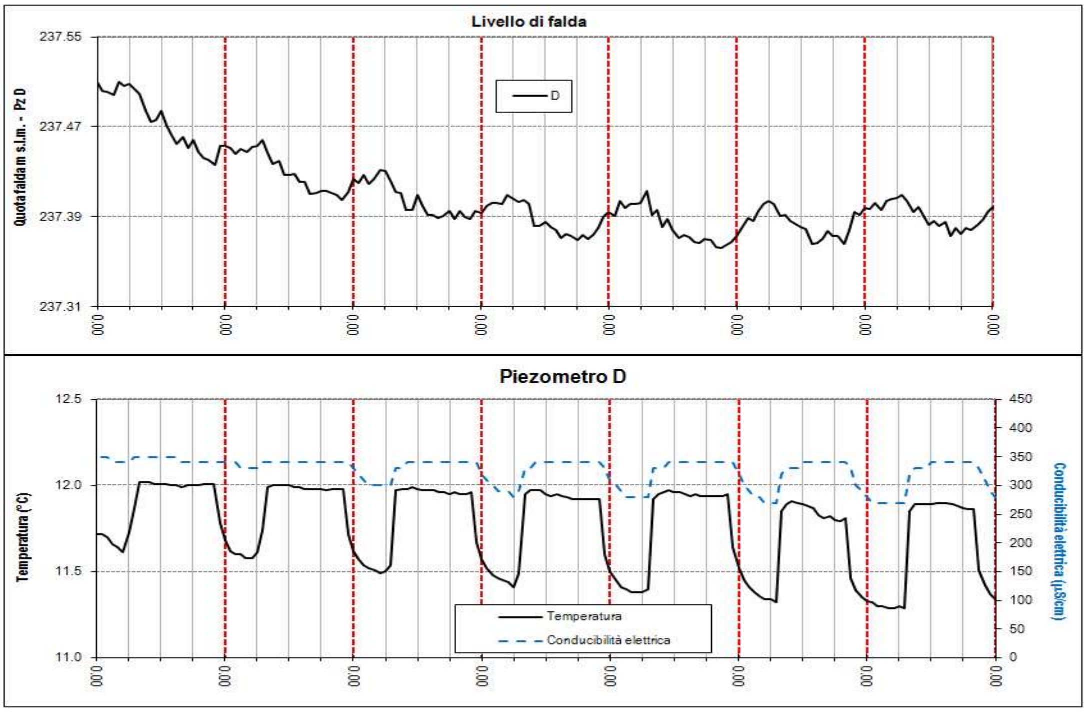

Figure 2 – Correlation between groundwater level (above) and temperature/conductivity (below) registered for a week in a monitoring well placed within a production site. Cycles of 24 hours are outlined by dotted red lines. There is a clear correlation between the rise of water level (first 6 hours of the day) and a fall in temperature and electric conductivity. Whenever the water level starts to decrease again, just after 6.00 A.M., there is a sudden increase in temperature and electric conductivity. These two parameters remain constant afterwards until a new cycle begins. This behaviour most likely depends on the withdrawal of groundwater for industrial purposes.

POLLUTED AQUIFER INVERSE PROBLEM SOLUTION USING ARTIFICIAL NEURAL NETWORKS

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Key-words: artificial neural networks inversion; inverse problems; groundwater modeling; groundwater pollution source identification.

1. Introduction

The identification and remediation of polluted aquifers represent nowadays an important challenge in groundwater resource management. This work aims to define a method to identify the spatial location (X,Y) and the duration of the activity (T) for a theoretical unknown pollution source based on the measures of contaminant concentration acquired in the monitoring wells at a certain time *t*, which represents the current time. The problem of identifying an unknown pollution source in polluted aquifers, based on known contaminant concentrations measurement in the studied areas, is part of the broader group of issues, called inverse problems. This paper investigate the feasibility of using Artificial Neural Networks (ANN) for solving the inverse problem of locate in time and space the source of a contamination process in a homogeneous and isotropic two dimensional domains. ANNs are trained through an input-output relationship. Once the output of the system is known, the input is reconstructed by inverting the trained ANNs. The approach is applied for studying a theoretical test case where the inverse problem is solved on the basis of measurements of contaminant concentrations in monitoring wells located in the studied areas. Groundwater pollution sources are characterized by varying spatial location and duration of activity. Concentration measurement data from monitoring wells may be utilized to identify these unknown pollution sources in terms of spatial location and duration of the activity. Therefore, the identification of an unknown groundwater pollution source becomes more difficult in the lack of complete breakthrough curves of historical contaminant concentration data. If concentration observations are missing over a length of time after an unknown source has become active, it is even more difficult to correctly identify the unknown pollution source. A missing data scenario is take into consideration, in particular, concentration measurement data in monitoring wells is not available for the entire duration of the pollutant source activity consequently one single value of concentration measurement at the current time *t* is available.

2. Material and Methods

Multi Layer Perceptron (MLP) ANNs are trained by using a set of patterns created by means of a flux and transport contaminant modelling software, where the patterns describe both spatial location and duration of activity of the source of contaminant and the set of contaminant concentrations measurements in the monitoring wells. The ANNs are trained by using the Levenberg-Marquard algorithm and for ensuring satisfying sample generalization performances the Leave one Out Cross Validation (LOO) learning rule has been applied. In this procedure, the examples pattern is divided in *p* sets, where *p* is the number of the couple input/output patterns. Each set is divided in two subsets: one composed of *p*-1 examples is used for the training and the other one composed of 1 example that may be used for validation or test. One by one, each couple is part of the training set and of the test set. Once the training of the ANN is terminated, the trained network is inverted for solving the inverse problem, namely, on the basis of the output of the ANN the corresponding input is calculated by exploiting the method described in (Carcangiu S. et al., 2007) and (Fanni A. and Montisci A., 2003).

The performance of the proposed methodology has been evaluated by applying it to a theoretical case of aquifer pollution in order to define the time-space coordinates (X, Y, T) of unknown contaminant sources based on the measures of contaminant concentration acquired in the monitoring wells at a certain time *t*.

The data for training the ANNs are simulated using a groundwater flow and contaminant transport numerical simulation model that takes under consideration the restricted hypothesis of groundwater contaminated by a single generic conservative pollutant injected in a single point. Training patterns are constructed by simulating 40 different initial source locations for the 3 timing of activity source duration (10, 20 an 30 years), resulting in 40*3=120 sample maps of contaminant distributions. Each source of pollution has been assigned 100 μg/m^3 of contaminant concentration (see Fig.1).

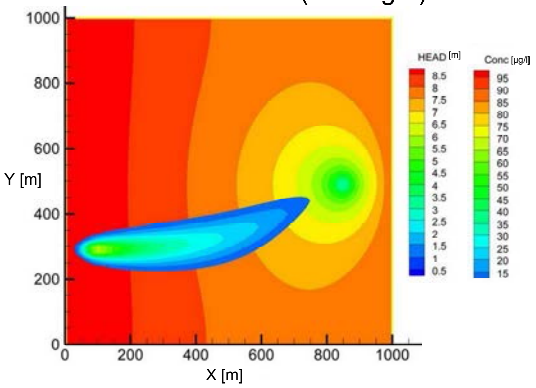

Fig. 1 – hydraulic head and solute concentration for a generic pollutant source after 10 years activity at the top of the aquifer domain.

The samples obtained from the simulation model were the contaminant concentration curves acquired in the 50 cells distributed uniformly in the domain. The huge amount of data carried out by each time step of simulation of the domain is not suitable to be inputted in an ANN. Feature extraction techniques have been therefore implemented to reduce data dimensionality. For output data reduction, the restricted hypothesis of the total absence of historical data concerning the aquifer pollution has been taken into consideration, in particular, the case of a contamination detection for the first time in a generic domain. Only the last value of contaminant concentration in time, obtained through simulations, was considered for the 50 cells. These 50 cells correspond to 50 hypothetical monitoring wells. An ANN based approach was applied in order to reduce the number and choose the best location of the monitoring wells in the domain: only 8 cells have been kept into consideration.
Based on the LOO learning rule, 120 3-8-8 MLP networks were trained, with different training set and test set, in order to solve the direct problem. Each network was trained with 119 examples and tested with one example (kept out from the original training set). The test example allows us to estimate the network generalization capability. In particular, ANNs were trained to solve the direct problem. The objective was to combine the input patterns (which represent the pollution source characteristics named time-space coordinates) with the output patterns (which represent the contaminant concentrations measures acquired in the monitoring wells). In order to solve the inverse problem and to identify the unknown pollution source, the trained ANN has been inverted. By fixing the output pattern, the ANN inversion algorithm has been able to reconstruct the corresponding input. On the basis of the known contaminant concentration data in monitoring wells, the pollution sources position and the duration of the activity have been identified.

3. Results

In general, the results show very good performances in locating the pollutant source. In the most of the time the identification error is less than the size of one cell, in fact the cell size is equal to 20*20 m^2. At the same time, the maximum error, which represents the worst case, is less than the size of two cells. Less satisfying results have been obtained concerning time step prediction with the 76% of correct duration activity approximation. Concerning the sources duration activity of 10 and 30 years, only one case time approximation was wrong. For the 20 years sources duration activity, the wrong cases were higher than the correct cases with 26 wrong cases out of a total of 40 cases.

4. Conclusions

The inverse problem solution method developed allow to estimate time-space coordinates of unknown contaminant sources. Various source scenarios have been constructed in order to generate the examples patterns used for training and testing the ANNs. These scenarios have been performed by varying the pollutant source position and the duration of the source activity in the domain. The inverse method based on ANN technology has been used to identify unknown pollution sources. In particular, the inverse problem has been solved using measurements of contaminant concentration acquired in the monitoring wells at a certain time *t*. The methodology applied may be useful not only to identify the location and activity of unknown pollution sources, but also to delimitate the study area and optimize the investigation costs by determining the best monitoring wells location.

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WATER FLOW AND TRANSPORT OF HEXAVALENT CHROMIUM IN UNSATURATED SOIL AND REMEDIATION BY "SOIL FLUSHING"

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Key-words: Hexavalent Chromium, Soil Flushing, Flow and transport models.

1. Introduction

This work is based on the study of water circulation and transport of a pollutant in the unsaturated soil in a site contaminated with Cr(VI) in Asti (Italy), subject to reclamation by washing the soil in situ (soil flushing) with water.
The initial maximum contaminant concentrations were 2000mg/kg in soil and 700mg/l in groundwater for a volume of about 2700m^3 of contaminated soil, and an estimated mass of Chromium in the ground of 1000kg.
The injection system was composed of 7 piezometers with filters in the terminal segment (6.5 to 7.5m deep); injections of water with a volume of 5.13m^3 each have been made for about 3 years under two levels of low permeability in the unsaturated soil.
The washing solution was recovered hydrogeological downstream by recovery wells and treated. The Cr(VI) daily extract at start remediation was about 2kg per day, then began a decline in system performance up to a few grams per day when the injections were stopped by the decrease in the effectiveness of the technology.
This study has the purpose to improve the knowledge of the flow and transport of this area in order to optimize the recovery of hexavalent Chromium in the unsaturated zone.

2. Material and Methods

- Determination of the subsurface from stratigraphy’s data;
- Evaluation of the contamination of soil and groundwater;
- Characterization of unsaturated soil with processing data from in situ investigation techniques (Lefranc tests, gypsum blocks, lysimeters) and laboratory (particle size analysis, chemical analysis of soils and waters) and definition of hydrological and hydro-dispersive parameters of soils;
- Use of numeric codes to develop models of flow and transport to support the optimization of the remediation system using Soil flushing;
- Study of different techniques to continue and complete the site remediation.

3. Results

The subsoil consists of sandy gravel layers separated by two layers of low permeability silt at a depth of 3.5-4.5 m (1st level) and 6-7m (2nd level), from a depth of about 11 m is present over consolidated clay. The Quaternary alluvial deposits contain a shallow water table, depth 7m and variable thickness between 3 and 8m. Characterization data of unsaturated soil help to define retention and permeability curves for each level of the subsoil, as well as estimated values of dispersion, distribution coefficient and Cr(VI) coefficient of delay. Numeric codes SEEP/W and CTRAN/W were used to implement flow and transport models after been verified with the experimental data of the injections. These were useful to reconstruct the injection mode. Verification of the influence of the flow rate input, transport speed and input point distance from the source has been made with the models. Then a mass balance of the recovered Chromium was developed and an estimation of the duration of the soil reclamation is calculating by varying the volume of water injected into the unsaturated zone for values between about 5 and 8m^3. In this range of values the amount of Cr(VI) extract increases from 2kg up to 4.4kg per day, with a decrease of the period of remediation from 39 to 19 months.

4. Conclusions

The study of water flow and contaminant transport permit to be aware of the characteristics of the site and suggest an optimization of the existing remediation system.
One of the parameters that were considered during the simulations is found to be more sensitive than the others and then making changes on it can have significant changes in the way of remediation. This parameter is the volume of water introduced by each injection because with an increase in the flow of each injection would be able to decrease the duration of the reclamation by about 1 year.
It’s possible that a successive phase of fixing geochemistry can be achieved by inserting an

aqueous solution into the subsoil with the addition of a reducing compound, to initiate a reactions that reduces Cr(VI) to Cr(III) and subsequent immobilization of the trivalent form in the solid matrix, technique tested in Italy in Brugherio (MI) using water enriched in $FeSO_4$ [Beretta,2000-2003]. According to the study of treatability, the most effective compound to reduce the chrome in this case is the sodium metabisulfite (META) with a requirement of between 3 and 5g of META/g of Cr(VI), but different types intervention already tested and patented in Italy may been adopt, as "Sapio H_2 remediation" which is based on the use of reducing gas mixtures containing hydrogen and nitrogen, with electron donations as an alternative to the use of exogenous organic molecules, such as acids or alcohols . Or through the use of an organo-sulfide benign known as "Metals Remediation Compound" (MRC) produced by Regenesis ®.

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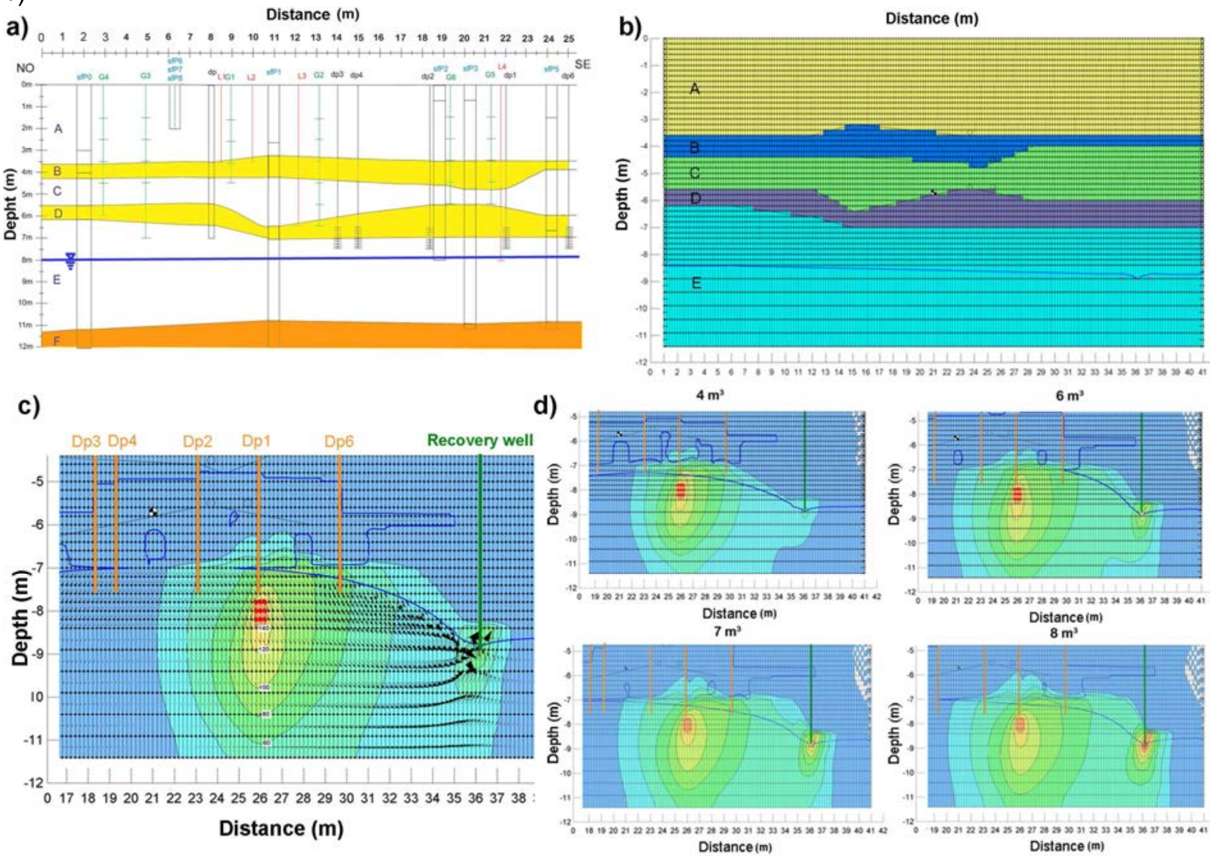

Fig. 1 – Steps carried out during studying the flow and transport of Cr (VI) characteristics. ***a)*** *Stratigraphic section, marked with unsaturated soil checkpoints (L= lysimeters, G=gypsum blocks, sfP= piezometers, dp= injection points) and stratigraphy (A= sand, B= sandy silt, C= sand with gravel, D= silt, E= gravel with sand, F= over-consolidated clay).* ***b)*** *Flux model in SEEP/W.* ***c)*** *Trasport model in CTRAN/W with 5,13 m^3 volume of water injections during a week.* ***d)*** *Simulations of transport with water volume injection variation during a week (4-8m^3).*

AMMONIA FATE TRANSPORT FROM LANDFILL LECHATE AND FLOWPATH NUMERICAL MODELING: A CASE-STUDY OF ALICE CASTELLO LANDFILL (ITALY).

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Key-words: Landfill, ammonia lechate, reactive transport

1. Introduction

This study presents the groundwater remediation status carried out using an Air Sparging (AS) system at the Alice Castello landfill.

The local hydrogeology is characterized by two different aquifers: a superficial aquifer mainly comprised of fluvio-glacial sediment, and a confined deep aquifer, comprised of fluvial clay-silt and gravel-sand deposits.

Groundwater in the superficial aquifer is affected by ammonia-nitrogen compounds leaching from the bottom of the landfill.

The AS system has been active since January 2008. The effects of air stripping are the ammonia removal and nitrification processes. The physical and chemical processes that affect contaminant migration in the superficial aquifer have been monitored and modeled in order to predict the remediation efficiency.

The monitoring system would also allow evaluating the optimal kinetics of in-situ ammonia removal.

Several researchers have studied how to remove the ammonia-nitrogen from landfills leachate (Cheung et al., 1997; Hoilijoki et al., 2000; Ilies and Mavinic, 2001; IM et al., 2001; Marttined et al., 2002; Shiskowski and Mavinic, 1998).

In this case-study a steady-state flow numerical model has been calibrated against hydraulic head data, collected since 2004 to 2009 (before starting the AS). Using the results of the flow numerical model, a transport model for the ammonia has been built. Then the transport model has been calibrated against monitoring data collected after starting the AS system.

2. Material and Methods

The methodology used in this study is based on Anderson & Woessner (1992) protocol for the conceptual and numerical models development.

FEFLOW 5.3 (Diersch, 2007), based on finite elements method, has been used for numerical simulation.

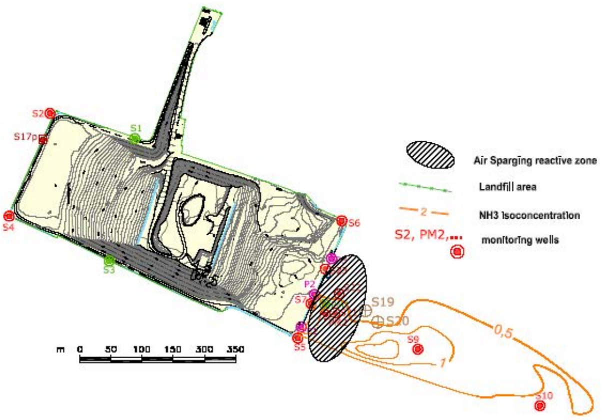

Fig.1 – Landfill plant, with ammonia plume after 2 years since the starting of AS system.

3. Results

The simulation results show some decreasing in ammonia concentration within the AS system reactive zone. Using these results, predictions have been made about the ammonia plume fate downgradient the AS system reactive zone (Fig. 1).

The contamination source is represented by the average values of ammonia concentration inside the landfill basin, from where the lechate is released. The fate transport processes considered for ammonia are: advection, dispersion, linear adsorption and nitrification.

A first order kinetic has been chosen in order to simulate the removal rate of ammonia concentration value, with a decay constant of: $k = \ln 2 / t_{½}$.

The AS system effect on the ammonia plume has been simulated considering, inside the AS wells influence area, the $t_{½}$ values from monitoring data (table 1).

A *trial-and-error* calibration method has been applied for dispersion coefficients and for contamination source area, based on continuous checks against monitoring data, collected before starting the AS system.

A six months simulation shows a continuous decrease in ammonia concentration within the AS reactive zone. The contamination plume is

larger along S7, PM2 and S21 wells (Fig.1). Downgradient the AS system, ammonia concentration is expected to decrease because of the AS system influence.
Further simulations, considering a constant released of ammonia from the source, shows a decrease in concentration inside the AS reactive zone. Consequently the contamination plume, moving downgradient, is likely to lose mass of ammonia while moving in the aquifer.
Predictions so far made will be confirmed using monitoring data. Calibration against analysis results is useful in order to validate the assumptions used in the numerical model, especially for the decay constant of ammonia.

4. Conclusions

Simulations of reactive transport downgradient respect to the source contamination area suggest that a decrease in concentration of ammonia, within the reactive zone of the AS system, is likely to be observed. A continuous calibration of the model is useful in order to validate the hydraulic head distribution and the assumption about fate transport and processes of ammonia compound. A first order kinetic has been used to simulate dispersion and adsorption of contaminant. Further simulations will be useful to test kinetics and to investigate nitrification processes of ammonia.

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Sampling date	PM2 (mg/l)	S19 (mg/l)	S20 (mg/l)	S21 (mg/l)	S22 (mg/l)
09/01/08	0,60	-	-	-	-
28/01/08	0,29	-	-	-	-
25/02/08	2,43	-	-	-	-
10/03/08	3,45	0,40	14,60	-	-
07/04/08	6,47	-	-	-	-
28/04/08	1,04	1,00	3,93	-	-
09/05/08	7,84	3,64	4,34	-	-
27/05/08	7,43	-	-	-	-
01/07/08	11,10	2,79	5,84	-	-
28/07/08	6,93	2,77	4,10	-	-
25/08/08	4,87	1,79	2,71	-	-
29/09/08	3,38	0,18	2,14	-	-
27/10/08	2,22	1,56	2,34	-	-
24/11/08	0,96	0,49	0,96	-	-
19/12/08	0,25	0,14	0,52	-	-
27/01/09	0,38	0,57	0,51	-	-
23/02/09	0,00	0,32	0,30	-	-
30/03/09	1,63	0,61	0,86	-	-
30/04/09	1,33	0,34	0,67	-	-
27/05/09	1,88	0,92	1,07	-	-
29/06/09	1,79	0,95	0,91	-	-
30/07/09	1,85	1,43	1,11	-	-
25/08/09	1,99	0,70	1,45	-	-
30/09/09	1,98	0,52	1,48	-	-
16/10/09	4,48	0,19	1,77	-	-
27/11/09	5,60	0,68	1,98	-	-
28/12/09	-	0,39	2,16	-	-
25/01/10	6,96	0,47	1,97	-	-
03/03/10	5,25	0,06	0,90	4,85	1,19
09/03/10	5,02	0,01	0,65	4,63	1,29
31/03/10	3,34	0,42	1,65	4,53	1,22
15/04/10	2,00	0,24	1,22	1,96	1,31
26/04/10	4,30	0,08	1,12	3,92	1,15
14/05/10	1,86	0,01	1,02	1,98	0,84
31/05/10	1,85	0,11	0,99	1,70	0.97
21/06/10	1,79	0,27	0,98	1,57	1,18
23/07/10	1,44	0,16	0,46	1,14	0,53
30/08/10	1,10	0,16	0,46	0,80	0,25
30/09/10	1,03	0,09	0,14	0,77	0,45
26/10/10	0,82	0,16	0,16	0,83	0,59
30/11/10	0,99	0,00	0,46	0,82	0,24
29/12/10	1,25	0,00	0,02	1,12	0,10
31/01/11	1,25	0,00	0,01	0,82	0,11
22/02/11	1,68	0,01	0,17	1,38	0,12
30/03/11	1,69	0,00	0,52	1,52	0,05
29/04/11	1,21	0,00	0,15	1,41	0,11
30/05/11	1,04	0,00	0,05	0,83	0,01
27/06/11	1,14	0,00	0,00	0,99	0,00
19/07/11	0,90	0,00	0,00	0,76	0,00
16/08/11	0,94	0,00	0,00	0,52	0,00
28/09/11	1,22	0,13	0,15	1,27	0,14
28/10/11	0,97	0,02	0,61	1,14	0,08
30/11/12	0,82	0,00	0,63	0,70	0,03
30/12/11	2,19	0,83	1,88	2,19	0,28

Tab.1 – Concentration of ammonia in PM2, S19, S20, S21, S22 monitoring wells, since 2008 to 2011.

Long term monitoring of chlorinated solvents using carbon isotopes: effects of source removal and natural attenuation

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Key-words: source removal, TCE, carbon isotope

1. Introduction

At a site contaminated with chlorinated solvents, as a part of the remediation treatment the two main contaminant sources were removed. The source removal effect and biodegradation processes were assessed by a long term monitoring program (2 years long) including the use of the Compound-Specific Isotope Analysis (CSIA). The objective of this work is to show how isotopes can be useful to evaluate the efficacy of remediation when a combination of different treatments is applied. In the present study Monitored Natural Attenuation (MNA) and source removal were implemented.

2. Material and Methods

The study site is located in Catalunya, Spain, on a low permeability unconfined fractured bedrock. Previous forensic studies highlighted two main plumes, related to different sources: a disposal lagoon (along transect A) and an underground wastewater tank (along transect B) (Fig.1a). Only one of the plumes (along transect B) was affected by biodegradation processes. In March 2006 the 2 sources were removed and the site was monitored until January 2008.

Groundwater samples were obtained from 10 multilevel nested wells, called S-1 to S-10 (Fig.1a). On site geochemistry data (including Eh, pH, dissolved oxygen [DO] and Dissolved Organic Carbon, DOC) were measured, and alkalinity, major cations and trace elements, major anions, Volatile Organic Compounds (VOCs) concentration, and carbon isotope ratios ($\delta^{13}C$) of chlorinated ethenes (PCE, TCE, and cis-DCE) were determined.

3. Results

With regards to plume along transect A (Fig. 1b), after the source removal TCE concentration in S-1 decreased by 75% in the upper part, and by 50% in the deeper part of the aquifer. The $\delta^{13}C$ data in S-1 did not show significant variations along time, with an average value -22.5‰, (Fig. 1b) similar to measured values of the lixiviated contaminants close to the disposal lagoon sampled before its removal (the same behaviour was observed in S4, and for the other contaminants). The decrease in TCE concentration together with no fractionation suggested the absence of biodegradation processes along the monitoring period; hence the decrease in contaminant concentration was only attributed to a source removal effect.

Regarding the plume long the transect B, TCE concentration in S3 decreased by 40-55% after the source removal, remaining approximately constant in the last two surveys (Sept. 2007 and Jan. 2008), indicating that a certain steady-state was reached again after source removal (Fig. 1c). $\delta^{13}C_{-TCE}$ values in both S3-11.5 and S3-15.5 shifted from -13.5‰ to -9.8‰, whereas in S3-19.5 it remained constant around -8.3‰. Together with enriched values, this plume also presents a high cis-DCE concentration suggesting that biodegradation processes are taking place. Despite this shift towards $\delta^{13}C_{-TCE}$ enriched values, cis-DCE molar fraction in S-3 decreased during the studied period whereas $\delta^{13}C_{cis-DCE}$ remain depleted indicating no cis-DCE increase in degradation, especially in the upper zone, (S3-11.5 and S3-15.5), suggesting that the reduction of TCE concentration is probably the result of the source removal, more than a potential increase in biodegradation processes. Results in the plume could be explained also by mixing with another source enriched in $\delta^{13}C_{-TCE,}$ or by aerobic biodegradation processes. Aerobic biodegradation would change $\delta^{13}C_{-TCE}$ without production of additional cis-DCE, however, the observed redox conditions were not favourable to aerobic processes. The temporal evolution of $\delta^{13}C_{-TCE}$ might indicate that the source removal had effects both on TCE concentration and on the isotopic composition, after excluding differences in $\delta^{13}C_{-TCE}$ owing only to biodegradation. The trend to enriched $\delta^{13}C_{-TCE}$ values throughout the studied period could be the consequence of the absence of a continuous TCE input with a constant $\delta^{13}C_{-TCE}$ of -16.5‰

from the source (as a result of source removal). This conclusion is confirmed also by a vertical trend along S3, with $\delta^{13}C_{-TCE}$ values varying especially at 11.5 m and 15.5 m depth, but not at the bottom levels. This is also indicating, indirectly, that before the source removal, a continuous leaching from the source was masking the isotope enrichment in the residual TCE owing to the biodegradation.

4. Conclusions

Results obtained demonstrated that source removal was successful in reducing contaminant concentration in the aquifer. In the area of the vicinity of the disposal lagoon a reduction in concentration in between 50% and 75% of the contaminant mass was observed. This pattern is accompanied by no changes in $\delta^{13}C$ values indicating that the decrease in contaminant concentration can be attributed to the source removal, and not to biodegradation processes throughout the monitoring period. The situation was more complex for the area in the proximity of the underground wastewater tank, where biodegradation processes are taking place. After the source was removed, no more TCE was leaching from the source, with the $\delta 13C_{-TCE}$ moving to the values owing only to the biodegradation already active in the plume. Stable isotopes (^{13}C), together with concentration measurements in a long term monitoring program, significantly improved the evaluation of the efficacy of remediation in contaminated sites, offering a better conceptual model understanding.

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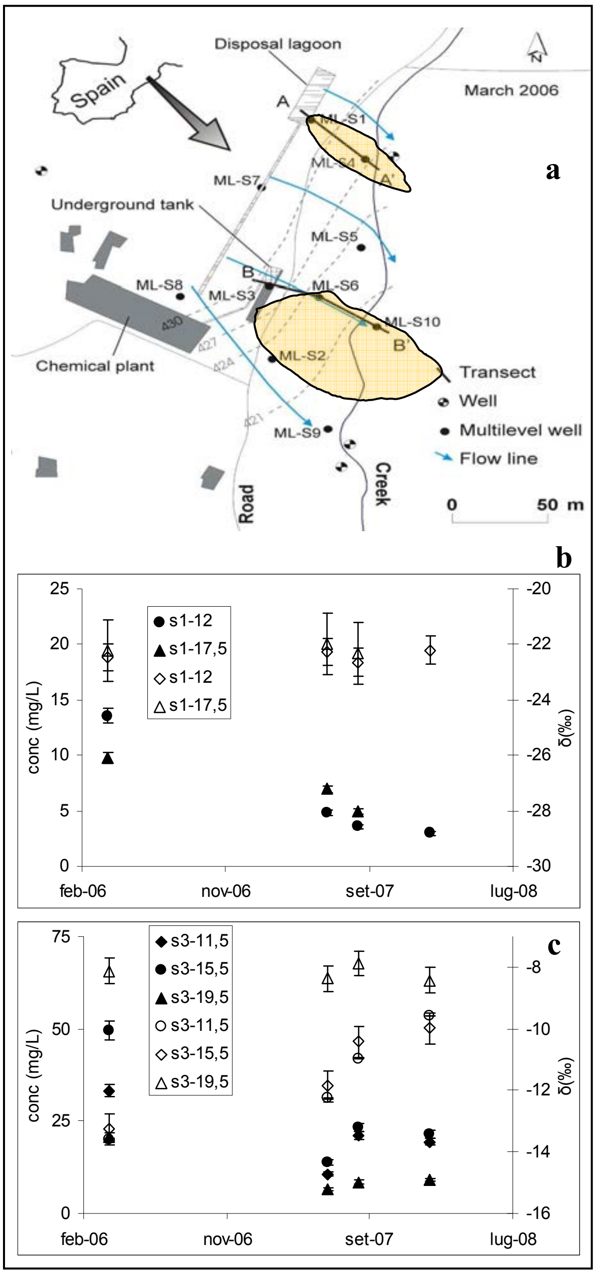

Fig.1. (a) Site map showing the location of multilevel monitoring wells, plumes along the transect A and B, and the areas interested by the source removal; (b) Temporal trends for $\delta^{13}C$ values and TCE concentration at S1 (b) and S3 (c).(As e.g. S1-12 is piezometer S1 at 12m depth).

Characterization and modeling of a BTEX plume originated by a sulphur rich NAPL source

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Key-words: PHT3D; sulphate; electron acceptor; BTEX; stable isotopes.

1. Introduction

The biodegradation of the aromatic hydrocarbons benzene, toluene, ethylbenzene, and xylene isomers (BTEX) has been the topic of numerous laboratory studies (Mazzeo et al. 2010; Xie et al. 2010) and field studies (Chapelle et al. 2002; Cozzarelli et a. 2010). Microbial consortia present in the aquifer have the potential to degrade a wide range of organic pollutants in addition to BTEX (Weelink et al. 2010). In situ studies and laboratory experiments have shown that biodegradation can abate contaminants concentration below or near to regulatory threshold levels (Anderson and Lovley, 2000; Cozzarelli et al. 2001). However, within the contaminated aquifers, often biodegradation reactions are limited by the availability of electron acceptors (Christensen et al. 2000).

In fact, bacteria usually rapidly consume electron acceptors like oxygen and nitrate when inhibiting substances are not present. Following the Gibb's law, the energy yield of organic matter oxidation falls rapidly (Appelo and Postma, 2005). Then, lower energy yield degradation processes, like iron reduction, sulphate reduction and methanogenesis became relevant in long-term pollutant attenuation (Christensen et al. 2000). Recently, reactive transport modeling has been employed to quantify biodegradation rates and contributions of other relevant processes like dispersion, sorption, precipitation and dissolution reactions (Prommer et al. 2006; Colombani et al. 2009). In addition, several field studies employed stable sulfur isotopes of dissolved sulfate to identify bacteria sulphate reduction in contaminated aquifers (Spence et al. 2001; Spence et al. 2005). In this study we used stable isotopes information to validate a reactive model that takes into account a sulphur rich NAPL source.

2. Material and Methods

The study site is a 1 km^2 portion of a chemical plant in Italy. The presence of BTEX has been recognized in the unconfined aquifer underlying the plant. An unknown volume of NAPL was released and over time it migrated above the saturated zone. A pump and treat remediation strategy was implemented in 1994 to prevent migration of the plume into a canal down gradient of the site.

The overall aquifer parameterization and modeling at the study site has been documented in a previous paper (Colombani et al. 2009). The groundwater was sampled from MLS and fully-screened wells. Samples were recovered in air-tight containers and transported to the analytical laboratory for analysis within 2 hrs. Field parameters were determined towards the end of purging using a multi-parameter instrument WTW Multi 340i. The major cations were determined by AAS, while anions were determined by ICS-120 Dionex. BTEX as well as methane and carbon dioxide were analysed by a GC-FID Trace Thermo Finnigan apparatus. $\delta^{18}O$-SO_4^{2-} and $\delta^{34}S$-SO_4^{2-} isotopic analyses were performed on a Delta Plus TC/EA and Micromass Eurovector TC/EA as reported by Spence et al. 2005.

3. Results

Developing from the source zone, the organic compounds formed thick and long hydrocarbons plumes with the benzene and ethylbenzene plumes reaching lengths of approximately 400 and 500 m, respectively. On the other hand, the toluene and xylene plumes were shorter. Toluene had a limited extension due to its elevated degradation rate, while the xylene exhibited a short plume because of its small molar fraction (less than 1%) within the NAPL mixture, which leaded to rather low dissolved xylene concentrations. Aerobic degradation and denitrification appeared to be the degradation processes that take place at the fringe of the plume. This was evidenced by a complete depletion of oxygen within the plume. Nitrate was also removed completely, except near the water table. In the plume's core anaerobic degradation processes dominate, as indicated by the increasing concentrations of dissolved Fe^{2+} and Mn^{2+}.

Sulphate concentrations were much higher in the core area of the plume due to its release from the NAPL phase. These elevated concentrations most likely resulted from the oxidation of pure sulphur S(0) recovered in the floating NAPL. This means that the NAPL source contained an internal electron acceptor source. Methane was found at lower concentrations in core samples respect to fringe samples. This was in agreement, with the evidence of S(0) in the NAPL, since its oxidation to sulphate provided a most favourable electron acceptor than methane. The development of a site-specific reaction module was required to adapt the numerical model to the conceptual model of the site, for example, to address the differential degradation rates of individual hydrocarbon compounds and the sulphur presence within the NAPL. To assess the role of sulphur/sulphate in the electron budget, a scenario without sulphates in the source was simulated. The scenario results showed that the hydrocarbon plumes became longer than the observed plumes while significant methane production occurred.

The results from the stable isotopes showed relatively low background values upstream to the NAPL source with values of 6.1±0.5 and 10.3±0.7 for $\delta^{18}O\text{-}SO_4^{2-}$ and $\delta^{34}S\text{-}SO_4^{2-}$, respectively. On the contrary, a marked enrichment of both $\delta^{18}O\text{-}SO_4^{2-}$ (10.2±0.4) and $\delta^{34}S\text{-}SO_4^{2-}$ (32.6±0.4) was found directly below the NAPL source. Even higher enrichments (14.9±3.5 $\delta^{18}O\text{-}SO_4^{2-}$ and 37.0±3.5 $\delta^{34}S\text{-}SO_4^{2-}$) were found in the MLS downstream to the NAPL. The elevated enrichment of both the stable isotopes of sulphate within the plume is a proof of ongoing sulphate reduction and the relatively constant values found suggest that this process is ubiquitous within the plume.

4. Conclusions

This study points out that the reactive transport model have been shown to be essential for a good understanding of the coupled flow/transport and geochemical processes. To proof that sulphate reduction is one of the major electron acceptor in the plume's core, stable isotopes of sulphate were employed to validate the reactive model assumptions. The elevated enrichment of both $\delta^{18}O\text{-}SO_4^{2-}$ and $\delta^{34}S\text{-}SO_4^{2-}$ confirmed the assumption made, although since the enrichments were relatively constant throughout the plume a sulphate reduction rate cannot be derived and directly compared with the one obtain by model calibration.

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HYDRODYNAMIC AND ISOTOPIC CHARACTERIZATION OF A SITE CONTAMINATED BY CHLORINATED SOLVENTS: CHIENTI RIVER VALLEY, CENTRAL ITALY

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Key-words: multilayer aquifer, polluted site, conceptual model, isotope analysis

1. Introduction

The study area is an alluvial aquifer up to 30 m-thick impacted by contaminant sources attributed to the shoe manufacturers.
During the ‘80s and ‘90s of last century the main chlorinated compound used was TCA, which was substituted by PCE in the last fifteen years (ARPAM, 2007).
Hydrodynamic tests coupled with multilevel hydrochemical samplings were performed for the development of a conceptual and numerical model that can be use for a future remediation plan. To validate the conceptual model, to verify the origin of the contamination and to identify the main processes involved in the attenuation of contaminants in the alluvial aquifer, isotope analyses of chlorinated solvents have been conducted in selected sampling sites

2. Material and Methods

Alluvial deposits of the Chienti River lower valley host a multilayer porous aquifer, represented by gravels in a sand-silt matrix (Nanni, 1985). Local silty-clay low-permeability layers created the existence of local multilayer and perched aquifers, while at the site scale groundwater flow can be considered homogeneous.
The following site surveys have been performed:
a) two piezometric monitoring events (180 measurement points);
b) vertical log of main chemical-physical parameters, (pH, electric conductivity, temperature, Eh and dissolved oxygen) by one-meter interval (18 observation wells);
c) vertical hydrodynamic of groundwater flow by heatpulse flowmeter prob (8 monitoring wells). By heat wave emission, termistors recorded possible difference due to the presence of vertical component of flow into the observation well (Petitta et alii, 2010);
d) Multilevel sampling using a "Multilevel Sock-Packersystem". External sampling ports placed in a flexible tube can withdraw groundwater from selected different levels in the multilayer aquifer. Observation wells SC3 and SI3, respectively located in the upper and lower valley were monitored.
e) Carbon and chlorine isotope analysis of chlorinated solvents in groundwater collected in 20 sampling locations, including wells and multilevels, have been done for fingerprinting and evaluation of the fate of the contaminants at the study site (van Warmerdam E. M et alii, 1995).

3. Results

a) The piezometric map confirmed a main groundwater flow from west to the coastline, showing a mean hydraulic gradient of 5‰.
b) The vertical logs in SC3 show an electric conductivity increases from 1450 µS/cm to 4520 µS/cm, while the DO increases and then decreases and Eh drops from -71 to -250 mV in the deeper part of the well. Downgradient well SI3 shows sharp changes at 12 m of depth, at the boundary between a silty-clayed aquitard and the deep aquifer: electric conductivity decreases from 1515 µS/cm to 1028 µS/cm, while Eh changes from 200 to -100 mV and dissolved oxygen (DO) drops from 13.5 to 3.4% .
c) Flowmeter tests in SC3 show a positive flow upward (up to 0.27 L/min) at the depth corresponding to the top of the gravel aquifer, indicating semiconfined conditions in the upper valley, due to the presence of low permeability sediments close to the ground. For SI3, several episodes of flux downward, increasing in magnitude below 12 m b.g.s., from 0.2 L/min to 2 L/min have been recorded, indicating preferential flow to the bottom of the aquifer. Comparing vertical flow and electrical conductivity in SI3, a similar vertical profile can be inferred testifying changes in the aquifer hydrodynamic in correspondence with low permeability layers located 12 m b.g.s..
d) The concentration profiles of contaminant recorded in multilevel sampling showed a vertical stratification. In case of SC3, the main daughter product is 1,2-DCE reaching a high value of 50 µg/L at a depth of 10 and 12 m. This interval corresponds with the upward flow conditions and with changes in DO values. No evidence of the previously used 1,1,1-TCA is observed in the shallow part of the aquifer. In

SI3 (lower valley), the maximum concentration of the parent compound 1,1,1 TCA and its degradation products, 1,1-DCE, 1,1-DCA and VC are observed around 16 and 22 m deep. Also in this case, a clear stratification of contamination has been recorded, with a correspondence of the depth of maximum concentration and existence of vertical flow components.

e) The isotope data showed a wide range in $\delta^{13}C$ values for PCE that varies between -23.7 and -29.0 ‰. The $\delta^{37}Cl$ values vary between -2.5 and 3.8 ‰. No evidence of biodegradation was observed for PCE excepting at the location where the PCE is characterized by the more enriched $\delta^{13}C$ and $\delta^{37}Cl$ values. This pattern indicated that dilution is the main process that controls the concentration of PCE in the aquifer.

Based on the concentration and isotope data and flowpath, it is suggested that source of PCE for the drinking water wells is located upgradient in the central and eastern part of the site. It is highly possible that due to the wide range of $\delta^{37}Cl$ values in this area, additional $\delta^{37}Cl$ data in the drinking water wells will provide a more definitive answer concerning the source of PCE in these wells.

No evidence of TCA were found in the most part of the aquifer, excepting in the areas near the coast where beside TCA, biodegradation products 1,1-DCE and 1,1-DCA were also found. The role of biodegradation is further documented by the isotope data collected in the multilevels.

The isotope data collected at SC3 located in the upper part of the study area showed that ^{13}C values for cis-DCE range between -25.8 and -26.9‰, indicating that cis-DCE has not been transformed to VC, which is also supported by the concentration data. Very low concentration of daughter products of TCA in this location indicated that the concentration of this old source of VOC have been control by biodegradation and dilution.

In SI3 (near the coast) the VOC is composed of TCA, 1,1-DCE, 1,1-DCA and PCE. The isotope data showed a range of $\delta\ ^{13}C$ values that varies between: -22.5 and -32.5‰ for TCA; -9.1 and -13.4‰ for 1,1-DCE; -24.5 and -29.4‰ for 1,1-DCA: and -31.5 and -33.4 ‰ for PCE. The concentration and isotope data showed that TCA and its daughter products have been affected by biodegradation, however this process does not seems to be controlling the concentration of PCE.

4. Conclusions

All data are in accordance with a conceptual model of groundwater flow and pollution influenced by low-permeability layers, separating a shallow sandy aquifer and a deep gravel aquifer, locally confined.

Validation of this model and consequences in terms of pollution source and fate have been evaluated using chlorinated solvents isotope analyses.

Concentration data collected in 20 wells located downgradient of the different sources showed VOC's levels lower than 100 ppb in the upper part of the valley and levels around 300 ppb in the near shore areas. No evidence of TCA was found in the upper valley areas, however the occurrence of very low concentration of its daughter products indicated that TCA has been controlled by biodegradation and dilution. Evidence of TCA biodegradation were also observed in an area near the shore, where TCA and its degradation products were predominant. No evidence of the role of biodegradation, excepting in one location in the upper part of the basin, was observed for PCE. The concentration and isotope data showed dilution is the main process that controlled the distribution of PCE in the aquifer.

The results obtained in the multilevels, SC3 and SI3, clearly showed the existence of a VOC stratification. In addition, the vertical distribution of the contaminant reflects the vertical flow pattern inferred from the hydrogeological data and flowmeter tests. In the upper valley, contamination is prevalent in the shallow part of the aquifer, while in the lower valley the contaminants are concentrated in the deeper levels of the main aquifer. This pattern is confirmed by vertical components of groundwater flow which result to have an upward flow in the upper valley and a downward component in the lower valley.

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IRON, MANGANESE AND BORON DISTRIBUTION IN THE ABRUZZO REGION GROUNDWATERS

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Key-words:
Hydrochemistry – Groundwater contamination - Iron – Manganese - Boron

1. Introduction

In this paper preliminary results of a study concerning distribution of some inorganic pollutants in the Abruzzo region groundwaters are discussed.
This work was carried out since very often, abnormal concentrations (surpassing legislation threshold values) of Manganese (Mn), Iron (Fe) and Boron (B) were found in the Abruzzo region groundwaters.
These elements have been classified as pollutants in national legislation (D.Lgs. 152/06), therefore, this study aims to identify their genesis, studying the existing relations between groundwaters and aquifer's hydrogeological settings.
Studies about groundwater contamination in inorganic pollutants (Kloppmann et al., 2005; Pennisi et al., 2006; Pennisi & Mutti, 2008; Pezzetta et al., 2011) were carried out both in Italian and European areas, even if none of them concern the central Adriatic region.
This research aims to identify hydrogeochemical processes occurring in groundwater bodies, which are able to justify abnormal concentrations detected, which aren't, at first analysis, attributable to anthropogenic pollution.
Results of these study will also be used to support the derivation of natural background levels notwithstanding the current regulations.
Ultimately this research is finalized to highlight that groundwater status assessment should be conceived as a scientific evaluation procedure, which has to be based on geological framework and on hydrogeochemicals process occurring in aquifers.

2. Material and Methods

This survey was carried out by collecting many chemical analyses concerning groundwater samples, in addition to hydrogeological and hydrogeochemical data.
The groundwater survey has been carried out on the basis of about 500 chemical analyses attributable to ARTA's (Regional Environment Protection Agency) monitoring network, named "Inquinamento diffuso" and about another 200 chemical analyses attributable to regional monitoring network named "Acque sotterranee"
A geo-referenced database was evolved using all the information collected. Using these data some graphics to represent contamination levels in the studied area were developed.

3. Results

The data were referred to the 3 main hydrogeological domains of the Abruzzo region, which are the Apennine carbonate domain, alluvial domain and intramontane basin domain.
Chemical analyses were observed focusing on the distribution of Mn, Fe and B. For these elements spatial distribution and contamination levels were observed (Tab.1)

Acquifer	*Element*	*Findings in significant concentration*	*Highest values (μg/l)*	*Threshold values (μg/l)*
Carbonate domain	Mn	17 (7)	115	50
	Fe	31 (8)	419	200
	B	2 (2)	942	1000
Intramontane basin domain	Mn	26 (8)	190	50
	Fe	17 (5)	856	200
	B	0	/	1000
Alluvial domain	Mn	184 (152)	2775	50
	Fe	134 (103)	22800	200
	B	73 (28)	7573	1000

Tab.1 – Manganese, Iron and Boron distribution in the Abruzzo Region groundwater. In brackets in red, values exceeding legislation threshold levels.

Observing the table above, exceeding legislation threshold values in all the aquifer bodies are noted. The most important contamination levels are found in alluvial domain aquifers, where Iron and Manganese concentration is more than 50 of the thresholds values.
The distribution of contamination levels seems to be very heterogeneous and it isn't possible to recognize a specific trends in the concentration of pollutants (Fig. 1).

4. Conclusions

Concentrations of Mn and Fe, in the carbonate domain aquifer appear to be tendentially low, instead B was found in only two monitoring points. These 3 elements are rarely associated, therefore it's impossible to establish a correlation.

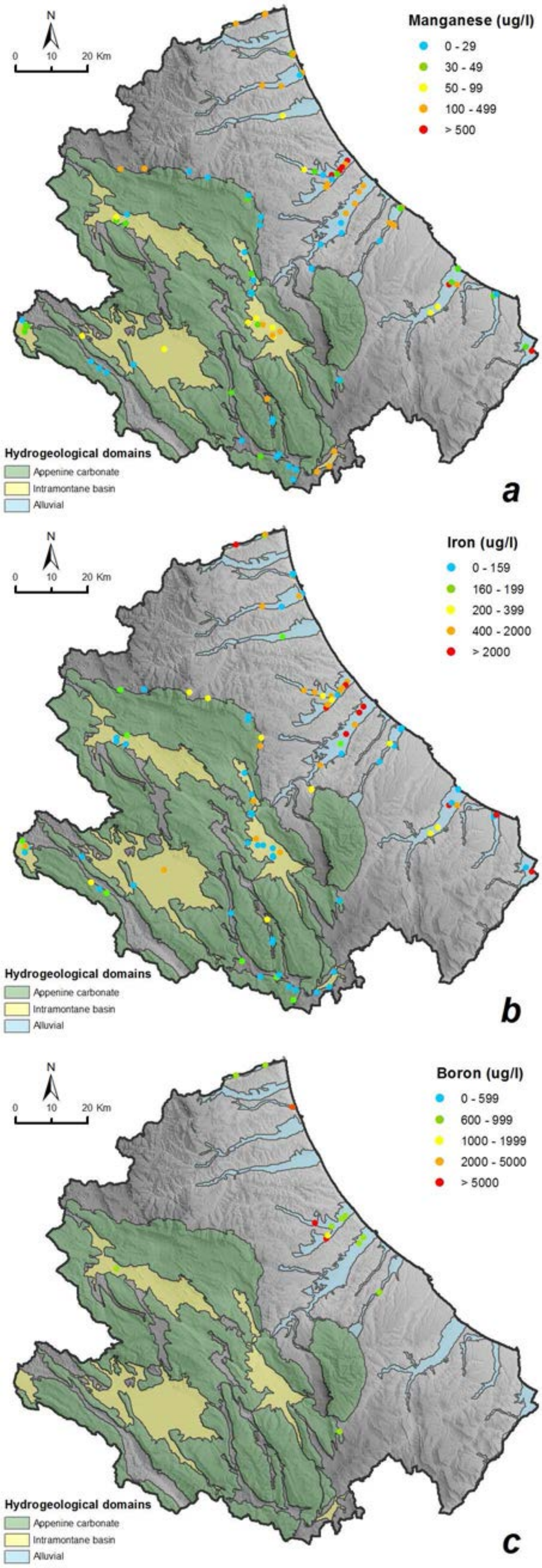

Fig. 1 – Distribution and concentrations of Manganese (a), Iron (b) and Boron (c). The images were processed using only a part of the "Acque sotterranee" database.

Furthermore many of the anomalous concentrations are found in monitoring points far away from possible anthropogenic contamination.

Speaking about intramontane basin aquifers, Mn and Fe have higher concentration, whereas B concentration is meaningless (< 600 µg/l).

Generally speaking, alluvial aquifers have the highest concentration in Mn, Fe and B that have been identified in the studied area. Spatial distribution of contamination is very variable. Moreover Fe e Mn are found together only in some floodplains. B distribution is up to 1000 µg/l (threshold value) only in some floodplains.

Preliminary observations reveals no smooth distributions of the three elements, which are apparently distributed at random.

Future developments of this research aims to develop a methodology to define natural background levels basing on hydrogeochemistry in addition to the statistical method that is used at present.

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Characterizing origin and fate of groundwater nitrate contamination (Catalonia, NE Spain) using multi-isotopic data

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Key-words: Nitrate contamination, isotopes, denitrification

1. Introduction

Throughout the last three decades anthropogenic nitrate (NO_3) inputs into our environment have significantly increased, giving rise to important loads of NO_3^- in both surface water and groundwater worldwide. Nitrate pollution has become a major threat to groundwater quality as the maximum nitrate concentration allowed by the European Directive 98/83/CE in waters for human consumption (50 mg/L) is reached in most of the regional aquifers in Europe. An understanding of the origin and fate of nitrate, as well as of the biogeochemical processes controlling nitrate attenuation in aquifers, is crucial for improving water resources management, and preserving the quality of groundwater supplies and groundwater-dependent surface waters. Nine areas have been declared vulnerable to nitrate pollution from agricultural sources in Catalonia (NE Spain). Six of them (Maresme, Osona-Lluçanès, Baix Empordà, Selva and Garrotxa) have been studied by coupling hydrogeochemical data with a multi-isotopic approach, in a research project focused on tracking the sources of nitrate pollution and assessing the chemical reactions linked to denitrification processes.

2. Material and Methods

Samples for chemical and isotopic characterization were collected in different surveys from 2000 to 2007. The wells were continuously pumped and groundwater was sampled when the Eh values stabilized. Groundwater samples were stored at 4ºC in a dark environment. Multi-isotopic characterization included the analysis of the water stable isotopes (δD and δ^{18}O), the nitrogen and oxygen isotopic composition of dissolved nitrate ($\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$), the sulfur and oxygen isotopic composition of dissolved sulfate ($\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$), and the carbon isotopic composition of dissolved inorganic carbon ($\delta^{13}C_{DIC}$). Boron isotopic compositions (δ^{11}B) were also analyzed in the Baix Empordà samples.

3. Results

According to dissolved nitrate and sulfate isotopic compositions, the main sources of nitrate pollution in the different areas are: synthetic fertilizers (Maresme; Vitòria et al., 2005), animal manure (Osona-Lluçanès, Baix Empordà), and a mixed contribution of these sources in Selva and Garrotxa areas. The use of boron isotopic composition (Widory et al., 2005; Widory et al., 2012) in the Baix Empordà demonstrated that sewage is not a potential pollution source in this area. Moreover, the coupled use of δ^{15}N and δ^{18}O of dissolved NO_3, well known as a useful tool to evaluate the occurrence of natural denitrification processes, confirmed active natural denitrification in the Osona-Lluçanès, Baix Empordà and Selva areas, but not in the Maresme and Garrotxa areas (Fig. 1). The isotopic composition of the ions involved in denitrification reactions (NO_3^-, SO_4^{2-} and HCO_3^-), i.e. δ^{15}N, δ^{34}S and δ^{13}C, indicated a relationship between pyrite oxidation and nitrate attenuation in the Osona area. On the other hand, in the Baix Empordà, Selva and Lluçanès areas, natural denitrification is mainly linked to the oxidation of organic matter. Both reaction paths for denitrification are governed by the specific lithology, as well as groundwater flowptahs, of each one of the studied areas. Further research is needed to improve our current knowledge on both the influence of organic carbon and sulfur electron donors in natural attenuation of nitrate, as well as on the quantification of natural denitrification rates.

4. Conclusions

The main origin of N is synthetic fertilizers (Maresme), pig manure (Osona-Lluçanès, Baix Empordà) and a mixed source (Selva and Garrotxa areas). Active natural denitrification is occurring in the Osona-Lluçanès, Baix Empordà and Selva areas, and is not significant in the Maresme and Garrotxa areas. In the Baix Empordà, Selva and Lluçanès areas, natural denitrification is mainly linked to the oxidation of organic matter, while in the Osona area it is linked to pyrite oxidation.

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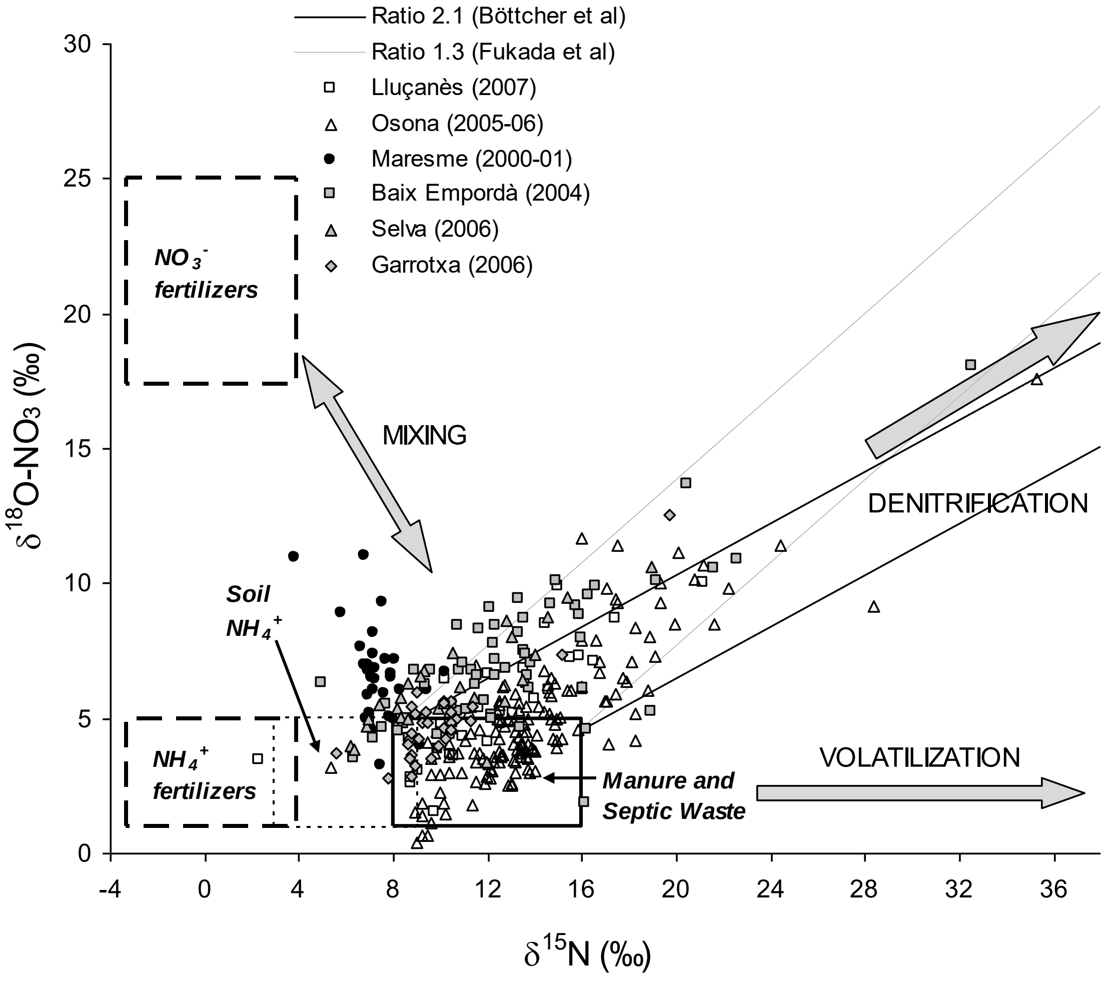

Figure 1. $\delta^{15}N_{NO3}$ vs. $\delta^{18}O_{NO3}$ diagram for groundwater samples. Boxes represent the typical ranges of potential nitrate sources in the studied areas. Values of $\delta^{18}O$ of NO_3^- derived from nitrification of NH_4^+ of fertilizers and/or manure were calculated following the expression: $\delta^{18}O_{NO3} = 2/3(\delta^{18}O_{H2O}) + 1/3(\delta^{18}O_{O2})$, where the $\delta^{18}O_{H2O}$ is assumed to be that of the studied areas groundwater and the $\delta^{18}O_{O2}$ is assumed to be that of atmospheric O_2 (+23.5‰).

FIRST RESULTS OF THE CHARACTERIZATION OF SOME HAEAVY METALS CONCENTRATION IN AN INDUSTRIALISED AREA AT NORTH OF ROME

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Key-words: trend, moving average, Stuart Cox test, natural background

1. Introduction

The area of concern is known for high anthropogenic impact: in the past this land has intensively exploited by agricultural and quarries activities, such as outcropping of gravel and sand used for building construction, which have produced significant changes in the natural morphology. Actually, there are different anthropogenic sources: managing solid wastes, petroleum industries, medical waste incinerators; oil refinery. This area is drained by Galeria Streamlet, tributary in right bank of Tevere river. It serves the city of Rome, Ciampino, Fiumicino and Vatican City (Fig.1).

The geology of the area is dominated by the sediments of Ponte Galeria Formation (Middle Pleistocene Period), which is about gravel and clay sediments that formed a delta environment with continental facies transition from tidal and infralittoral facies. This geological formation is limited to the roof by an unconformity surface which is below volcanic deposits, gray tuff. Since 2000 a network of 23 monitoring wells (called Z1-Z23) has been functioning for the environmental surveying of groundwater in this area, and now they are available the chemical analysis results referred to samples collected any three months in these wells. This paper presents the first results of statistical and geochemical characterization of these data, aimed to identify the origin of the presence of some heavy metals and to set up the background values of them, applying different methods.

2. Material and Methods

This work presents the first results of a background analysis methodology applied to this investigation site.

The study mainly focuses on the levels of Arsenic, total chromium, manganese, nickel, iron, mercury, lead, sulphate and fluoride, in order to assess their range of background concentration, following different approaches. The database for determining the background value consists of groundwater samples for each element for the years (2000-2010).

After evaluating the local and regional geology, hydrogeologic and geochemical characteristics, a spatial and temporal groundwater data analysis has been carried out for each element within each individual well.

The Italian document, *Guidelines for the evaluation of Background values in groundwater,* provides step-by-step instructions for characterizing background conditions at groundwater site based on a statistical and geostatistical assessment.

The techniques presented in these guidelines focus primarily on the identification of the numbers of non detect, and the extreme values that may be potential outliers.

For each analyte in the selected dataset, statistical analysis computes the main statistical parameters useful for studying the appropriate data distribution (Tab.1). The statistical evaluation of each selected parameter for each monitoring well was performed to determine if the data are best represented by a normal or lognormal distribution, to choose the appropriate statistical test for data that follow a particular distribution, to identify potential outliers. Graphical representations of the data may also indicate unexpected events that may influence the analysis of the data. They play an important role to select the range values that fit more observations and to check homogeneity.

In this study, the degree of continuity and the spatial trends, among neighboring location around the investigation site, of the time series of analytical data revealed appropriate for use in aquifer characterization and in the groundwater chemical status assessment.

The analysis of the behaviour of the aquifer and its variations over time, the spatial and temporal trends evaluations, allowed to distinguish the anthropogenic potential contaminant source from other causes such as the natural background concentration, seasonal fluctuations of concentrations in time periods, an accidental contamination during sampling operations.

With regard to the temporal trend concentrations of analytes of concern in the different monitoring stations, the method “moving sample” has been applied in order to detect downward or upward trends in the data. The moving sample is the sequence of the moving average of the concentration samples.

Unlike the adaptation of a curve analytical mathematical type, the equalization of a curve through the moving average has a lower rigidity better adapted to the peculiarities of the real curve. The moving average reduces the random variability of individual data by highlighting the underlying trend. For this goal, the Stuart Cox test has been applied, using the simple moving average and the moving average centered of order k = 4.

3. Results

Results of the study indicate for some elements that the concentration background is constant in within each well, and their systematic variations are strongly correlated to dry and rainy seasons.

4. Conclusions

The large mass of available data, referred to the chemical composition of groundwater in a anthropogenic high impacted area in the north of Rome, allowed the application of statistical analysis, over the common methods, suggested by Italian guidelines, which drove to the conclusion that this area is characterized by new background values for some heavy metals, affected by the past and recent intensive exploitation of the area, and are not due a nowadays contamination event.

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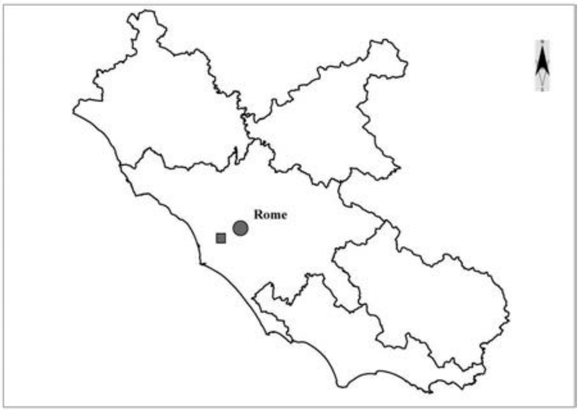

Fig. 1 – Location map, investigation site in the Latium Department - Central Italy.

Parameters	Arsenic (µg/L)	Total chromium (µg/L)	Mercury (µg/L)	Fluoride (mg/L)	Iron (µg/L)	Nickel (µg/L)	Lead (µg/L)	Manganese (µg/L)	Solphate (mg/L)
Number of Samples	473	443	468	469	657	578	584	657	651
Mean	214.82	14.78	1.52	0.48	3559.50	108.46	103.52	1113.01	215.63
Standard Deviation	537.09	40.71	8.33	0.30	8214.86	101.46	261.51	1523.90	607.11
Minimum	0.90	0.04	0.10	0.03	1.00	1.00	1.00	1.00	0.35
Maximum	5264.00	513.30	179.70	3.10	65000.00	1134.00	4200.00	9300.00	3562.50
Median	59.00	9.10	0.70	0.44	278.00	85.50	34.00	366.00	28.75
Percent Nondetects	0.00%	6.77%	0.21%	0.85%	4.41%	0.17%	14.90%	5.02%	0.00%

Tab. 1 – Descriptive statistics

Anaerobic transformation of chlorobenzene in highly contaminated groundwater

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Key-words: chlorobenzene, microbial transformation, groundwater

1. Introduction

The halogenated groundwater pollutant chlorobenzene (MCB) is ubiquitously found in the environment and seems to be persistent and to accumulate under anoxic groundwater (GW) conditions. However, our group could provide evidence for the transformation of chlorobenzene under anoxic conditions [1].

In the last century, MCB has been released to the environment as a result of intense industrial production and its numerous applications as agrochemical and irresponsible disposal, like at the industrial field site Bitterfeld-Wolfen (Germany), where about 200 million m^3 of GW are polluted with MCB as one of the major contaminants. Thus, the remediation of MCB contaminated GW is of our interest. In terms of remediation we focus on the investigation of biotransformation processes that could significantly reduce the contamination. Natural wetlands as transition zone between GW and surface water may play an important role in the remediation of MCB as they are an environment with steep redox gradients potentially enhancing the transformation of organic GW contaminant. This study aimed to investigate the microbial transformation of MCB in the complex environment of a constructed planted model scale wetland.

2. Material and Methods

The microbial biotransformation of MCB was investigated based on a 3 step approach. (i) The microbial GW community was investigated using molecular biological methods including a clone library of *bacteria* and *archeae*. (ii) Anaerobic laboratory microcosms of the contaminated GW were prepared by adding different e^--donors and -acceptors e.g. non-labeled and ^{13}C-labeled MCB to use the CSIA (compound specific stable isotope analysis) to identify transformation products under different redox conditions. (iii) Moreover, we tested the *in-situ* biotransformation of MCB in constructed subsurface flow wetland system.

3. Results

The microbial community analysis (i) showed the presence of a diverse community composite of methanogenic *archeae*, sulphate (*Desulfobacterium*) and iron reducing (*Geobacter*) *bacteria* as well as aerobic *β-proteobacteria* (*Burkholderia*). In particular, we could confirm microbial activity in the GW using the laboratory microcosms (ii). For the first time, we could show MCB mineralisation under nitrate and iron reducing conditions.

In addition, the results of the wetland (Fig. 1) study revealed an overall removal of >90 % of MCB from the inflowing contaminated GW (iii). Concurrent sulphate and iron reduction was observed. The original groundwater pumped into the wetland was anoxic and contained ferrous iron and high concentrations of sulphate. Along the flow path, the geochemistry changed. We observed increasing sulphide and iron (II) concentrations in the anoxic and deeper sediment part whereas the upper zone became oxic and less sulfidic.

4. Conclusions

Our approach provided evidence for MCB mineralisation under nitrate and iron reducing condition in a defined microcosm whereas *in situ* transformation in the wetland system is likely linked to both, iron reduction and aerobic degradation. The microbial community present in the GW reflects the major redox conditions in the wetland system (Fig. 1; conceptual model). Overall, our study gives new insights into the *in situ* biodegradation of MCB and helps to understand the redox processes talking place in wetlands. Therefore, natural wetlands may play an important role as buffer and remediation zone for contaminated GW before entering the surface water.

Acknowledgements

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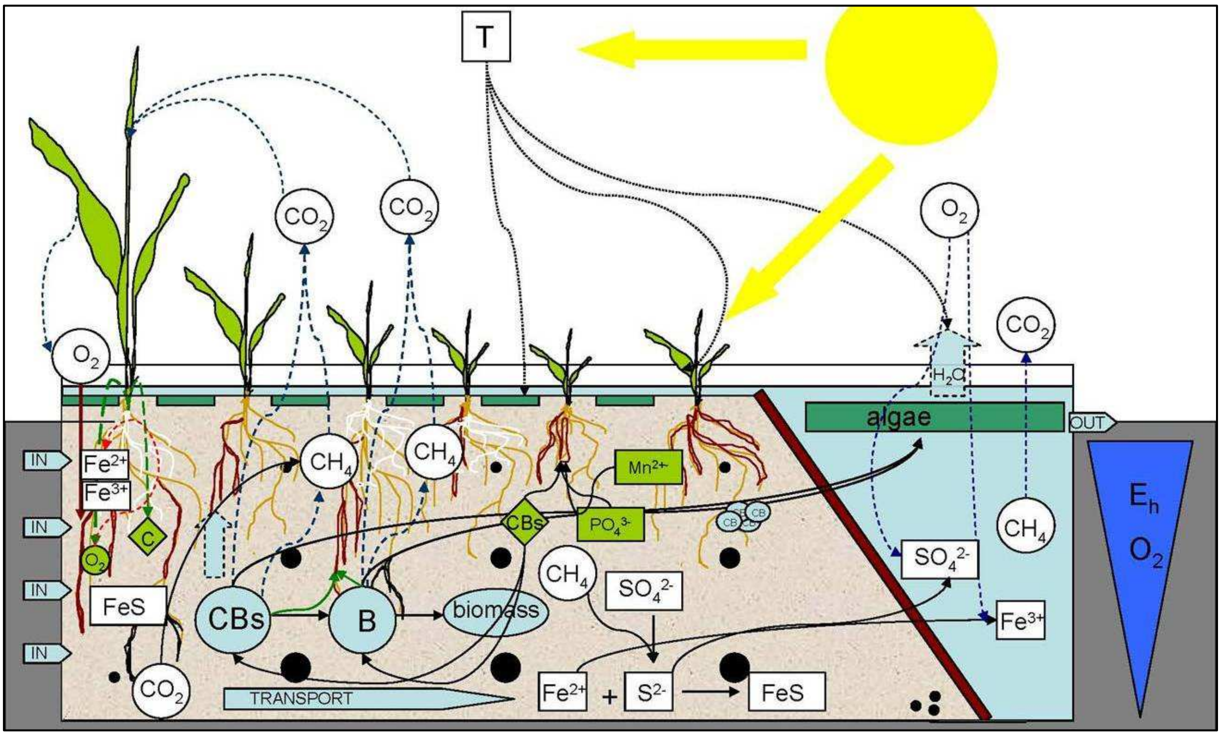

Fig. 1: Conceptual model of important transformation and redox processes in a constructed wetland system. (Eh-redox potential, T – temperature, CBs – chlorinated benzenes, B – benzene, IN – inflow ports, OUT – outflow port, C – organic carbon). The arrows indicate major and potential pathways going on in the sediment filter of the system.

Impact of the NAO on the hydrological cycle of karst aquifers in southern Apennines

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Key-words: NAO, hydrological cycle, karst aquifer, Southern Apennines.

1. Introduction

The karst aquifers represent important groundwater resources in Italy, Europe and in the world. In southern Italy they are the main source of drinking and thermo-mineral waters, due their annual groundwater flow approximately amounting to 4.100×10^6 m^3/year (Celico, 1983; Allocca et al., 2007). Recent researches (De Vita et al., 2012; Allocca et al., 2012) provided evidence of a decadal relationship between the NAO (North Atlantic Oscillation), the regional rainfall and the discharges of some karst springs. In this paper we discuss about the impact of the NAO on the long-term components of the hydrological cycle for the karst aquifers of the southern Apennines (Fig. 2).

2. Material and Methods

In order to examine the decadal variability of karst aquifers recharge, we used rainfall data collected by 18 rain gauge stations and air temperature data recorded in 9 thermometric stations, for the period 1921÷2010 (Fig. 2). We reconstructed time series of regional normalized indexes (De Vita et al., 2012) for precipitations (MAPI), air temperature (MATI), effective precipitation (MAEPI), real evapotranspiration (MAEI) and effective infiltration (MANII) (Fig. 1). To the scope of analyzing the relationship between the NAO and the hydrological cycle of the investigated area, we have also considered the winter NAO Index (NAOI) existing between the station in Lisbon (Portugal) and the one in Stikkishlomur (Iceland), calculated for the period 1921÷2010.

3. Results

The pattern of the hydrological parameters was observed as characterized by a cyclical evolution, which resulted strongly correlated with the variation of the NAO Index (Fig. 1).

Moreover, a significant correlation between the NAOI and the MAPI, MAEPI, MAEI and MANII was found. The respective correlation coefficients (r), calculated by using the moving average (11 years) of each series were: –0,76, –0,66, –0,82 and –0,32. The correlation between the NAOI and the MATI was not significant (r = +0,29). Finally, during last decades (1980÷2010), the analysis showed a reduction of 10% in the volume of total annual rainfall, respect to the average of the whole time series. Similarly, a reduction was observed also for the real evapotranspiration (–2%) and in net infiltration (–15%) (Fig. 2). By contrast, an increase in air temperature (+0,05 °C) was recognized.

4. Conclusions

The significant correlations found between the NAOI and the examined hydrological time series demonstrated the strong influence of the NAO on the hydrological cycle of the karst aquifers. Therefore, the winter NAOI can be considered as an effective proxy to forecast the decadal variability of the groundwater resources in Mediterranean karst areas, allowing the modelling, forecasting and planning of their sustainable management.

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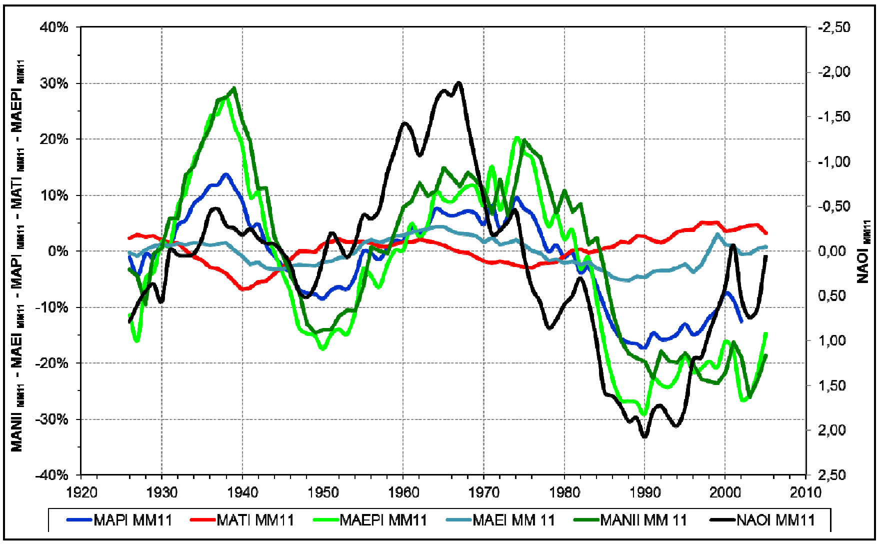

Fig. 1 – Comparison of the 11-yr moving averages (MM11) of winter NAOI (Nord Atlantic Oscillation Index), MAPI (Mean Annual Precipitation Index), MATI (Mean Annual Temperature Index), MAEPI (Mean Annual Effective Precipitation Index), MAEI (Mean Annual Evapotraspiration Index) and MANII (Mean Annual Net Infiltration Index) time series.

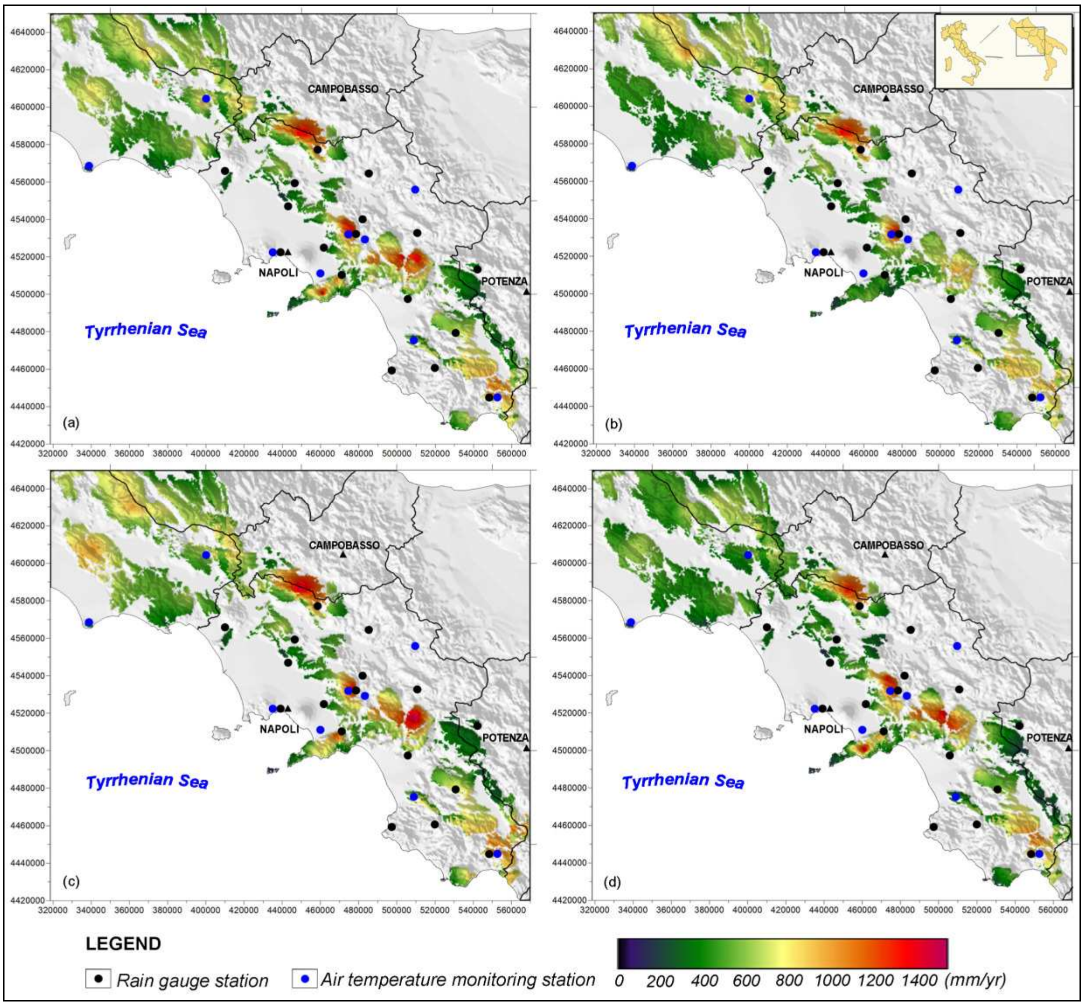

Fig. 2 – Spatial and temporal variation of mean net infiltration; (a): 1921÷2010; (b): 1926÷1950; (c): 1951÷1980; (d): 1981÷2010.

PRELIMINARY RELATION BETWEEN DIFFERENT SPRING VULNERABILITY METHODS APPLIED ON TWO ALPINE SPRINGS. (Regione Autonoma Valle d'Aosta).

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Key-words: hydrogeology, spring, cross-correlation, vulnerability

1. Introduction

This paper compares the results of three different methods for estimating the spring vulnerability. The three methods that we used in this study are: MDHT method (Maximum Discharge Half Time) (Civita 1988), V.E.S.P.A. index (Vulnerability Estimation for Spring Protection Area) (Vigna et al, 2010) and the statistical method of cross – correlation.

The statistical method of cross - correlation was already used to describe the relationship between precipitation and discharge in karst environment (Fiorillo, 2010; Kresic and Stevanovic, 2010) which is found to be a useful tool for the spring's assessing vulnerability to pollution.

Since 2010 we have started to monitor different springs in Aosta Valley. Among them we had chosen the most representative ones to verify the application of this statistical method in a porous media in Aosta Valley.

2. Material and Methods

Linear function are wildly used to determine the relationship between two or more random data sets. These linear relationships are normally extracted with the correlation function.

We have to consider two signals in real values X (the precipitation) and Y (the discharge or the electrical conductivity) that differ only for a shift on the axis t (in days). The cross-correlation shows how the first signal (precipitation) has to be anticipated to make coincident with the second one (discharge or the electrical conductivity). The formula essentially anticipates the second signal along the axis t, calculating the integral of the product for each possible value of the displacement. When the two signals coincide, the value is maximized, because when the waveforms are aligned, they only contribute positively to the calculation of the area.

At the same time to study the vulnerability of the springs two other methods were applied: MDHT method and the VESPA index.

3. Results

In specific we had chosen two springs that are located at altitudes above 1300 m above sea level, where the risk of pollution is primarily lack of grazing.

The application of the three methods gave different results. In specific MDHT method and VESPA index indicated the same value of springs vulnerability (medium-low). While, the method of cross – correlation showed a high value of springs vulnerability. This method showed a time lag in a range 0 ÷ 2 days between precipitation - discharge and precipitation – electrical conductivity, affirming that the two sources have a high vulnerability.

The input data derived from monitoring survey from 2010. Despite the time series was short, the results showed a distinction between the methods (Table 1).

4. Conclusions

The method of cross - correlation indicated a high value of springs vulnerability compared with MDHT method and VESPA index, which showed the same value of springs vulnerability (medium-low).

However, since this methodology is widely used in other study fields and proved to be quite accurate, study area was considered to be had high degree of vulnerability.

In order to understand the real value of spring vulnerability, we have to acquire more data from monitoring and perform several tests in situ (es. Use tracers).

Acknowledgements

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Figures and tabs

Alpe Perrot (Comune di Chandepraz)			
MDHT method	VESPA	Cross-Correlation	
		discharge precipitation	conductivity precipitation
Low	Low	2 days	1 day
Valmeriana 2 (Comune di Pontey)			
MDHT method	VESPA	Cross-Correlation	
		discharge precipitation	conductivity precipitation
Medium	Medium	1 day	1 day

Tab 1 – Comparisons between the different metodologies

ANALYSIS OF THE INTERACTIONS BETWEEN OVERLAPPING AQUIFERS IN THE VITERBO HYDROTHERMAL AREA (CENTRAL ITALY) FROM PUMPING TESTS

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Key-words: overlapping aquifers, pumping tests, thermal waters, groundwater management

1. Introduction

The area around the city of Viterbo (central Italy) is of great geothermal interest. Several thermal springs and wells are present in this area with water temperatures up to 62 °C. In the same area, a shallow aquifer carries cold and fresh water, used for irrigation and drinking water supply. Increases in spa tourism and the use of geothermal energy are expected in the near future. This multi-purpose water demand also exists in other volcanic aquifers of central-southern Italy. In these complex systems, it is important to examine the local response of the aquifers to withdrawals with the aim of addressing future groundwater management.

In this paper, we present data concerning pumping tests recently conducted in both overlapping aquifer. Results provide insights into interactions between aquifers with different water qualities.

2. Material and Methods

Twelve pumping tests concern the shallow volcanic aquifer. The tests were performed measuring the drawdown in the tested well and sometimes in an observation piezometer. Temperature of the pumped water was also monitored.

Four pumping tests were performed on the thermal wells. Measurements of discharge, water level and hydrochemical parameters of wells and springs near the pumped well were also monitored.

Water level, temperature and electrical conductivity were measured by a multiparametric probe. For flowing wells, the water level was determined through fluid pressure with a manometer installed on the wellhead. Flow measurements were taken using tank or current meters in relation to the rate of discharge and the type of monitoring point.

Some water samples were collected during the pumping tests. The alkalinity was determined on-site by means of titration. Major anions (Cl^-, SO_4^{2-}), nitrate (NO^{3-}) and fluoride (F^-) were determined by ion chromatography using a Dionex-DX-120 system. Major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}), Sr, Li and Fe liquid were determined by atomic absorption spectrophotometry using a Perkin-Elmer 2100 system. A few samples were also analyzed to detect selected environmental isotopes. Stable isotopes of water, ^2H and ^{18}O, and ^{18}O and ^{34}S of dissolved sulfate were determined through mass spectrometry. Tritium concentration was also determined by a scintillation counter following electrolytic enrichment.

The pumping data were processed using analytical techniques and modeling a significant volume of the tested aquifers.

3. Results

The pumping tests on the shallow volcanic aquifer permitted to determine transmissivity between 10^{-5} and 10^{-2} m^2/s and storativity between 10^{-3} and 10^{-2}. For a well located near a thermal spring, the water temperature increased from 16.0 °C before the test to 16.8 °C after 25 hours of pumping. For a well located in an area with a significant thickness of the aquitard that separates the two overlapped aquifers, the pumped water did not show variations in temperature or electrical conductivity during pumping.

A first test involving the thermal aquifer was conducted on a 125-m-deep well that penetrates fractured flysch formations with a constant flow rate of 38.6 L/s maintained for 68 hours. Drawdown was measured in the tested well and in two observation piezometers, one penetrating the same aquifer and one penetrating the shallow volcanic aquifer. Discharge of a flowing thermal well and other springs were also monitored. During the test period, the piezometer in the shallow volcanic aquifer did not show significant variation. The flowing thermal well dried up after 41 hours of pumping and flowed again approximately 20 hours after the shutdown of the well. The electrical conductivity and temperature of the pumped water were constant, as well as those measured in the piezometer intercepting thermal waters. Other chemical and isotopic parameters did not show significant variations during the pumping period. Different models were used for the interpretation of results considering the drawdown and recovery data and analyzing the drawdown derivative data. Applying the double porosity model, the best match to the observed

drawdown data from the piezometer was obtained for a transmissivity of 8×10^{-4} to 1×10^{-3} m^2/s and a storativity of 2 to 4 $\times10^{-4}$.
A second test was conducted on a thermal flowing well drilled during geothermal exploration during the 1950s and kept shut. The flowing well was opened and tested for 48 hours at a constant rate of 46.4 L/s measuring the fluid pressure. When the flowing well was closed again, the pressure immediately returned to its initial value. During the test period, the physical-chemical characteristics of the water did not change, nor did the other monitored chemical and isotopic parameters. Among the wells and springs monitored during the water flowing, only a thermal spring 78 m away from the well, showed significant variation. Rough estimates of transmissivity were obtained applying the Cooper-Jacob time-drawdown method (2.8×10^{-2} m^2/s) and the distance-drawdown method (between 1.4×10^{-2} and 2.3×10^{-2} m^2/s).
A third test on the thermal aquifer was conducted by closing a well that normally flows six days a week at a constant rate of 21.5 L/s. Recovery was observed at a second well 129 m away. The two wells are 42 and 93 m deep, respectively, and capture thermal water from the volcanites. Transmissivity was estimated to be 3.9×10^{-3} m^2/s.
A fourth test was conducted on a thermal flowing well that penetrates fractured flysch formation. The flowing well was tested for 72 hours at a variable rate (from 6.3 to 13.3 L/s) measuring the fluid pressure. Drawdown and temperature were measured in two observation piezometers penetrating the shallow volcanic aquifer. When the flowing well was closed, the pressure immediately returned to its initial value. During the test period, the water temperature of the piezometers decreased approximately of 2 °C. Values of specific capacity from 4.1 to 9.9×10^{-3} m^2/s was obtained by discharge-drawdown data measured in the production well.
A first simple numerical model was built to investigate the response of the thermal aquifer to pumping and the interactions between the two overlapped aquifers. Based on the hydrostratigraphy and hydraulic parameters, a three-dimensional reconstruction of the aquifer system was buildup. Calibration was performed through the heads of the two aquifers and their discharge rate measured during the pumping tests. The results of the model were used to simulate different scenarios of pumping both from the thermal and shallow volcanic aquifers.

4. Conclusions

Following the results of pumping tests and of flow modeling, some considerations regarding interactions between the two overlapped aquifers can be made.
As a first critical point, an increase in withdrawals through wells from the thermal aquifers may lead to a decrease in discharge from the thermal springs (Fig.1A). This already occurred in the past, and was verified during the pumping tests. As a second point, an excessive drawdown in the wells tapping the thermal aquifer can modify the vertical gradient between two overlapped aquifers lowering the natural flow from the deep aquifers towards the shallower one (Fig.1B).
The effects of withdrawals from the shallow volcanic aquifer may also be significant, since the pumping from the shallow volcanic aquifer may increase the vertical gradient between the two overlapping aquifers, causing an increase in flow from the deep aquifer towards the shallower one (Fig.1B-bottom-right). This could imply an increase in temperature and salinity of the shallow volcanic aquifer as verified during the tests.

Acknowledgements
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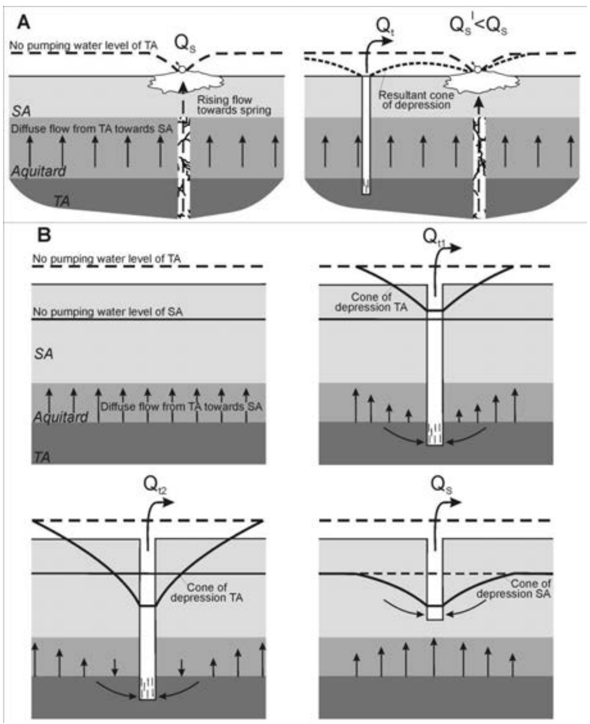

Fig. 1 – Schematic cross-sections showing the possible impacts of withdrawals from shallow and thermal aquifers. A) Possible impact of withdrawal through well from thermal aquifer on thermal spring. B) Possible impact of withdrawals on the flow between the two overlapping aquifers.

Numerical simulation of vertical flow within monitoring wells in a sloping layer

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Key-words: Electromagnetic Borehole Flowmeter, vertical flow, numerical modeling

1. Introduction

The measurement and monitoring of vertical flows within boreholes provide useful information for aquifer characterization. In fractured aquifers, vertical flow allows to identify hydraulically active fractures (Paillet, 1987; Le Borgne, 2007) and to study the interconnections in the fracture system (Paillet, 1993; Le Borgne et al, 2006). In porous aquifers, vertical flow measurements have been used to derive a log for hydraulic conductivity distribution along the borehole (Moltz, 1989; Young and Pearson, 1991; Molz and Young, 1993). Moreover, vertical flow measurement support the interpretation of temperature and electric conductivity profiles (Chatelier et al., 2011). However, only a few studies analyzed the effect of the aquifer hydraulic head on the vertical flow within boreholes (Hu et al., 2011). Our study is aimed at relating quantitatively the vertical flow within boreholes to the aquifer hydraulic head, in order to provide a simple tool for assessing the hydraulic head distributions based on measurements of vertical flow.
For this purpose, a numerical approach was adopted, by developing numerous models to simulate the ambient flow distribution around a test well in an aquifer with different permeability, heterogeneity, slope of the groundwater table and hydraulic head boundary conditions.

2. Material and Methods

Finite element analysis were used to obtain the distribution of the vertical fluid flux along a well located in the center of a 3D model of a sloping aquifer.
The 3D model domain is 100 m long, 50 m width and 50 m high (Fig. 1a), vertically, subdivided into 200 layers. To better calculate rapid changes of hydraulic head and Darcy Flux near the well, the mesh cells is progressively refined toward the well.
A first order boundary condition (i.e., constant head) was applied to upstream and downstream lateral boundaries of the model domain, while no flux condition was applied along other boundaries.
In order to simulate different flow conditions, we developed an homogeneous model, a layered model with three different materials (hydraulic conductivity ranging between 10^{-4} and 10^{-6} m/s) which are cyclically repeated for the 200 layers, and a chaotic model with the inclusion of random lenses. For each model, we simulated 10 hydraulic head differences between 5 and 50 m.
To describe and compare the results of the different simulation with an overall indicator we introduce a Borehole Activity Flow Parameter (BAFP) (Basiricò, 2011), which is calculated as:

$$BAFP = \frac{1}{Sc}\sum_{i=1}^{n}\left|\frac{\Delta Q_i}{z_{i+1} - z_i}\right|$$

Where:

ΔQ_i = differential ambient flow = $Q_{(z_{i+1})} - Q_{z_i}$

Q_{z_i} = ambient flow at a depth z

$Q_{(z_{i+1})}$ = ambient flow at a depth z+1

$Sc =$ length of the screen section

$z =$ elevation where flow readings are taken

Finally, simulating pumping in the well, we applied the Molz's relation (Molz, 1989) to recalculate the permeability distribution around the borehole and to compare this distribution with the permeability of an heterogeneous model. Different pumping rates have been applied.

3. Results

The simulated vertical ambient flow resulted to be directed downward for all models (Fig. 1b).
BAFP was calculated for each simulation and compared to the hydraulic gradient upstream, i.e., calculated from the well to the upper edge of the model domain. As a result, BAFP values shows a strong linear relationship with the hydraulic gradient (Fig. 1c). Moreover, despite the trend of total flow changes significantly among homogeneous and heterogeneous models (Fig. 1b), the relationship between BAFP and hydraulic gradient is very similar among the models for the same average transmissivity of the aquifer.
The permeability profiles obtained by applying Molz's relationship using different pumping rates were compared with the actual permeability profile of a heterogeneous stratified slope aquifer. We can observe that the Molz's relationship seems to be sensitive to pumping

rates, and to provide unreliable estimates for small pumping rates.

4. Conclusions

The simulations proposed in this work confirm the importance of monitoring vertical flow within well to improve the hydrogeological characterization in a sloping aquifer.
BAFP demonstrates to be a reliable parameter to compare the vertical ambient flow within observation well and the hydraulic gradient upstream the well. In particular, a linear relationship have been observed for both homogeneous and heterogeneous aquifers. These relationships seem poorly sensitive to the aquifer heterogeneity, but depend on transmissivity. Hence, a set of linear relationships can be computed for different transmissivities. These relationships can be used for a fist-order estimation of the hydraulic gradient based on the measurement of vertical flow with a borehole flowmeter. Moreover, repeated time-lapse BAFP measures can provide information about the hydraulic gradient changes in response to external inputs.
The results of analysis of the permeability profiles with Molz's relationship highlight the importance of pumping rate to obtain reliable results. In general, it seems that the pumping rate should be greater than or equal to the value of the vertical ambient flow. However, high pumping rates can generate head losses due to by-pass flow in the gravel pack, where present.
Concluding, this contribution demonstrates the importance of borehole flowmeters tools for the characterization of aquifer properties, with particular reference to sloping aquifers.

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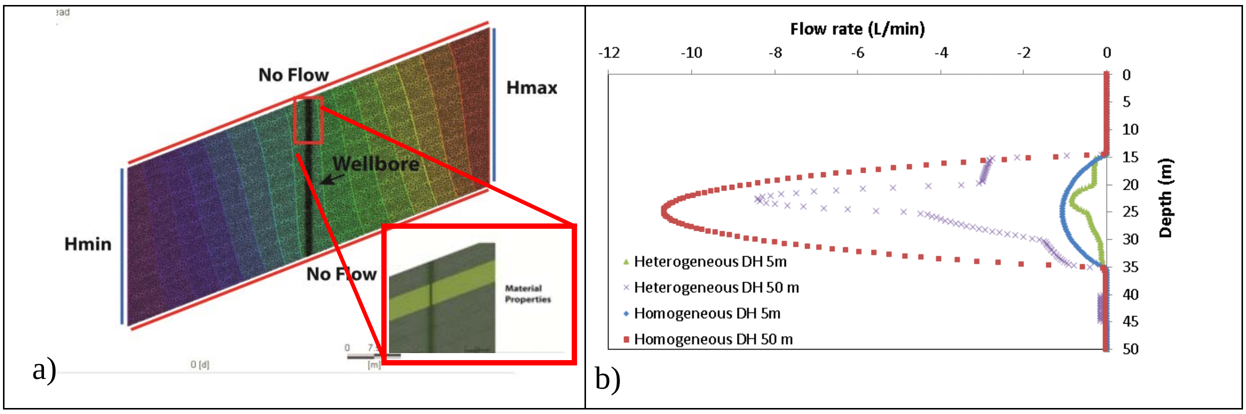

Fig. 1: (a) model domain in x-z direction; (b) simulated vertical ambient flow for two hydraulic head difference (5 and 50 m) for homogeneous and heterogeneous model.

PRELIMINARY GROUNDWATER MODEL OF THE AOSTA VALLEY AQUIFER (NORTHERN ITALY)

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Key-words: Flow model, Modflow, SFR2 package, Hydraulic Conductivity, well database

1. Introduction

This study has been developed through a scientific cooperation between the University of Milano-Bicocca and Regional Agency for Environmental Protection (ARPA) of Valle d'Aosta Region. Its aim was to produce a specific tool able to help Public Administration's choices in groundwater management, with respect to both quantity and quality. The specific study area is the plain of Aosta, between the cities of Aymavilles and Brissogne; in this area groundwater represents most of the public water supply. The valley is oriented in a west-east direction, along the Dora Baltea river. The modelled valley is 13.1 km long and 4.6 km wide. The textural and hydrogeological properties of the deposits are strictly connected to glacial erosion and the subsequent sedimentary processes which took place in glacial, lacustrine and fluvial systems.

The previous hydrogeologic studies (Armando & Dal Piaz, 1970 e 1971; P.I.A.H.V.A, 1991, 1994, Pollicini, 1994, Novel 1995) attempted to reconstruct the hydrogeological structure of the valley and to model groundwater and its relation with the river. They underline the presence of silty lacustrine deposits 80 m deep in the western side of the valley and 50 m deep in the eastern side, which represent the bottom of the known aquifer system. In some areas of the eastern valley silty lacustrine deposits also occur at 25 m depth , where they act as a aquitard, separating the water-table aquifer from a confined aquifer.

Steady-state groundwater models (Triganon, 2003; De Maio, 2010) have been implemented in order to understand the hydrogeological balance and the relations among groundwater, precipitation, and surface water. Recently ARPA implemented an improvement in the monitoring network and carried out a geophysical study whose first results indicate the possible presence of an aquifer below the deepest silty lacustrine layer, which could be used for water supply.

2. Material and Methods

The study methodology started from the collection of the available well information in the Aosta plain, which have been coded and stored in the well database TANGRAM (Bonomi et alii, 2005) The data are related to water wells (133) and piezometers (121), among which 140 have stratigraphic logs codified into TANGRAM. The database allows both an easier interpretation of the well data, even by the Public Authorities, and a three-dimensional definition of the geometrical and hydrogeological characteristics of the subsurface system, by means of a database codification and of an ordinary kriging interpolation.

The 3D parameterization of hydrogeological properties, such as permeability and effective porosity, together with the analysis of the geological information, informed the conceptual model of the valley.

The mathematical model, implemented with the USGS finite-difference code Modflow 2005 (GwV interface) consists in 20 layers, 655 columns and 243 rows with 20mX20m cell size. The model structure has been built in such a way that it can be both integrated with further aquifer knowledge and modified in order to better accommodate the Public Authorities needs.

The relation between groundwater and rivers was modelled by means of the SFR2 package (StreamFlow-Routing) with ICALC = 1, which allows water exchange between the two simulate systems and the stream to route water or to get dry.

The model considers the precipitation recharge, deprived of evapotraspiration rate and well withdrawals. In the area 28 pumping wells have been simulated.

Both steady-state and transient simulations have been made for the 2009-2010 period, with 24 monthly time-step. The model was calibrated to head (n.26) and flux targets (n.2), which are groundwater level data and Dora Baltea flow data, measured by Arpa VdA.

3. Results

The modelled aquifer is comprised between the topsoil and the deep silty lacustrine sediments (Fig. 1) and is penetrated by all the wells in the valley. No well goes through the silty lacustrine sediments, so at the moment the characteristics of the deposits which fill the glacial excavation is unknown. Although new geophysical studies indicate the presence of gravelly deposits from 30 m to 60 m depth, at least in the eastern valley, the present model does not take this aquifer material into account, although it could be modified in the future to do so.

As a consequence of the 3D interpolation used, the modeled aquifers show complicated permeability and effective porosity trends. This heterogeneity reflects the different energy conditions at deposition. In detail, the western and middle valley presents high permeability values, as the mountain side gravelly deposits dominate. The values are comprised between $1 \cdot 10^{-3}$ and $4 \cdot 10^{-3}$ m/s. In the eastern valley, sand and silt are present in the fluvial and lacustrine deposits and the permeability values range between $1 \cdot 10^{-5}$ m/s and $1 \cdot 10^{-3}$ m/s. Effective porosity variability is correlated with permeability.

The surface-water network is constituted by the Dora Baltea river and its tributaries, which is represented by 1908 cells grouped into 31 segments, each with its own riverbed properties (stage of stream, streambed elevation, thickness and hydraulic conductivity of streambed, length, width and slope of stream, streambed roughness and flow entering segment).

The steady-state and transient models are being calibrated by adjusting the values of permeability, recharge, and river bed conductance to match targets. Preliminary simulations reproduce adequately the observed value of the flux and head targets for steady-state conditions, but the work is still ongoing to better match the seasonal variations simulated by the transient model,

When the model will be calibrated, the Public Administration could simulate different scenarios to forecast the influence on groundwater of new wells, or of dry or wet periods, in order to prevent unwanted consequences. In addition, groundwater contamination events, and consequent remediation actions, could be studied by means of detailed specific local transport and flow models downscaled from this flow regional model.

4. Conclusions

The study is designed to achieve two objectives. The first one is to provide the Aosta Public Authorities with a well database in order to simplify groundwater management; the database can be updated little by little as the data pertaining to new wells or new piezometric measures become available. The second one is to provide Public Authorities with a model of the local aquifer. The model integrates surface and subsurface flows in order to fully account for all important stresses, both natural and anthropogenic, on the groundwater system.

It provides a tool for testing hypotheses (such as the impact of new wells on water levels or the vulnerability of the water supply to a source of contamination) and thereby allows science-based management of the aquifer resource.

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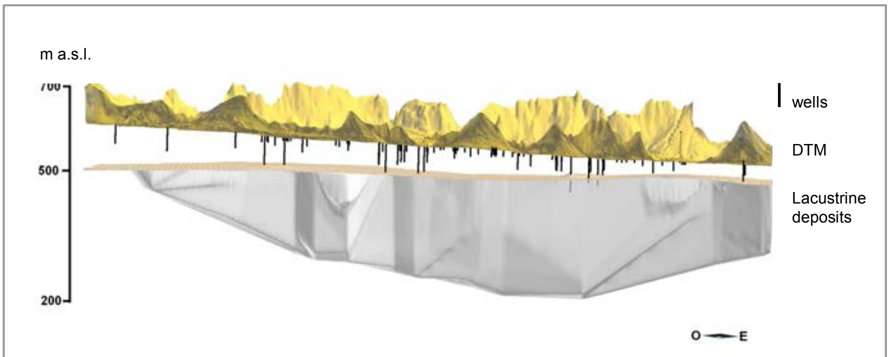

Fig. 1 – Structure of Aosta Valley: the modelled aquifer is between the Digital Terrain Model (DTM, yellow surface) and the silt of lacustrine deposits (grey surface). The black paths are the wells.

Activities of the Arno River Basin Authority to support the Environmental Observatory AV Florence as regards to the modeling of groundwater flows in the Florentine subsoil

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Key-words: numerical flow model; permeability; water balance; modflow

1. Introduction

The project plan for the high speed rail link passing through the city of Florence required specific and comprehensive studies to assess its impact on the Florentine subsoil. A numerical flow model was implemented to support the projecting of the necessary mitigation works. A deep knowledge of the hydrogeology in the area, in particular as regards to the groundwater balances was the necessary condition to develop a modeling tool that could predict the effects and support the projecting of the necessary infrastructure. The Arno River Basin Authority gave a subject–oriented contribution concerning the hydro-geological aspects of the underground rail link. The underground works will concern the Florentine subsoil that is characterized by the presence of the Arno alluvial gravel aquifer. Gravels have a maximum thickness of 20 meters in the centre of Florence and in the Cascine park area. The underground passing rail interacts, above all in the new station area, with the latter aquifer.

2. Material and Methods

The modeling activity was carried out with the help of the numerical code Modflow 2000 on the Groundwater Vistas interface; it checked, in particular, the hydro-geological water balance parameters. Specifically, the absolute values of the permeability coefficients, the aquifer's size and a few water balance figures (abstractions and upstream flows) were re-calculated. The implemented model was "feasible", given that it only modified some input data to check their correctness by the means of the model itself.
The Water Balance Plan of the Arno River Basin Authority provided the input data.

3. Results

The model features are illustrated in the following paragraph.
Geometry: the initial model geometry was used. The vertical discretisation of the Florentine subsoil identified 4 hydrostratigraphic units. The first layer is the surface cover, the second and third layers include the main aquifer; the fourth layer belongs to the lacustrine substrate.
Permeability: the water balance plan and the knowledge framework were the input data source. In addition, data were calibrated.
Natural recharge: data provided by the Water Balance Plan.
The Arno River was considered in the model as a specified head, whereas the northern sector recharge were considered as a specified flow. Well abstractions were also taken into consideration (Water Balance Plan).

		2. M m^3/y
Aquifer river exchange flow	INFLOW	1.94
	OUTFLOW	2.08
Abstractions	OUTFLOW	3.56
Upstream Recharge	INFLOW	2.74
Direct infiltration	INFLOW	0.96
TOTAL RECHARGE		5.64

Tab.1 – Water mass balance data.

Calibration was carried out with the "trial and error" procedure. In particular, the permeability parameter (K) and the northern sector water recharges were calibrated. The calibration process showed that the model converges to acceptable values according to the input data.
The development of a "feasible model" with new input data highlighted the possible existence of a different scenario from the one initially foreseen. In particular, an higher groundwater exchange rate volume and a permeability of about one order of magnitude higher underlined the need of further investigations.

4. Conclusions

The Environmental Observatory for the High Speed Rail Florentine Hub, established a technical board with the aim of assessing the Florentine subsoil groundwater flow model as regards to the high speed train infrastructure facilities construction.

As a result of these activities the following conclusion can be drawn concerning the use of hydrogeologic modeling to support infrastructure surface and underground construction works. The hydrogeological inquiry shall concentrate on a much larger area than that of the rail track itself.

In fact, a data collection limited only to the rail track area could cause major mistakes as a much vaster area, than that taken into consideration for geotechnical issues, has to be investigated as regards to groundwater exchange fluxes. In this context, knowledge of the water balances of an extensive area is fundamental because it contributes to the creation of the flow model baseline conditions. It is necessary, above all, to understand the interactions between the high speed train infrastructure facilities and groundwater resources. This consideration acquires an uttermost importance in an highly anthropized alluvial plain where groundwater abstraction volumes can represent a significant variable.

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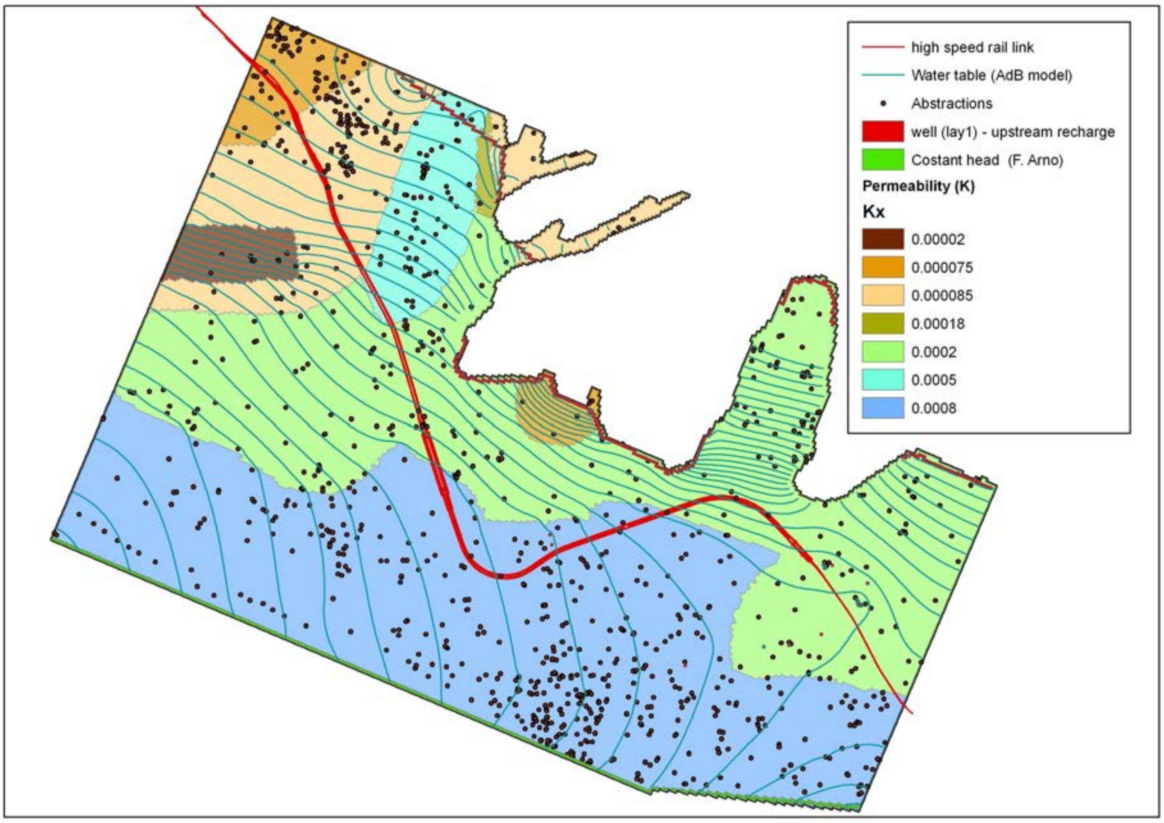

Fig.1 – Permeability and boundary conditions in the study area.

MODELING THE IMPACT OF DEWATERING IN THE ACQUE ALBULE BASIN (TIVOLI, ITALY): OPTIONS FOR A MORE SUSTAINABLE GROUNDWATER USE

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Key-words: dewatering, flow modeling, groundwater management, Central Italy

1. Introduction

The Acque Albule area is a structural basin characterized by regional groundwater flow mixing with mineralized thermal fluids that flows upwards through deep discontinuities. The main aquifer is represented by travertines, whose bedrock is made by marine clays and pyroclastic rocks; a deeper circulation in the buried and downthrown carbonates is interacting with the travertine aquifer by seepage along discontinuities. At the top of the sequence, low-permeability peats and clays caused confined flow in the travertine aquifer. A progressive decline in groundwater levels has been recorded in the basin since 1970s. Since 2002, the water exfiltrating from the primary thermal spring (Regina Spring) suddenly ceased and ongoing subsidence resulted in damage to adjacent private buildings. In 2007, an emergency plan was carried out to ensure an adequate water supply to the Regina Spring. The groundwater flow system is impacted by pump stations operating in travertine quarries to permit large scale mining operations and to supplying thermal water to spa facilities. Understanding the complex hydrogeology of the basin is necessary to define the groundwater flow pattern and to deep into the observed water-level declines. This work aims to determine the causes of the observed groundwater declines and to suggest alternative management strategies for a more sustainable use of groundwater resources.

2. Material and Methods

The numerical code chosen for this study was FEFLOW, which utilizes the Finite-Element technique. The flexibility of triangular finite elements gives the model the capacity to simulate the complex groundwater features of the basin. The well logs for 109 boreholes, geologic maps and cross sections were used to define a number of hydrostratigraphic surfaces which were imported into Grid Builder to reproduce the three-dimensional mesh. Arc View and ArcMap were also used for georeferencing operations and spatial analysis.

The travertine aquifer is intensely fractured and contains large conduits in its matrix. Therefore an equivalent porous media approach was taken for the model in view of the scale of the problem. The model covers an area of about 32.5 Km^2 and circumscribes the travertine aquifer system. The top of the model is the land surface and its base is the lower boundary of the aquifer.

The model was refined in areas of interest (i.e. active open pits, area affected by land subsidence, springs) and consists of 37 layers. The top soil was represented by 15 layers, each about 1 m thick and the travertine units were represented by 22 layers, each approximately 5 m thick. The hydrogeologic properties of the aquifer were determined by pumping tests and were included in the model as starting calibration points.

The boundary conditions were assigned and subsequently refined during calibration. To the northern margin of the system a constant flux value was included to simulate the lateral recharge from the regional system. Constant heads were assigned to the nodes corresponding to the course of the Aniene River and no flow boundaries were set at the bottom of the model and along the eastern and western margins of the domain. A specified flux boundary condition was assigned to the base of the model in the area beneath the Regina Spring to simulate the thermal water entering the system from the deep thermal complex. Constant head values equal to the ground surface with additional flux constrains were used to simulate the primary and secondary springs. Recharge boundary conditions were assigned at the top surface based on the land usage at the basin.

The effect of the main quarries was accounted for via eight pumping wells. The rates assigned to the wells were manually adjusted until hydraulic head values at each quarry fell just beneath the observed pit floor elevation. The pumping station which supply thermal water to the spa was simulated with a 700 L/s rate pumping well. Multi-layer wells were used to simulate the pair of wells at the Civil Protection Department well field with a flow rate of 250 L/s each. The water extracted from the Civil Protection Department well field and piped into Regina Spring was incorporated into the model via a 500 L/s injection well.

In order to examine long term water level trends, the model was calibrated for steady state

conditions with the field observations documented at the basin during three separate time periods: scenario 3, corresponding to 1970-2002 period, when only quarry dewatering operations occurred; scenario 1, between summer 2002 to June 2007, when quarry dewatering operations and the spa extraction well were the only anthropogenic activities; scenario 1, since 2007 to present, when the provisional emergency plan was operating.
The model was validated by applying it to a pre-disturbance scenario (i.e. Scenario 0) which considered basin hydrodynamics under pristine conditions (Maxia 1950b). A sensitivity analysis was performed and the calibrated model was used in a predictive mode.

3. Results

The majority of the calibrated model resulted in three hydraulic conductivity values that represented the topsoil (1.5×10^{-7} m/s), the upper travertine (1.2×10^{-3} m/s) and the lower travertine (1.5×10^{-3} m/s). A highly conductive (10 m/s) vertical conduit was defined at the Regina Spring to simulate the fracture/conduit by which the mineralized thermal fluids rapidly migrate upwards from the deep thermal complex. The vertical conduit is part of an intensely fractured N-S trending fault zone with a high hydraulic conductivity (7×10^{-2} m/s).
The rate of groundwater flow recharging the system from the regional aquifer was estimated to be 3530 L/s, according with regional budget. Hydrothermal waters enters the system from below at a rate of about 1420 L/s and recharge from precipitation was computed to be about 250 L/s. The simulations suggested that groundwater discharges into the Aniene River at a rate of about 1400 L/s. The overall amount of water extracted at the active quarries was about 2650 L/s, in agreement with field measurements.
The calculated head at Regina Spring in the Scenario 1 indicated that groundwater was not discharging, in accordance with the observed installation in 2002 of a pumping station to supply water to the spa facilities. A large cone of depression around the quarries area extended far enough to influence the Regina Spring and the area affected by land subsidence.
The comparison of Scenario 2 with the previous Scenario 1 suggested that the inclusion of the Civil Protection Department emergency plan did not change dramatically the regional pattern, positively affecting only the Regina Lake area.
When compared to Scenario 1, Scenario 3 resulted in an average computed water level rise of about 2.8 m in the quarries and of about 2.9 m in the area affected by land subsidence. Moreover, the historical seepage face at Regina Spring was reestablished with an estimated rate of about 390 L/s. It was estimated that pumping operations associated with the commercial spa had an adverse effect on the hydrothermal resources, contributing to the disappearance of the Regina Springs and to the discharge shortage of other springs.
Water budget differences in the Scenario 0 and Scenario 3 suggested that the mining operations reduced the Regina Spring flow from 2600 L/s to about 390 L/s and the secondary springs discharge from 800 L/s to about 660 L/s. These results evidenced a considerable impact of quarry dewatering on the thermal resources.
The model predicted that when quarry dewatering rates are reduced by 30% the system would recover the natural seepage face conditions at the Regina Spring and groundwater level would rise by about 3.0 m in the area affected by land subsidence. Uncertainties and limitations of the model includes the hydrothermal fluid entering the aquifer from secondary unknown fractures and the thickness of the aquifer within the N-S trending fault zone.

4. Conclusions

A natural discharge of 2600 L/s at Regina Spring was calculated under pre-disturbance conditions. This value agreed quite well with the flow rate measured when mining activities did not affect groundwater flow (Lombardi 1977).
The results also indicated that groundwater withdrawals by the mining industry and the commercial spa constitute approximately 64% of the total aquifer discharge, calculated on a long term basis. Quarry dewatering operations generated a detrimental effect on the basin scale water budget with a 85% reduction of the Regina Spring discharge and a drastically impact on the groundwater flow pattern at the basin. In addition, the pumping station employed since 2002 to supply the thermal spa contributes to the cessation of the Regina Spring discharge.
Finally, the modeling approach suggested that reducing quarry dewatering rates by 30% can be considered a potential remediation strategy, representing a valid compromise between anthropogenic activities and aquifer sustainability. About subsidence risk, the flow model represents a first step to further evaluations of the effects on the low-permeability top layers of the water table lowering.

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Groundwater movement in a terraced slope: comparison of the results of two different scale models

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Key-words: dry-stone walls; finite elements; perched groundwater tables; raster analysis;

1. Introduction

The aim of this work was to understand and reproduce the hydrogeological dynamics of a slope subject to instability phenomena and whose peculiarity is to be terraced by dry-stone retaining walls. In particular the study area is located uphill the village of Tresenda in Valtellina (northern Italy), and it was affected by soil slip/debris flows events in 1983 and 2002.

As a final consequence of the rainfall infiltration and groundwater movement processes, the formation of perched groundwater tables (PGTs) can be considered as one of the most influential factors controlling slope stability in different environments (Zhang and Liu 2010; Xu et al. 2011) among which terraced slopes (Crosta et al. 2003).

Terraced slopes are usually composed by a wall backfill soil with a relatively high hydraulic conductivity which overlies to a bedrock with a very low hydraulic conductivity. This context is very suitable for the formation of PGTs that, in spite of their transient nature, can develop pore-water pressures sufficient to trigger local slope instabilities, (Li et al. 2005; Dahal et al. 2009). This occurrence is often critical because it develops along the contact area between layers with different mechanical characteristics, where failure surfaces are more likely to evolve.

The knowledge achieved in this study, by monitoring and modeling the dynamics of the formation of PGTs, is crucial in order to manage the stability of terraced environments, and to ensure the safety of the involved mountain communities.

2. Material and Methods

Numerical modelling of the infiltration process, considering both unsaturated and saturated conditions, has proven to be the most effective tool to relate landslides to rainfall events (Rahardjo et al. 2010). Therefore, first the processes of interest were analyzed with a traditional approach by means of a 2D unsaturated-saturated finite elements analysis, reproducing the geometry of a single terrace. Then, the problem was moved to the entire slope performing a raster analysis. Also in this case both the unsaturated and saturated components of flux are taken into account.

Regarding their parameterization both the models required the saturated hydraulic conductivity (k_S) of the materials involved (backfill soil, dry-stone wall and bedrock) and their Soil Water Retention Curve (SWRC). For the backfill soil it was possible to derive the k_s from field and laboratory permeability tests and then adjust it for calibration, while its SWRC was computed from grain size analyses applying the Gupta & Larson method (1979). k_s of wall was considered one order of magnitude higher than that of soil for a new or well-maintained wall able to perform its drainage function, while one order of magnitude lower than that of soil for an old, bad-maintained wall, whose voids are clogged with fine material. Bedrock was considered impermeable respect to both wall and soil. Then, considering that changes in soil moisture conditions in the bedrock and the wall have a very small impact on groundwater circulation, their SWRCs were considered to be flat, i.e., constituted by a constant value of water content.

Regarding the 2D detailed model, that represents a single terrace with a wall 2 m high a constant bedrock slope angle equal to 44°, and a topographical slope of about 35°, the aim was to reproduce groundwater hydrograph registered on site by a specifically installed piezometric datalogger in consequence of real rainfall events. Two different measured hydrographs were use to calibrate and validate the model, then a sensitivity analysis was performed on some parameters such as wall height, bedrock slope angle and variations of k_s assuming both isotropic and anisotropic conditions. The model was also used considering probabilistic rainfall events, derived from intensity-duration frequency curves, with a duration similar to the one that caused the triggering of the instabilities in 1983 and 2002.

When the study was devoted to the slope scale (total area 0.6 km^2), it was first necessary to define the Digital Elevation Model (DEM) and the soil depth map at an appropriate detail (cells 1 m x 1 m) in order to allow for the presence of the dry-stone walls. Moreover, other processes such as evapotranspiration and superficial runoff are taken into account. The calibrated and validated parameters from the 2D model were assigned to the materials involved and the same two rainfall events used for calibration and validation were considered. By extracting the hydrographs from the cell that correspond to the location of the installed piezometric datalogger, and a series of hydrographs along a single terrace section, it was possible to compare the result of the two models.

3. Results

During the calibration and validation of the 2D model, a good agreement between the recorded and the calculated value of PGT height was reached. The timing of the peak was good, but the descendant limb of the calculated groundwater hydrograph, declined faster than the measured one.

It was observed that an increase in wall height often causes a higher level of groundwater table, whereas an increasing slope angle of bedrock in most cases produces the opposite effect. These trends can be simply explained because a greater height corresponds to a larger quantity of soil in which the water can be stored, whereas a higher slope angle can cause an increase in the mobility of the water and lessen its ability to accumulate. Moreover, the effects of k_s variations were explored: if k_s increase is expected to produce a decrease of water table maximum height, because of the greater velocity of groundwater flow in the saturated zone. On the contrary, the response of the maximum length is less straightforward due to the combination of more different factors. It should be considered that saturated groundwater flow occurs along an 'imposed' path, i.e. with an angle of about 45° corresponding to the bedrock dip angle. When k_x is higher than k_v the flow along the 'imposed' path is too high with respect to the infiltration rate, and a saturated zone can develop only where the soil has low thickness. The length of this zone increases as the k_r value (k_v/k_x) increases from zero to the isotropic condition k_r=1. A further increase of k_r does not modify the modulus of the k vector along the 'imposed' path where groundwater flow occurs. Thus, the maximum length of the saturated zone remains unchanged.

Using the 2D model with statistical project rainfall the different behaviour of a well or bad-maintained wall is well marked.

The slope scale model was run both with a daily and a hourly timestep. In the first case it is able to reproduce the water table peak in terms of height but it cannot describe the processes of infiltration with precision, while with the hourly timestep the peak is perfectly reproduced in terms of time, but the maximum water table level is underestimated. Analyzing the results along the terrace section, it can be also noticed that this model is not able to differentiate as well as the 2D model the different behaviour of a draining wall respect to a clogged one. On the other hand, the slope scale model is able to identify preferential ways of infiltration along the slope.

4. Conclusions

The results of the 2D simulations were useful to represent and describe the process of PGTs development in these contexts, in which a progressive increase in soil thickness from the top of the slope to the wall plays a key role. It was demonstrated and detailed how the possibility that a significant water table reaches the back of the wall mainly depends on the combination of soil hydraulic characteristics, soil geometry, rainfall intensity and duration. On the other hand the slope scale model is not able to describe the processes with the same precision, but considering that it can well reproduce the maximum water table levels and identify zone susceptible to preferential infiltration it seems to be a good tool for prediction purposes.

The two models are therefore complementary.

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THE ALLUVIAL AQUIFER OF THE RIVER ROJA IN VENTIMIGLIA NUMERICAL FLOW MODELLING IN TEMPORARY REGIME AND INSTRUCTIONS CONCERNING TRANSPORTATION

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Key-words: aquifer, model, balance

1. Introduction

The modelled aquifer is contained within a portion approximately 3 km long and between 450 m and 600 m wide and is made up of Quaternary alluvial and detrital sediments that crop out to the north of the city of Ventimiglia (Liguria, Italy) and extend for around 2 km^2 in the area of confluence between the Rivers Bevera and Roja.

The groundwater of River Roja has a strategic regional and cross-border importance since it represents a source of drinking water for both a part of Liguria and of the French coast.

The aim of the analysis is that of realizing a numerical flow model - in temporary regime – in order to learn which the actual potentialities of the groundwater body are and to set the main characters of a transportation model considering some pollutant elements to foresee their diffusion.

2. Material and Methods

The geometrical/structural reconstruction of the subsurface was carried out on the basis of the lithostratigraphic data obtained from geognostic drilling and of the geophysical surveys performed in the ambit of the "Eurobassin" and "Risknat" European Community Projects. It was underlined the presence of a single unconfined aquifer, with an average thickness of 32 m (Barazzuoli et alii, 2012, in press), mainly composed of sandy – sometimes muddy - gravel, with pebbles and characterized by a high degree of permeability (0,7-3 * 10^{-2}m/s) as emerged from the two permeability surveys carried out with the use of tracers. This aquifer is confined below by a substratum with low permeability, composed of Ventimiglia Flysch.

The hydrodynamic characterization of the aquifer was carried out not only by means of the two above mentioned surveys, but also by a piezometric survey of 16 measurement points (wells and piezometers) which made it possible to represent the groundwater flow field in the period between June 2010 and June 2011.

Thanks to this background knowledge, it was possible to develop a conceptual model of the aquifer through which was possible to determine the inflows (River Roja, River Bevera and infiltration) and outflows of the system (pumping and River Roja), from which, despite the strong impact of water pumping, a positive hydrogeological balance was seen.

In order to reach the objective of a correct and integrated management (quality/quantity) of this water resource, in both space and time, once the conceptual model had been elaborated, we proceeded with the construction of a numerical model which, by means of a process of iteration, made it possible to verify the hypotheses formulated regarding the aquiferhydrogeological and hydrodynamic properties. The aquifer system was represented by means of a three-dimensional numerical model with finite elements (FEM), with the use of the FEFLOW 6.006 numerical code (Finite Element subsurface FLOW system), considering both permanent and temporary regimes.

The input data inserted into the model by means of the allocation of boundary conditions of hydraulic head, water exchanges and water pumping and of material properties such as permeability, porosity and infiltration (Barazzuoli et alii, 2011, in press), made it possible to accurately represent the groundwater flow field and its variability during the analyzed year, as the good fitting between calculated and measured piezometric values confirms (Fig. 1).

Starting from the above described modelling, conditions relative to the Transportation Model like "mass concentration" and longitudinal and transverse dispersion were set.

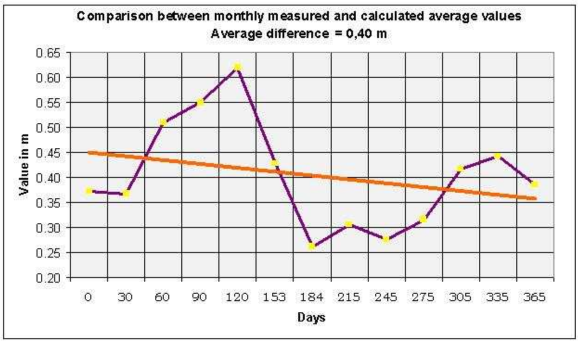

Fig. 1 – Comparison between measured valued and values calculated from the numerical model.

3. Results

The analysis of the results of the numerical model in temporary regime made it possible to evaluate both on a global and local level the volumes of inflows and outflows of the analyzed area. On the global level there is an optimum correspondence between the numerical and conceptual model. Comparing, on annual basis, the volumes of the inflows (River Roja, River Bevera and infiltration) and the outflows (River Roja) of the aquifer, it is possible to observe that they are very similar for a total amount of approximately 44 * 10^6 m^3 (about 1.4 m^3/s). Water exchanges between river and aquifer present in the analyzed area should be also considered and they respectively represent approximately 105 * 10^6 m^3 (from the river to the aquifer) and 38 * 10^6 m^3 (from the aquifer to the river).

The considered water volumes (table 1) underline not only the importance and the key role of river Roja but also the quantity of water exchanged with the aquifer that is able to balance and maintain in equilibrium all the system in despite of the annual 64 * 10^6 m^3 (approximately 2 m^3/s) collected from present wells, mainly for potable use.

A further confirmation derives from the measurements of stream discharge of River Roja where the inflow (River Roja and River Bevera) is 7.6 m^3/s and the outflow (River Roja) is 5.6 m^3/s.

Then possible criticalities within the analyzed area were identified and in order to perform this the model was divided into three portions (north, centre and south) and relative balances were calculated. The analysis did not underline critical situations but identified the south portion as the most stressed, confirmed also by the high values of water exchange between river and aquifer (approximately 57 * 10^6 m^3 per year) mainly induced by the strong pumping, more numerous than in the other portions. Analyzing the balances of the two other portions, it emerges that the central portion is the less subjected to pumping and consequently the most suitable for the strengthening of the existing drinking water source.

Finally, it emerges that the majority of the aquifer is very susceptible to waterborne pollution, which gives rise to the necessity for suitable measures for its safeguard, also because of its great importance to both the Italian and French communities as a strategic source of drinking water. For such purpose the calibration of the transportation model in relation to possible pollution scenarios is in progress.

Particularly, the object of the evaluation has been represented by the diffusion, in space and time, of benzene and caustic soda for an accidental, pretty instantaneous dumping of a tank and by a continuous pollution of sodium nitrate on all the area.

4. Conclusions

The analysis of the aquifer of River Roja permitted to realize, starting from a conceptual model of the aquifer, a numerical flow modelling in temporary regime that allows to quantify in detail the inflows and the outflows of the system and the water exchanges within the same.

The elements having a key role in this aquifer system are the two rivers and above all the River Roja that, as results from the analysis of the global balance, compensates the water pumping of wells.

Acknowledgements

Authors thank the Province of Imperia and particularly Dr. Ennio Rossi and Dr. Francesco D'Adamo.

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WATER VOLUMES – NUMERICAL MODELLING IN TEMPORARY REGIME		
BOUNDARY CONDITIONS AND INFILTRATION	INFLOWS (10^6 m^3/y)	OUTFLOWS (10^6 m^3/y)
1st Type (Hydraulic Head)	42.23	45.07
3rd Type (Fluid Transfer)	105.58	38.49
4th Type (Pumping/ Injection)	-	64.17
INFILTRATION	0.35	-
TOTAL	148.16	147.73
BALANCE	0.43	

Tab. 1 Annual water volumes divided accordingly to different types of boundary value problem

MODELING GROUNDWATER RECHARGE IN AN ALLUVIAL AQUIFER OF SOMALILAND WITH THE NEW GROUNDWATER FLOW MODEL YAGMOD

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Key-words: *water resources, groundwater, arid regions, aquifer recharge, mathematical modeling*

1. Introduction

Water for the city of Hargeisa (Somaliland) is supplied by some wells drilled in the alluvial aquifer of the Ged Deeble (GD) basin. This study has the finality to develop a mathematical model of this basin; special effort has been devoted to model aquifer recharge sources. Different exploitation scenarios has been examined to verify and try to predict if the future water demand of the city could be satisfied, so that the results of this study could be used to plan and manage future water resources.

2. Material and Methods

The well fields were started in the 1970’s and some new wells were drilled later. The water production raised from 6000 m³/day in the first years of the millennium up to 10.400 m³/day at the beginning of 2010. This trend reflects in the variation of the water table depth with time. An EU project (Buggiani & Petrucci, 2007) allowed to perform some exploration activities from 2003 to 2007, including: a detailed geological survey, a geoelectrical campaign, a series of pumping tests, a continuous monitoring activity prolonged for two years.
The data permit a first reconstruction of the basin geometry, of the hydrogeological structure and of the mechanisms of the aquifer recharge. The aquifer consists of unconsolidated sediments deposited in lacustrine or fluvial environments and is bounded by a Precambrian crystalline bedrock. From a structural point of view, the basin is the result of the intense tectonic thrusts that gave birth to the Gulf of Aden rift: it probably formed by two major tectonic trenches, E-W oriented, connected by a long fracture with N-S alignment. The GD basin is crossed by two seasonal wadis: Tog Ged Deeble and Tog Kalqoray. A wide outlet was found at the N-E edge which connects the GD basin to the Laas Dhuurre-Damal (LDD) basin.
The annual average of some recharge sources could be considered constant during the time interval under study: they include mainly infiltration of rain and wadis water through the soil and the unsaturated zone. The coverage of fine grained material strongly limits the infiltration of rain through the soil, which should be very small, whereas the infiltration of water along the wadis courses could be more important, because they could have eroded this impermeable materials and deposited permeable coarse-grained sediments during their recurrent floods.
The mathematical model (YAGMod: see Cattaneo et al. 2012 for a description) considers a 2D hydraulic flow approximation, pseudo-steady conditions corresponding to the average annual flow, no-flow boundary conditions in correspondence of the crystalline bedrock and fixed head at the edge with the widespread and thick LDD basin. This particular boundary condition is modelled as a Robin boundary condition, with two different conductance values for inflow and for outflow water exchange. This choice permits to take into account the different geometries of the two connected basins: the smallest GD basin and the largest LDD basin.
The calibration of the mathematical model was quite difficult for the uncertainties on the old data, so that also sensitivity analysis has been conducted.

3. Results

The interpretation of the data and the model calibration give some new important suggestions to describe the current state of the Ged-Deeble basin. From the geological point of view, there is a division of the basin in two sections, separated by an area of low permeability. From the hydrological point of view, recharge could not be limited only to rain and wadis infiltration: increasing extraction generates additional recharge sources, that in the upstream (southern) section probably comes from an underground fracture-fault network, whereas in the downstream (northern) section comes from the LDD basin. It would be useful to improve the knowledge of the structural setup of the basin, in order to improve the estimate of the areas characterized by fractures in the crystalline basement and the potential flow paths. At the

moment quantification of fractures flux comes from model calibration.
Moreover, it should be very important to extend the piezometric survey, with a more uniform spatial distribution throughout the whole basin and close to the wadis. This could be useful to get a more precise quantification of wadis recharge.

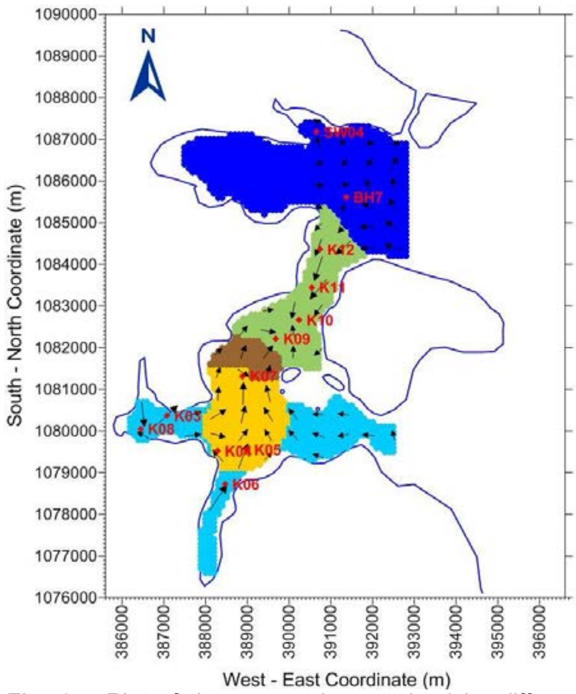

Fig. 1 – Plot of the zones characterised by different values of hydraulic conductivity. See Table 1 for the values of K in each zone. Red diamonds are active wells. Black arrows represents flow lines .

4. Conclusions

From the point of view of resource management it appears that the GD basin alone cannot satisfy the future water demand of the city without a further, more dramatic depletion. However, a shift of the production from the wells in the southern section to those located in the northern one or even to the much wider LDD basin could support the growth of the city water demand.

Zone	Hydraulic Conductivity (m/s)
K1	$5.0\cdot10^{-4}$
K2	$4.0\cdot10^{-4}$
K3	$3.5\cdot10^{-4}$
K4	$5.0\cdot10^{-5}$
K5	$1.0\cdot10^{-5}$

Tab.1 - Values of the hydraulic conductivity obtained with calibration for the zones represented in Fig.1

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Modeling groundwater flow in heterogeneous media with YAGMod

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Key-words: water resources, groundwater, mathematical modeling

1. Introduction

Modeling groundwater flow and transport in alluvial aquifers is quite common and a great number of effective and validated codes is already available. In principle they can consider complex chemical and physical processes (such as variable saturation, interactions with the porous matrix, variable fluid density, heat transport) and complex hydrostratigraphic structures, which control hydraulic conductivity and, therefore, the flow field and solute transport. Since codes that fully consider both chemico-phyiscal and hydrostratigraphic complexity require a large and rarely available data set, an original code YAGMod (Yet Another Groundwater Flow Model) is proposed to solve specific problems.

In particular the objective is to develop a modeling tool which is robust enough to be used for the simulation of groundwater flow in conditions of strong heterogeneity. This is very important to apply methods of joint inversion of hydrological and geophysical data, when different sets of model parameters have to be tested, so that, for instance, strong contrasts of hydraulic conductivity might occur between adjacent discrete cells and give rise to numerical difficulties or solutions of doubtful physical significance.

2. Material and Methods

YAGMod, developed in FORTRAN90, solves the 2D or 3D hydraulic forward problem. Numerical solution of the steady-state balance equation in porous media, which describes the 2D or 3D groundwater flux, is found using the finite difference scheme method. Space is discretized with a grid of cells, which are rectangular in the horizontal plane (Δx and Δy spacing are assumed to be constant values for all the grid), but could be vertically distorted. A short list of some characteristics, that are not common to other software packages, is given below. Different types of source terms and boundary conditions are considered: in particular, it is possible to simulate variable sources, like draining systems, river/aquifer interactions and recharging fractures, with a more general formulation than that used in other software packages. With YAGMod, total extraction rate of a well could be distributed among the cells the well fills up, proportionally to hydraulic conductivity assigned to that cell. Moreover, YAGMod models the effects that the water head drawdown below the top of the screened interval of a water well can have on discharge. The cells saturated thickness is taken into account when calculating hydraulic transmissivity, during the simulation. So, horizontal flux between dry cells is forbidden, but not vertical one. Finally, an original approach is implemented to simulate the drying of shallow cells. With these features, YAGMod allows to simulate saturated-unsaturated groundwater flow in an original and simple way, without the need of solving the Richard's equation, which requires the knowledge of the characteristic suction and conductivity curves of the subsurface materials.

3. Results

YAGMod has been validated by comparison of its results with those obtained with MODFLOW 2005 (MODFLOW, 2005).

Firstly, a 2D simple simulation has been run: in homogeneous hydraulic conductivity field media (10^{-4} m/s), 5 fixed well, whose extraction rate was about 0,05 m^3/s, are posed. Results from YAGMod and MODFLOW code show very good agreement (see Fig. 1: A,B). Very good agreement is obtained also for a simple 3D simulation.

Then, a particular 3D example has been run: a low conductivity lens is included in a homogeneous permeable medium: a deep well, whose extraction rate is about 0.2 m^3/s, is located beneath the lens. Three different solutions (see Fig.1: C, D, E) are obtained with MODFLOW 2005 (C), YAGMod with the new screened well type (D) and YAGMod with a single cell fixed well (E).

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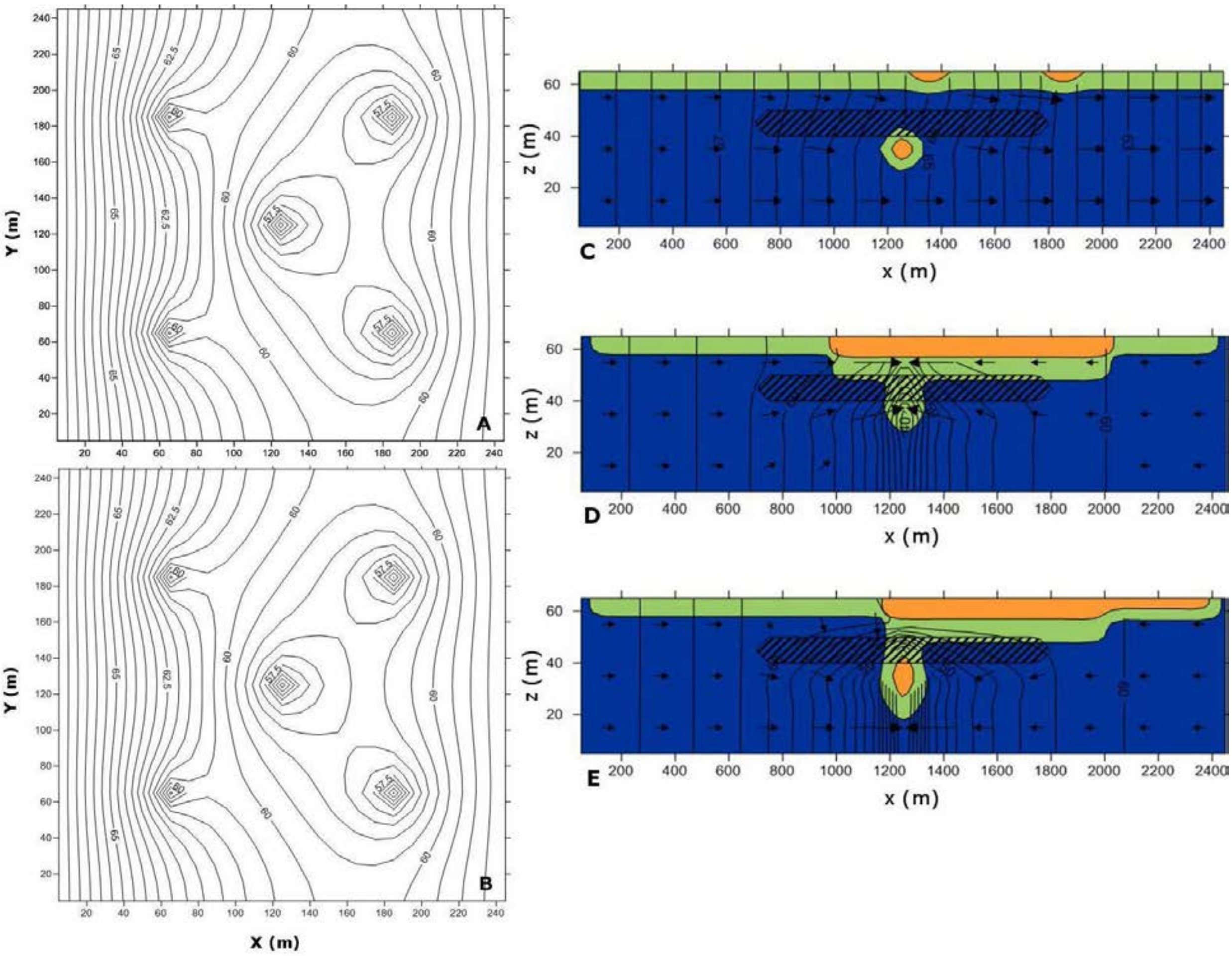

Fig. 1- A,B) Contour Lines for the solution of a 2D problem obtained wit MODFLOW 2005 code (A) and with YAGMod (B). C,D,E) Contour lines and hydraulic flow paths (black arrow) for a 3D problem solved with MODFLOW 2005 (C) and with YAGMod (D,E). A well is located at x = 1250 m and z = 40 m, beneath a low conductivity lens (dotted zone). The simulation represented in D is obtained with a screened well, while the simulation represented in E is obtained with a single cell deep well. Three different saturation zone are shown: saturated (blue), partially desaturated (green) and totally desaturated (orange). Flow lines represented with black arrows.

GROUNDWATER MODELLING APPLICATION: AN OPERATING TOOL IN GROUNDWATER RESOURCE EVALUATION

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Key-words: groundwater, modelling, water budget.

1. Introduction

In groundwater model developing, three main steps are usually involved: implementation, calibration and application. The model construction (implementation) is always the first step, according to all available knowledge and data sets, followed by model calibration. The final step is the model application. This work refers to a groundwater modelling application as a part of a decision support system tool in which the model is used as a basis for quantitative groundwater state estimation.

The study case herein discussed deals with the alluvial fan of the Marecchia River, located in the southeastern part of Emilia-Romagna Region, near Rimini (North Italy). This is the major groundwater reservoir of the whole Romagna region, from which, withdrawals of about 25 million cubic meters, satisfy about 25 % of the whole drinking water annual needs of this territory (Romagna Acque, 2012). Further sources, both groundwater and surface water, are distributed on the territory of the three Romagna provinces: Forlì-Cesena, Ravenna and Rimini.

In the last ten years, several situations of water crisis (2003, 2007 and 2011) occurred due to prolonged drought periods. In such situations, the lower the amount of surface water available, the greater the need for withdrawals of groundwater. As a consequence, groundwater quantitative state evaluation, as well as withdrawal sustainability assessment, become a strategic element. The application of groundwater modelling helps to achieve this goal as described in this note.

2. Materials and Methods

The groundwater model of the Marecchia alluvial fan was firstly developed in 2006, with unsteady calibration data referring to eight seasonal stress periods in the years 2001-2002.

The territorial extension of the model is about 140 km^2 and the number of cells is about 48,000, distributed over 50 layers along the vertical dimenson. The model resulted from a very extensive hydrogeological study (Arpa Emilia-Romagna & Regione Emilia-Romagna 2006) which defined geometry and structure of all aquifers of Marecchia alluvial fan, referring to the scheme reported in Emilia-Romagna & ENI-AGIP (1998). The study also allowed to quantify the main stress terms that affect the hydrogeological balance of the whole alluvial fan: recharge from river and rain and groundwater withdrawals. A local monitoring netwok was finally defined in that study and measures of piezometric levels on 72 wells still countinue today.

The groundwater quantitative state evaluation by means of the model requires construction of several scenario simulations, depending on different values of the ratio between recharge and withdrawal. Results from groundwater model runs, provide a reference pattern for the next groundwater state evaluation.

At the same time, Marecchia groundwater model could be used as a tool inside a cycle of model controls (by new groundwater levels data from monitoring network) and updates (from new recharge and withdrawal data collection). This cycle could be repeated several times and in this way the model is able to represent and follow over time the current groundwater state on a “real time” basis. Moreover, starting from each model update, forward simulation could be performed for forecasting purposes. Both current and predicted groundwater state can be now compared to the reference pattern described above.

Starting from all model outputs, a way to evaluate the groundwater state resulting from all model runs must be then defined.

The methodology here proposed is based on model water budget calculations and groundwater storage volume changes computation over time. Groundwater storage volume variations are cumulated starting from a reference critical point set equal to the minimum piezometric levels occurred in 2007. In this way, a distance from that critical situation is provided.

As a result of the Marecchia groundwater model application, a simple evaluation of the current and the predicted groundwater quantitative state could be depicted. Methodology details and results are discussed in the next section.

3. Results

The graphical tool with all the results of the methodology described above, is shown in the example reported in Fig. 1. The application of Marecchia groundwater model refers to the model update done in May 2011. The methodology works as follows:

1. the model is first updated up to December 2010. This is the starting value of the graph, corresponding to the amount of groundwater available at December 2010 referring to the critical reference time of September 2007;
2. six model simulation runs are performed combining four different natural recharging possibilities (main percentiles based on historical data) with three levels of system exploitation (average, minimum and maximum). The simulation runs are carried out for the next 12 months (from January to December 2011). Model results are shown as colored bands from orange to blue that are respectively associated to a poor or good evolution of groundwater quantitative state (see Fig. 1). This is the 2011 reference simulation pattern;
3. a new model update is done (orange curve in Fig. 1). In the example the last point of the orange curve is on May 2011;
4. two forward simulations referring to the following four months (green curves) are then performed, depending on seasonal rain forecast simulations (Pavan et al., 2008) and on expected groundwater withdrawals for drinking needs in the same period (green lines);
5. both current update results and forecasted simulation results could be compared to the reference simulation pattern.

Following this scheme, steps 1 and 2 are performed once a year, at the beginning of the reference evaluation period. During this period, steps 3, 4 and 5 are repeated as many times as required depending on specific situations.

All the values in Fig. 1 represent groundwater cumulative storage volumes computed by the numerical groundwater model of the Marecchia alluvial fan during the year 2011. On the left axis, these volumes are measured starting from the critical situation set on September 2007. On the right axis, volumes are accounted for since the beginning of the current year.

By comparing orange/green curves position into the colored bands of the graph, a measure of the current/predicted quantitative state of Marecchia alluvial fan reservoir is provided. At the same time, a comparison with previous years value (colored curves) is allowed.

All curves in the graph show the behaviour of the groundwater system: seasonal increasing of groundwater levels (increasing storage volume in Fig. 1), usually from October to March, followed by groundwater levels lowering in late spring-summer period (decreasing storage volume in Fig. 1).

4. Conclusions

This work shows how groundwater modelling could be applied as an operating tool for evaluating groundwater resouce availability over time. The example herein reported refers to Marecchia alluvial fan whose aquifers are constantly kept under control. In the last 4 years, from 2008 to 2011, the groundwater model of Marecchia alluvian fan was updated 24 times, on average every two months.

The presented methodology could be of great help for decision-makers to face water emergency management and prevention.

Moreover, this tool can be used for further purposes: designing, planning, ordinary management of water resource, by adapting proper scenario and/or prediction simulation construction to the specific situation.

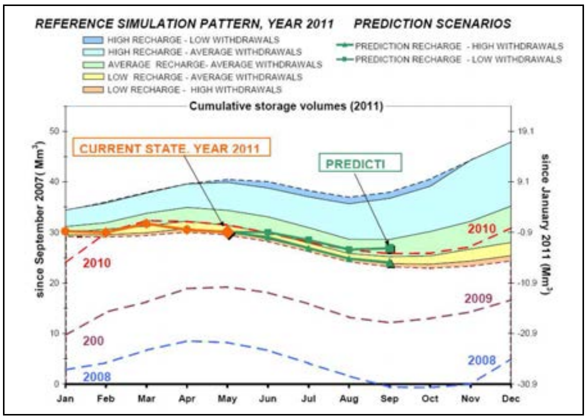

Fig.1 - *Evaluation of groundwater quantitative state by model budget analysis.*

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GROUNDWATER FLOW MODEL MANAGEMENT: EXAMPLES IN EMILIA-ROMAGNA (ITALY)

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Key-words: groundwater**,** model management, water budget, simulation

1. Introduction

This work concerns some groundwater modeling applications in the aquifers of Emilia-Romagna, north Italy, which represents a long-term experience in model management. The experience made it possible to verify both the appropriateness of certain operative choices keeping into account their use and their objectives, and the improvement of the efficiency in the start up phase of modelling.

A set of numerical models can be operationally improved through a continuous process of updating and verification. This allows to best represent the state of groundwaters, from which the simulation scenarios for managing of resources can start. Here we can more correctly speak of *model management*.

For this, it is of fundamental importance to keep alive data flow that feeds the model, both for what concerns monitoring networks (hydraulic head and concentrations) and sources (groundwater withdrawals, river and rain recharge) that regulate aquifers in terms of stresses.

2. Materials and Methods

Groundwater flow model cases here described have been developed with several spatial scales: the scale of the entire regional aquifer (Chahoud et al., 2012), designed to support Emilia-Romagna Water Protection Plan and then detailed scales (Arpa Emilia-Romagna, 2008; Chahoud et al., 2010, 2012) applied in more specific situations, that are however strategic for both the local need of exploitation and any environmental known fragility, e.g. nitrate transport, land subsidence.

All these flow models have been developed with MODFLOW-2000 (Harbaugh et al., 2000). They share the same three-dimensional structure and the unsteady state flow regime. Other features are reported in Tab. 1.

These choices have allowed the above cited process of continuous updating of lithological and structural features of the base reference model (Regione Emilia-Romagna & ENI-AGIP, 1998), for example when new well logs or structural information have become available. This has not precluded the chance of coupling the main flow model with other applications (e.g. contaminant transport and soil compaction).

All applications have been made under unsteady state flow conditions to evaluate storage changes, a key aspect in the water balance analysis. To comply with the effective availability of experimental data and to limit the calibration time, it has led to choice "seasonal" main time steps of simulation. Subsequent model updates, where the calibration phase has been significantly reduced as a consequence of the former work, have then led to use smaller time steps, taking also benefit of the availability of better hydrogeological data (Tab.1).

Furthermore, a constant link has been mantained between the regional model and other local models, in order to have a mutual exchange of information and to facilitate the models updating process.

3. Results

The experience gained in this model management process has allowed to apply the same evolving hydrologic layout to all applications:

1) in all studied cases, the same recharge and drainage from the first meters of soil has been used, as obtained from a daily water balance soil model (Arpa Emilia-Romagna, 2011), which takes account of soil textural characteristics and its ability to retain or release water. The advantage of this tool is its constant updating, as it is mainly used for agrometeorological purposes by the Regional Agency for Environmental Protection; and it is constantly updated with the regional rain gauges network;
2) the 3D knowledge of withdrawals required by the model structure;
3) the available hydraulic head observations, that is assured by the existing monitoring

networks (Arpa Emilia-Romagna & Regione Emilia-Romagna, 2008).

The management process itself has been focused over the following objectives:

1) to maintain the same hydrogeological and computing organization for all models, despite the evolution from year to year;
2) to develop the skill of extracting a local model from a regional one with the support of automatic or semi-automatic procedures.

This last point has been acquired with *Emiro II – Coastal Zone* model, whose construction was possible in a very short time extracting the child model from the parent and redefining the new boundaries with the solutions of the parent.

Another basic point of building models over the years is to provide decision-makers with all necessary information. This means that many efforts must be done in order to represent the model results in a synthetic and effective way. Flow model outputs are basically hydraulic head and water budget. They can be aggregated in space and/or in time, according to the objectives of the analysis. In most cases a comparison of results of multiple simulations simultaneously (scenario runs) is required. In the present work some study cases of such analysis are discussed.

4. Conclusions

The technology here employed results from almost 10 years of research development. For this reason, groundwater models can now be employed as a systematic service, even in terms of forecasting purposes.

The obtained results have evidenced that these tools can be properly used for many purposes: designing, planning, management, even for water emergencies and can be adapted to specific situations through the construction of adequate scenarios and / or predictions.

In any case, it is important to improve both models and management techniques over time to achieve and maintain this kind of results.

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Groundwater model name	Emiro II – Regional	FC-RA Aquifers	Reno alluvial fan	Marecchia alluvial fan	Emiro II –Coastal Zone
Years of work	2003/2007/2009	2004	2005/2008	2006/2008-2012	2010
Model extension (km2)	12.000	1.600	420	140	2.400
Cells dimension (m)	1.000	1.000	500	350	1.000
Cells number (active)	401.000	64.000	120.000	48.000	68.000
Number of layers	35	40	70	50	35
Calibration period	2002-2003	1997-1998	1983-1998	2001-2002	2002-2006
Number of stress period per year (average)	4	4	1	4	4
Number of calibration wells	442	52	25	83	82
Average annual calibration data	900	158	75	375	189
Last model update	Oct-Dec/2006	Sept-Dec/1998	Dec/2006	Dec/2011	Oct-Dec/2006
Actual number of stress period per year	4	4	12	12	4
Actual number of observation wells (manual/automatic)	(484/40)	(68/6)	(40/5)	(72/3)	(96/9)
Coupled model available	Nitrate transport	-	Soil compaction	Nitrate transport	Soil compaction

Tab.1 – Main features of groundwater flow models developed by Arpa for Emilia-Romagna decision makers

Bias between flowmeter measurements and numerical model in a contaminated coastal aquifer

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Key-words: SEAWAT; flowmeter; groundwater fluxes.

1. Introduction

During the characterization of the subsurface fluxes, the use of different techniques (geophysical, hydrological, hydrochemical) usually help to understand the processes taking place within the aquifer (Schürch & Buckley 2002). Generally, low-permeability, non-reactive, horizontal flow barriers (HFBs) are used to contain contaminants in aquifer and prevent further spreading of contaminants in groundwater. Grout curtains HFBs, which are the focus of this study, are supposed to be impermeable. Barriers are typically used in conjunction with interior and exterior extraction wells to help maximize containment inside the barrier and capture leakage outside the barrier (U.S. Environmental Protection Agency, 1996). Extraction wells locally steepen hydraulic gradients, which can increase groundwater flow velocities near a HFB. If the groundwater flow distortion near a HFB is not taken into account, the conceptual model can be non-optimal, which could result in low efficient remedial actions. Therefore, a range of different monitoring techniques must be employed to guarantee that appropriate methods are used to best reflect field conditions (Harte et al., 2006).

Numerical flow models are generally employed to assess magnitude and direction of groundwater fluxes but the field data required for the implementation and calibration of three dimensional variable density models are usually more complex than the ones needed for simple flow models (Abarca et al., 2007; Shoemaker, 2004). In this study a range of geophysical, and hydrogeological monitoring methods have been used in order to validate a variable density numerical model near a HFB emplaced perpendicular to the coast.

2. Material and Methods

The study site is a portion of an industrial area in Italy located near the shore line, affected by groundwater petroleum hydrocarbons contamination. A pump and treat remediation strategy by hydraulic barrier (HB), combined with a HFB was implemented from 2002 to prevent the plume migration outside of the site boundaries. The overall aquifer parameterization and modeling at the study site has been documented in a previous paper (Mastrocicco et al. 2011). Briefly, the groundwater flow is perpendicular to the coastline, downstream to the HB, towards the beachfront area, the piezometric surface is higher than in the upstream area, where the pumping wells are located. In proximity of the HB and HFB, piezometric contouring showed significant disturbances of the flow lines, both in direction and magnitude. At the selected section the HFB does not penetrate the aquitard and this feature does not guarantee the complete sealing of the system. Thus, flow meter tests were used to verify the presence, the direction and the velocity of vertical fluxes near to the HFB. The instrument used was a Heat-Pulse Flow Meter of Mount Sopris. SEAWAT-4.0 (Langevin et al.,2007) was used to simulate the variable-density transport processes. The model was calibrated versus heads measurements in 230 piezometers and 15 salinity profiles (Mastrocicco et al., submitted).

3. Results

The flow meter tests were performed to identify possible vertical component of groundwater flow near to the HBF. The velocity profile along a piezometer located 5 m down-gradient to the HBF showed a down warding flux of -0.25±0.03 m^3/d. This pattern was well reproduced by the model only when (i) the numerical grid was refined to reproduce the piezometer shape, (ii) the vertical hydraulic conductivity (*k*) within the piezometer was set very high ($1e^{+5}$ m/d) to mimic fluxes within an open tube. On the other hand, the piezometer located 5 m up-gradient to the HFB showed a down warding peak of -3.1 m^3/d at -5 m a.s.l. that the model was not able to reproduce. This effect was probably due to local heterogeneities. In fact, the inclusion of an elevated *k* lens ($1e^{-3}$ m/s), which connect the up gradient piezometer with pumping wells located 150 m inland, improved model results. The new model was able to better reproduce the fluxes also in the up-gradient piezometer. Although, the magnitude of the recorded peak at -5 m a.s.l. was not captured even with the refined numerical and conceptual model. In addition, it should be noted that the modelled vertical fluxes in figure 1 are elevated only within the piezometers, while in the rest of the model domain vertical fluxes are very low as expected in a sedimentary porous aquifer.

4. Conclusions

This study points out that flowmeter measurements could be employed as additional constraints to verify the numerical and conceptual model of complex sites affected by seawater intrusion and petroleum hydrocarbons contamination. But care must be taken when comparing model results and flowmeter data, since model should account for intra-borehole fluxes and local scale *k* field reconstruction. It should be stressed that even with all these information the numerical model wasn't able to reproduce an elevated peak flow recorded by flowmeter. This could be due to damages of the piezometer screen or voids in the gravel pack, which are both conducible to insufficient knowledge of the *k* field at the metric and centimetric scale. Finally, the numerical modelling showed that the magnitude of the fluxes recorded with the flowmeter were most probably induced by the fully screened piezometers, which their gravel pack act as a preferential pathway for groundwater movement.

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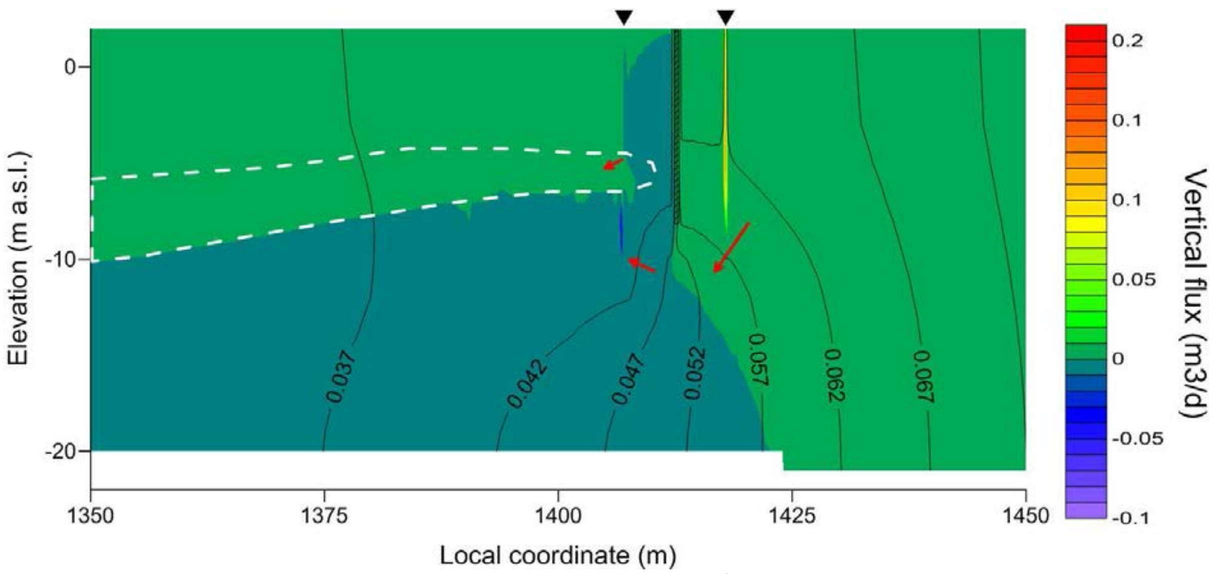

Fig. 1 – Model section perpendicular to the shore line with vertical fluxes contoured with rainbow colors (positive values represent down ward fluxes), piezometric heads contoured with black lines, the HFB is depicted with a forward slashes rectangle, piezometers location is highlighted by black triangles, the high k lenses is depicted by a white dashed polygon and the red arrows indicate the flow direction in the piezometers located up and down gradient to the HFB.

DATA-DRIVEN MODELLING APPLIED TO MULTIPLE GROUNDWATER SCENARIOS

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Key-words: Data-driven; EPR-MOGA; groundwater; porous; karst.

1. Introduction

Data-driven techniques today are among the most powerful approaches to model environmental phenomena. Their popularity has been improved nowadays by the large availability of monitoring/measurement information.

These kind of approaches provide a reliable mathematical description of the relationship between the physical variables of the systems. Evolutionary modeling constitutes and interesting approach able to combine the regressive feature of data driven modeling with the power of evolutionary optimization. This returns results which consists in optimized models, which achieve both a good fitness to data and a good structural parsimony. Multi-Objective Evolutionary Polynomial Regression, EPR-MOGA (Giustolisi and Savic, 2009) proved particularly effective at modeling the dynamics of groundwater, in terms of response to rainfall and can give an important contribution in groundwater management.

It is an hot topic in regions deprived of shallow water resources, like for southern Italy, where groundwater is the main water resource. It is characterized by a general poor availability of shallow water as well as by a typical semi-arid Mediterranean climate. These imply high-complexity and uncertainty in water management. Therefore, the investigation of groundwater dynamics should not be dominated by the unquestioned application of general rules based on indirect data but, rather, sound management ought to be based on a combination of rainfall analysis and monitoring, aquifer characterization and, in general, system modeling. Here EPR-MOGA is used in order to model scenarios of karst and porous aquifers. In both the cases, EPR-MOGA identified models which are consistent with past studies and with the hydrogeological characters of the studied sites, allowing for explicating the main rainfall components influencing the water table and the lag between rainfall and water table oscillations.

Specifically, EPR-MOGA was applied to three aquifers located in southern Italy: the deep karst aquifer of Lecce, the shallow porous aquifer of Brindisi and the shallow porous aquifer of Metaponto plateau. Brindisi and Lecce are located in Salento Peninsula, south of Apulia region, extreme southeast of Italy. The investigated aquifer of Metaponto is located on the south coast of Basilicata, south Italy, between the rivers Basento and Cavone (Doglioni et al., 2011).

2. Material and Methods

EPR-MOGA is a multiobjective evolutionary modeling technique (Giustolisi and Savic, 2009), successfully applied to multiple problems related to environmental engineering (Doglioni et al., 2010; Giustolisi et al. 2008). In particular, it proved quite effective at modeling the dynamic relationship between groundwater levels and rainfall heights for a specific case study related to a porous aquifer (Doglioni et al., 2010; Giustolisi et al. 2008, Mancarella and Simeone, 2008). Here EPR-MOGA deals with three particular case studies, each one characterized by a singular behavior of the response of water table to rainfall. In particular, the modeled dataset encompassed the period 1953-2002 for the shallow porous aquifers of Brindisi and the deep karst aquifer of Lecce, while the period 1951-1975 was studied for Metaponto aquifer. EPR-MOGA models monthly data: total monthly rainfall heights and average monthly water table levels were used. The use of EPR-MOGA returned for each of these aquifers a set of equations, among which one for each case was selected.

3. Results

EPR-MOGA returned a set of equations for each of the modeled aquifers. In particular, the models return the prediction of groundwater level at the time *t*, H_t, where the input data are monthly rainfall heights up to n months before (P_t, P_{t-1}, P_{t-2}, … P_{t-n}) and past measured groundwater levels, up to two months before (H_{t-1}; H_{t-2}). The best models identified in the order for Brindisi porous aquifer, Lecce karst aquifer and Metaponto porous aquifer follows.

$$H_t = 10.1\cdot\sqrt{H_{t-1}} + 5.94\cdot 10^{-6}\cdot p_{t-2}\cdot\left(H_{t-2}\right)^2\cdot \sqrt{H_{t-1}\cdot p_{t-3}\cdot p_{t-4}} - 25.3 \quad (1)$$

$$H_t = 0.0080995\cdot P_t^{0.5} + 0.9819\cdot H_{t-1} \quad (2)$$

$$H_t = 0.0021289\cdot P_{t-1} + 0.096254\cdot H_{t-1}^2 + 2.4205 \quad (3)$$

In particular, the relationship between rainfall and water levels for Brindisi aquifer is complex, equation (1), as it is reasonable for a porous aquifer where infiltration processes, percolation and groundwater flow is quite slow. It is interesting to observe that the precipitation since the last three-four months before the predicted water level gives a reasonable contribute, and that the contribution of the rainfall of different months is non-linear. Indeed, water table levels do not respond to impulsive rainfall events, while they are mainly conditioned by relatively long precipitations or dry periods. This implies relatively low and slow oscillations of the water table. The model returned by EPR-MOGA for Lecce karst aquifer, equation (2), is simple and water levels are solely related to the persistence term and to the rainfall of the same month for which the groundwater level is sought. This implies water table level quickly responds to rainfall, consistently to measured data, since Lecce shows relatively quick and broad oscillations of the water table levels. This is also consistent with the structure of the aquifer, which is karst and then characterized by preferential flow paths for the infiltration. For Metaponto aquifer, EPR-MOGA returned a quite simple equation, equation (3), whereas the only significant selected input are the total monthly rainfall of the month before the predicted water level and the water level preceding the forecasted one. This emphasizes that the aquifer is responsive to precipitations with one-month lag, while an important role is also related to the persistence of the phenomenon. However, this variable is raised to power 2, implying that the effect of the persistence is somehow amplified. This behavior is far from being similar to that of Brindisi, where the best equation is more complex, and the persistence term is raised to power 1. Here, the power 2 of the persistence term is related to a high memory effect. This pertains to occurrence of high piezometric levels, which force groundwater to flow in a confined condition. In this condition, piezometric levels become sensitive to aquifer recharge.

4. Conclusions

The introduced case studies showed the potentialities and the effectiveness of a data-driven approach aimed at modeling the dynamics of groundwater levels. In particular, evolutionary modeling can successfully provide models hydrogeologically different aquifers. These models proved consistent with the hydrogeological features of the investigated scenarios, and then useful both for predictive purposes and for scientific knowledge discovery.
These models were identified just on measured data and making some very broad assumptions on model structures, e.g. polynomial structure, candidate exponents. However, this somehow constitutes a limitation, since if poor datasets were available, it would prevent the approach from returning results. On the other hand, an important advantage of this approach is that no calibration of specific parameters is needed, as well as no pre-assumed equations have to be used. Finally, EPR-MOGA also proved to be effective, when the boundary conditions change, i.e. for Metaponto aquifer. However, in this case, even if an equation able to reproduce the average response of water levels to rainfall is returned, it sometimes can fail to predict groundwater fluctuations. In fact, the change of boundary conditions affect the behaviors of the water levels, but these episodes are quite rare and time confined, and then poorly described by data. This emphasizes that data-driven approaches and in particular EPR-MOGA do not necessary return results, in particular when a phenomenon s not completely described by data. Nevertheless, for the cases of Brindisi and Lecce, the available timeseries well describe the fluctuations of water tables, and at the same time no parasite phenomena yield. Therefore, EPR-MOGA models show a very good performance.

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A 3D HYDROSTRATIGRAPHIC MODELING TO AQUIFER FEATURES ASSESSMENT IN AN URBAN ENVIRONMENT

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Key-words: 3D model; groundwater levels; urban sprawl; Naples.

1. Introduction

The study deals with the rise of the piezometric levels in the eastern part of the town of Naples (Italy), which intercept the foundations of many building and underground infrastructures (garages, subway tracks, etc.).

The process started fifteen years ago. It was caused by changes in the hydrogeological cycle that resulted from the reduction in the exploitation of some hundreds of litres per second for industrial use and, especially, the drastic reduction in the exploitation for drinking water (Corniello & Ducci, 2002; Corniello *et alii*, 2003). The supply public wells are located at the north of the study area (Fig. 1), but in the same groundwater body (the eastern Plain of Naples - Piana ad Oriente di Napoli, NAP). In this area the withdrawal is decreased from up to 3 m^3/s in 1990 to almost 0 in the year 1998.

In order to deal with this problems, the local council of Naples is carrying out a series of projects to avoid the problem, or rather to take advantage of this amount of groundwater.

So far, these projects are drawn up not on the basis of deep and comprehensive stratigraphic and hydrogeological schemes. Therefore it's helpful a 3D model reconstruction as support for application of balance or groundwater flow models (Ducci *et alii*, 2012 in print) in order to assess aquifer features and groundwater quantitative status.

2. Material and Methods

In the eastern part of the town of Naples, the 207 available boreholes are scattered in an area of approximately 39 km^2 and attest to a depth variable between 12 and 230 m below the ground level (60% between 20-60 m). The boreholes localization is suitable to modeling because of their homogeneous distribution and the density of the available boreholes (more than 5 per km^2).

The reconstruction of the stratigraphy was carried out by the stratigraphic data organized in a geographic database provided by the available boreholes, collected during the last years by one of the authors and integrated by about ten new data (National Archive of boreholes due Law 464/84). Stratigraphic successions, obtained by analysing the boreholes, are very articulated and miscellaneous. Therefore a critical reinterpretation of the stratigraphic succession has been necessary. The area of interest is a flat zone located in the eastern part of the town of Naples belonging to the wider Volla Plain, named "Fosso Volla", oriented SW-NE, from the Lufrano village toward the sea, and delimited along the south-eastern side from the Vesuvius Volcano and along the north-western side from the hilly part of the town. The depression is filled by alluvial deposits, with insert of pyroclastics derived from the Vesuvius and the Phlegrean Fields activities. During the last 40.000 years, the pyroclastic and lavic deposits impeded the flow of surficial waters toward the sea and caused the creation of a marsh testified by the presence of levels of peat.

Fig. 1 – Study area (in red) and boreholes location; the red line bounds the groundwater body of the eastern Plain of Naples.

Boreholes' stratigraphy identifies 6 different units, divided into 13 levels:
- The main aquifer: alluvial and pyroclastic deposits of medium or fine grain size (sediments formed in an environment and subsequently reworked in another environment);
- Aquitards or minor aquifers: 1 level of Vesuvian tuffs; 1 level of Neapolitan Yellow Tuff ("Tufo giallo napoletano" or TGN; 15 kyr BP); 1 level of Vesuvian lavas; 1 level Somma lavas;
- Impervious: 2 levels of peat (lacustrine-palustrine deposits) above the top of TGN and 1 level below the bottom of TGN (Bellucci, 1994).

The boreholes have been managed in order to make a reconstruction of lithostratigraphic 3D model with detailed geostatistics analysis (Gallerini & De Donatis, 2009), using interpolating algorithms (D'Agnese *et alii*, 1997). The Neapolitan Yellow Tuff has been considered as guide level to correlate the stratigraphic units (Bellucci, 1994) The real topographical surface was represented in the 3D model by 5 m resolution DTM. The piezometric level and his modifications have also been taken into account.

3. Results

The 3D lithostratigraphic model reconstructs accurately the subsoil of the study area. Layers of Vesuvian and Yellow tuff and lenses of peat are faithfully reconstructed (Fig. 2). The model allows to identify with accuracy the location and extension of each stratigraphic unit.

4. Conclusions

The precision of the stratigraphic unit information, combined with a careful study of the hydrodynamic characteristics, has led to a precise definition of the aquifer.

The hydrostratigraphical model is a good platform on which to base the hydrogeological balance and the groundwater flow model. Moreover, it is crucial coupled to the evaluation of human factors affecting the hydrological cycle. This evaluation will be very difficult due to the widespread urbanisation (urban sprawl) and hence to the land use changes in the area, managed by different Subjects and Institutions

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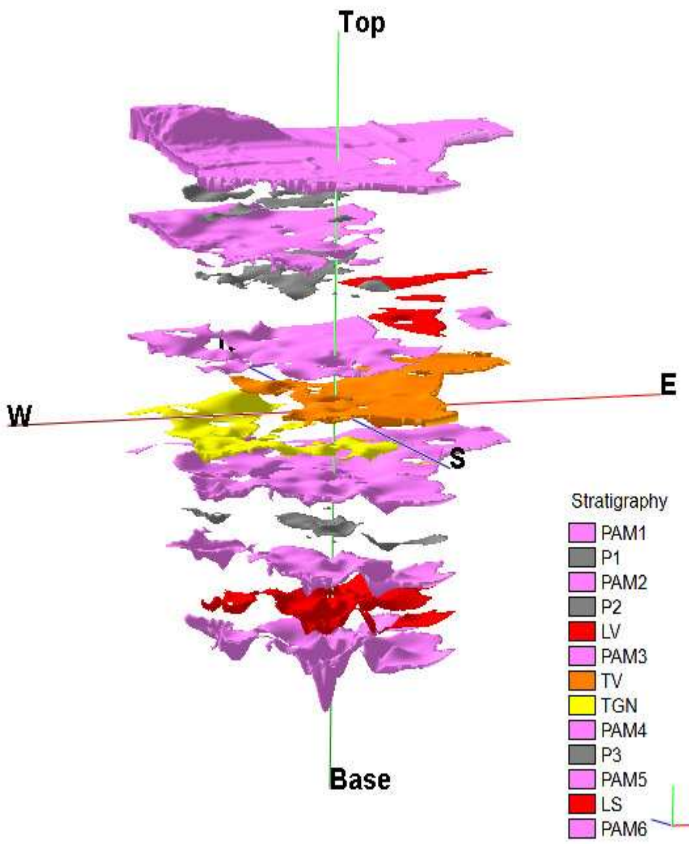

Fig. 2 - 3D representation of the stratigraphic model: PAM=pyroclastic, alluvial and marine deposits; P= peat; LV=Vesuvian lavas; TGN=Neapolitan Yellow Tuff ("Tufo giallo napoletano"); TV=Vesuvian tuffs; LS= Somma lavas.

TRIAD APPROACH IN ITALY

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Key-words: Triad, Systematic project planning, Dynamic Work Strategies, Real-time Measurement Technologies

1. Introduction

The objective of the Triad approach is to manage decision uncertainty, increasing confidence that project decisions (about contaminant presence, location, fate, exposure, and risk reduction choices and design) are made suitably and cost-effectively. Triad gets sufficiently accurate conceptual site model that is the basis for site-related decisions by proactively identifying and managing data and decision uncertainties.

2. Material and Methods

The word Triad is intended to convey that there are three elements:

- Systematic Project Planning that begins by clearly defining desired project outcomes, exploring and managing the uncertainties in a way of obtaining data and decision of a known quality.
- Dynamic Work Strategies is the element that allows projects to be completed “faster” and “cheaper” than ever possible under traditional, static work strategies. Work planning documents written in a dynamic or flexible mode, guide the course of the project to adapt in real-time as new information becomes available.
- Real-time Measurement Technologies that gather data fast enough to support real-time decisions.

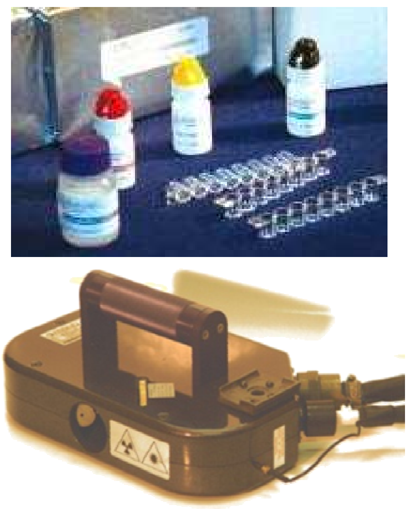

Fig. 1 – Colorimetric Test Kit and Portable XRF.

Fig. 2 –VOC sensor and Membrane interface Probe.

The range of technologies supporting real-time measurements includes field analytical instrumentation (Fig.1-2), in situ sensing systems, geophysics, rapid turn-around from traditional laboratories, and computer systems that assist project planning, and store, display, map, manipulate, and share data.

3. Results

The first-generation data quality model, still in use, considers data quality only in terms of analytical method performance and considering those as definitive data, ignores sampling uncertainties and the impacts of matrix heterogeneity. The Triad Approach reveals the recognition, based on 30 years of experience, of the need for a second generation model for sampling and analysis to tackle those uncertainties (Tab. 1) reducing the financial and liability risks created when non-representative data lead to erroneous decisions.

Uncertainty Sources	Symbol	Analytical Sample
Intrinsic Measurement Effects	IME	Instrument Calibration Standard
Spike Preparation Effects	SPE	Initial Calibration Verification Standard
Preparation Method Effects	PME	Laboratory Control Sample
Matrix Interference Effects	MIE	Matrix Interference Sample Matrix Spike/ Duplicate Sample
Sample Collection Effects	SCE	Field Replicate Sample (Collected from same location and same time)
Sample Location Effects	SLE	Co-Located Sample (Collected 0,5 – 3 feet away from field sample)
Sampling Site Population Effects	SSE	Site field sample collected from the environmental site for the study

Tab.1 - Uncertainty Sources and QC Samples

The Triad approach is a scientific and technical initiative, not a regulatory approach, though it is hoped that regulatory bodies will take note of advancing scientific knowledge and technical capability and integrate them better into their regulatory frameworks.

4. Conclusions

In Italy, Annex 2 to the part IV of D.Lgsl. 152/06 establishes that field analysis, soil gas surveys, geophysical technologies can be exploited to obtain a better areal coverage of the information on the subsoil and multi-step characterization can be used subsequently to the approval of the control authorities. But despite the fact that there are no evident conflicts with the legislation in force, the stakeholders don’t leave easily their comfort zone and there are just few application of real time technologies used just for screening or monitoring.

Acknowledgements

We would like to thank the www.triadcentral.org, a website where the Triad community exchanges documents, successful and unsuccessful case studies.

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INTERPRETATION OF HYDROGEOCHEMICAL DATA OF THE WESTERN PO PLAIN (PIEDMONT) BASED ON THE THEORY OF METAMORPHIZATION OF CHEMICAL COMPOSITION OF WATER

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Key-words: groundwater classifications, metamorphization, nitrates

1. Introduction

In assessing the quality of drinking water and the developing of the forecast of its change with time, as it is known, hydrogeochemical researches play a major role on basis of which the processes of formation of water chemistry are deciphered. There is currently no universal method that satisfies the objectives of the eco-hydrogeochemical works. There are numerous classifications of natural waters, among which the classifications based on the predominant components and with elements of a genetic basis are marked out (Samarina, 1977).

2. Material and Methods

In this work, for the processing and interpretation of hydrogeochemical data, the technique based on the theory of metamorphism of the chemical composition of natural waters was used. The term "metamorphization" means the interaction of natural water with a substance of the environment and with a living substance, leading to difficultly reversible or irreversible changes in the composition of water (Valyashko, 1955). A chemical type of water, established in accordance with the Kurnakov–Valyashko natural waters genetic classification, based on the account of the main components of the chemical composition of water, gives an indication about the direction of metamorphization processes. According to this classification natural waters can be subdivided into four varieties: Cl-Ca water (mostly intrinsic to the deep parts of the earth's crust); Cl-Mg (typical for the ocean and seas); SO_4-Na and HCO_3-Na waters formed in conditions of the overhead parts of earth crust (water of lakes, rivers, shallow groundwater, atmospheric waters). For rating waters as one or another variety the corresponding coefficients are calculated (in meq/l):

$$\frac{Na-Cl}{SO_4}$$ > 1 – HCO_3-Na type
< 1 – SO_4 type (SO_4–Na subtype)

$$\frac{Cl-Na}{Mg}$$ > 1 – Cl-Ca type
< 1 – SO_4 type (Cl–Mg subtype)

By Valyashko (1955), Cl-Ca and HCO_3-Na waters belong respectively to the chloride and carbonate types, Cl-Mg and SO_4-Na waters classified as subtypes of sulfate type. The general scheme of metamorphization of composition of natural waters can be represented as follows:
HCO_3 type → SO_4 type → Cl type.

Metamorphization in either directions occurs with obligatory participation of all components of the rock – water – gas – living organisms system and leads to transformations of water composition – appearance in it some particular components, specific for one or another type or subtype of waters. Determination of the specific most soluble components, that are not necessarily dominant in the chemical composition of water, distinguishes the Kurnakov–Valyashko classification from others, according to which the type of water is determined by the dominant ions. For HCO_3-Na type as the specific components can be called carbonates and hydrocarbonates of sodium characteristic only for this type of water. The specific components of the sulfate type are magnesium (sodium) sulfate and magnesium chloride. For the Cl-Ca type the specific component is calcium chloride that present only in the waters of this type.
On the basis of the presented method there was executed systematization of data of the regional groundwater quality monitoring network of Piedmont for 2000-2006, including 4919 analysis of 607 wells of the unconfined aquifer and 2515 analysis of 244 wells of the confined aquifer of the Western Po alluvial plain. For processing there were used the analysis with error not more 5% by the difference in the amounts of anions and cations (in meq/l) on the basis of electroneutrality of solutions.

3. Results

The results of processing and systematization of the data are presented in table 1. For comparison, the calculations of types of waters according to the Kurnakov–Valyashko classification were performed for each of aquifers.

As it is evident from the table, all four varieties of waters are presented in the study region. Since the main pollutants of groundwater in the territory under research are nitrates, it is rational to compare their concentrations within of each of the water types in the considered classification.
The majority of water analyses of the unconfined aquifer (more than 50 %) with the average concentration of nitrates of 34,8 mg/l and about 15 % of analyses of the confined aquifer with the average concentration of nitrates 24,0 mg/l refer to Cl-Mg subtype. In this case it is possible to highlight an incomplete anthropogenic metamorphization (Samarina, Gayev et al., 1999) of groundwater, when waters change their composition within one – sulphatic type of classification (from SO4-Na subtype to Cl-Mg subtype). A part of the analyzes are referred to the Cl-Ca type with an average concentration of nitrates 57,4 mg/l (the unconfined aquifer) and 40,6 mg/l (the confined aquifer). It should be noted that within the Cl-Ca type there are marked out analysis with high concentrations of chlorides and low concentrations of nitrates, as well as with low concentrations of chlorides and high - of nitrates. This is confirmed by spread of values of standard deviation. The last case corresponds to the full anthropogenic metamorphization (sulfate type is changed to chloride type under influence of nitrates). HCO_3-Na type are characterized by minimal concentrations of nitrates and generally reflect their natural content.

4. Conclusions

The classification of Kurnakov–Valyashko allows to reflect the general eco-hydrogeochemical condition of the region under study for a certain period of time and can be applied to agricultural areas, where the main contaminants of groundwater are nitrates.

Acknowledgements
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Aquifer	Type according to the Kurnakov-Valyashko classification	N	Concentration of NO_3 (mg/l)				Predominant chemical composition
			Mean	Percentile 10	Percentile 90	Std. Dev.	
Unconfined aquifer	HCO_3-Na type	322	9.2	< 1	19.4	14.3	HCO_3-Ca-Mg; HCO_3-Ca-Mg-Na
	SO_4-Na subtype	2034	26.1	2.6	58.0	24.3	HCO_3-Ca-Mg; HCO_3-SO_4-Ca-Mg
	Cl-Mg subtype	2529	34.8	5.7	68.2	27.4	HCO_3-Ca-Mg; HCO_3-SO_4-Ca-Mg
	Cl-Ca type	34	57.4	1.8	105.0	37.1	HCO_3-Cl-Ca
	in total	**4919**	29.7	3.0	62.0	26.6	HCO_3-Ca-Mg
Confined aquifer	HCO_3-Na type	1055	3.0	< 1	7.5	3.9	HCO_3-Ca-Mg; HCO_3-Ca-Mg-Na
	SO_4-Na subtype	1064	10.9	< 1	22.7	9.3	HCO_3-Ca-Mg; HCO_3-Ca
	Cl-Mg subtype	384	24.0	9.9	39.8	13.8	HCO_3-Mg-Ca; HCO_3-Ca-Mg
	Cl-Ca type	12	40.6	23.3	44.6	21.2	HCO_3-Cl-Ca
	in total	**2515**	9.7	< 1	25.7	11.4	HCO_3-Ca-Mg

Table - Mean concentration of NO_3 (mg /l) in groundwater of the Western Po plain (Piedmont) according to the type of water in the Kurnakov–Valyashko classification

MODELLING THE CARBONATIC AQUIFER SYSTEM OF SALENTO (PUGLIA, SOUTHERN ITALY): A SENSITIVITY ANALYSIS

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Key-words: hydrostratigraphy, coastal aquifers, carbonatic aquifers, mathematical modeling, sensitivity analysis

1. Introduction

Management of groundwater resources requires tools which permit to analyze the water budget and the evolution of the physical system in response to anthropic (e.g., ground water withdrawal) and climatic forcing A first mathematical model of the carbonatic aquifer hosted in cretaceous rocks (Calcare di Altamura) which is the main water resource of the Salento peninsula (Southern Italy) has been developed by Giudici et al. (2012b). The conceptual model was obtained from a GIS-based reconstruction of the 3D geological and hydrostratigraphic model, which permitted to map the geometry of the fractured and karst aquifer and of the overlaying rocks, which are mainly characterized by low permeability rocks and at most local and relatively thin aquifers.

The mathematical model yields a water balance for the carbonatic aquifer at the regional scale; however some parameters are known with some uncertainty and therefore, in this presentation, a sensitivity analysis is conducted in order to quantify the uncertainty and therefore to provide a measure of the reliability of the model forecast.

2. Material and Methods

The mathematical flow model is based on a finite-differences conservative scheme and on the Ghyben-Herzberg's approximation to determine the depth of the salt/fresh water interface and therefore the thickness of the fresh water aquifer. The boundary conditions take into account the aquifer recharge by subsurface flow from North through the border with the Murgia hills, as well as the relationships with sea along the coast, taking into account in different ways the areas where the aquifer is phreatic, i.e. the cretaceous rocks outcrop along the coastal line, or confined, i.e. the sea/aquifer contact occurs off-shore. Pseudo-steady conditions are considered, which simulate the average situation during a typical hydrological year. Groundwater abstraction is taken from published data, whereas aquifer recharge is estimated on the basis of the interpolation of rainfall data and of the hydrostratigraphic architecture, which is used to compute an effective infiltration coefficient, which is similar to the Aquifer Vulnerability Index (AVI) proposed by Van Stempvoort et al. (1993).

The model is based on several parameters, some of which are known with rather large uncertainty and therefore a sensitivity analysis (Hill & Tiedeman, 2008; Saltelli et al 2010) is necessary to quantify the uncertainty on model predictions.

3. Results

The model has been calibrated with respect to hydraulic conductivity by application of an automatic inverse procedure (the comparison model method; see Vassena et al. 2012 for a recent description of the method together with the application to a model of groundwater flow at the scale of an hydrogeological basin), which permits to reproduce the reference piezometric head of the aquifer system at the regional scale within a maximum absolute error of 3 m. Thus a reference set of parameters is available for which local, one-at-a-time sensitivity with respect to different parameters can be easily obtained. However, first-order sensitivity indices, which take into account the non-linear dependence of the model outcome on the model parameters, are computed with a simplified procedure, which was already successfully applied on highly non linear models (Baratelli et al., 2011; Giudici et al. 2012a).

The parameters that are considered for the sensitivity analysis are: the salt water density used in the Ghyben-Herzberg's approximation, the coefficients used to estimate the aquifer recharge, the prescribed water heads assigned as boundary conditions, the conductance used to model fresh water discharge toward the sea along the coastal areas where the aquifer is in phreatic conditions.

4. Conclusions

This presentation shows the application of a sensitivity analysis to quantify the uncertainty of the forecast of a regional groundwater flow model for the cretaceous fractured aquifer of the Salento peninsula. This area is an interesting example of Mediterranean basin, where, on one hand, urbanization, industrial and touristic activities progressively increase the request of fresh water, and, on the other hand, limited precipitation, high evapotranspiration rates and poor surface water bodies make the area prone to the risk of desertification.

Acknowledgements

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HYDROGEOLOGICAL CARACHTERIZATION OF VOLCANIC AREAS: THE SABATINI VOLCANIC COMPLEX

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Key-words: hydrogeological conceptual model; hydrogeological survey; groundwater resource management.

1. Introduction

Hydrogeological studies in volcanic areas are influenced by several factors, as the different grain size of the deposits, way of emplacement, deposits thickness according to paleomorphology (Custodio, 2004; Izquerido *et alii*, 2011; Capelli *et alii*, 2005). The target of this study was a detailed regional reconstruction of the Sabatini Volcanic Complex (SVC), and the application of numerical models in two small subsets, to understand some uncertain hydrogeological aspects. The hydrogeological data have been collected using conventional techniques during a survey carried out in 2009. The simulation code used was MODFLOW-2005 (Harbaugh, 2005).

2. Geological and hydrogeological setting

SVC started his activity about 600 Ky ago (De Rita et alii, 1993). During his evolution many eruptive centers have developed, with different emission styles. The volcanic products are composed of lava flows, pyroclastic flows and pyroclastic falls. These products overlay two kind of pre-volcanic sedimentary basements. The first one is represented by allochthonous flyschoid *nappe* units (Civitelli & Corda, 1993). The second is about neoautochthonous Plio-Pleistocene clayey successions (Carboni et alii, 1993). These pre-volcanic units represent the aquiclude of the regional volcanic aquifer. The morphology of this sedimentary basement is strongly affected by tectonics which has created an *horst* and *graben* setting. This structure affects directly the groundwater flows determining areas with an higher hydraulic head due to a shallow aquiclude. In the central part of SVC the aquiclude goes down due to a volcano-tectonics collapse. This collapse corresponds to the Bracciano Caldera, which hosts the Bracciano Lake. The lake level is strictly related to the regional water table (Capelli et alii, 2005). Regional groundwater flowpaths converge into the lake coming from N, W and E, while in the south side, flowpaths are directed southward because of an existing structural depression of the aquiclude. In this area there is the only natural emissary of the lake, the Arrone River.

3. Material and Methods

The dataset obtained during the studies is about:

- 236 piezometric levels in wells, using a phreatimeter;
- 24 spring discharge measures, using the volumetric method;
- 72 river flows, using a current meter.

All measurements were associated to a chemical-physical parameterization using a pH-meter and an electro-conductivity-meter.

The dataset was improved through stratigraphic data coming from different databases:

- LINQ (Numerical and Quantitative Hydrogeological Laboratory, Roma Tre University);
- ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale)
- municipal service bureau data;
- geological reports data by freelance geologists.

The dataset was introduced in a Microsoft Access database and managed in a GIS system. Piezometric map (Fig. 1) was realized using the triangulation method and hydrogeological sections were realized to understand the relationships between volcanic units and piezometric pattern. The hydrogeological complexes of this area defined by Capelli *et alii*, (2005), were used to distinguish low permeability units during the realization of the piezometric map. Six geological sections were realized in order to identify the hydrogeological units and to synthesize a conceptual groundwater flow model.

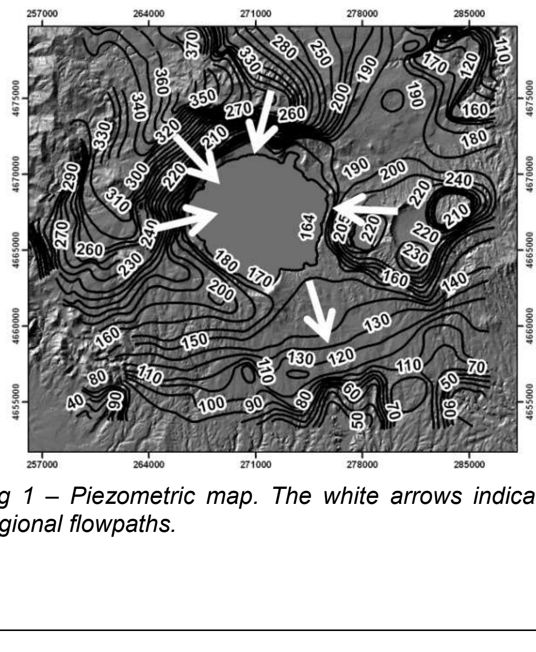

Fig 1 – Piezometric map. The white arrows indicate regional flowpaths.

Numerical models were applied to two small areas, to analyze the hydrogeological settings in detail. MODELMUSE, a freeware graphic user interface developed by USGS (Wiston,2009), was used. The first model was applied in the area of Bracciano City, to understand the relationship between the piezometry and a buried lava body, previously defined with the geological dataset. The second model, in the upper Arrone Valley, was developed to identify the relationship between the groundwater and the Arrone River.

4. Results

The piezometric pattern shown in the map is similar to previous works (Camponeschi & Lombardi, 1968; Lombardi & Giannotti, 1969; Boni *et alii*, 1986; Capelli *et alii*, 2005). There are no evidences of critical reduction of piezometric levels. The water output volume from the volcanic units was quantified about 1200 l/s through discharge measures along the rivers.

The underground knowledge was improved through the realization of detailed geological sections. They show the relationship between the pre-volcanic basement and the piezometry. They also provide information about the potential of units composing the regional aquifer.

In the model areas the survey detail was higher due to the different scale of study. In the Bracciano area has been possible to characterize the geometry of the buried lava body in detail. During several simulations has been possible to evaluate different piezometric scenario. The most similar scenario to the experimental data, has been obtained after calibration of the hydraulic conductivity of the lava body, starting from a literature value (Spits & Moreno, 1996). The second model was implemented using an hydraulic conductivity value deduced by an available pumping test in that area. After calibration the difference between observed and simulated data was satisfactory, in particular the piezometric pattern and the Arrone River discharge.

5. Conclusions

Regional hydrogeological analysis is important despite of the increased urbanization of the studied area during last decades. It doesn't seem to exist critical conditions for groundwater resources. Detailed geologic analysis can provide an excellent instrument to evaluate groundwater resource availability.

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HYDROLOGICAL CHANGES DUE TO THE IRPINIA EARTHQUAKE, CERVIALTO M. AQUIFER NUMERICAL MODEL, PRELIMINARY RESULTS

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Key-words: baseflow recession analysis, near-field, numerical model calibration.

1. Introduction

The aim of this work is to study the hydrological variations observed at the Sanità di Caposele Spring (Campania Region, Italy) in consequence of the 23th November 1980 Irpinia earthquake (Mw 6.9). The Caposele Spring is located about 5 km away from the earthquake epicenter (near-field), and represents the only important spring of the Cervialto M. carbonate aquifer (about 120 km^2), the seismogenic fault had a normal displacement.

As Celico (1981) observed, it is confirmed that just after the occurrence of the earthquake, the Spring discharge fastly increased rising value never observed before (since 1920) and anticipating the annual discharge peak of 5/6 months. It is widely accepted that the discharge increase is caused by the earthquake and not by the rainfall, because the 1980 wasn't a particular rainy year (Fig. 1).

2. Material and Methods

The data series analyzed for this case study includes the Caposele Spring discharge from 1920 to 1963 twice data a month and daily data from 1964 to 1999. On the daily data the recession curves has been analyzed to estimate the α value variation in the years. The recession analysis has been performed with the Maillet (1905) equation, approximating the discharge curve decreasing part as an exponential low:

$$Q_t=Q_0e^{(-\alpha t)}$$

The α value is related to the aquifer hydraulic properties. Manga (2001) analyzed the hydrographs of stream near the epicenter of the 1989 Loma Prieta earthquake, before and after the earthquake to investigate the possible change in aquifer permeability. In this case, even though discharge increased by an order of magnitude after the earthquake, no significant change in baseflow recession was found before and after the earthquake.

In the Cervialto aquifer there are no experimental data about the hydraulic properties of the aquifer. So there are no data to compare with the α analysis results. For this reason has been settled a numerical model with MODFLOW 2000 (Harbaugh et al., 2000), interface Visual Modflow Pro to simulate the aquifer in pre- and post-seismic conditions and deeply understand the hydraulic parameters variation with the earthquake occurrence. The model is settled in steady state. The hydraulic parameters (hydraulic conductivity, K in three dimensions) of the model are results of calibration. The calibration is settled using the Caposele spring discharge data series.

3. Results

The α analysis results shows that the α value decrease after the earthquake occurrence, it pass from a mean value of 1.2 $*10^{-3}$ before the quake to $7.9*10^{-4}$ days^{-1} after the earthquake. It should means that the aquifer permeability should have been decreased after the earthquake. This hypothesis is supported by the King and Muir Wood (1994) theory by which the behaviors of the hydrological changes with the earthquakes are critically dependent on the fault displacement style. The seismogenic faults moved with a normal style, so the hypothesis of a general permeability decrease is possible.

The pre-seismic model calibration first results allow us to consider the K value in x, y and z direction of about $1*10^{-4}$ m/s. The aquifer piezometric level seems to be of about 550 m a.s.l., this is in agreement with the usual hydraulic head low gradients in carbonate aquifer.

4. Conclusions

Even though the results are in progress, the importance of this work is the new approach to the "earthquake and water" topic.

Worldwide there are many cases of hydrological changes related to earthquakes and there are many theories about these phenomena, but nobody used the MODFLOW code to simulate the hydrological changes to seismic events.

The next step will be to calibrate the numerical model on the post-seismic period to confirm (or not) the α results, that is the aquifer permeability decrease.

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Figure

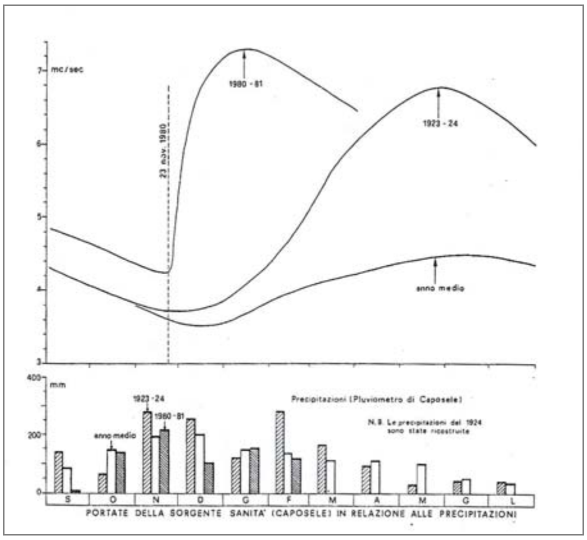

Fig. 1 – The graph above represent the hydrograph of the Sanità di Caposele spring showing three hydrological years: the 1980-81 is year of the Irpinia earthquake occurrence, the 1923-24 is the year of the maximal discharge, and mean year. The dashed vertical line represent the moment of the earthquake occurrence.
The graph below represent the rainfall corresponding to the discharge represented above. From Celico (1981).

TEMPORAL EVOLUTION OF THE VOLUMETRIC WATER CONTENT PROFILE IN A HOMOGENEOUS SOIL LAYER FROM ANALYTICAL SOLUTIONS

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Key-words: soil moisture, linearized Richards equation, finite-thickness domain, surficial aquifers, unsaturated zone

1. Introduction

The water content of the soil surface zone plays a fundamental role in the hydrologic cycle and it is crucial in determining the partition of precipitation into infiltration, surface runoff and drainage to groundwater.

The governing unsaturated flow equation, derived by Richards (1931), is highly non linear and, consequently, difficult to solve exactly in closed form. However, exact solutions may be used as realistic checks of numerical schemes. Linear approximation is usually needed to facilitate analytical solution of the equation (see for example Warrick (1975), Basha (1999), Chen et al. (2001), Chen et al. (2003)). Menziani et al. (2007) obtained solutions of the linearized one-dimensional Richards equation, in a semi-infinite unsaturated porous medium domain, for any discrete surface flux boundary condition and soil water content initial condition.

The solution of the linearized Richards equation in a limited homogeneous soil layer domain for any initial condition of the volumetric water content profile and any top and bottom boundary conditions is computed approximating the supplementary conditions with step functions.

2. Theory

In some cases, the vertical transport of water in the unsaturated soil can be modelled considering a horizontal layer of finite thickness H. The space and time evolution of the soil volumetric water content ϑ is described by the one-dimensional Richards equation. The linearization of this highly non linear equation has been obtained assuming a constant hydraulic diffusivity (D) and the hydraulic conductivity ($k(\vartheta)$) linearly dependent upon ϑ.

$$\frac{\partial \vartheta}{\partial t} = D \cdot \frac{\partial^2 \vartheta}{\partial z^2} - V \cdot \frac{\partial \vartheta}{\partial z} \qquad (1)$$

In the equation t is the time, z is the soil depth, positive downward, $V = \partial k / \partial \vartheta$ is a constant. The temporal evolution of the volumetric water content $\vartheta(z,t)$ is computed assigning the initial condition (IC), $\vartheta_i(z)$, and the temporal behaviour of ϑ at the two boundaries (z=0; z=H) (BCs). Alternatively the BCs can be assigned to the flux

$$\Phi(z,t) = V \cdot \vartheta - D \cdot \frac{\partial \vartheta}{\partial z} \qquad (2)$$

Therefore, $\vartheta_0(t)$ and $\vartheta_H(t)$ or $\Phi_0(t)$ and $\Phi_H(t)$ are given; mixed conditions are not considered.

3. Results

Making use of the variables separation method and of the superposition principle, due to the linearity of the equation, the general solution of equation (1) is obtained as the sum of two solutions: $\vartheta(z,t) = \vartheta_1(z,t) + \vartheta_2(z,t)$. The solution $\vartheta_1(z,t)$ is derived for null boundary conditions and an arbitrary initial condition; $\vartheta_2(z,t)$ is derived for a null initial condition and two arbitrary boundary conditions. Two cases are considered: (a) boundary conditions on ϑ; (b) boundary conditions on Φ.

Case (a). The solution $\vartheta_1(z,t)$ is, at first, derived for a constant IC; consequently, for any IC approximated by a step function, $\vartheta_1(z,t)$ is a sum of as many solutions as the steps of the IC are; similarly, the solution $\vartheta_2(z,t)$ is the sum of as many terms as the steps functions approximating the BCs are. If, in general, the two boundary conditions are given by continuous time functions, the solution ϑ_2 is obtained applying and extending the Duhamel theorem (Carslaw and Jaeger, 1986), (Menziani et al., 2007, Vincenzi et al., 2010).

Case (b). The flux Φ satisfies the same linearized Richards equation (1) written for ϑ. Therefore, given the IC for ϑ, and so for Φ (eq. 2), and the BCs for the flux, the spatial and temporal evolution of the flux is obtained, with a procedure similar to the previous case (a).

Finally, equation (2) allows obtaining the soil water content behaviour.

In fig. 1 a simple example of the case (b) is presented. The IC is $\vartheta_i(z) = 0$ and the BCs are $\Phi_0(t) = 5$ and $\Phi_H(t) = 0$ mm h^{-1} with the following values of the soil parameters: $D = 1 \cdot 10^{-6}\, m^2 \cdot s^{-1}$; $V = 7 \cdot 10^{-6}\, m \cdot s^{-1}$. The soil volumetric water content increases, at first, more at the top boundary than at the bottom one. The profile presents a minimum value of ϑ which moves towards the top of the layer as the time increases. At a time t*, $\theta_0(t^*) = \theta_H(t^*)$, thereafter $\theta_0(t) \langle \theta_H(t)$. It must be stressed that ϑ cannot exceed the saturation value, which will be reached at one of the two boundaries before the other, depending on the values of the soil parameters and of the applied flux. After saturation a different formalism has to be adopted to solve the problem.

4. Conclusions

This simple model gives $\vartheta(z,t)$ for a surface limited layer, having any initial soil volumetric water content profile (IC) and any measured entering flux at the top of the layer (BC). The flux at the surface can be extimated by standard meteorological measurements.

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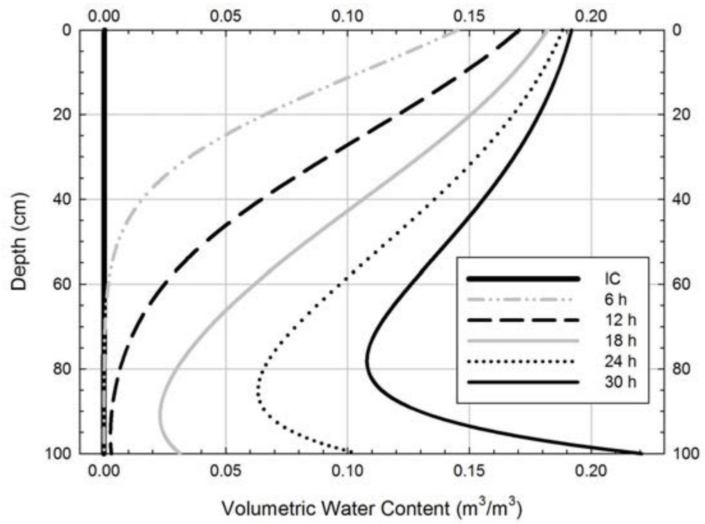

Fig. 1 – Temporal evolution of the volumetric water content profile in a homogeneous soil layer. The IC is $\vartheta_i(z) = 0$ *and the BCs are* $\Phi_0(t) = 5$ *,* $\Phi_H(t) = 0$ *mm h*$^{-1}$*. Initially, the soil volumetric water content increases more at the top boundary than at the bottom one. The profile has a* ϑ *minimum moving upwards as the time increases.*

LARGE SCALE 3D GROUNDWATER FLOW MODELING IN FRACTURED ROCKS: THE CASE OF MT. AMIATA VOLCANIC AQUIFER (SOUTHERN TUSCANY, ITALY)

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Key-words: *Volcanic aquifer, anisotropic media, hydraulic conductivity tensor, numerical modeling.*

1. Introduction

The hydrogeological study of the Mt. Amiata volcanic complex, one of the most important natural reservoirs of Tuscany (central Italy), (Barazzuoli *et alii*, 2004), aims to the modeling of fractured anisotropic aquifer media, focusing on the characterization of flows within fracture networks. The paper reports results based on finite element method based on a detailed definition of the state of fracturing.

2. Material and Methods

The approach adopted can be defined as “equivalent anisotropic porous media continuum”; the anisotropy generated by various fracturing systems was represented by means of a hydraulic conductivity tensor (Kiraly, 1969) calculated on the basis of a structural survey campaign intended to create a database of the main characteristics of discontinuity present in the volcanic complex, as well as to identify the families of fractures that govern water circulation (Louis, 1974). Data collection was carried out in the period of April-September 2008 and September-January 2010, for a total of 150 survey stations and approximately 2,200 measurements an area of about 80 km^2; a characteristic shared by the various families was sub-vertical inclination (immersions between 75° and 90°), while directions were more widely distributed, with a prevalence of the sector N20°-90°). Numeric flow modeling was performed using FEFLOW software (Diersch, 2006), operating in quasi steady-state conditions (long transient simulations). A strategy of increasing complexity was applied, beginning with the calculation of the tensor of conductibility for the entire domain (fig.1), and then moving on to tensors for zones with similar fracturing; the direction of maximum conductibility was almost always sub-vertical. Calibration of the numeric model was based on chronological series of spring flow measurements (average discharge of hydrogeological year 1987-2007) and only one piezometric data.

3. Results

Preliminary calibrations (equivalent isotropic porous media) produced unsatisfactory results, particularly with regard to the flows simulated, even though comparisons were made based on zones large enough to limit the effects of localized fracturing. Modeling with only one tensor of hydraulic conductivity revealed a significant NNE-SSW anisotropy in the aquifer media which coincides with the main areas of groundwater inflow; there is good congruity between measured and calculated flows. Division of the domain in 2 zones, along with the individuation of the main families of discontinuity and the definition of the ellipsoid of conductibility for each zone, allowed us to realistically define the hydraulic conductivity field and the reduced disparities between measured and calculated flows particularly with regard to the zone of S. Fiora, by far the most important in terms of water discharge.

4. Conclusions

In spite of simplifications and approximations required in the large scale modeling of fractured aquifers, the adoption of the continuous equivalent and anisotropic porous medium (hydraulic conductivity tensor), based on structural data collected directly in the field, can achieve a significant improvement in the modeling of flows and heads within the volcanic complex.

The research project aim is to carry out transitory simulations capable of reproducing the evolution of spring flows measured over significant periods of time - in practice, with reference only to the Ermicciolo Spring (from 1939 to the present) and the Galleria Nuova di S. Fiora (from 1990 to the present), which, however, together represent approximately 2/3 of the overall water discharge of the Amiata complex. Positive results will allow us to adequately reproduce the aquifer's hydrodynamic behavior, and thus to effectively propose new modes of management (well-spring techniques), simulate the effects of potential pollution and demarcate realistic wellhead protection areas.

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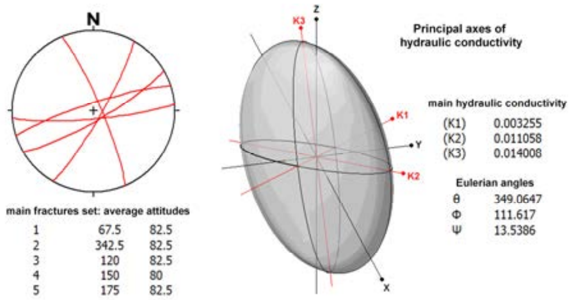

Fig. 1 – Main fracture sets and ellipsoid of hydraulic conductivity valid on the entire domain (the semi-axes of the ellipsoid correspond to the three main conductivity whose directions are defined by three Eulerian angles).

MAINTENANCE AND REHABILITATION OF AN INFILTRATION GALLERY FOR WATER SUPPLY BASED UPON HYDROGEOLOGICAL INVESTIGATION AND NUMERICAL MODEL

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Key-words: infiltration gallery, MODFLOW, riverbank filtration, clogging.

1. Introduction

IREN ACQUA GAS S.p.A. has built and has been managing, during the last fifteen years, the infiltration gallery of Cerezzola; it is placed, perpendicularly to the flow, in the permeable river bottom sediments of Enza river in the Commune of Canossa, Province of Reggio Emilia, Italy. Starting from summer 2007, a significant decrease of flow rate occurred; consequently hydrogeological investigations and studies were carried out in order to understand the factors impacting gallery performance.
Construction details (gallery length, depth, diameter) and operating data (water levels, pumping rate) were known.
The type of intake is referable to as an RBF (Riverbank Filtration) system, widely used and studied in a number of European and North American countries.

2. Material and Methods

The site characteristics have been investigated through a topographic survey, seismic refraction exploration, drilling and control of monitoring wells and pumping tests. In order to understand river vs. alluvial aquifer interactions and dynamic behaviour of the system as a whole, a three-dimensional finite-difference ground-water model MODFLOW (McDonald and Harbaugh, 1988) was developed.
Model domain, extended 0,4 Km^2 (500 m wide x 800 m long), was discretised with a grid of regular cells 5 x 5 m wide and with 3 layers (top layer 4 m thick, medium layer 3 m thick, bottom layer 3 m thick). Enza river and the infiltration gallery were simulated as a head-dependent boundary condition.

3. Results

Transferring field data into the grid and using model to gain insight into the controlling parameters in site-specific setting (Anderson, 1992), it has been possible to estimate hydraulic conductivity values of the ground-water system, with different zones and vertical anisotropy: K_{horiz}=2.5 – 5.0*10^{-3} m/s, K_{vert}=1/10 K_{horiz}. The streambed conductance (Mc Donald and Harbaugh, 1988) influences the flow through riverbed; water pumped from the gallery is a mixture of both groundwater originally present in the aquifer, and infiltrated surface water from the river. This groundwater extraction system is similar to riverbank filtration system (RBF), largely used for water supply purposes in Europe and the United States (Ray, 2003).
Based on the time series of monitoring wells and gallery water-levels, interpreted by model simulations, important clogging of interstitial space of riverbed was reckoned. Clogging (Hubbs, 2006) is caused by deposits of fine materials due to a decrease of river flow velocity and continuous infiltration of river water caused by extraction from the gallery. This process is also influenced by periodic floods and produces a significant reduction of riverbed hydraulic conductivity causing the progressive fall of water levels in the infiltration gallery and consequent fall of intake flow.
The simulations also permitted to characterise the stretch of river mostly contributing to feeding the infiltration gallery and, consequently, places where to intervene with riverbed cleaning by scrapping the fine deposits. This stretch is situated 150-200 m upstream the gallery.

4. Conclusions

The conspicuous loss of intake flow in the Cerezzola infiltration gallery is not due to the plugging of the screen and filter pack surrounding the gallery itself, but to the clogging of the riverbed with fine deposits carried by river flow. The removal of these deposits permitted to restore the initial intake flow rate.

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A SEMI-AUTHOMATIC METHOD IN GROUND WATER MODELLING CALIBRATION

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Key-words: groundwater, inverse problem, calibration, combinatorial analysis

1. Introduction

One of the essential characteristics of flow equations in groundwater is the difficulty to solve them *directly*, since their coefficients (i.e. permeability and storage in flow equations, dispersions in solute transport, compressibility in soil compaction) are not known a priori. For this reason, these systems are known as *ill-posed* problems.

In the common hydrogeological practice, the problem is addressed searching for an *inverse* solution, namely by means of a calibration phase, which in turn can be *direct* (e.g. permeability is defined as a new unknown to be solved with a known distribution of the hydraulic head), or with *trial & error* methods, i.e. by imposing presumable values to the *ill-posed* coefficients and evaluating the results against the hydraulic head (or concentration, or compaction) in the form of available observed values and their regionalizations. Normally, the calibration is stopped when the difference between the computed and the target hydraulic head is acceptable.

Calibration is supported by suitable software tools to make it as simple and fast as possible, but researchers have always been attracted by the chance of an *automatic* solution (*direct* or not) to the inverse problem; however, the many possibilities today available in literature have never been established in practice, due to several operating limits: the difficulty to ensure the physical correctness of solutions, the applicability in complex hydrogeological contexts, the very high consumption of computing time, the necessity of developing a specific set of new equations for each coefficient like k, S, dispersions etc.

This work is not a review of the solutions developed over time to the inverse problem; here it needs only recall that it can be approached in stochastic or regressive forms and the support of more or less complex combinatorial analysis (McLaughlin, 1996). Anyway, the most widespread is the *manual* trial & error method, which is itself limited by required computing time and operator's time.

The approach presented here lies in the area of trial & error calibration, but makes use of forms of combinatorial analysis associated with strategies that allow to limit in a very significant way the amount of combinations to be developed in order to minimize the weight of the computing time.

2. Development

The environment of these solutions is SutraWin, which is a GUI developed for Sutra3D of Voss & Provost (2010) and integrated with the GSLIB of Deutsch & Journel (1992) for what concerns the 3D regionalizations. These computer codes have been selected for several reasons, but the main one is that they are open sources, a basic characteristic to allow a so deep connection between the user and computing procedures.

This environment allows the user to perform all operations for the preliminary definition of the model (irregular mesh discretization, experimental data acquisition and analysis, discretization of litho-stratigraphic sections, boundary conditions set up etc.), and a traditional user interface for controlling the input/output data flow at any level.

The case studies here presented involve some calibration strategies which have been developed to extend the results of two 3D transient flow models to an equivalent set of 1D soil compaction equations to simulate land subsidence (Verruijt, 2004, 2005). The application was initially made to compute the land subsidence of the Reno alluvial fan, near Bologna in northern Italy (Chahoud et al., 2010), then in the whole longshore area of Emilia-Romagna, from the mouth of Po to Cattolica again in northern Italy (Chahoud et. al., 2012).

Each column *j* of the model (fig. 1) is described with a small number of lithological classes, for which the number *n* of combinations to be tested may be indicated by:

$$n_j = \{N_{class}\} \cdot \frac{m_{v\max} - m_{v\min}}{\Delta m_v}$$

where N_{class} is the number of lithological classes, m_{vmax} and m_{vmin} respectively the maximum and minimum compressibility coefficient of each class, and Δm_v the scan range of the class. In this way, two main objectives have been achieved:

1) the number of combinations to be evaluated is greatly reduced;
2) a good physical adherence is ensured, as each class is evaluated integrally

independently from its amount and occurrence in the column.

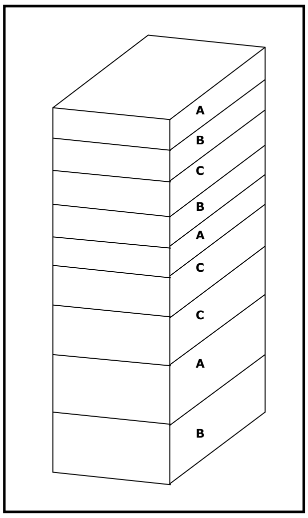

Fig. 1 – Litological sequence (schematic)

3. Results

The above mentioned tests have showed good characteristics of reliability, efficiency and efficacy.

The reliability has been evaluated as more than the 90 % of confidence compared to the available interferometric observations of land subsidence in the studied areas (Bonsignore, 2008), while the efficacy was verified by examining the results in the light of all the available knowledge concerning flows withdrawals (water and gas) in the areas of investigation (Chahoud et al., 2010, 2012).

As for efficiency, finally, the calibration process has needed less than 3 hours on a Pentium PC to run.

4. Conclusions

The experiences described here showed that the use of combinatorial techniques assisted by careful application of adequate strategies can provide results of good interest in very short time with a degree of reliability more than acceptable. While writing this note, similar activities are underway to extend the technique to 3D cases involving flow and transport calibration processes.

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To Gianmaria Zuppi

A NEW HYDROTHERMAL CONCEPTUAL AND NUMERICAL MODEL OF THE EUGANEAN GEOTHERMAL SYSTEM - NE ITALY

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Key-words: Euganean Geothermal System, strike-slip fault, fault damage zone, numerical modeling.

1. Introduction

The Euganean Geothermal Field (EGF) is the most important thermal field in the northern Italy. The EGF extends on a plain band of about 36 Km^2, east of the Euganei Hills and southwest of Padova (Veneto; Italy), and comprises the famous spa towns of Abano and Montegrotto Terme. At present about 250 wells are active and the total average flow rate of exploited thermal fluids is 17 Mm^3/year. The temperature of thermal waters ranges from 65°C to 86°C and their T.D.S. is 6 g/L (primary Cl^- and Na^+). ^3H and ^{14}C measurements suggest a residence time greater than 60 years, probably a few thousand years. Oxygen isotopes analyses show that the thermal waters are of meteoric origin and infiltrate in an area up to 1500 m a.s.l. . Recently, Zampieri et al. (2009) demonstrated that the previous conceptual model of the Euganean Geothermal System (EGS) (Piccoli et al., 1976) cannot work. The aim of this research is to renew the hydrothermal model of the EGS using the new knowledge developed in the last 30 years of study and during the research. The new conceptual model is constrained with a numerical simulation. This is the first numerical model developed for the EGS. A sensitivity analysis is performed, with the aim to evaluate how different parameters could affect the temperature and the flow in the subsurface of the EGF.

2. Material and Methods

All available data (published and not) of central Veneto is collected to renew the structural setting of studied area, with a main focus on the Schio–Vicenza fault. In fact, the EGF is located close to this 100 Km-long regional fault and, according to the present conceptual models (Faulkner et al., 2010), a structural control of the fault on the development of EGF is supposed. The data are also used to construct a standard cross-section of the EGS. Starting from the conceptual model, a numerical model of the EGS is performed using the software HYDROTHERM (Kipp et al., 2008), that simulates thermal energy transport in three-dimensional, two-phase, hydrothermal, ground-water flow systems.

3. EGS Conceptual Model

The collected data show a complex buried fault system (Schio-Vicenza fault system; SVFS) that extends northward from the Po delta to the Schio area. The faults (main faults: Schio-Vicenza fault; Travettore-Codevigo fault; Conselve-Pomposa fault) are mainly oriented NW-SE, dip towards NE at high-angle and at present are affected by a sinistral strike-slip kinematics. A close inspection of the SVFS shows a left stepover structure (*transtensional relay zone*) between two distinct fault segments, just in coincidence with the EGF. Given the sinistral strike-slip kinematics superimposed on the bounding faults, this structure accommodates along-strike local extension.

The new knowledge on the SVFS is used to propose a new conceptual model of EGS. The waters are of meteoric origin and infiltrate about 80 Km to the north of the EGF in the Sette Comuni-Tonezza plateau and the reliefs facing the area. The altitude (max altitude=2341 m a.s.l.; mean altitude=1317 m a.s.l.) is consistent with the oxygen-isotopic composition and the hydrological mass balance of the area (Aurighi et al., 2004) shows that 23% of the infiltrations (260 mm/y) is not balanced by the discharge of the springs located at the base of the relief. Therefore, the potential recharge of the EGS could be about 230 Mm^3/y, enough to feed the 17 Mm^3/y of thermal waters exploited in the EGF. The waters infiltrate thanks to the high secondary permeability of the outcropping rocks and flow to the south in a Mesozoic carbonate reservoir. The Schio-Vicenza fault acts as a conduit for the hot waters thanks to higher permeability of the damage zone of fault (Faulkner et al., 2010). A network of secondary fractures (similar to the mesh depicted thanks to a field structural work on the footwall of the Schio-Vicenza fault) could enhance the fluid flow. In the middle part of the EGS, the waters reach a depth of about 2000-3000 m and warm up by a normal geothermal gradient. Near the EGF area, the thermal fluids are intercepted by the transtensional relay zone linked to the SVFS. This structure increases the rock fracturing, permits the development of permeability and enhances the migration to the surface of the thermal waters. The structural study on the fractures of Montirone travertine Hill (Abano Terme) confirms the local extensional regime in the EGF and permits to reconstruct the fracture mesh developed in the subsurface. In particular, ESE-WNW tensional fractures permit the quick uprising of the thermal waters from the deeper part of the reservoir.

4. EGS Numerical Model

The conceptual model is used as starting point for the numerical simulation of the EGS. A 82-Km long and 6-Km deep cross section composed by 9 layers is performed. A collection of values of parameters (porosity, permeability, thermal conductivity, density) of the formations involved in the EGS is obtained by a literature research. The boundary conditions of the model are: a recharge/precipitation of 260 mm/y at the upper boundary in the recharge area; a seepage-face at the upper boundary in the EGF area that permits the outflow of groundwaters from the simulated region maintaining the enthalpy of thermal waters; a basal heat flux of 100 mW/m^2 at the lower boundary; a constant value of initial pressure/temperature at the upper, right and left boundary. The pumping wells are simulated using two point sources in the subsurface of EGF with a total outflow rate of 17 Mm^3/y. The simulations are divided in two simulation periods: a first period of variable time-length in which the water flux is affected only by the boundary condition; a second period of 100 years in which the water flux is affected also by the point sources.

A first explorative simulation is performed using the mean value of the parameters and an isotropic permeability that permits to have quick simulations (about 2900 time steps). The simulation time necessary to obtain the development of the stable conditions of fluid flow and temperature in the EGS is 5100 years (5000+100). The simulated temperature ranges from 47°C to 63°C in the main thermal aquifer of the EGF, not enough compared with the 70-80°C measured in the thermal wells. The simulation is affected by the development of convective cell that permits the uprising of isotherms in the EGF area and influence the water flux from the recharge area to the discharge one. Starting from this simulation, a sensitivity analysis (mainly on permeability and thermal conductivity of the rock units) is performed with the aim to obtain a configuration of parameters that permits the development of an higher temperature in the thermal aquifer of the EGF. The best values are: the mean value of the permeability for all the formations, low values of thermal conductivity for the formation of thermal aquifer, high values of thermal conductivity for the formation below the thermal aquifer. These values are tested in a new simulation. The temperature in the subsurface of the EGF ranges from 50°C to 60°C and a chaotic development of fluid flux affects the distribution of temperature. An anisotropic configuration of permeability is used with the aim to reduce the fluid flux and to permit a better development of temperature in the EGF. The best result is obtained using the previous configuration of thermal conductivity, a permeability of the thermal aquifer a little bit lower than the mean one and an anisotropic permeability Kz/Kx=0.2. The simulation period of this model is 55100 years (55000+100). This period confirms that the EGS has been active since 30 kY (minimum age of the travertine of Montirone Hill). This simulation shows an 60-70°C temperature-plume in the EGF area (temperature in the middle part of the plume of 72°C near the surface; t=55000y), according to the temperature of 70-80°C measured in the thermal wells of the EGF.

4. Conclusions

A new conceptual model of the EGS is proposed. It highlights the linkage between the thermal system and the active faults, as depicted in several geothermal field worldwide. The numerical model constrains the conceptual model thanks to the simulated temperature that approach the real one.

Acknowledgements

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NUMERICAL MODELLING TO SUPPORT THE MANAGEMENT OF COASTAL KARSTIC AQUIFER (SALENTO)

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Key-words: Seawater intrusion, groundwater modeling, groundwater management, coastal karstic aquifer

1. Introduction

The seawater intrusion phenomenon is a pervasive problem affecting coastal aquifer, where the concentration of population and the increasing water demand creates risks of overexploitation, especially in those areas where is the only resource of drinking and irrigation water. The whole effect could be a groundwater quality and quantity degradation. This is very often the case of coastal karst aquifers, as observed in many Mediterranean countries and in some Italian hydrogeological structures (Friuli, Sardinia, Sicily, and Apulia). This paper aims to describe the beginning of a Ph.D. activity finalised to define new management tools for groundwater resource of Salento (Apulia) and criteria to reduce the quantitative and qualitative degradation risks.

In Salento, the unique local water resources is due the karstic coastal aquifer, groundwater of which are largely utilised to satisfy the agricultural demand and drinking demand with huge effects in terms of reduced availability and increasing salinity (Polemio et al. 2009).

2. Description of the study area

Apulia can be divided into four main hydrogeological structures: Gargano, Tavoliere, Murgia and Salento. The karstic Murgia and Salento, made of Mesozoic rocks, form a lithological, geological and groundwater continuum (Cotecchia et al. 2005) but with a different degree of fracture, karstification, and different values of permeability and storage (Grassi 1983). Murgia groundwater feeds Salento hydrogeological structure due a favourable piezometric gradient. The border between Murgia and Salento in morphological and hydrogeological terms is due to a paleo-structure partially reactivated by the tectonic activity and today buried by sediments of Plio-Pleistocene cycle. Focusing on Salento, it is constituted by limestone and dolomitic-limestone basement of Cretaceous age, generally very permeable due to fracturing and karst processes. This rock formation constitutes the so called "deep" aquifer. This Cretaceous basement is widespread covered by transgressive deposits of Miocene-Quaternary age, constituted of calcarenites, sands and conglomerates, with different thickness and permeability.

3. Material and Methods

The computer codes selected for numerical groundwater modelling were MODFLOW (McDonald and Harbaugh 1998) and SEAWAT (Guo and Langevin 2002). The approach chosen was a partially-physical partially conceptual model (Rozos 2006). This groundwater flow modelling is based on the concept of a equivalent homogeneous porous medium by which it is assumed that the real heterogeneous aquifer can be simulated as homogeneous porous media within cells or elements (Anderson 2002). This simplifying hypothesis is to be considered as the most reasonable approach for the flow and transport representation on regional scale (Schwarz 1988, Scanlon 2003) and for predictive management models, as in this case (Smith 1994, Dufrense 1999, Abbo 2003).

To define the boundary of the study area, separating it from the rest, in which Murgia is located, the piezometric surface was determined in almost natural conditions. For this purpose, mean piezometric data of thirties, collected in the historical hydrological database of CNR-IRPI, were elaborated with geospatial criteria (Polemio et al. 2001) to obtain a piezometric contour line map. This choice is due the very low or negligible discharge level of thirties.

A line with no flow, going across the peninsula form the Adriatic coast to the Ionian coast, was recognised; the peninsula portion located on the southeast side of this line was assumed to be the study area. As defined the study area, the Murgia outflow (or feed) towards Salento is negligible in terms of hydrological balance.

The modelled aquifer portion extends for 2230 km^2, and it was uniformly discretized into a finite difference grid of 8100 squared cells 400 m in lenght, for each one of 5 layers. The cell size was determined optimising or considering the Peclet number (minimum value equal to 5), the numerical solution stability (to be enough) and convergence, the numerical dispersion and the calculation time (to be the minimum) (Huyakorn, 1983). In this preliminary stage of activity literature values of hydraulic conductivity, are used, assuming a hydraulic conductivity anisotropy ratio Kh/Kv equal to 10. The recharge amount is assed using an affordable approach based on the use of rain and temperature monthly data (Polemio and Ricchetti 1996). The piezometric surface of ’30s was used as initial condition for the model. For the boundary conditions, inactive cells were used along the boundary with the rest of Murgia-Salento aquifer, as conceptual underground watershed due to the absence of flow. About the sea boundary, two types of choices will be experimented: CHB boundary cells (Constant Head Boundary) and GHB (General Head Boundary), in both cases assuming the sea constant salt concentration.

4. Results and Discussion

Preliminary results of steady flow and of groundwater salinity spatial are now available. These results are the basis for next phases of Ph.D. research. The next phase will be the calibration; a number of piezometers data and piezometric time series will be used, moving, at the end, from steady to transient simulations.

The implementation of this correction will be used to obtain a model to simulate the space-time evolution of the seawater intrusion phenomenon and to define sampling procedure and tools for sustainable management of groundwater resource.

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THE CONTRIBUTION OF SHALLOW ELECTRICAL AND SEISMIC IMAGING TO THE STUDY OF THE HYDROGEOLOGY OF MUD VULCANOS: AN EXAMPLE FROM ABRUZZO

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Key-words: salt water, mud volcano, ERT, reflection seismic, shallow geophysics.

1. Introduction

The presence of mud volcanoes has hydrogeochemical implications on the nature of the groundwater. In particular, rising mud volcano fluids often increase the salinity of shallow groundwater (Nanni and Zuppi, 1986). The assessment is straightforward in those areas where there are clear mud volcano structures, apparent outflows of high salinity fluids and mud. On the other hand, the hydrochemistry is difficult to interpret in those areas where rising fluids are often buried and/or the volcano structures are naturally or artificially eroded by anthropogenic activities. Also, in these areas, the low activity of the fluids from the mud volcanoes can sometimes make them less apparent at the surface. There are occasions when the mud volcanoes give rise to groundwater with anomalous chemistry (Desiderio and Rusi, 2004; Desiderio et al. 2010) with consequent environmental issues, and these sometimes include legal issues.

Subsurface exploration techniques were used within this study to define the hydrogeological characteristics of a mud volcano characterised by rising cold brine, mud and gas.

This mud volcano appears as a dome of about 15x10 m in size. The height is approximately 2 m with a crater that is 2.5 m in diameter. Upper Pliocene-Lower Pleistocene foredeep pelitic deposits (clays with silty-sandy levels) overlain by clayey-silty deposits outcrop in the area. Below the Middle Pliocene deposits, a NNW-SSE anticline which runs approximately 2 kilometers to the WSW of the site (Scisciani and Montefalcone, 2005) represents the main element of the compressional tectonic setting. Ditches and streams in the area run along fault systems that are oriented NW-SE and NE-SW . These could be related to the upward migration of deep mud fluids (Etiope et al. 2003).

2. Methodology

Geophysical techniques were carried out using 2D-ERT and SH waves Hr seismic reflection profiles. The 2D-ERT results were used to determine the geometry of the high conductivity body related to the uprising of mud fluids and detecting changes in the deposits. Detailed geometry reconstruction of the shallow upward migration of mud fluids was obtained by using 3D-ERT. A shear wave reflection seismic survey was undertaken with the objective of determining stratigraphic limits and assessing the occurrence of fractured zones along which mud fluids could migrate towards the surface. Shear waves were used for seismic energising. These have known benefits when compared to P waves. In fact, they achieve better imaging of complex structures in porous media and through the gas. They also deliver improved resolution and pore-pressure prediction (Rainone and Torrese, 2007; Rainone et al., 2009).

Geological logs of boreholes up to 15 m deep and logs from oil exploration wells were analysed. Micropaleontological analysis of the mud was also undertaken. The hydrochemical aspects were addressed with the classical hydrochemistry techniques and with ^{18}O and ^{2}H isotopic analysis. Multiparametric chemical-physical logs were undertaken in some boreholes used for irrigation purposes.

3. Results

Shallow boreholes show the presence of alluvial deposits in spite of the closeness of the Calvano stream and the occurrence of the bedrock pelitic deposits at about 10 meters of depth.

Detailed geometry reconstruction of the shallow upward migration of mud fluids was obtained by using 3D-ERT. A shear wave reflection seismic survey was undertaken to determine stratigraphic limits and to assess the occurrence of fractured zones along which mud fluids could migrate towards the surface. The survey results revealed that the uprising of deep fluids doesn't occur exactly below the mud volcano at present (fig. 1). Instead, a high conductivity body occurs at approximately 60 m to the ENE, within a fractured zone in the under-compacted clays. The probable occurrence of a silty-sandy level approximately between 20 m and 30 m below ground level, confined by clay layers, gives rise to an over-pressured mud reservoir. This is the source of mud fluids which flow to the surface

through a mud conduit that appears nearly horizontal at depth and then inclined towards the surface up to the mud volcano crater.
The chemistry of the groundwater is sodium chloride in nature with slight seasonal changes (tab. 1). The isotopic analysis has revealed a substantial difference in the ^{18}O-^{2}H ratio when compared to recharge from rainfall. This indicates that there are mechanisms which increase the ^{18}O within the groundwater.

4. Conclusions

The results indicate that, besides the usual hydrogeochemical investigations, the integrated use of 2D-3D electrical resistivity tomography and shear wave reflection seismic surveys allowed the reconstruction of the local hydrogeological system where the uprising of highly mineralised mud fluids is clearly revealed by the presence of the mud volcano. It should be noted that this approach can also be extended to the investigation of naturally contaminated groundwater where the upward migration of deep fluids does not show any evidence at the surface.

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Season	T (°C)	χ (μS/cm)	pH	Eh (mV)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	Cl^{-}	SO_4^{2-}
Spring	15.6	8726	8.2	- 230	15.6	43.9	2612	41.3	832	3550	0.1
Summer	22.0	8180	8.1	- 250	52.1	27.2	3270	57.9	1023	4749	7.3

Tab. 1 - Chemical-physical parameters and the major ion concentration of the mud volcano's pond water.

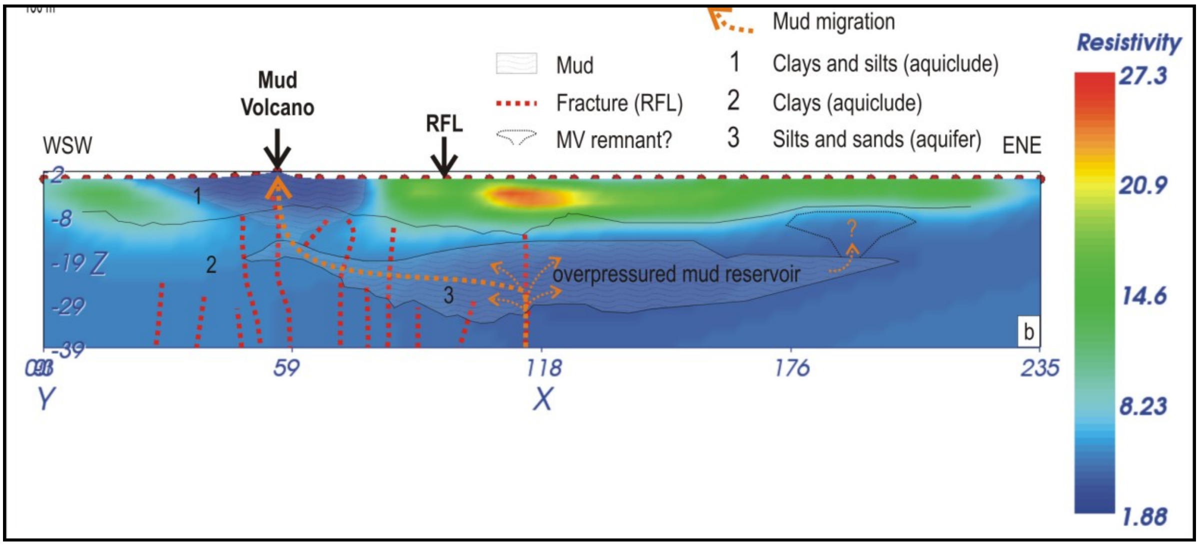

Fig. 1 - Conceptual model showing the migration mechanism of the mud fluids from a deep fractured zone within the bedrock clays to the mud volcano crater: the 2D-ERT section.

THE GIS EMBEDDED SID&GRID HYDROLOGICAL MODEL

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Key-words: Hydrological modeling, open source GIS, MODFLOW2005, LGR, VSF, unsaturated zone

1. Introduction

During the last decade, regulations and recommendations have been issued by the EU focusing on the need for the implementation of new tools and technologies to manage the water resource. In fact, although several kind of data are nowadays collected, qualitative or analytical approaches (as spreadsheet or basic GIS or statistics analysis) do not provide required spatially and temporally distributed solutions. The SID&GRID research project, started April 2010 and funded by Regione Toscana (Italy) under the EU POR FSE 2007-2013 program, aims at addressing such issues by developing a Decision Support System (DSS) for water resource management and planning. Such framework will be based on open source and public domain solutions to build a modular GIS embedded hydrological model where the whole hydrological cycle may be simulated and spatial-temporal analysis performed.

2. Material and Methods

The SID&GRID philosophy (Rossetto et al. 2010) is to develop a modular hydrological model which will allow to simulate the groundwater flow (GWF) in a saturated medium only, or the GWF and the unsaturated zone (USZ) or the whole hydrological cycle by coupling surface water processes to the USZ and the GWF. In order to build the hydrological model and the application, the project choice was: i) to analyse and then select existing open source and public domain codes in terms of their proven capacity to simulate hydrological processes and to manage spatial data, ii) to couple the selected codes along with newly developed ones where specific hydrological process code were missing, iii) to embed the resulting code within a GIS interface, applications and library, to manage all the input and output data by means of DataBase Management System (DBMS). The following codes were selected and are being integrated:

1. Postgresql/PostGIS (PostGIS 2012) for the GeoDatabase Management System;
2. gvSIG with Sextante (Olaya 2012) geo-algorithm library capabilities and Grass tools (GRASS Development Team, 2012) for the desktop GIS;
3. Geoserver (2012) to share and discover spatial data on the web according to Open Geospatial Consortium;
4. new SID&GRID tools based on the Sextante GeoAlgorithm framework;
5. MODFLOW-2005 (Harbaugh 2005) as groundwater flow modeling code;
6. VSF (Thoms et al. 2006) for the variable saturated flow component;
7. new developed routines for overland flow;
8. MODFLOW-LGR (Mehl and Hill 2005) for local grid refinement (LGR);
9. new algorithms in Jython integrated in gvSIG to compute: (i) the PET (potential evapotranspiration) parameter; (ii) the net rainfall rate reaching the soil surface. The results of these algorithms are used as input for the unsaturated/saturated flow model.

The SID&GRID hydrological model is then pre-processed, run and post-processed in an unique modelling environment by means of a Graphical User Interface (GUI) based on the open source gvSIG GIS framework (Asociación gvSIG 2012). A new gvSIG "model" project object has been implemented. This object has its own dashboard controller and property setting.

Concerning the relations between the subsurface and surface water, a newly developed module allows the computation of surface water flow and head and related exchanges through semipermeable beds. The new module is based on a 1D solution of Saint-Venant equation, where the leakage term directly depends on the stream depth during the computation of the surface outflow. Such method (widely used in other codes, i.e. PARFLOW-CLM; Maxwell and Miller 2005) was implemented in a new version of MODFLOW SFR2 package (Niswonger and Prudic 2005): the main difference consists in the computation method of stream depth and leakage.

As LGR was originally programmed for MODFLOW-2005, the LGR capability (to better simulate areas where high hydraulic gradient is encountered) has been extended to the MODFLOW VSF flow process (Thoms et al., 2006), which solves the 3D Richards' equation.

This improvement allows to investigate in detail the USZ only where required by applying the VSF solution in locally refined zones within large areas (i.e. in irrigation areas or wellhead protection zones – 20 to 25 km^2 areas). Within a basin scale model it will be possible to define *child models* linked to the *parent model* by specifying required boundary conditions. There, the VSF code can be applied to precisely describe the boundaries, so that also specific processes like roots uptake, ponding and seepage flows can be successfully considered. In the meantime, the LGR method avoids the dramatic increase of the solution time, maintaining it in a reliable range.

3. Results

The resulting SID&GRID is then a 3D fully distributed and physically-based model. It will allow the calculation of hydrological variables (such as interception, evapotranspiration and surface runoff rates, surface-/groundwater exchanges, hydraulic head, soil moisture, and so on) in space and time.

Of course several data are needed in order to implement real cases; these are i.e. hydrostratigraphical data and hydrodynamic parameters, surface water data (head and flows), DTM land cover data, climate data, and so on. The model is being bench-marked against synthetic solutions in its various processes and tested in the Lucca hydrological system as well as in some small basins as beta-tests run by water authorities in Regione Toscana.

At this stage of the research (which will end April 2013), two components of the master control panel are being developed: i.) a new SID&GRID model project object within gvSIG; ii.) a SID&GRID toolbar integrated into gvSIG map context. The groundwater part of the code has been fully integrated and tested and 3D visualization tools (Fig. 1) are being developed.

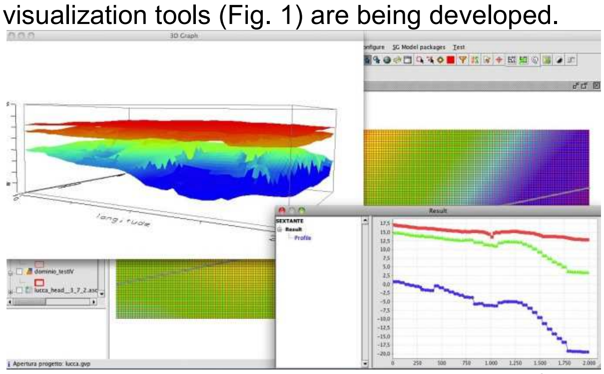

Fig. 1 – Elementary 3D visualization capabilities of the SID&GRID interface.

4. Conclusions

Within the SID&GRID research project a GIS embedded hydrological model is being developed in order to build a complete tool for planning water resource allocation in space and time. Given its modular construction, such a model is suitable for application and management at river basin scale, irrigation areas, well fields, and so on.

To be updated about the project, please follow us at the website: http://sidgrid.isti.cnr.it/.

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PRELIMINARY CONCEPTUAL MODEL OF GROUNDWATER CONTAMINATION BY Mn, Fe, & As IN A MULTI-LAYER ALLUVIAL AQUIFER, THE CASE STUDY OF CREMONA (NORTHERN ITALY)

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Key-words: Arsenic, Iron, Manganese, Conceptual model of groundwater contamination, Cremona.

1. Introduction

This study was developed within the framework of a scientific collaboration between the University of Milano-Bicocca and the Province of Cremona. The main aim is to define the level of As, Fe and Mn groundwater contamination, which affects the multi-layer alluvial aquifer of Cremona area, incorporating some hypotheses about the dynamics and the origins of the contamination. The specific study area is situated near the confluence between the Adda and Po rivers. It covers a 50 km^2 wide area around the urban territory of Cremona. The considered depth is around 200-250 m. The whole province area was subject to previous hydrogeologic and hydrochemical studies (i.e. Beretta *et alii*, 1992; Zavatti *et alii*, 1995) which underlined the presence of high levels of As, Fe and Mn generally in deep aquifers (deeper than 50 m), assuming natural origin. For As in particular, high concentrations were identified in the Oglio river area (up to 200 µg/l), while lower concentrations were found close to the study area, involving aquifers between 50 and 120 m deep (Zavatti *et alii*, 1995). Within the framework of international researches, the problem of groundwater contamination by As, Fe and Mn in alluvial aquifer is exhaustively analyzed in Bangladesh and India (i.e. McArthur *et alii*, 2001; Rowland *et alii*, 2006). These studies assume a natural origin of the contamination which is governed by organic matter (i.e. peat) degradation process.

2. Material and Methods

The applied methodology involves the (a) collection of historical data related to water quality, water levels and well logs, (b) storage of collected data in specific databases and geographical information systems, (c) design and execution of a field survey of water levels and water quality, realized in July 2010 (d) construction of a 3D model of textural distribution of the aquifer deposits, built by means of ordinary kriging interpolation of the percentages of fine (clays, silts, peats), medium (sands) and coarse (gravels, pebbles) deposits, which are derived from the numerical coding of well data logs, according to the method reported by Bonomi (2009); (e) analysis of the hydrodynamic properties of the system, (f) spatial and time analysis of water quality data considering the hydrodynamic properties and the lithological and textural structure of the aquifer, (g) elaboration of a general hydrogeochemical conceptual model, incorporating some hypotheses about the mechanism and the origin of the contamination.

3. Results

The simulated 3D textural model underlines the presence of an alternation of sandy layers and silt-clay lenses with a significant presence of peat deposits and lead to the identification of 5 aquifer units. In relation to the hydrodynamic analysis these 5 units are classified like (1) phreatic (F), from 0 to 25 m deep, (2) semi-confined (S) from 30 to 50 m, (3) confined 1 (C1) from 65 to 85 m, (4) confined 2 (C2) from 100 to 150 m and (5) confined 3 (C3) from 160 to 250 m. The aquifer F can locally assume semi-confined characteristic (Fs) due to the presence of superficial silt-clay lenses, while in the other parts it remains phreatic (Ff). Considering the water level measures executed in July 2010, the groundwater flow direction of aquifers F & S is N/S, influenced by the drainage effect of Po river, while for the aquifers C1, C2 and C3 it is NW/SE, according to the general flow direction evidenced for the province area by Beretta *et alii* (1992). Considering the vertical difference of head levels between the 5 aquifers, the possible vertical exchange of water, generated by the discontinuity of silt-clay lenses, can be directed, in the upper part of the system, from the aquifer F to S and again to C1 while, in the deeper part of the system, from the aquifer C3 to C2 and again to C1. The analysis of water quality data underlines, with the exception of Ff zones, the general presence of reduced hydrochemical *facies*, characterized by high concentration of ammonia, manganese, iron and arsenic. Considering the water quality measurements executed in July 2010, ammonia was detected with low concentrations in the Ff zones and generally with high concentration (1-5 mg/L, up to 18.9 mg/L) in the Fs zones and in the underlying aquifers. High levels of iron and manganese were measured (Fig.1): they range respectively from 100 to 6000 µg/L and from 10 to 1200 µg/L. Generally the highest levels were found in the upper aquifers: in Fs for Mn and in Fs & S for Fe. Arsenic was also found with high concentrations (Fig.1; it ranges from 1 to 180 µg/L) especially in the 30-100 m depth range, corresponding to S & C1 aquifers. The measurements of July 2010 can represent the natural background levels because no direct or indirect human source of Mn, Fe and As was found. In order to understand the origin and the dynamics of this contamination we elaborate a conceptual model which considers the process of natural organic matter degradation like the primary control factor on the As, Fe and Mn contamination, according to McArthur *et alii* (2001) and Rowland *et alii* (2006). Degradation of peat, that also generates high ammonia levels, is associated with the progressive reduction of O_2, NO_3^-, Mn(IV), Fe(III), SO_4^{2-}, CO_2. The reductive dissolution of Mn & Fe oxides lead to high levels of dissolved Fe and Mn, but also to high levels of dissolved As, which is generally sorbed on the surface of Mn & Fe oxides, subject to release during their reductive dissolution. The dynamic of arsenic mobilization is complicated by processes that reduce its dissolved concentration, like the co-precipitation in iron sulphide and the precipitation in arsenic sulphides, according to O'Day *et alii* (2004) - sulphide ions that are the products of sulphate reduction process. This conceptual model is actually being validated and developed with the July 2010 data by means of hydrogeochemical models, using PHREEQC code (Parkhurst & Appelo, 1999).

4. Conclusions

This work contributes to understand the origins and dynamics of As, Fe and Mn contamination in the low Po plain. It concerns an hydrochemical analysis combined to hydrodynamic analysis and aquifer texture modelling. The hydrogeochemical modelling is actually under development.

The elaborated conceptual model can support the management and protection of groundwater resources by public authorities. This work may also represent a first step toward a future implementation of reactive transport modelling.

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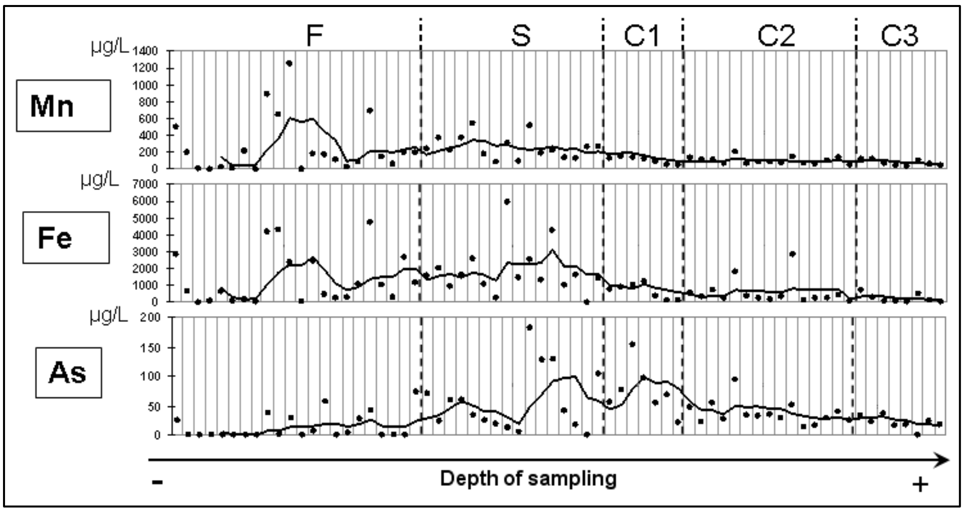

Fig. 1 – [Mn], [Fe] and [As] measured in July 2010 and displayed along the x-axis for increasing depths of sampling; the dotted lines subdivide the graph area into 5 parts corresponding to the 5 identified aquifers (F, S, C1, C2, C3); the solid line represent the moving average calculated using 5 points subsets.

CONSIDERATIONS ON HYDROGEOCHEMICAL CHARACTERISTICS OF GROUNDWATER FROM CARBONATE AQUIFERS OF SOUTHERN LATIUM REGION

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Key-words: geochemical modeling, saturation index, water-rock interactions

1. Introduction

Spring and well water samples, from carbonate aquifers of Latium region, have been characterized to determine the hydrochemical processes governing the evolution of the groundwater. Most of the spring samples, issuing from Lepini, Ausoni and Aurunci Mts., are characterized as HCO_3^-- alkali earth waters, however, some samples show a composition of Cl^- -alkaline- SO_4^{--} waters. Groundwater samples from Pontina Plain shows three different hydrochemical facies: HCO_3^- alkali-earth type, Cl^- - alkaline SO_4^{--} type and SO_4^{--}-Cl^- alkali-earth type waters. Geochemical modeling and saturation index computation of the sampled waters shows an interaction with calcareous and calcareous-dolomitic lithologies. Most of the springs and wells were kinetically saturated with respect to calcite and dolomite, and all the samples were below the equilibrium state with gypsum. The relationship between saturation indexes of gypsum as a function of SO_4^{--} concentration shows that dissolution of gypsum is the probable source of sulphate in these waters. Hydrochemistry results show that the dissolution of carbonate formations as dominant processes in controlling the hydrochemical characteristics of groundwater in this region.

2. Material and Methods

Water temperature, electrical conductivity and pH values were determined in the field using PC 300 Waterproof Hand-held meter. Bicarbonate content was measured by titration with 0.1 N HCl. Chemical analyses were carried out at the Geochemical Laboratory of Sapienza-University of Rome using Metrohm 761 Compact IC ion chromatograph (replicability ± 2 %). The geochemical program PHREEQC software, version 2.10.0.0 (Parkhurst and Appello 1999), with the thermodynamic dataset wateq4f.dat, was employed to evaluate the saturation status of minerals (i.e. calcite, dolomite and gypsum) in spring and well water samples.

3. Results

Spring and well water samples were classified by analysing their main groups of cations and anions and by determining their reaction values (relative percentages) (Chebotarev, 1955). Three distinct groundwater types occur in the study area (Fig.1). Bicarbonate is the dominant anion in spring and well samples, belong to the group of HCO_3^--alkali earth waters, followed by calcium, chloride, magnesium, sodium and sulphate. The springs and groundwater, belongs to or have a tendency to the group of Cl^- - alkaline-SO_4^{--} waters show enrichment in chloride, sodium and sulfates. The variations of ion concentrations in spring and well water samples are probably controlled by water–rock interactions along the groundwater flow paths. This fact was confirmed by geochemical modeling and saturation index computation of the Lepini, Ausoni Aurunci Mts. springs and Pontina wells. The results of geochemical modeling suggest that most part of the spring and well samples are saturated with respect to calcite and undersaturated with respect to dolomite and gypsum. However, some samples are saturated or oversaturated with respect to calcite and dolomite, which implies to a great dissolution and strong mineralization along groundwater flow paths. The saturation with respect to calcite and dolomite is consistent with the observed high concentrations of Na^+ and Cl^- . Undersaturation with respect to gypsum indicates dissolution phenomenon, which would increase the concentrations of Ca^{++}, Mg^{++} HCO_3^- and SO_4^{--} in the solution (Stumm and Morgan, 1996). Conversely, groundwater samples from Pontina Plain showed the highest values of SO_4^{--} Cl^- and Na^+ concentrations according to the Lepini, Ausoni and Aurunci Mts. springs due to the their proximity to the coastline (Tab.1). Considering these high concentrations, it is noticeable that the groundwater is influenced by seawater in this area.

4. Conclusions

The geochemical characterization of the spring and well water samples, from the carbonate aquifers of Southern Latium, show different types of groundwater evolution consisting of modifications of chemical composition because of different water-rock interactions along the flow path as well as possible manifestation of saltwater intrusion. The dissolution of carbonate rocks allows for waters close to saturation with respect to calcite and dolomite and gypsum to remain undersaturated, resulting in continued dissolution along flow paths. The relationship between saturation indexes of gypsum as a function of SO_4^{--} concentration shows that dissolution of gypsum is the probable source of sulphate in these waters. Comparatively, the samples collected farther from the recharge areas show high TDS and major ions concentrations suggesting long groundwater flow paths and residence times. Other chemical processes adding calcium is cation exchange. The high Mg^{+2}/Ca^{+2} ratio indicates weathering of Mg-rich dolomite, which is common in calcareous and calcareous-dolomitic lithologies.

Acknowledgements

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Figures and Tables

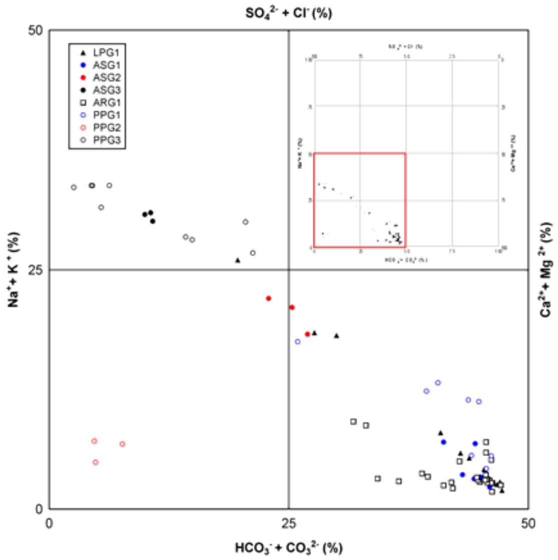

Fig. 1 – Chebotarev plot of major anions and cations of all sampled springs and wells.

Sampling Locations		T °C	pH	χ 25°C µS/cm	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	HCO_3^- mg/L	SO_4^{2-} mg/L	TDS mg/L
Lepini Springs	**Mean**	13	7,69	517	64,3	13,7	37,4	2,9	55,4	239,8	16,4	432
	Median	13	7,70	400	67,2	6,6	6,75	1,2	9,6	235,9	4,3	337
	Min	10	6,91	138	15,4	1,4	2,9	0,1	3,9	67,1	1,7	101
	Max	15	8,12	1540	111,0	44,7	221,0	15,8	338,4	448,0	85,4	1264
Ausoni Springs	**Mean**	13	7,73	826	65,2	18,2	73,5	3,5	128,4	234,2	27,2	555
	Median	12	7,79	404	61,6	9,2	8,6	0,8	13,3	232,0	5,8	327
	Min	12	7,10	315	41,5	3,8	4,1	0,2	7,5	176,9	3,8	259
	Max	15	7,98	2310	89,2	47,8	293,1	15,4	524,9	305,1	110,9	1320
Aurunci Springs	**Mean**	12	7,73	545	70,7	25,6	10,6	2,9	12,7	316,5	34,6	483
	Median	12	7,73	429	63,6	9,9	7,6	1,1	9,8	244,1	5,3	340
	Min	3	7,23	311	36,8	1,5	4,2	0,3	4,5	170,9	2,7	248
	Max	31	8,15	1217	197,3	93,4	50,5	21,6	46,7	805,5	195,8	1154
Pontina Plain Wells	**Mean**	15	7,76	1901	124,0	43,1	232,6	17,7	445,0	297,2	117,2	1284
	Median	14	7,86	1449	125,6	38,9	58,0	17,2	397,8	284,5	55,6	970
	Min	12	7,26	412	50,2	15,1	10,3	1,1	9,4	92,0	6,1	340
	Max	18	8,01	4180	198,1	76,5	705,6	41,5	1220,0	610,0	348,7	2797

Tab.1-Descriptive statistics summary of the chemical analyses on the sampled waters.

GROUNDWATER VULNERABILITY ASSESSMENT USING POSITIVE AND NEGATIVE WEIGHTS-OF-EVIDENCE METHODS TO CORRECT FOR SAMPLING BIAS

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Key-words: *Groundwater vulnerability assessment; Weights of Evidence; Sampling bias; Adjusted contrast, Map reliability.*

1. Introduction

Nowadays, statistical methods are extensively used in geosciences and in many other fields for addressing spatially-related issues. The Weights-of-Evidence (WofE) method [1], following its first applications for assessing groundwater vulnerability in the early 2000's [2, 3], has been increasingly used over the years in the field of contaminant hydrogeology [4, 5, 6, 7, 8, 9].

The WofE can be defined as a data-driven Bayesian method, expressed in a log-linear form, that uses known-occurrences of an event (i.e., response variable) as training points (TPs) to define the spatial association (i.e., contrasts) between the occurrences and multiple weighted evidences (i.e., explanatory variables), in order to generate predictive probability outputs (i.e., response themes)

Its use requires to express the response variable as binary and to select a threshold distinguishing between positive and negative indicators of contamination that are usually identified as occurrences and non-occurrences, respectively. The traditional approach when using statistical methods estimating the conditional probability of occurrence of an event, such as the WofE, uses only positive indicators as TPs in the analysis. However, this approach may be prone to unrecognized sample bias if care is not taken to control or correct for non-random variation in sampling density (for example more monitoring-well may have been placed in known contaminated areas than in other areas). Thus, in this study both positive and negative indicators were used as TPs (positive and negative TPs, respectively) in the WofE analysis and two original quantitative methodologies to recognize sample bias and correct for its effects on the resulting groundwater vulnerability maps were compared and successfully tested.

2. Study area and methods

The new approach briefly described in the Introduction was used to assess groundwater vulnerability to nitrate contamination of the shallow, unconfined, porous aquifer located within the provinces of Milan and Monza-Brianza (Fig 1).

The first methodology to correct contrasts for sampling bias consists of subtracting the ones calculated using the negative TPs (NegC; Tab. 1) from the ones calculated using the positive TPs (PosC; Tab. 1). This is similar, in some ways, to a Bayesian variation of the odds ratio formulation used in logistic regression.

The second methodology consists of subtracting the contrasts calculated using all monitoring-wells as TPs (AllC; Tab. 1) from the ones calculated using the positive TPs (PosC; Tab. 1). Indeed, since in an ideal random-sampling setting AllC values would be near zero for all evidence classes, AllC values significantly different from zero represent a measure of sample bias.

Uncorrected and corrected contrasts were then used to produce three response themes (Fig. 1) that were calibrated/validated and compared each other to evaluate the effects of sample bias on the resulting vulnerability maps.

In this study contrasts and response themes were obtained using the Spatial Data Modeler extension for ArcMAP 9.3 [10].

3. Results and conclusions

Results showed that, due to a sample bias with respect to their evidence classes, explanatory variables could appear to be good and statistically significant predictors of both types of occurrences showing an equivocal relationship with the presence of the positive and the negative indicators of contamination.

Furthermore, comparisons among the uncorrected groundwater vulnerability map (Fig 1a) and the two corrected ones (Fig. 1b, 1c) demonstrated that if sampling bias is not recognized and corrected, when assessing groundwater vulnerability by methods estimating the conditional probability of occurrence of an event, the use of such evidential themes in the analysis can produce unreliable maps. However, once the spatial associations between the TPs and the evidence classes of each explanatory variable were corrected for sampling bias effects, the WofE was found to be a reliable modeling technique for assessing groundwater vulnerability and proved to be capable of identifying areas characterized by different degrees of vulnerability.

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Groundwater depth evidence class	Evidence class range (mm/y)	PosC	First approach		Second approach	
			NegC	Corrected PosC (PosC minus NegC)	AllC	Corrected PosC (PosC minus AllC)
1	<220	1.11	-0.22	1.33	0.58	0.53
2	221-350	1.10	0.91	0.18	1.01	0.09
3	351-1000	-1.01	-0.17	-0.84	-0.58	-0.44
4	>1000	-1.13	-0.67	-0.46	-0.88	-0.25

Tab.1 – Example of correction for sampling bias of the contrasts calculated using the positive TPs (3rd column) by applying the first (4th and 5th column) and the second methodology (6th and 7th column) described in the text. The example refers to the effective infiltration evidential classes considered in this study (1st and 2nd column).

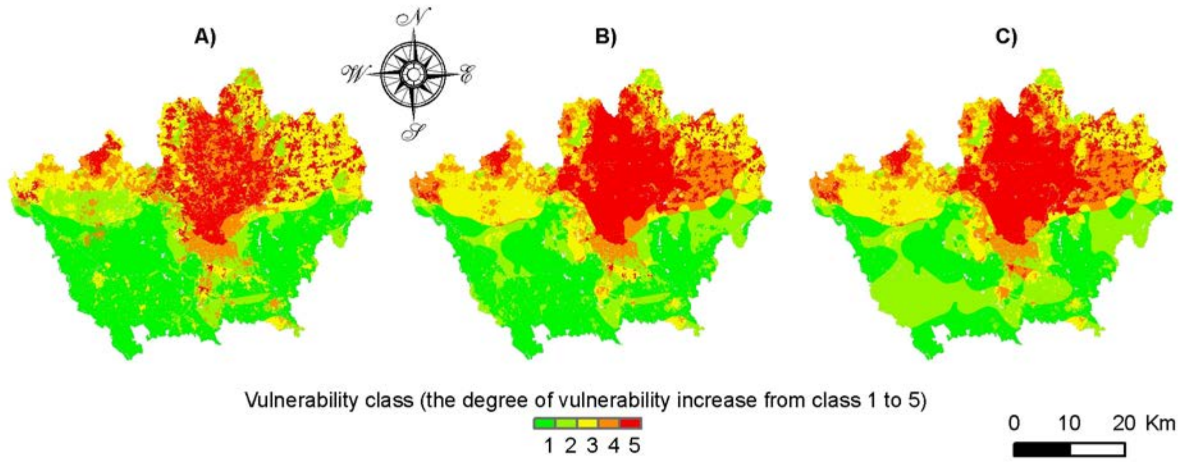

Fig. 1 – A) Groundwater vulnerability map obtained using the positive contrasts uncorrected for sampling bias. B) and C) Groundwater vulnerability maps obtained using the positive contrasts corrected for sampling bias by applying, respectively, the first and the second methodology described in the text.

Modeling riverbank infiltration into an unconfined aquifer in central Italy: evidences and remarks from ^{222}Rn and hydrochemical tracers

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Key-words: Natural tracers, ^{222}Rn, riverbank infiltration, alluvial plain, surface water-groundwater interactions, Italy

1. Introduction

The scientific community has spent many efforts in the last decades to point out that rivers and groundwater have to be considered as part of a unique hydrologic system. In fact, the understanding of the processes regulating their complex interactions is of great importance in order to realize an effective management of connected water resources, in terms of quality and quantity of the two resources. In particular, the assessment of the infiltration mechanisms of river water into the adjacent aquifer becomes an issue when travel times of river water to production wells have to be determined in the framework of groundwater remediation plans.

The purpose of the present work is to investigate the process of direct infiltration of stream water into the shallow aquifer of Petrignano d'Assisi alluvial plain (Perugia), in central Italy, using the combined information obtained from hydrogeologic techniques, ^{222}Rn and major ions measurements and modeling.

2. Material and Methods

River water degassed in radon, entering the aquifer through the bank, progressively becomes enriched in radon along the infiltration pathway until a steady state is reached, when the rate of ^{222}Rn loss from solution by radioactive decay is balanced by the rate of supply by radioactive decay of ^{226}Ra present in the aquifer rocks, in agreement with the law describing the equilibrium between parent and daughter nuclides (Bertin and Bourg, 1994; Hoehn and von Gunten, 1989):

$$A(d) = A_e \cdot (1 - e^{-\frac{\lambda d}{v}}) \quad (1)$$

Where d is the distance from the river (d) of an observation point; A(t) is the ^{222}Rn specific activity measured in the observation well; A_e is the steady-state ^{222}Rn specific activity in equilibrium with ^{226}Ra; λ is ^{222}Rn radioactive decay constant (0.18 d^{-1}); v is the infiltration velocity (m d^{-1}). ^{222}Rn increase along the infiltration flow path can be described in each observation point by the following mixing equation (Bertin and Bourg,1994), assuming that the flow of river water into the aquifer is occurring continuously:

$$^{222}Rn_w = A(d) \cdot X + A_e \cdot (1 - X) \quad (2)$$

where $^{222}Rn_w$ is the specific activity of ^{222}Rn measured in the well, *X* (mixing index) is the fraction of freshly infiltrated water feeding the well and *(1-X)* the fraction of groundwater at the observation point. *X* is obtained by measuring a conservative tracer (*CT*):

$$X=(CT_{well}- CT_{gw})/(CT_{river}- CT_{gw}) \quad (3)$$

For the purposes of this study, the mixing index trend has been parameterized by:

$$X(d) = e^{-\frac{d}{k}} \quad (4)$$

where k is the mean horizontal infiltration distance. The horizontal infiltration distance (k), which is the space comprised by mixing index X=1 and X=1/e, is influenced by the hydraulic gradient between the river and the groundwater; the higher is k, the longer will be the distance run by river water into the aquifer.

A model, run on measured ^{222}Rn data and mixing calculations, allowed to estimate average riverbank infiltration velocity, considering ^{222}Rn ingrowth and the mixing between surface water and groundwater along the ideal transect of wells. The output of the model is the riverbank infiltration velocity, obtained by a fitting procedure to adjust simultaneously the radon ingrowth along the infiltration pathway, described by eq. (2), and the mixing index, described by eq. (4), to the respective measured values.

Seven sampling campaigns were carried out from July 2003 to May 2004 during which the hydraulic head in 20 wells was measured and water samples in the river (R1 in Figure 1) and in 5 agricultural and domestic full-screened wells were collected for ^{222}Rn and hydrochemical determinations.

3. Results

^{222}Rn gave information about the river water residence times within the aquifer and hydrochemical data, in a two-component mixing model, allowed to estimate the extent of mixing between surface waters and groundwater in wells at increasing distances from the river. The mixing measured in the well closer to the riverbank indicated a higher contribution of river water (up to 99 %) during the groundwater recession phase and a moderate contribution (up to 64%) during the recharge phase. The stream bank infiltration velocities obtained by the model ranged from 1 m day^{-1} during groundwater recharge periods, when river water infiltration is lower, to 39 m day^{-1} during recession phases, when river water infiltration is larger (Table 1).

Parameter (unit)	Oct-03	Nov-03	Dec-03	Mar-04	Apr-04	May-04
v (m d^{-1})	173^{+3927*}_{-96}	39^{+33*}_{-16}	21^{+6*}_{-5}	16^{+9*}_{-6}	11^{+12*}_{-7}	1^{+7*}_{-1}
k (m)	126 ± 8	123 ± 11	175 ± 14	143 ± 11	83 ± 9	98 ± 10
χ^2_{Rn}**	6.6	3.1	3.0	1.9	2.0	2.7

**value determined by the model and the associated uncertainty interval (see text for explanations).*
***χ^2 values refer to the best fitting procedure to reproduce measured radon data (d.f.=3).*

Tab.1 - Flow velocities (v) of infiltrating river water and average infiltration distances (k) obtained from the model.

In Figure 1 a conceptual model of the riverbank infiltration processes occurring in the Petrignano d'Assisi plain is represented.

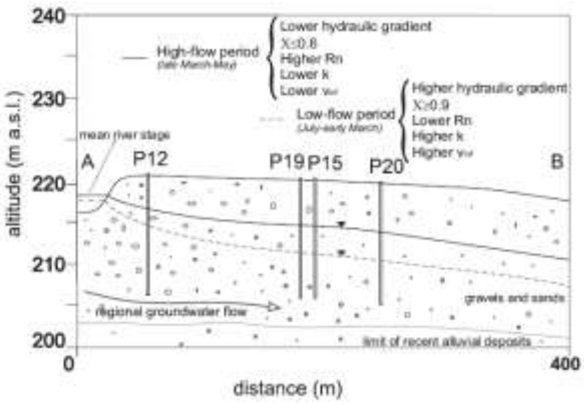

Fig. 1 – Conceptual model of the riverbank infiltration process at the study site in the Petrignano d'Assisi plain.

Two distinct seasonal scenarios are observed: the high-flow and the low-flow scenarios. Both of them are characterized by a persistent influent river condition. During the high-flow period, the lower hydraulic gradient between river and groundwater causes the mean infiltration distance of river water to be smaller if compared to that estimated in the recession period, when river water influences larger portions of the aquifer (Figure 1 and Table 1).

4. Conclusions

^{222}Rn measurements and hydrochemical determinations were used to calibrate a model which describes the river water infiltration process along an ideal transect of the porous unconfined aquifer, taking into account the mixing between surface and groundwater (Bertin and Bourg, 1994). The output data of the model are the infiltration velocity of river water, which is assumed to be constant along the infiltration pathway, and the mean horizontal infiltration distance of river water within the aquifer.

Throughout the sampling campaigns, we found a very good agreement, measured by a χ^2 test, between the functions describing ^{222}Rn increase along the flow path and the mixing, and the respective experimental data (Table 1).

In a broader context, an important advantage of the ^{222}Rn method is that infiltration velocities are calculated without information on hydraulic conductivity, effective porosity, and hydraulic gradient between river and groundwater, which are often very difficult to measure accurately. The main shortcoming of the technique is, as already evidenced by Hoehn and von Gunten (1989) and others, the definition of a steady-state radon activity concentration, since ^{222}Rn is very sensitive to aquifer's geolithological characteristics. Moreover, the study of the temporal and spatial fluctuations of the mixing zone has important implications for river management and restoration measures, as well as for stream ecology functioning since the extent of the mixing zone can influence the release or the retention of nutrients and the occurrence of biochemical reactions, the aeration of the sediments, the movement of the benthic fauna.

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Vertical thermal aquifer stratification related to an open-loop ground-water heat pump system: numerical modeling results and experimental evidences

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1. Introduction

Open-loop groundwater heat pumps (GWHP) are considered one of the most energy efficient and environmentally friendly air-conditioning systems for temperate climate zones. One of the fundamental aspects in the realization of an open loop low-enthalpy geothermal system is the capacity to forecast the effects of thermal alteration produced in the ground, induced by the geothermal system itself.

The impact on the groundwater temperature in the surrounding area of the re-injection well (Thermal Affected Zone - TAZ) is directly linked to the aquifer properties. Physical processes affecting heat transport within an aquifer include advection (or convection) and hydrodynamic thermodispersion (diffusion and mechanical dispersion). If the groundwater flows, the advective components tend to dominate the heat transfer process within the aquifer and the diffusion can be considered negligible.

The transient dynamic of groundwater discharge and temperature variations should be considered to assess the subsurface environmental effects of the plant.

The experimental groundwater heat pump system used in this study is installed at the "Politecnico di Torino" (NW Italy, Piedmont Region). This plant is constantly monitored by multiparameter probes measuring the dynamic of groundwater temperature.

A finite element subsurface flow and transport simulator (Feflow; Diersch, 2005) was used to investigate the vertical thermal aquifer alteration. Numerical modelling is useful for delineating temperature anomalies.

The simulations were performed during the cooling period (May-October 2010) to assess the warm TAZ development around the injection well.

2. Material and Methods

The test site (Politecnico di Torino) is located in the urban area of Turin (NW Italy, Piedmont Region; geographical coordinates 45°03'45''N, 7°39'43''E, elevation 248 m a.s.l.). This plant provides summer cooling needs for the university buildings and is composed by a pumping well, a downgradient injection well and a piezometer that monitors the aquifer. Downhole log data in the study area indicate the presence of two lithologic zones with distinct hydraulic properties (Lo Russo et al., 2010):

Unit 1 - (Middle Pleistocene-Holocene; from the surface to 47 m depth). Continental alluvial cover composed mainly of coarse gravel and sandy sediments derived from alluvial fans aggraded by the Alpine rivers downstreaming towards the east.

Unit 2 - (Early Pliocene-Middle Pleistocene; from 47 m depth). Originally deposited in a shallow marine environment (Sabbie di Asti and/or Argille di Lugagnano), composed of fossiliferous sandy–clayey layers with subordinate fine gravely and coarse sandy marine layers or by quartz-micaceous sands with no fossil evidences. The top of the Unit 2 has been eroded away and covered by the alluvial deposits of Unit 1.

Two multi-temporal thermal logs have been conducted in the piezometer during the geothermal plant functioning phase (August 2010) and after the plant closure (October 2010), in order to verify the thermal stratification in the aquifer.

The subsurface environmental effects of the GWHP system, were evaluated using the finite-element Feflow® package developed by Diersch (2005). A conceptual model with two units was simulated using physical properties appropriate to the hydrogeology of the formations. The initial groundwater temperature for Units 1 and 2 was set at 15.0 °C as experimentally determined. The horizontal hydraulic conductivity (K_{xx}, K_{yy}) was derived from the step-drawdown pumping test results. The vertical hydraulic conductivity (K_{zz}) and the storativity were determined by means of a constant-rate pumping test. The porosity and the volumetric heat capacity for water and rocks was set by examining the logs recorded during the wells drilling in Unit 1. The remaining parameters for Unit 1 and all the other ones characterizing Unit 2 were set equal to the Feflow default values (Tab. 1).

The model was assumed to be closed to fluid flow at its top and bottom; rainfall infiltration was not included in the calculations due to a lack of measured infiltration data. Instead, the recharge to the system was simulated by fixing groundwater levels at all the outer boundaries of the model (Dirichlet conditions). These levels were determined by calibrating the model initially against the steady-state groundwater heads obtained from a potentiometric surface map (Civita et al., 2004). The numerical simulations of the heat transport in the aquifer were solved with transient conditions and were performed by considering only the heat transfer within the saturated aquifer, without any heat dispersion above or below the saturated zone due to the lack of detailed information regarding the unsaturated zone. Appropriate Feflow time-varying functions for discharge and temperatures have been implemented for injection well and only discharge function for pumping well. These functions were derived from groundwater monitoring. The simulations were performed during the cooling period (summer - May to October 2010) to assess the warm TAZ development around the injection well (Fig. 1).

3. Results

The multi-temporal thermal logs have highlighted the thermal stratification in the aquifer and the progressive restoring of the initial temperature vertical homogeneity occurred only several weeks after the plant closure.

Simulated temperature values were compared with experimental ones derived from groundwater monitoring in the surrounding area of the injection well and from two multi-temporal thermal logs conducted in the piezometer.

In general, good agreement is obtained between the experimental aquifer temperatures measured every meter and the simulated values.

Model results were validated through two statistical methods: Root Mean Square Error (RMSE) and Method of Efficiencies (EF). Such analysis have demonstrated the reliability and the good accuracy of the model implemented in Feflow.

4. Conclusions

The aim of this study was to model trends in temperatures around a real GWHP system and to verify the vertical thermal aquifer stratification.

The good agreement of the experimental aquifer temperatures with the model results demonstrates the accuracy and the practical applicability of Feflow code.

Furthermore, the results obtained highlight the importance of the hydrodynamic parameters correlated with groundwater flow; the thermal stratification in the aquifer can be explained by the prevailing advection phenomena.

The modeling effort has focused exclusively on cooling mode; future work will include heating applications.

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UNIT 1	
PARAMETERS	VALUE
Conductivity Kxx [m/s]	0.0025
Conductivity Kyy [m/s]	0.0025
Conductivity Kzz [m/s]	0.0005
Storativity	0.106
Porosity	0.2
Volumetric heat capacity of the fluid [10^6 J/m^{3}K]	4.18
Volumetric heat capacity of the solid [10^6 J/m^{3}K]	1.3
Heat conductivity of the fluid [J/msK]	0.65
Heat conductivity of the solid [J/msK]	3
Longitudinal dispersivity [m]	5
Transverse dispersivity [m]	0.5
UNIT 2	
Conductivity Kxx [m/s]	0.00027
Conductivity Kyy [m/s]	0.00027
Conductivity Kzz [m/s]	0.000054
Storativity	0.106
Porosity	0.2
Volumetric heat capacity of the fluid [10^6 J/m^{3}K]	4.2
Volumetric heat capacity of the solid [10^6 J/m^{3}K]	2.52
Heat conductivity of the fluid [J/msK]	0.65
Heat conductivity of the solid [J/msK]	3
Longitudinal dispersivity [m]	5
Transverse dispersivity [m]	0.5

Tab.1 - Thermal parameters used for Feflow modeling.

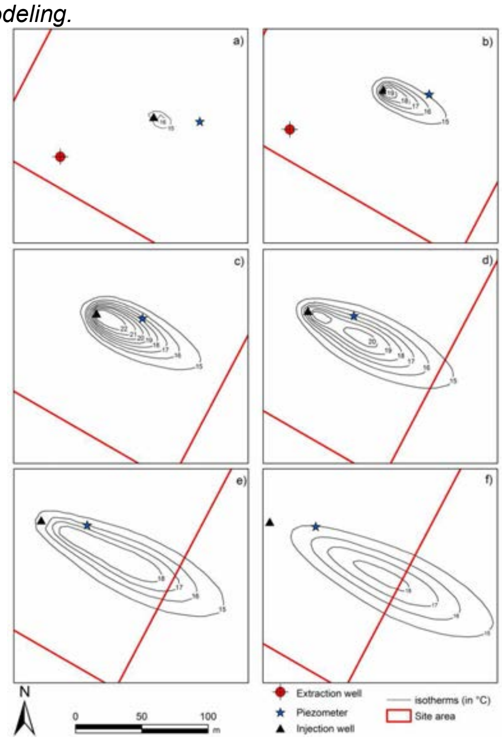

Fig. 1 - Study area. Temperatures [°C] in the Unit 1 unconfined aquifer during the cooling period - May-October 2010. Isotherms: (a) May, (b) June, (c) July, (d) August, (e) September, (f) October.