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IAH Italian Chapter

ABSTRACT VOLUME

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UNIVERSITÀ DEGLI STUDI DELLA Tuscia
Dipartimento di Scienze Ecologiche e Biologiche

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FOREWORD

FLOWPATH 2014, the National Meeting on Hydrogeology, Viterbo 2014, follows up on previously organized and successful meeting FLOWPATH 2012 held in 2012 in Bologna. According to the aim of the 1st Edition, the conference will be an opportunity for Italian hydrogeologists to exchange ideas and knowledge on diversified groundwater issues. The IAH Chapter organized the 2nd Edition to ensure the continuation of this stimulating debate within the scientific and professional community, giving priority to proposals and ideas of young hydrogeologists.

This Abstract Volume contains abstracts of technical oral and poster contribution accepted to the FLOWPATH 2014, and of the invited keynotes presentations. The abstracts were evaluated by the members of the Scientific and Organizing Committees. More than 80 abstracts have been submitted for oral or poster presentations, mainly but not only by Italian hydrogeologists. Significant and interesting contributions were also received from many counties such as Algeria, Austria, Belgium, Canada, Egypt, France, Germany, United Kingdom, Guatemala, Portugal, Russia, Serbia, Slovenia, Spain, Switzerland, Tunisia, USA.

FLOWPATH 2014 focuses on four themes of great importance:

1. Contaminant Hydrogeology,
2. Groundwater Quality Protection,
3. Hydrogeology of Mineral and Thermal Waters,
4. Climate Change and Groundwater Sustainability.

The Table of Contents of the Abstract Volume is organized according to the four topics of the conference. Within each topic, the abstract of the keynote lecture opens the Session and is followed by the technical contributions in alphabetical order of the first Author's name. In order to facilitate the use of the volume, the Index of Authors is placed at the end of the volume.

The printing of this volume was made possible thanks to the contribution of the Executive Committee and of the Department of Ecological and Biological Sciences, Università degli Studi della Tuscia.

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Francesca Lotti
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SESSION 1

Contaminant hydrogeology

Chairs: Alessandro Gargini, Micol Mastrocicco

[1] SOME ASPECTS OF THE STATE OF THE ART OF CONTAMINATED SITES REMEDIATION IN ITALY

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Keywords: remediation, emergency measures, in situ interventions, pollutants concentration and mass

From nearly forty years at the international level and thirty years, also in Italy, the problem of soil and groundwater remediation has been addressed in order to ensure the use of the territory under conditions compatible with human health and the respect for environment, in areas of very different sizes.
The difficulty of the problem is mainly related to:
• the knowledge of a complex and heterogeneous environment;
• the different behavior of contaminants (solubility, volatility, biodegradability, etc.)
• the measurement of chemical-physical low values with complicated techniques in field and in laboratory:
• the application of traditional and innovative technologies;
• the achievement of very low target concentrations;
• the knowledge, sometimes limited, to the relationship between human health and environmental conditions.

Groundwater contaminants are similar both in Italy and Europe, with a prevalence of CHC and BTEX in Italy.
In a first stage, the approach to the problem was to consider the contaminated soil as a waste to be confined in landfill.
In a second stage the remedial actions and emergency measures were achieved by the application of traditional hydraulic and geotechnical techniques.
Dig and dump, vertical engineering barrier and hydraulic barrier (with pump & treat) have required significant capital and O&M costs, especially in sites of national interest (SIN) such as Cengio, Pieve Vergonte and Porto Marghera.
This has also led to a significant consumption of water resources in the face to a reduced mass of contaminant extracted.
Therefore the application to these remedial measures at large scale has revealed a low efficiency and effectiveness, in relation to the expected environmental improvement, in the face of high costs, often due to the state of emergency.
In effect some emergency measures, made without an appropriate geological, hydrogeological and hydrochemical knowledge, have often anticipated and influenced the further remediation measures.
Therefore, in the recent time, the need to introduce new in situ techniques that tend to really break down the pollutant load, and reuse natural resources arose.
New technologies for the remediation of contaminated sites (soil vapor extraction, air sparging, permeable reactive barrier, soil flushing, in situ oxidation and reduction, etc.), already available at the international state of the art, have been applied in Italy, also with some but few original interventions.
In general, the site characterization requires many geological and hydrogeological data that can be processed with advanced methods such as geostatistics: a proper conceptual model is the basis of the subsequent processing of the data
Furthermore the new approach has included flow and transport groundwater numerical modeling (finite difference or finite elements) used in the design.
The need for the application of in situ methods required the improvement of the instrumentation for the site characterization, such as active and passive soil gas survey, the flow chamber, the direct push techniques, the membrane interface probe, the flowmeter, the low flow purging, etc, with the integration of geophysical techniques.
In any case, some technical and economic elements have mainly influenced and limited the choices of the adopted method:
• the presence of screening values (table values) also considered as final target values of groundwater cleanup, and the difficulty to achieve them by the techniques even if highly performing;
• the need for a quick use of the urban areas, with high economic value per unit, without the constraints resulting from the adoption of remediation with emergency measures;
• the difficulty of using hot techniques (thermal desorption at low and high temperature, incineration) ;
• the slowness of the administrative process;
• the costs sustainable in the presence of brownfield sites.

Therefore the achievement of the objectives of groundwater reclamation, notwithstanding the application of best available technology for long life, has not been achieved.
In fact, despite the recovery of the mass of pollutants even up to 90-99%, have not been achieved values of cleanup (expected concentrations of the order of µg/L) which are established by national legislation.
It can be stated that the scientific community is considering the new paradigm expressed by the "order of magnitude of the flow of pollutant mass" to replace the old paradigm consisting in the 'limit value of final concentrations".
Thus, the control of water quality and the monitoring of the natural attenuation of the residual concentrations and mass following a treatment in contaminated site assume considerable importance.
Finally, the hydrogeological knowledge governs the choice of the technology (with chemistry, biology and engineering) and especially the success of groundwater remedial actions.

[2] IN-SITU TREATMENT OF HEXAVALENT CHROMIUM IN GROUNDWATER

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Keywords: Hexavalent Chromium, *in situ* treatment, bioremediation

Introduction

Hexavalent Chromium is a highly soluble and toxic element. The mobility of hexavalent Chromium in the environmental compartments (soil, subsoil and groundwater) depends on the redox potential and the pH of the system (Stumm and Morgan 1996), as these parameters can vary its oxidation state (transition from Cr^{6+} to Cr^{3+}). Trivalent Chromium compounds are non-toxic and less mobile (Stumm and Morgan 1996).

It was assessed to implement a remediation by an *in situ* treatment of the saturated system at a site of a former Chromium plating, located in Veneto (Italy), under the environmental procedure under Legislative Decree no. 152/06, where soil and groundwater were contaminated with hexavalent Chromium. Before *in situ* application, and to verify the effectiveness of the method, a laboratory test was prepared in accordance with a specifically designed protocol (Accoto et al. 2014).

At the site a thin semi-confined aquifer is present, mainly consisting of fine-silty sand; the depth to the water table is about 2 m from ground level and the saturated thickness is about 2 m. The hydro-chemical monitoring results showed that the highest concentrations of hexavalent Chromium in groundwater were approximately 200 mg/L.

As verified by the preliminary laboratory test, the goal of treatment was to obtain a chemical reduction of hexavalent Chromium to trivalent Chromium. The main remediation technologies applied to cases of contamination by Cr (VI) are based on the achievement of reducing conditions and/or on the availability of electron donors (such as, for example, the zero valent iron) (EPA 2000).

EHC®-M was the tested compound selected, a solid material which, once mixed with water, was injected at high pressure into the aquifer, or into the unsaturated zone, using piston pumps with direct push method (FMC© 2013).

Description

The treatment area was divided into two sectors, based on the areal distribution of aquifer contamination and on the hydrogeological features: the source area (i.e., the immediate surroundings of the 5000 L tank-of-plating, once containing the Chromium plating baths) and the plume (i.e., the portion of saturated sandy zone downstream of the tank contaminated by hexavalent Chromium).

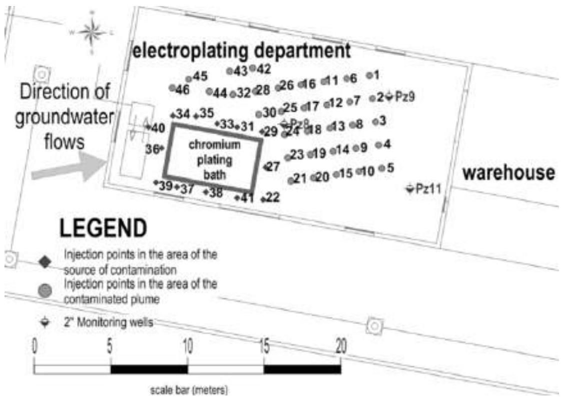

Fig. 1 – Pattern of the injections points and piezometric monitoring network.

The used product, EHC®-M, is a specially formulated integrated treatment material containing controlled-release organic carbon, ZVI, a source of sulfate, and other additives and it's designed for treatment of dissolved trace metals. The treatment helps in developing biological processes that lead to the reduction of the redox conditions. The removal of the reduced form of Chromium from the environmental components is also gained by the presence of ZVI and sulphide generated by sulphate reduction (FMC© 2013). The injection technology used is "direct push" Geoprobe.

The injection's activity started from the plume area, at the more distant points from the source of contamination, and consisted of 5 points aligned, perpendicular to the groundwater flow, 1.5 m equal distance apart, for a treatment line of 9 m (see Fig. 1). Injection depth ranged between -3 m and -4.5 m below ground level.

The plume area was treated injecting 70 L of reactant mixture (including 30 kg of product EHC®-M and water) into each of the 33 injection points showed in Fig. 1.

The source area, centered around the former underground plating bath, was treated injecting 210 L of reaction mixture (90 kg of EHC®-M and water) into each of the 13 points. Injection depth ranged between 1.5 m and 5.0 m below ground level.

After the treatment activities, a program of groundwater hydrochemical monitoring for the determination of Chromium VI, Chromium III and other chemical of concern (Sulfates, Iron, Manganese) started.

Immediately after the treatment the oxidation-reduction potential of the water at piezometers Pz8 (in the middle of the treated area), Pz9 and Pz11 (downgradient of the treated area), at the groundwater surface, and at the bottom of each monitoring well (see Fig. 2) was monitored.

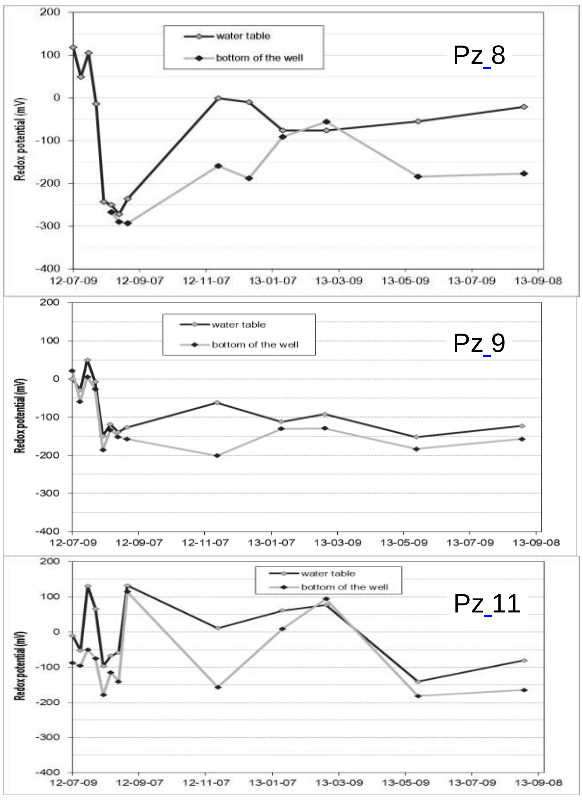

Fig. 2 – Trend of the post-treatment redox potential to the monitoring piezometers: Pz8, Pz9 and PZ11.

It was observed a decrease in the redox potential at the wells in the first month of monitoring, which reached strongly negative values (-300 mV at Pz8, -200 mV at Pz9 and PZ11). Later, there was a stabilization of redox potential at the piezometer Pz9 and a shift to less reducing conditions at the other two wells (at the piezometer PZ11 even the previous positive values were restored).

Regarding to Chromium VI, concentrations began to decrease after one week of treatment, reaching values below the detection limit after 20 days (see Tab. 1).

Sampling period	Stage	Pz 8 (ug/L)	Pz 9 (ug/L)	Pz 11 (ug/L)
2011-08	Before injections	87000	240	< 5
2011-12		132000	240	5
2012-04		109000	70	< 5
2012-07-09	After injections monitoring	70500	<5	<5
2012-07-16		7900	<5	<5
2012-07-23		130	<5	<5
2012-07-30		<5	<5	<5
2012-08-06		< 5	< 5	< 5
2012-08-13		< 5	< 5	< 5
2012-08-20		< 5	< 5	< 5
2012-08-28		< 5	< 5	< 5
2013-02	Next quarterly monitoring	<5	<5	<5
2013-05		<5	<5	<5
2013-08		<5	<5	<5

Tab.1 – Concentrations of chromium VI to the monitoring piezometers in the pre-and post-treatment.

With regard to the concentration of the other monitored chemicals of concern, it was observed a limited post-treatment increase, with a decreasing trend in time and space.

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[3] INTEGRATIVE APPROACH FOR CHARACTERIZATION OF CHLORINATED BENZENES AT CONTAMINATED SITES: LABORATORY AND FIELD STUDY

Luca Alberti[1], Giorgio Bianchi[2], Francesca De Ferra[3], Giovanna Carpani[3], Andrea Franzetti[4], Massimo Marchesi[1], Ilaria Pietrini[1] and Ramon Aravena[5]

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Keywords: monochlorobenzene degradation, isotopic fingerprinting

Introduction

Chlorinated benzenes (CBs) are commonly found as groundwater contaminants at chemical production sites. Oxygen is usually depleted at contaminated sites so reductive dechlorination could represent the main process for CBs biodegradation. However, dechlorination processes become less favorable with a decreasing number of chlorine substituents, hence monochlorobenzene (MCB) is believed to be highly recalcitrant in anaerobic aquifers. (Kaschl et al. 2005) Still, recent studies have shown that MCB can be degraded in anaerobic conditions to Benzene (Liang et al. 2011) or sequentially transformed to CO_2 and CH_4 (Liang et al. 2013). Whereas CO_2 and CH_4 are non-toxic compounds, benzene is more toxic than MCB, having a lower EPA Maximum Contaminant Level (MCL, 5 µg/L) compared to MCB (100 µg/L). Because of this adverse effect a comprehensive site characterization and natural attenuation assessment is required, especially at MCB contaminated sites where also benzene is detected. Compound Specific Isotope (CSIA) and biological tools are commonly used in groundwater studies but very few have focused on MCB. This study investigates the combined application of CSIA with biological molecular techniques for fingerprinting, site characterization and natural attenuation assessment at MCB contaminated sites. The project involves Politecnico di Milano, ENI E&P laboratories, ENI Corporate Laboratories (TEAMB), Syndial and Università degli Studi Milano-Bicocca aiming to create a center of excellence able to integrate standard hydrogeological approach with isotopic and microbiology tools for contaminated site characterization.

Methods

The laboratory activities included a series of aerobic and anaerobic microcosms under different conditions: incubated with pure cultures and with in-situ microbial populations, amended with nutrients and under natural conditions. The main goal is to investigate the ^{13}C fractionation and the kinetic of MCB and Benzene biodegradation under aerobic and anaerobic conditions. The isotopic enrichment factors (ε) obtained in the laboratory will be used to better (i) distinguish between aerobic and anaerobic processes, (ii) asses and quantify natural attenuation, (iii) to understand the fate of MCB and Benzene when present as co-contaminant or degradation product and, overall, to refine the CSIA application for (iv) fingerprinting purposes at MCB contaminated sites.

Laboratory results will complement data collected at a large-scale MCB and benzene (among others organic contaminants) contaminated site, located in Italy. The contaminated site presents evidences of multiple sources and biodegradation processes. Biodegradation kinetic rates and enrichment factors obtained from the microcosms will be incorporated in a reactive transport model to simulate the contaminated site's contaminant $\delta^{13}C$ and concentrations (for MCB and benzene) to assess natural attenuation, potential mixing processes, and finally to link the multiple plumes to their original sources.

Preliminary results

LABORATORY: 8 control wells were sampled to collect water for the incubation of microcosms with site-specific microbial population. Preliminary laboratory results obtained indicate conditions suitable for aerobic and anaerobic biodegradation of MCB. Under aerobic conditions all the microcosms have shown a rapid decrease in MCB concentration even after several MCB spikes of 90 mg/L.

In case of the anaerobic microcosms, they showed a significant MCB reduction only for 3 microcosms, obtained by incubating the water collected in some wells. Furthermore, under anaerobic conditions MCB degradation was much slower (only one microcosm showed a 90 % decrease in 20 days), while in all the aerobic microcosms amended with nutrients MCB disappeared in 10-15 days. No benzene was produced in the anaerobic process and most likely the MCB degraded to CO_2 and CH_4.

FIELD STUDY: $\delta^{13}C$ and concentration data for MCB and benzene showed no significant differences for the 2010, 2011 and 2013 sampling events (except for wells P-32, P-33 and P-37). These data allowed distinguishing two distinct sources and plumes for MCB: the area A with $\delta^{13}C$ values ranging between -25 ‰ to -26 ‰ and a second area, B characterized by more depleted values between -36 ‰ and -40 ‰.

	Concentrations (µg/L)			Isotopic values (‰)	
	Benzene	MCB	CH_4	Benzene	MCB
P7	97	1325	1024	-27.2 ± 0.4	-25.5 ± 0.1
P8	11	8	419	-26.4 ± 0.3	-33.2 ± 0.5
P9	6	952	675	-24.8 ± 0.5	-25.8 ± 0.1
P12	39	114	1053	bdl	-36.2 ± 0.5
P15	275	402	41.5	-39.9 ± 0.1	-40.8 ± 1.2
P26	3	54	233	-30.9 ± 0.6	Bdl
P29	1221	14020	2296	-28.1 ± 0.1	-25.± 0.1
P32	11	3	66	-26.9 ± 0.5	-29.4 ± 0.5
P33	2	13	2273	-27.4 ± 0.8	-31.9 ± 0.1
P37	196	147	238	-31.6 ± 0.5	-33.9 ± 0.5
P40	196	362	16.6	-39.9 ± 0.6	-40.4 ± 0.3
P41	2	211	2132	-23.7 ± 2.1	-26.0 ± 0.7

Tab. 1 - Field data (concentrations and isotopic signature) for 2013.

The $\delta^{13}C$ data also seem to indicate mixing between the two distinct plumes in some areas. High CH_4 concentrations of 1 to 2 mg/L were detected mostly in the monitoring wells in area A (P-7, P-29, and P-41) accompanied with enriched $\delta^{13}C$ values. Concerning benzene, the $\delta^{13}C$ data showed more depleted values for benzene than MCB at the source areas, which is expected for benzene associated to biodegradation of MCB (Liang et al. 2013) The more enriched $\delta^{13}C$ values for benzene than MCB observed in the groundwater with the lower concentration for both compounds can also be related to biodegradation of benzene which can occurred at field sites (Liang et al. 2013). Further, the microcosm results for site-specific enrichment factor also for benzene will be useful to confirm the most realistic conceptual model at the field site. The isotopic enrichment factors obtained in the microcosms will be used to calculate the degree of biodegradation and hence the original isotopic composition of the source in area A.

Conclusions

The CSIA approach allowed distinguishing two sources and two plumes at the study site. An enrichment of ^{13}C on MCB and benzene together with high concentrations of CH_4 suggested active anaerobic biodegradation for the plume located in the area A. This hypothesis was also confirmed by the anaerobic microcosms results performed with water from Area A. Moreover, the fast response from the aerobic microcosms suggested the suitable conditions for a significant contribution also from aerobic degradation activity, although O_2 and nutrients are probably the limiting factors at the site.

These preliminary results demonstrated the potential of combining CSIA with biological molecular techniques for MCB and benzene characterization at contaminated sites.

Acknowledgment

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[4] MULTIDISCIPLINARY APPROACH FOR THE CHARACTERIZATION OF SITES CONTAMINATED BY HYDROCARBONS

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Keywords: hydrocarbons, chemical and microbiological fingerprinting

Introduction

Thousands of chemicals are daily employed in our society and many of them can be detected in all the compartments of the environment Contaminants of particular interest, within this project, are the refined products of crude oil widely used as fuels in cars, aircrafts and ships; for heating and electricity generation, as lubricants in machinery; as asphalt for road and in the production of plastics. Refined products contain complex mixtures of hydrocarbons and non-hydrocarbons and their chemical, physical (i.e. API Gravity and sulfur content), and compositional (such as ratio pristane/phytane and percentage of benzothiophenes) properties vary with the different geographical origin or refinering processes giving them a peculiar chromatogram (or fingerprint) (Kaplan 1996).

Once in the environment these contaminants are subjected to several weathering processes that have as consequence the alteration of their composition and thus of their fingerprints (Murphy and Morrison 2002). For this reason sometimes is hard to characterize contaminated sites avoiding uncertainties and then identify the real responsible of a contamination. In this respect, there are two analytical methodologies, respectively called “*compositional fingerprinting*” (based on the use of a gas chromatography – mass spectrometry_GC/MS) and “*isotopical fingerprinting* (based on the use of a gas chromatography – isotope ratio mass spectrometry_GC/IRMS), that allow the identification of the source of contamination among different possible sources and the determination of degradative effects on it (Wang 2003). The first methodology, employed in this study, pursues this aims by the analysis of the composition of contaminants evaluating the presence and the abundance of individual compounds, in the first case.

In Italy there are a lot of sites contaminated by hydrocarbons and most of them are located along the coastline. Trying to apply the compositional fingerprinting to an oil storage facility in the south of Italy, we gained good results by the identification of a diesel contamination in the internal area of the site, and inconclusive results in the area close to the sea, in correspondence of a salt wedge. On the basis of these results, we have decided to investigate the possible influence that might have the salinity in weathering phenomena, and especially in the biological process of biodegradation that can occur naturally but not in all the environmental conditions, in which microorganisms metabolize organic pollutants to inorganic material such as carbon dioxide methane, water and inorganic salts (Leahy and Cohwell 1990; Boopathy 2000). In addition, the different compounds contained in the refined products are more or less susceptible to biodegradation due to their chemical structures, leading to the possibility to evaluate compositional changes of the whole contaminant mixture, during the time starting from the n-alkanes (more susceptible) to the terpanes (less susceptible).

For all the previous reasons, integration between geochemical data (hydrogeological study, presence/absence contamination and its rate of biodegradation) and microbial data (structure and function of microbial communities exhibit significant spatial and temporal variability linked to the presence/absence of contaminants) is essential. Thus the main aim of the laboratory study carried on has been the definition of a valuable survey instrument, built by coupling compositional and microbial fingerprinting and useful in resolving uncertainties related to the usual procedures applied to characterize the polluted sites. The *microbial fingerprinting* is the study of the microbial population of the site and can be used to determine how the community composition varies in relation with the contaminants biodegradation occurring.

During the experiment were studied both the biodegradation of gasoline and diesel, once released in the environment, and the physical-chemical parameters that most affect the action of microorganisms in this process. In this sense, we have focused on some parameters that have been already recognized in the literature as factors that largely effect/limit natural attenuation (i.e. granulometry of the soil, organic matter and concentration of the contaminant) and two other parameters (i.e. presence of mixtures of contamination and salinity).

Material and methods

The environmental conditions investigated were reproduced in aerobic soil/water microcosms prepared in sealed serum bottles and sampled at four different times (0,10,70 and140 days). For each parameters a different number of levels was investigated, specifically two levels for the granulometry (50-50% gravel-sand; 50-50% sand-silt), for the salinity (0.45 g/L and 4 g/L concentration of sodium chloride), for the organic matter (f_{oc}=0.0002 and f_{oc}=0.002) and for the concentration of pollutants (100 ppm and 1000 ppm). The parameter mixture was investigated at three levels (100% diesel fuel; 100% gasoline fuel; 50% gasoline+50% diesel). To get the covering of all the combination of variables (parameters) it was employed a fractionated experimental design, reaching a total number of 96 microcosms (24 for each sampling time). At each sampling time, both water and soil were sampled. The samples from the microcosms containing gasoline were analyzed at the GC-MS to verify the presence of its typical volatile organic compounds (VOCs) and to determine their concentrations. With the same instrument but with a different analytical protocol, samples from microcosms containing diesel were analyzed to determine the presence of semivolatile and non-volatile compounds characteristic of this refinery product. A series of ratios, indicative of the state of degradation of the contaminants, such as B+T/E+X (B=benzene, T=toluene, E=ethylbenzene, X=xylenes) for gasoline and C_{17}/pristane, C_{18}/phytane for diesel, were determined (Kaplan 1996). Soil samples from the all microcosms were also used to determine the composition of the microbial communities, by T-RFLP (Terminal Restriction Fragment Length Polymorphism) analyses.

Results

The data obtained showed a trend in biodegradation of both the contaminants and, after elaboration through the program "R", indicated a good correlation between the parameters statistically significant in both the methods used (compositional and microbial fingerprinting). In this study, the parameters mainly significant were the contaminant concentrations, the time of sampling and the granulometry, the latter only in microcosms contaminated by diesel. Surprisingly, the salinity was not significant but we suspect that this result is due to the concentrations used and we are planning to further investigate this parameter.

Moreover, the result obtained on a detailed analysis of the T-RFLP profiles showed trend in the communities that might be useful information for the construction of a survey instrument coupling the two methods. In fact, the profiles change with the changing in contaminant concentration and in particular, after 70 days, there is an increase of specific strains in microcosms containing gasoline. This increase corresponds at the major decrease in the concentration of the BTEX.

Discussion and conclusion

This work showed that, as supposed, there is good correlation between the chemical and the microbiological data allowing to the possibility to build a valid tool to characterize contaminated sites. . Moreover, the data can be further strengthened using different molecular techniques that can allow identifying the strains of microorganisms and then the metabolic capability of the communities present in the site. Then, using this multidisciplinary approach for each site it is possible to determine the degradative pathway undergoing and get valuable data to better characterize the site and then to choose the most efficient remediation strategy, in order to reach the goal of the remediation.

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[5] HYDROGEOLOGICAL CHARACTERIZATION AND MODELLING OF A CONTAMINATED SITE IN CECINA COASTAL AQUIFER (TUSCANY, ITALY)

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Keywords: aquifer, chlorinated solvents, MODFLOW, MODPATH, MT3D

Introduction

This study, carried out as part of a program agreement with the Tuscany Region, aims to get a deeper hydrogeological knowledge of the aquifer system contained in the Cecina coastal plain and to develop a calibrated groundwater flow and chlorinated solvents (mainly TCE and PCE) transport model, using the software MODFLOW MT3D (user interface GROUNDWATER VISTAS). The pollution, detected by ARPAT in 2004, was caused by past industrial activity and craft (laundry and tanning) laying over a territory (Poggio Gagliardo) of the Province of Pisa, near the River Cecina. The groundwater model will be used for the optimization of the pump and treat system, set up in the pollution site, and to support the groundwater monitoring.

Conceptual Model

Hydrostratigraphy of aquifer structure: The reconstruction of the geometrical and hydrogeological features of aquifer system was obtained through a stratigraphic database “DBGEO” (ARPAT 2007) that store and show stratigraphical data by hydrogeological, or alternatively geological, cross-sections.

Cecina coastal area is characterized by Quaternary (mainly Pleistocene) sand, gravel and sandstone marine and alluvial sediments alternate with lower sandy and silty interstrata, with average thickness of 40 m. They constitute, on the whole, a single aquifer system with several degrees of confinement. Substrata of this clastic sequence, is represented by sandy to clayey geological formation of Pleistocenic age named Arctica Islandica.

Particularly, in the studied area two aquifers separate by a sandy-clayey horizon, 5-10 m thick are present. Benvenuti et al. (2008) reports a recent block faulting in this area, and the conceptual model take into account an important fault along the Linaglia Creek as interruption of aquiclude interlayer continuity.

Hydrodinamic parameters: T, K and S parameters have been determined by pumping test and interpolated firstly by geologic domain and age, and finally by thickness and hydraulic classification (acquifer, acquitarde, acquiclude) of stratigraphic data.

Piezometric and chlorinated solvents distribution: Piezometric map of 2002 published by IGG-CNR-LAMMA (2009) and unpublished Regione Toscana map from 2006 to 2009 have been considered.

Piezometric morphology is characterized by central drainage area intercepting groundwater fluxes originated by surrounding reliefs where high gradients induced by less permeable deposits. The contaminated plume, influenced by seasonal change of piezometric levels, spread to Cecina town affecting many drinking wells. Since 2004, when contamination was discovered, in the source of contamination was installed a P&T system that has allowed a partially plume restrain.

Numerical Model

Implementation and calibration: The numerical model implemented by Groundwater Vistas interface to USGS MODFLOW code take into account two distinct source of hydrologic inputs:

- recharge supplied by the regional calibrated hydrological model MOBIDIC,
- Cecina river profile linked to Steccaia hydrometer observation.

The role of Cecina river to acquifer feeding has been debated; finally we’ve opted for a fully comunicating river boundary conditions regulated by variable conductance strongly reducing proceeding from Steccaia strait toward the sea. First numerical model of “natural conditions”, that evaluate absence of pumping, has evidenced that strong gradients toward sandy clayey hills dispose numerical instability; therefore recharge from this area as supplied by MOBIDIC model has been concentrated by linear constant flux boundary conditions directly feeding middle pleistocene aquifer. Numerical model has been calibrated starting from a stationary single layer model and following by a multilayer model able to reproduce: by layer 1 the acquitard cover that progressively restrict Cecina feeding and by layer 3 distinct aquiclude interlayer that locally disconnects groundwater flux in two acquifer, the superficial and the deeply. Transitory model has been run firstly with seasonal average conditions replicate for three years, and finally with real 2005 to 2010 hydrologic conditions. In this period transport model has been able to reproduct observed feature of contamination evolution.

Validation :The hydrologic year starting from fall 2011 until summer 2012 partitioned in four stress periods have been supplied to the model, starting from measured concentration. In this period transport model has been able to reproducing observed feature of contamination evolution. Considered complexity of chlorinated hydrocarbons groundwater flux as separate phases model results has been evaluated, above all, for general trend and magnitude. However, seasonal variations has been satisfactorily reproduced.

Forecast : Starting from two reference hydrologic years selected as 2008-2009 for the maximum influx and 2005-2006 for the minimum, two distinct question have been submit to Poggio Gagliardo model: how to improve P&T actual configuration and forecasting next hydrologic year 2013-2014.

A coupling of MODFLOW to MODPATH using particle data have clearly shown benefit or disadvantage of actual P&T versus more effective new configuration (Fig. 1). Maximum scenario have shown locally higher concentration, and, on the contrary, less diffused concentration, compared to minimum scenario (Fig. 2). We observe that concentration diluition can mask effective transport, that is, strong flux in maximum scenario transport anywhere much more contaminant. Finally we have also to consider the removal effect by P&T, certainly most effective in minimum respect to maximum scenario.

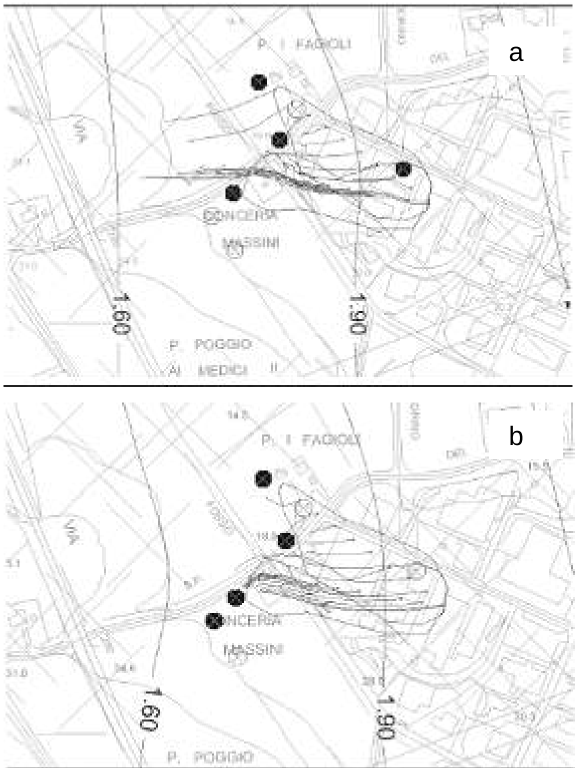

Fig. 1 (a-b) Actual (a) vs. Proposal P&T scenario (b).

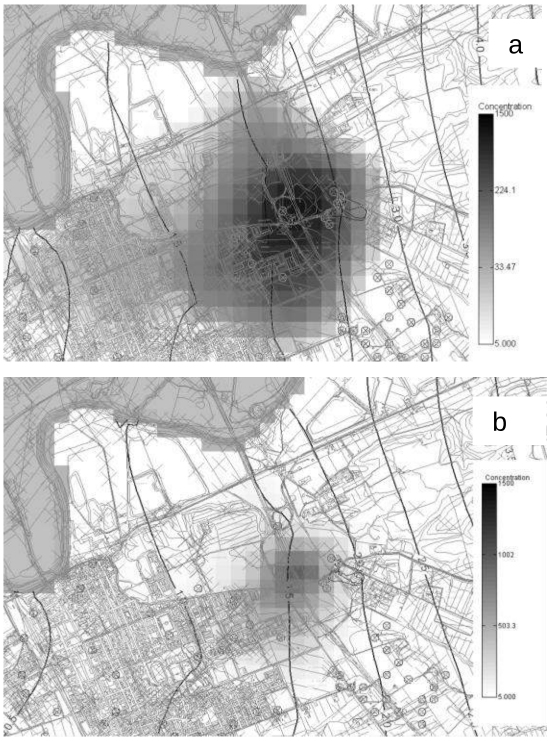

Fig. 2 (a-b) Transport previsional maximum (a) vs. minimum (b) influx scenarios.

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[6] AN INNOVATIVE TECHNIQUE FOR THE *IN SITU* TREATMENT OF HEXAVALENT CHROMIUM WITHIN UNSATURATED SOILS

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Keywords: Chromium VI reduction, unsaturated zone, sodium dithionite, geophysical monitoring

Introduction

In situ chemical reduction (ISCR) is a technique commonly used to transform highly toxic and soluble hexavalent chromium (CrVI) into relatively low toxic and less mobile trivalent chromium (CrIII). There have been several studies focussed on CrVI contaminated groundwater, but *in situ* remediation techniques of unsaturated soils have not been thoroughly tested (Fruchter et al 2000; Khan et al 2003; Ludwig et al 2007). The Spinetta Marengo (SM) industrial site (Alessandria, Italy) was contaminated with cromium (Cr) as a result of the activities of the chrome planting facility that was dismantled in the mid-1970s. Data indicated that the source of groundwater contamination was CrVI in the unsaturated soils. A novel pilot test study was conducted at the SM site to evaluate how effective different treatment techniques were in reducing CrVI concentrations in the unsaturated zone.

Material and Methods

Treatability tests. Core samples were submitted for preliminary laboratory treatability studies (batch and column tests). Results indicated that sodium dithionite was the most appropriate reagent for treating the subsurface contamination.

Field scale pilot tests were conducted that involved injections of sodium dithionite in an area historically used for dichromate ore processing where some of the highest solid phase CrVI concentrations had been observed in the unsaturated zone. Three distinct geological layers were identified within the unsaturated zone: filling materials (0-0.7 m bgl), brown silt (0.7-1.5 m bgl) and a deeper layer of sand and gravel (Fig. 1). Groundwater table at the site was approximately 10 m bgl. Previous pumping tests suggested a hydraulic conductivity for the shallow unconfined aquifer ranging from 10^{-3} to 10^{-4} m/s.

Pre-treatment sampling. Soil samples were collected to the maximum depth of 6 m bgl and analysed for solid phase total concentrations of Cr, CrVI, Fe, S, Mn, As, Ni and Fraction Organic Carbon (f_{OC}). The CrVI concentrations ranged from 650 to 3000 mg/kg in the silty unit. The sands and gravels presented CrVI concentrations from 78 to 1050 mg/kg (Fig. 1).

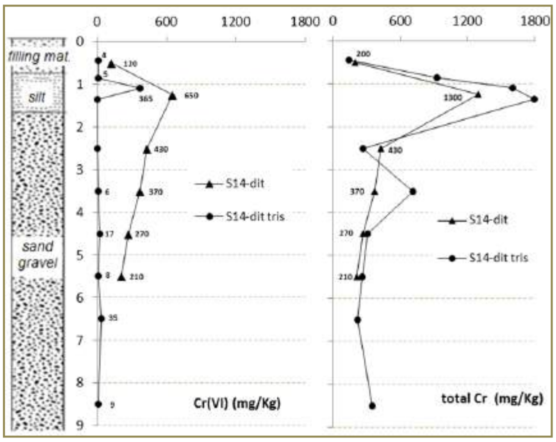

Fig. 1 - Direct push injection test III – pre- and post-injection CrVI and total Cr concentrations in soil samples collected at core drilling S14. Legend: S14-dit: pre-injection; S14-dit tris: post-injection.

The monitoring network implemented for the pilot test consisted of three fully screened piezometers and six boreholes for georadar investigation. An additional well was placed downgradient of the area, to be used in case of unexpected contaminant mobilisation generated by the treatment. Pre-treatment CrVI concentrations in groundwater ranged from 0.45 to 3.2 mg/L.

A stoichiometric excess of sodium dithionite was added to an aqueous solution with a sodium carbonate pH buffer. The solution was formulated and immediately injected to prevent dithionite reaction with O_2. The solution presented a negative redox potential (-600 mV vs NHE), a significant electrical conductivity (30-90 mS/cm), and alkaline pH (10-12) and temperature (20 °C). Three injection tests were conducted from June to October 2012.

Injection Test I consisted of a grid with four direct push injections, spaced 1.8 m from one another. At each point, 1000 L of solution were delivered between 2.0-4.0 m bgl, at a flow rate of 70 L/min. The direct push rod was fitted with a four-port Geoprobe® injection tip to facilitate reductant delivery at specified depths.

Injection Test II included two injection wells installed 1.8 m from one another. The two wells consisted of two inch diameter PVC screened from 2.0-4.0 m bgl. At each point, 1000 L of solution was injected at an average rate of 125 L/min.

Injection Test III included a single multi-step direct push injection. During injection, a 500 L solution was delivered between 0.5-1.0 m bgl, to force the reductant into the filling material and fine-grained silt unit, and an additional 2000 L solution was delivered between 2-4 m bgl.

Geophysical monitoring. High resolution electrical resistivity tomography, surface and borehole georadar techniques were performed before, during and after the injections, and a time-lapse geophysical approach was adopted.

Groundwater monitoring. Based on numerical modelling simulations, a groundwater monitoring campaign was carried out to determine baseline hydrochemistry and hydraulic heads and continued during and after the injections with defined intervals, approximately ranging from 24 hours to a week. All the groundwater samples were analysed on site for CrVI, electrical conductivity, temperature and pH. Additional groundwater samples were collected and analysed for total concentrations of Cr, CrVI, Mn, As, Ni, Fe, SO_4^{2-}.

Post-treatment soil sampling. Based on geophysical evidences, post-treatment soil samples were collected in the highly perturbed areas (resistivity anomalies lesser than -30%) to evaluate the effectiveness of the treatment.

***In situ* water flushing**. An injection of 1500 L of water into the treatment zone was accomplished with Geoprobe® technology in November 2012. Groundwater samples were collected and analysed before, during and after injection to verify the mobility of CrVI in the unsaturated soils.

Results

Geophysical evidences. The injection caused a significant reduction of resistivity in the unsaturated soils, ranging between -10% and -70%. The data indicated an average radius of influence of 1.1 m for each single direct push injection, with a maximum of 1.5 m, and a treated unsaturated soil volume ranging from 6-9 m^3. Approximately 30±5 m^3 of unsaturated soils were treated during injection test I.

Solid phase changes. Post-treatment soil samples collected in the treatment zone indicated a significant decrease in CrVI concentrations: less than the detection limit of 1 mg/kg (Fig. 1). As expected, the excess of dithionite rapidly turned to sulphate and insoluble metal sulfides were formed. The total sulfur concentrations in the unsaturated soils increased to 3490 mg/kg following the reductant injection. The average total Cr concentrations in the core samples collected before and after treatment showed no significant changes (Fig. 1), except for a small difference due to the impossibility of collecting two samples from the exact same location. This is consistent with the in situ chemical reduction of solid phase CrVI to CrIII. A general decrease in water extractable content of metals was also observed in the treated zone, with regards to the untreated area. Samples collected from downgradient piezometers showed no relevant changes in the groundwater chemistry with respect to initial background concentrations.

Conclusions

The investigations proved the capacity of geophysical monitoring to clearly evidence the reductant migration in the unsaturated zone. Concentrations of CrVI in the unsaturated soils were reduced by approximately 80-100% after injecting sodium dithionite with a four-port Geoprobe® tip between 2.0-5.0 m depth. The reductant distribution in the silty soils was overcome with an appropriate injection procedure. Finally, pilot testing indicated that direct push injections of sodium dithionite at specified depths is a viable treatment technology for unsaturated soil remediation at the SM site. Both chemical and geophysical data also indicated that injection well is not an adequate method of reductant delivery.

Acknowledgments

The authors would like to thank Solvay Specialty Polymers for funding this project.

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[7] NITRATE CONTAMINATION OF GROUNDWATER AND SURFACE WATER (FUCINO PLAIN, ABRUZZO): AN UPDATE ON NITROGEN CYCLE AND WATER QUALITY ISSUES

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Keywords: central Italy, agriculture, environmental isotope, nitrogen cycle

Introduction

The Fucino Plain, located in central Italy, is an endorheic basin with a surface area of 200 km^2 surrounded by carbonate ridges. It was filled by recent detrital alluvial and lacustrine deposits, mainly silt and clay with sandy layers, with a variable thickness ranging from 100 to 1000 m, due to the reactivation of main faults (Cavinato et al. 2002). The Plain was historically occupied by Lake Fucino which was the third largest Italian lake. A network of road and irrigation channels fed by runoff and spring waters was realised and the Plain became one of the most important agricultural areas of central Italy (Burri and Petitta 2004). Previous study (Petitta et al. 2009) demonstrated the relationship between the nitrate cycle, agricultural practices and seasonal changes in hydrology, in detail concerning the interaction between groundwater and surface water. The nitrate cycle of the alluvial aquifer of the Plain has been summarized (Petitta et al. 2009) in a seasonal-dependent conceptual model, where nitrate content in the irrigation channels is controlled by a complex interaction between nitrate contribution from manure and the shallow aquifer. The channels are fed on a seasonal basis by different water source contributions (rains, springs and groundwater from the carbonate and alluvial–lacustrine aquifers). Time-dependent processes are runoff towards irrigation channels, water–sediment interaction in shallow aquifer waters drained by the irrigation channels, dilution caused by the carbonate recharge spring waters, and denitrification induced by bacterial activity in nitrate pools in the shallow aquifer. The main objectives of this study are to evaluate (i) the evolution of water quality depending on the agricultural practices in the Fucino Plain, (ii) the processes affecting nitrate occurrence, (iii) its fate in surface water and groundwater and (iv) the implications for both water management and risk assessment of contaminant load in the aquifer.

Materials and Methods

Two sampling surveys, performed in July and November 2013 respectively, included sampling of groundwater and surface water and in situ measurements. Specifically, the present study investigated three springs, two wells and thirteen irrigation channels selected among more than one hundred sample sites monitored in previous studies (Pacioni et al. 2010). Physical and chemical parameters have been measured in-situ, including temperature, oxidation reduction potential (ORP), pH and electrical conductivity (EC) using Oxi 349i/SET probe. Laboratory analyses including major ions, $\delta^{18}O$ and δD, $\delta^{18}O$-NO_3^- and $\delta^{15}N$- NO_3^- have been performed. Major ions analyses have been carried out by chromatographic technique, with an analytical precision of ±0.5‰. $\delta^{18}O$ and δD analyses have been performed at the Isotope Lab of the University of Parma. The international standard is VSMOW and the analytical error is ±0.1‰ and ±1‰ respectively (Longinelli and Selmo 2003). To perform $\delta^{18}O$ and $\delta^{15}N$ isotope analysis in nitrate, 1L samples have been prepared and analysed with the procedure stated by Silva et al. 2000, at the Environmental Isotope Laboratory, University of Waterloo. The international standard for nitrogen isotopes is atmospheric nitrogen (AIR) and the analytical error is ±0.5‰.

Results and Discussion

The geochemical facies is Ca-HCO_3 based, with slight variation according to SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+ and K^+ content, due to contributions of different recharge areas and also to seasonal variability. Water isotope compositions ranges between -48.7/-63.6‰ for δD, and -7.1/-9.5‰ for $\delta^{18}O$ (July 2013). Based on isotope data, groundwater and surface waters show two main signals (Fig. 1) identifying a deep flowpath and a shallower recharge system. Less enriched isotope values represented by f1 and S4 seems to be connected with recharge coming from the regional carbonate aquifer. More enriched values (PZ5) denote a local recharge effect, related to the shallow alluvial aquifer. Intermediate isotope signals, such as most of the irrigation channels, S1 and PZ7, indicate a mixing between local and relatively higher altitude recharge.

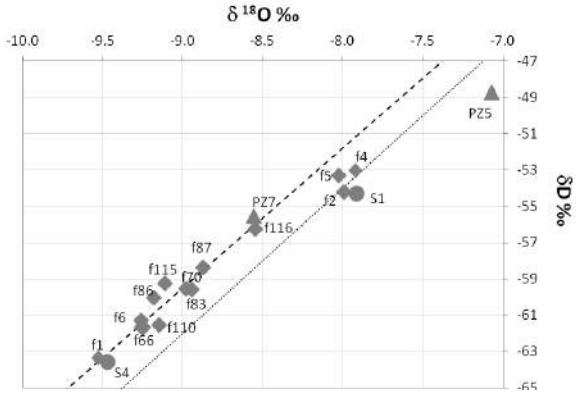

Fig. 1 - Environmental isotope plot. Dashed line from Barbieri et al. (2005) and dotted line from Craig et al. (1961).

Nitrate distribution varies considerably among the sampling points and ranges between 0.01 mgL^{-1} NO_3^- (f30, November 2013) and 26.65 mgL^{-1} NO_3^- (PZ7, July 2013). Ammonium and nitrite concentrations, when detected, are really low (<0.1 mgL^{-1}) and the only exception is represented by PZ5 (2.81 mgL^{-1} NH_4^+, July 2013). During November 2013, a decrease in nitrogen concentration has been observed. A pre-manure application period coupled with a copious rainy season lead to dilution processes, causing a lower anthropogenic nitrogen load in the study area. The $\delta^{15}N\text{-}NO_3^-$ values range between -0.2‰ and +46.8‰ and the $\delta^{18}O\text{-}NO_3^-$ values vary between -1.7‰ and +26.8‰ (Fig. 2). According to the isotope signatures, it is possible to distinguish different nitrate sources in the study area. Values that refer to S1, PZ5 and irrigation channels f1, f70 and f115 fall in the range of nitrate coming from synthetic fertilizers.

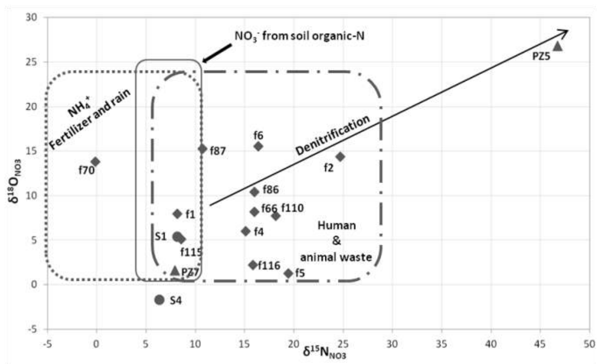

Fig. 2 - Plot of the $\delta^{15}N$ (AIR) versus $\delta^{18}O$ (SMOW) of the dissolved nitrate (July 2013). The fields of nitrate source come from Silva et al. (2000).

Conversely, the isotope signature of f4, f5, f66, f86, f110 and f116 is consistent with an origin of nitrate associated with manure. Moreover, an enrichment trend for both $\delta^{15}N\text{-}NO_3^-$ and $\delta^{18}O\text{-}NO_3^-$ is observed in f2, f6, f87 and PZ5, suggesting the occurrence of denitrification in the study area.

Conclusions

According to the hydrogeological setting and in situ measurements, chemical and isotopic analyses helped in distinguishing contributions to the channel discharge coming directly from surrounding and downthrown carbonate aquifers (S4), from runoff waters as observed in irrigation channels, and from the shallow alluvial aquifer of the Plain (PZ5). Thus, chemical and isotopic results confirmed the seasonal-dependent conceptual model proposed by Petitta et al. (2009), suggesting that the equilibrium among nitrate cycle, agricultural practices and seasonal changes in hydrology is still under steady condition. The nitrogen cycle keeps on controlling the nitrate load in correspondence with deep flowpaths; despite the high level of exploitation of the Fucino plain during the last decades, nitrate pollution is regulated by attenuation processes also in the shallow aquifer. Consequently, nitrogen load in channels seems under control, with local and seasonal peaks remaining under regulation limits. It is also confirmed that denitrification is still occurring in the Plain with higher reaction rates than the ones evaluated in the past.

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[8] DENSITY DEPENDENT TRANSPORT MODELLING OF TOTAL CHLORINATED HYDROCARBONS COUPLED WITH SALTWATER INTRUSION TO EVALUATE THE REMEDIATION STRATEGY IN A MEGASITE

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Keywords: modeling, saltwater intrusion, coastal aquifer, residual DNAPL, remediation.

Introduction

In the last two decades density dependent contaminants transport modelling has been widely applied, in order to gain a more quantitative and physically-based approach to simulate groundwater processes in coastal aquifers (Shoemaker 2004). In coastal sites the importance of density dependent flow and transport has been highlighted in conjunction with plume leachate from contaminated sites (Purnalna et al. 2003). The Megasite object of this study was already modelled to explore the behaviour of dissolved Petroleum Hydrocarbons (Mastrocicco et al. 2012), but so far less was known about the Total Chlorinated Hydrocarbons (TCH) fate and transport since the DNAPL residual existence is much more difficult to be assessed and it has not found until now.

In this work, heads salinity and TCH concentrations from a coastal Megasite were employed to calibrate a three dimensional variable density transport model, in order to evaluate the efficacy of the pump and treat system to capture the TCH plumes in presence of a saltwater wedge.

Methods

The study site is a petrochemical plant in Southern Italy located near the shoreline which covers an area of approximately 3 km^2. An unconfined aquifer consisting of alluvial Quaternary sand, with a variable thickness from 10 to 30 m is limited at the bottom from an underlying aquitard consisting of Quaternary clay, with thickness from 7 to 25 m. Over 70 pumping test data indicates that the hydraulic conductivity is log normal distributed in the aquifer, with an average value of 18.1 m/d.

Since 2002, 246 monitoring piezometers, typically screened between 10 and 25 m below ground level, are monthly monitored for piezometric level, physical-chemical logging and pollutants screening. In 2012, 15 piezometers were selected throughout the site to define concentration profiles within the aquifer. Groundwater was sampled from standard fully-screened piezometers with a Grundfos MP1 and with straddle inflatable packers Solinst for depth profiles. Piezometers were purged for 3 volumes and filtered with 0.45 μm filters, prior to collection of groundwater samples with no headspace. TCH were analyzed via GC-MS Thermo Electron MAT95 XP. SEAWAT-4.0 was used to simulate the interaction between sea water intrusion and the TCH plumes, taking into account the effect of variable-density transport processes. The Constant Head package was used to represent the northern regional flow boundary and the southern shoreline; the recorded pumping rates were incorporated for each well using the Well package; the River package was employed to simulate the river and an internal canal; the Recharge package was adopted to simulate effective precipitations (70 mm/y) and leaking pipes and sewers (200 mm/y). The Mass Loading Rate package was used to simulate the dissolution of TCH from the various residual DNAPL sources. A first order lumped rate of 0.002 1/d was used to account for the TCH biodegradation. The longitudinal, horizontal transverse and vertical transverse dispersivity were found to be equal to 2 m, 1 mm and 0.4 mm, respectively (Mastrocicco et al. 2012). A linear retardation of 1.15 was adopted.

Results and discussion

The maximum observed TCH concentrations near the main DNAPL source were up to 3 g/L, while in other residual sources were lower than 2 mg/L. The TCH concentrations rapidly decrease in the down gradient piezometers. In general, the calibration results are acceptable for the whole Megasite, with an R^2 of 0.88 and an absolute residuals error of 15.6 µg/L. However, it should be point out thet a considerable discrepancy between measured and calculated in part due to numerical errors attributable to the spatial discretization and in part due to the lumped degradation rate used.

In the first case a local mesh refinement would surely help to solve possible numerical oscillations, although a much more CPU time would be required (Colombani et al. 2013); in the second case sequential degradation rates should be employed in simulating chlorinated

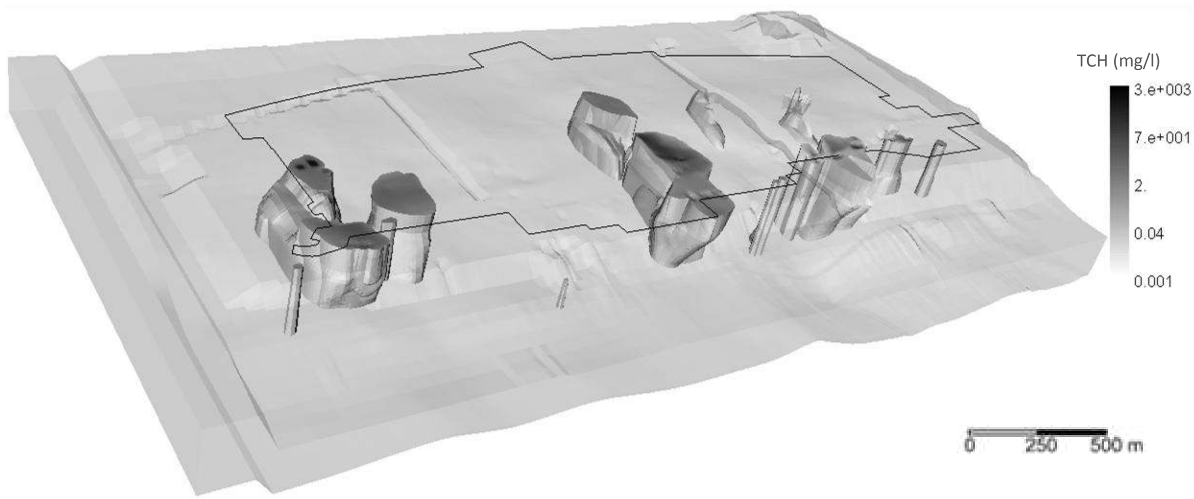

Fig. 1 - Three-dimensional TCH iso-concentration contours in mg/L calculated by the numerical model, in black are depicted the Megasite's limits, the grey shaded volume represents the unconfined aquifer thickness, the coast line is visible from the dipping of the topography in the lower portion of the picture. The vertical exaggeration is 1:10.

hydrocarbons degradation, but since more than 85% of the TCH was represented by 1,2-DCA, this could be reasonably lumped in a single first order degradation rate for large scale sites (Nobre and Nobre 2004). Figure 1 shows the results of the variable density model calibrated versus the measured concentrations of TCH in 2012. It must be stressed that the TCH plumes shape is not constant at various depths and locations in the aquifer. In fact, far away from the sea boundary, the core of TCH plumes is located near to the aquifer's bottom; while near the shore line the seawater wedge prevent the TCH migration towards the aquifer bottom. It can also be noted that the TCH contamination remains almost confined within the Megasite's limits and, therefore, that the efficacy of the remediation system for this class of contaminants is robust.

Conclusions

The calibrated tridimensional flow and transport model was a useful tool to assess the efficacy of the remediation strategy employed: the model showed that TCH were confined within the Megasite boundaries despite the presence of scattered residual DNAPL source zones. The shape of TCH plumes was primarily influenced by the saltwater wedge location, with the highest TCH concentrations located in the upper part of the aquifer near the shore line. To further improve TCH recovery and mitigate saltwater intrusion, shallow wells might be employed near the sea boundary.

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[9] HYDROGEOLOGICAL SCHEME AND STEADY-STATE FLOW MODEL OF VICO LAKE BASIN

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Keywords: Vico Lake, volcanic aquifer, hydrogeological scheme, numerical model.

Introduction

In 2010 two sites in the Vico Lake area were included in the list of contaminated sites of Regione Lazio. This work is a preliminary study to support the body responsible for the characterization and remediation of both sites.
Hydrogeological investigation were performed, the conceptual model was defined and a first numerical flow model helped to focalize on critical areas.

Hydrogeological scheme

The Cimino-Vico hydrogeological system is characterized by a continuous basal aquifer and perched aquifers of limited extension (Capelli et al. 2005; Baiocchi et al. 2006). Groundwater flows in volcanic and pyroclastic formations, whose substrate is formed by the Plio-Pleistocene and Meso-Cenozoic sedimentary formations.
The recharge area of the basal aquifer lies between the Cimini Mountains and Vico Lake. The lake represents an outcrop of the basal aquifer being fed in the northern sector and feeding the aquifer in other directions (Fig. 1).
Field investigations confirmed the presence of perched aquifers in the northern and eastern external sides of the caldera, due to the extreme heterogeneity of the deposits of Vico volcano (Sollevanti 1983). Concerning the lava domes, the aquifer turned to be dome-impounded (Baiocchi et al. 2014).
Temperature logging of wells highlighted the presence of a deeper thermal aquifer, with upflow towards the basal aquifer in the western sector of the lake.

Numerical model

A first steady state numerical model was implemented in MODFLOW-2000 (Harbaugh et al. 2000) and covered an area of 213 km^2. The discretization was performed by a grid of 21,280 cells (100x100 m) for a single layer (Fig. 2). The upper limit was defined by a DEM with the detail of 10 m, the lower one was inferred from hydrostratigraphic logs and results of conceptual model. The initial hydraulic heads were assigned according to the reconstructed potentiometric map (Fig. 1).

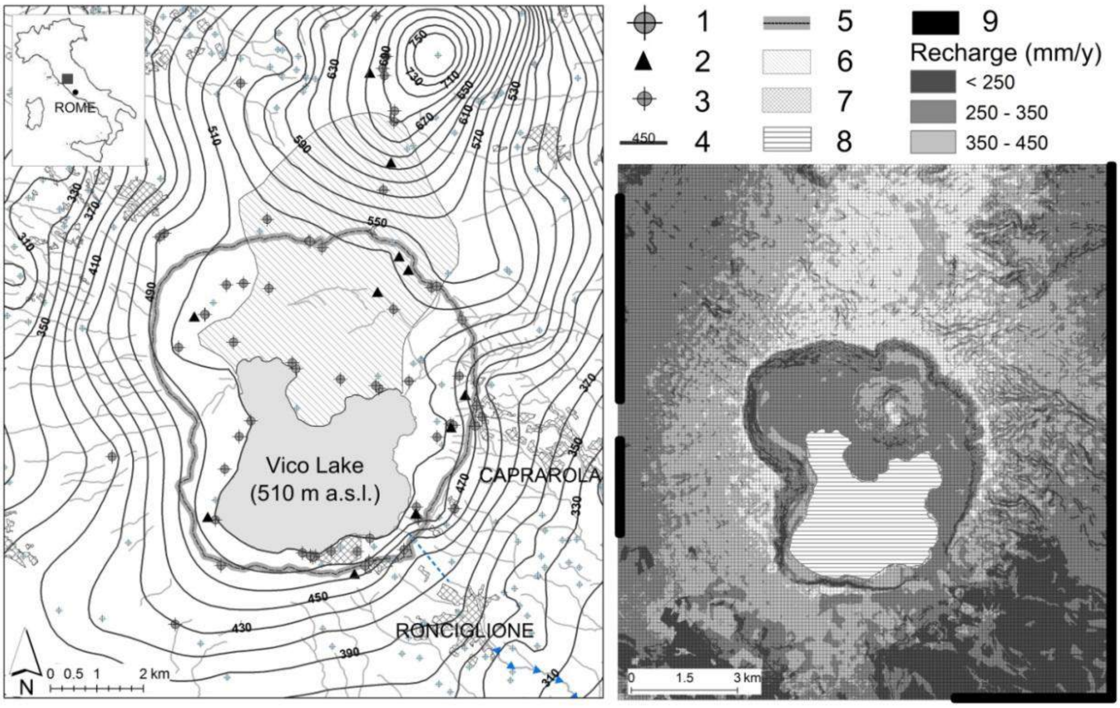

Fig. 1 - Potentiometric map (1-7), model grid (8-9) and recharge areal distribution. 1: Measured wells; 2: Measured springs; 3: Wells; 4: Equipotential lines in m asl; 5: Watershed; 6: Hydrogeological basin; 7: Towns; 8: Lake model pakage; 9 General head boundary condition.

The E, W and S limits of the model are head-dependent flow boundaries (GHB), function of the reconstructed potentiometric field (Fig.1). The lake is simulated with the LAK3 package (Merritt and Konikow 2000) with direct recharge on the surface of the lake (1.47 × 10^{-8} m/s) and runoff within the caldera (5.3 × 10^{-9} m/s) estimated through the budget. Aqueduct withdrawals were assigned according to official data (7.74 × 10^{-9} m/s).
The average annual recharge was assigned according to one out of four budget scenarios calculated in GIS environment.
The automatic calibration (using PEST 12.3; Doherty 2012) was carried out according to two different approaches: the first one considered values and geometry of the zones of hydraulic conductivity (ZC); the second applied the method of *pilot points* (PP) (Certes and De Marsily 1991). More than 100 observation points allowed to reach a good agreement between the measured and calculated heads, as well as between the water budget analytically estimated and the one calculated by the numerical model.
The two calculated potentiometric surfaces are consistent with measured data (Fig. 2) and volumes of the budget are comparable, especially in PP calibration (Tab. 1).

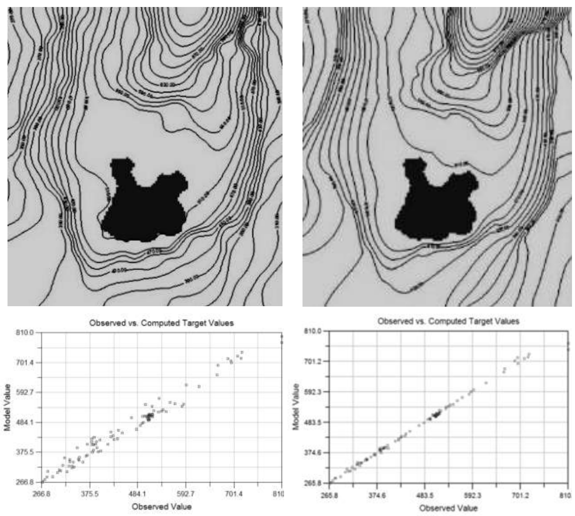

Fig. 2 - Potentiometric surfaces and scatter plots of the ZC (left) and PP models (right).

Water budget term (m^3/s)	Conceptual model	ZC Model	PP Model
Groundwater recharge from outside the catchment area	0.116	0.060	0.110
Groundwater inflows towards the lake	0.226	0.167	0.238
Runoff towards the lake	0.465	0.465	0.465
Lake outflows towards groundwater	*n.a.*	0.136	0.229
Average lake level (m asl)	510.37	507.90	510.14

Tab. 1 - Comparison between the conceptual budget and results of numerical models.

Conclusions

A detailed hydrogeological scheme of the Vico basin was defined through new investigations.
New elements acquired can be summarized as follows:

- Possible presence of contaminant in groundwater could only reach the waters of the lake from the northern sector; in other areas, flows are oriented from the lake towards the aquifer.
- The modeling provided estimates of water loss from the lake towards groundwater, previously estimated only indirectly from the water budget.
- The hydrogeological scheme is characterized by the interaction of different components: a basal continuous aquifer connected to the lake surface, a deep aquifer with upflows towards the basal volcanic aquifer and the lake, perched aquifers *s.s.* in the Vico volcanic deposits, and dome-impounded groundwater at the edge of the Cimini domes.

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[10] HIGH RESOLUTION VERTICAL PROFILES IN SITES CONTAMINATED BY CHLORINATED SOLVENTS: RELATIONSHIP BETWEEN HYDRAULIC HEAD, CONTAMINATION AND ISOTOPIC DATA

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Keywords: aquitards, DNAPLs, vertical profiles.

Introduction

The role of aquitards within hydrogeological systems is often oversimplified, considering them as impermeable barriers towards any type of flowpath. Indeed, aquitards can play very different roles within different systems, due to their integrity degree, lithological composition and other physical properties (Cherry et al. 2004; Meyer et al. 2007). The Caretti site (a residential area located in northern Italy - FE, showing a strong groundwater contamination by chlorinated solvents), represents a good test site to assess the role of aquitards concerning both water and contamination flowpaths. Beneath the site a multilayered aquifer system is present, which consist of an alternation of sandy and clayey–silty layers, down to a depth of 60 m b.g.s. (Fig. 1). Two dumps for domestic wastes were located at the site, which were filled, during ’60 and ’70, also with industrial wastes. DNAPLs, originating from the industrial wastes, were able to migrate through the local clayey-silty aquitards, allowing the development of different dissolved plumes, currently migrating in the three investigated aquifers (Nijenhuis et al. 2013). The collection of different detailed information (stratigraphic, hydraulic head, contamination concentration and isotopic data) along five vertical profiles, allowed identifying various roles of aquitards within the Caretti setting in terms of flowpaths, contaminant migration and degradation.

Methods

A transect composed of three vertical profiles down to 60 m b.g.s, disposed above the fringe of one of the two landfills source of contamination, was studied in Caretti site (Fig. 1). The cores resulting by five boreholes have been sampled at high spatial resolution, for several analytical purposes (determination of physical properties of the soil; total concentration of contaminants - Parker et al. 2003; isotopic composition of water - Stumpp and Hendry 2012; carbon stable isotope analysis of contaminants). A detailed stratigraphic reconstruction was performed for the three investigated profiles, and five multilevel systems (CMT Solinst®) were installed in the five boreholes composing the three profiles. Water samples have been collected from the 35 screens of the multilevel systems installed, in order to analyze the hydrochemical composition of water and the concentration of chlorinated solvents dissolved in groundwater. Hydraulic head have been monitored over 7 months, at the 35 multilevel screens.

Results and discussion

The time discrete hydraulic head monitoring of the multilevel systems allowed to identify two zones of limited thickness (3 to 4 m) within the two shallower aquitards, in which the total head losses expected to be provided by the aquitards occur. The detailed stratigraphic logs suggested that for the shallowest aquitard the head losses are localized in a peat rich belt, corresponding to Holocenic swamp deposits. In the deeper aquitard the higher vertical hydraulic gradient is located within a markedly clayey layer, corresponding to the bottom of a Pleistocenic flood plain. Any significant occurrence of organic matter has been detected within this layer.

The distribution of water isotopes, defined along one of the three vertical profiles (S1-S2, Fig. 1), shows a good correspondence with the conceptual model obtained by hydraulic heads, while the chlorinated solvents distribution, determined along another profile (S4-S5, Fig. 1), shows some differences if compared with water flowpaths. In the shallowest aquitard, strongly enriched in organic matter, high concentrations of chlorinated ethenes and ethanes were detected (primary compounds as well as dechlorination products), with the highest peaks localized in the peat rich belt mentioned above. The dechlorination activity taking place within this shallowest peat-rich aquitard is confirmed by the enrichment in carbon isotope composition of the target compounds in the same vertical profile. In the deeper part of the system, a pool of pure phase DNAPL is placed at the top of the clayey protective layer detected by means of hydraulic heads (which corresponds to the bottom of A1 sup aquifer - Fig. 1). An only slight dechlorination activity is detectable within this pool. Downward migration of DNAPLs is in this case slowed down by the aquitard but it is still capable o cross it, reaching the deepest investigated aquifer.

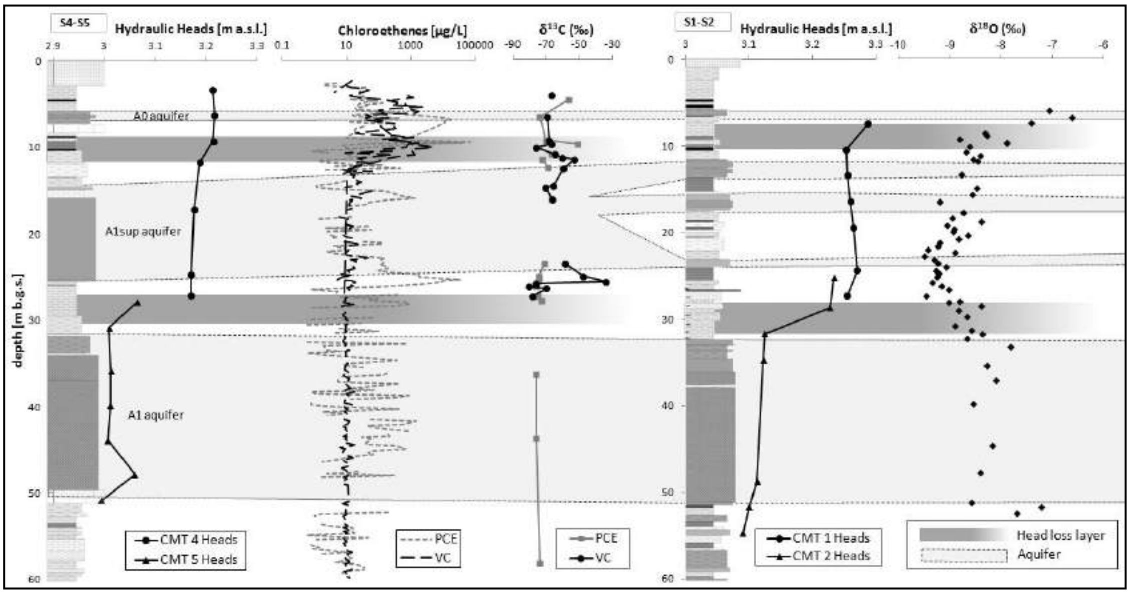

Fig. 1 - Caretti site's vertical profiles. Stratigraphic logs show the alternation of 3 sandy aquifers (from g.s. A0, A1sup, A1) with clayey-silty aquitards. Data collected along the profiles during and after coring are reported: hydraulic heads (averaged values – Sept. 2013/Mar. 2014) for S1-S2 and S4-S5 profiles; total concentration of two chlorinated ethenes (PCE and VC in DNAPL, sorbed and dissolved phase) along S4-S5 profile; $\delta^{13}C$ relative to the chlorinated ethenes molecules (S4-S5 profile); $\delta^{18}O$ relative to pore water along the S1-S2 profile.

Conclusions

The detailed vertical hydraulic head monitoring highlights the different degree of protection provided by different portions of aquitards, which cannot be considered a priori as permeability barriers towards water and dissolved contaminants on a mere lithological basis, as classical hydrogeological approaches often do. Moreover, in terms of aquifers protection, the results collected in Caretti site show how aquitards can play different roles concerning the migration of specific contaminants, due to their different physical and stratigraphyc features. The occurrence of peat-rich aquitards induces dechlorination processes, leading to the formation of Chloride-depleted compounds, such as Vinyl Chloride, in very high concentrations close to the ground surface (with consequent potential risk of vapor inhalation by residents).

In the broader Ferrara area, several industrial sites exist, in which the occurrence of chlorinated solvents in groundwater coexists with peat enriched aquidards, a few meters b.g.s. (Nijenhuis et al. 2013; Amorosi et al. 2004). In all of these cases, the occurrence of organic matter-rich aquitards plays then a double role, enhancing natural degradation of the contamination and, at the same time, facilitating the accumulation of strongly carcinogenic dechlorination products.

Where organic matter is not present along the Caretti profiles, an only slight dechlorination can be observed and the concentrations of primary chlorinated compounds prevail on dechlorination products. Coherent non-organic clayey layers seem to obstruct the downward migration of chlorinated solvents.

Nevertheless, pure phase DNAPLs can slowly migrate through clayey layers which act as permeable barriers for water, likely due to microfracturation or other micro-scale irregularities in clays.

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[11] NUMERICAL FLOW MODEL AS A TOOL TO MANAGE AN HYDRAULIC BARRIER

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Keywords: numerical model, hydraulic barrier

Introduction

A mathematical model can be considered as a simulation tool to compute the spatial distribution of the piezometric head describing the state of the system from a set of physical parameters which characterize the natural system (hydraulic conductivity, source terms, boundary conditions) (Giudici et al. 2007).

The aim of the work is the implementation of a numerical flow model for the environmental management of a National Interest Site contaminated mainly by aromatic hydrocarbons and secondary heavy metals. The calibrated and validated flow model has been built taking into account the results derived from site investigations (pumping well, slug test, geological survey) and from the geological conceptual model. This model has been used to reproduce the groundwater flow and to monitor and to manage a hydraulic barrier used in order to limit the spreading of the contamination.

Site description

In 2006, in order to limit the spreading of the contamination in the study area and prevent the incoming at sea of the contaminants, a hydraulic barrier of 63 wells located near shore line has been activated. Over time this hydraulic barrier has been improved with 9 small wells, 3 drainage trenches and, in 2012, with 16 new shallow wells. The total discharge (August 2013) is about 80 m^3/h. The proper efficiency of the new shallow wells is confirmed by the comparison between piezometric level measured in March 2012 and in April 2013, which highlights a significant drawdown of the water table in the central zone.

The unconfined aquifer is characterized by quaternary alluvial deposits without clear low permeability levels, but pumping and slug tests revealed a reduction of permeability with depth along the aquifer thickness. Average hydraulic conductivity of the aquifer ranges between 10^{-4} m/s and 10^{-7} m/s. Piezometric trend recorded in 2013 results W-E oriented with decreasing hydraulic gradients from upgradient to downgradient (shore line). In the central zone of the site a decrease of hydraulic gradient and a reversal of isoline trend has been observed (Fig. 1). This trend can be ascribed to leakages of technological pipeline networks of the plant, as confirmed also by water isotope analysis. A further evidence of these leakages is given by the limited drawdown recorded in monitoring wells between shallow wells placed near a leaky underground canal. Very limited salt water intrusion affects the aquifer, except with leakages of the canal.

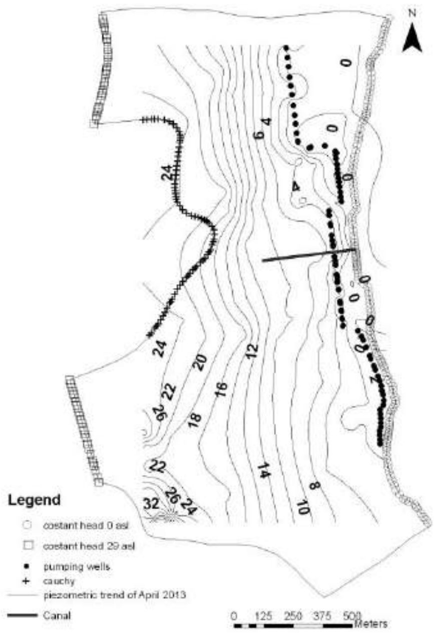

Fig. 1 – Piezometric trend of April 2013 and main characteristics.

Materials and methods

A numerical flow model has been built using the finite element software Feflow 6.1 which can be efficiently used to plan and design remediation strategies and capture techniques, and to assist in designing alternatives and effective monitoring schemes (DHI-WASY GmbH 2010).

The 3D model has been built defining and discretizing the domain in homogeneous unitary elements, to apply the set of algebraic equations of the mathematical model (Alberti 2008). The model domain has been divided in 4 layers and 5 slices. The applied k distribution (from 10^{-4} m/s to 10^{-8} m/s) is different in the various layers with the purpose of representing the real distribution of permeability. Constant head conditions were applied along eastern boundary (shore line, 0 m asl) and along the northern and southern part of the western boundary (29 m asl) (Fig. 1). Instead, in the central part of western boundary Cauchy conditions have been applied, with the purpose to simulate the drainage from outcropping fractured rocks. Cauchy condition has been applied, on the first slice, also along the leaky canal (Fig. 1), in order to take into account the contributions of this canal to the model budget. Finally, multilayer well conditions have been applied at the pumping wells of the hydraulic barrier. On the first slice also a natural recharge on the entire domain has been considered, while in the central area of the plant a surplus of anthropogenic recharge has been applied.

Final results (August 2013) have been obtained through a process of calibration realized through both trial and error approach and PEST software (solution of inverse problem) (Doherty 2002). The aim of calibration process was the identification of the optimal values of the model parameters, to obtain the best fit between model results and field data (Giudici et al. 2007).

Results and discussion

Simulated piezometric trend reflects the real W-E piezometric trend and the RMS (root mean square) is of 5,97%. The main result of the simulations is the budget analysis, which highlights a substantial equilibrium between inflows and outflows from the model (Fig. 2). In fact, the inflows are about 1800 m^3/d from upgradient, about 244 m^3/d from natural recharge and about 1000 m^3/d from anthropogenic recharge; instead, the outflows are about 1130 m^3/d along the shore line (constant head) and about 1900 m^3/d from pumping wells. A detailed budget analysis has been made in various sectors of domain. This analysis highlights that about 360 m^3/d flow out from central sectors, corresponding with the leakages of the canal. This observation confirms that the implementation of the hydraulic barrier allows the capture of the shallow portion of the aquifer, but also shows that the leakages of the canal are the only source of outflows at the moment not yet intercepted by the new wells; downgradient, the existence of additional pumping is guaranteeing the hydraulic containment. The leakages flow into an old riverbed, with very limited mixing with the main aquifer flow; indeed, hydrochemistry of a monitoring well located downgradient does not show significant pollution. The efficiency of the hydraulic barrier is also shown by piezometric heads measured in cluster monitoring wells. In fact, at aquifer bottom piezometric heads lower than heads in the upper part are recorded.

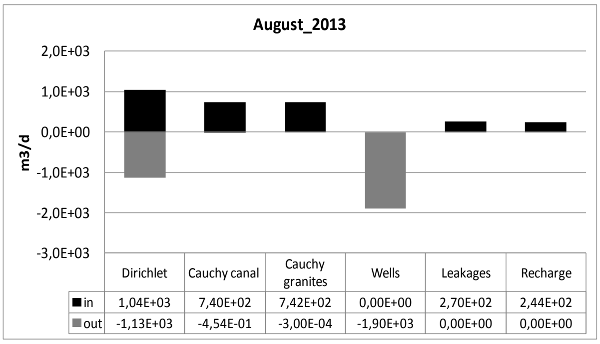

Fig. 2 – Budget analysis.

Conclusions

The presented model is in agreement with conceptual model of site, as it is shown by good correlation between simulated and measured piezometric level and by budget analysis. In fact, it is able to adequately simulate the real groundwater flow, taking into account the influence of k distribution and anthropogenic recharge. The numerical model shows the efficiency of the new shallow hydraulic barrier obtained after the implementation of the new shallow wells. The pumping system, including downgradient exploitation, allows the control of flow coming from upgradient; in order to reach total efficiency, specific measures to reduce leakages have been programmed. Therefore, this model can be used as an operative tool to monitor and to manage the hydraulic barrier, evaluating pumping rates, expected piezometric drawdown and consequently the efficiency of the hydraulic containment.

The next step of the study will be the simulation of groundwater/sea interaction by a density dependent numerical model.

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[12] SALT-WEDGE INTRUSION IN RIVER MOUTHS: ASSESSMENT OF THE WIND EFFECT

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Keywords: Tiber River, Salt-wedge, Seawater intrusion, Wind influence, Thermohaline

Introduction

In coastal areas, rivers are preferential way to lead seawater inland, through salt-wedge intrusion. In inland areas water pumping can determine an inflow of seawater from the rivers to groundwater, determining groundwater salinization. Salt-wedge shape can be influenced by the river discharge and morphology. Pritchard (1955) classified the river estuaries on the basis of vertical structure of salinity. This classification considers the competition between buoyancy forcing from river discharge and mixing from tidal forcing. De Castro et al. (2000) focused attention on wind and tidal influence on water circulation in an estuary, finding close connections between wind direction and the current developing at the sea surface layer. The aim of the study is to detect the connections between the wind-induced sea-flows movement and the related salt-wedge emplacement, based on the temperature pattern detected at the river mouth.

Geological and hydrogeological setting

Tiber River is 405 km in length, it rises in Tuscany and it flows into the Tyrrhenian Sea forming an estuary with two branches, the northernmost Traiano Canal (TC) and the southernmost Fiumara Grande (FG), divided by a small island. The Tiber River, nearby its mouth, flows in the alluvial sediments of the High Stand System Tract of the Tiber Depositional Sequence, developed from 6000 to 5000 years BP. This sequence is mainly composed by clay, silt, sand and organic matter lenses. These deposits allow a hydraulic communication between groundwater and the river. In general flow paths are directed toward the river, except in the area of Ostia Antica, where the ground level is below the river level and water table is below the mean sea level. Therefore the salt-wedge intrusion in the Tiber mouth can determine a lateral inflow to groundwater in the Ostia Antica area, accelerated by human pumping. Tiber River shows variable discharge, increasing in the October-June period and decreasing from July to September.

Material and methods

Hydrologic surveys were performed by means of a boat in two days in May 2012. 37 Thermohaline measurements (24 for FG and 13 for TC) were carried out using conductivity-meter which collected data about salinity and temperature. River level data were collected from three water gauges (WG) located along the Tiber course, with a time step of 15 min (IdrograficoLazio 2012). The period of data collection was from 1st January to 15th May 2012. Seawater level and temperature data were collected from the Anzio tidal gauge with data collected every 10 min (ISPRA 2012). Surface wind data were collected from two meteorological stations, located in Fiumicino (Wunderground 2012) and Ostia (Wunderground 2012), nearby the FG and TC mouths.

Results and discussion

Salinity pattern showed a salt-wedge intrusion affecting the whole Traiano Canal branch, while in the Fiumara Grande one, it penetrated up to 8.8 km from the mouth. This datum agrees with previous studies (Capelli et al. 2007). According to Pritchard (1955), FG and TC can be classified as salt-wedge stratified estuary and a strongly stratified estuary respectively.
A Fast Fourier Transform analysis was realized on the Fiumara Grande, Capo Due Rami and Mezzocammino WG and the Anzio tidal gauge data. It exhibited that the river level fluctuation in all the WG stations has close connections with the tide, as demonstrated by the same dominant frequencies of fluctuation, (1.0 d^{-1}, 1.94 d^{-1} and 2.0 d^{-1}). Given that the Tiber is subject to tidal fluctuation, it can be classified as a tidal river. The cross correlation showed that the tide-induced river level fluctuation exhibits a delay moving away from the mouth. The delay was quantified in 48.53, 61.32 and 110.51 min respectively for Fiumara Grande, Capo Due Rami and Mezzocammino WG.
The wind statistical analysis was developed using the criterion of De Castro et al. (2000), which presumes that winds with a speed above 4 m/s are able to develop a current at the surface. The statistical analysis showed a very

high wind intensity in April (51.31% of the wind data held a wind speed higher than 4 m/s), when the wind pattern turned to westerly.
Wind action affected sea level, determining a raising effect. It is proved by the maximum average high-tide levels, that passed from the 0.01 m of March to the 0.23 m of April.
Consequently seawater was forced to sink near the entrance of the river branches mouth due to its higher density, with the development of a salt-wedge. Salt-wedge intrusion noticed in May, probably emplaced during April, as demonstrated by the similarity between the thermal seawater data of April (16.63 °C) and the surveyed ones at the river branches bottoms (16.68 °C and 17.03 °C for FG and TC respectively). Finally, the high discharge rate seemed to not obstacle the salt-wedge emplacement. In fact the WG showed a different dispersion of the standard deviation values about the average daily time-lags, calculated using the Cross Correlation of the WG data: nearby the mouths they showed low dispersions, proving that they are more subject to tidal influences, whereas the farthest one (Mezzocammino) showed a major dispersion, being more influenced by discharge rate. Therefore the influence of sea level fluctuation at the mouth is stronger and it can determine salt-wedge intrusion independently from the discharge rate (Manca et al. 2014).

Conclusions

Thermohaline measurements carried out in May 2012 showed that the Tiber River branches are affected by salt-wedge intrusion. The thermal values of seawater collected at the river branches bottoms in May showed a great similarity with those of seawater of April. Therefore the salt-wedge intrusion likely emplaced in April. In fact in that month the wind pattern turned to westerly and wind with a speed higher than 4 m/s represented the 51.31% of the overall dataset. Wind action was able to ominate the sea current at surface layers, determining an increase in the sea level from March to April (0.22 m). It forced to sink near the entrance of the estuary due to its higher density, developing a salt-wedge.

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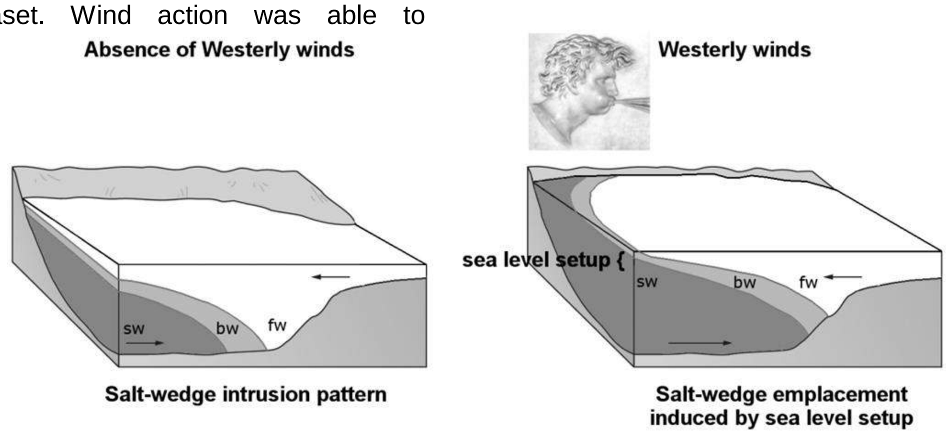

Fig. 1 - On the left is shown the salt-wedge intrusion in absence of wind action. On the right it is shown the westerly wind-induced sea level setup and the consequent salt-wedge emplacement. Sw is seawater, bw is brackish water and fw represents fresh water.

[13] VALIDATION OF AN UNSTEADY SCHEMATIC MATHEMATICAL MODEL AT THE DAILY TIME SCALE FOR COMPARTMENTALISED AQUIFER SYSTEMS: A STUDY CASE IN SOUTHERN ITALY

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Keywords: groundwater modeling, permeability fault zone, spring, equivalent porous media.

Introduction

Physically based mathematical models- developed for karstic hydrogeological systems- do not take into account permeability and hydraulic behaviour of fault zones, which are ruled out from modelling, as they were merely employed as physical constraint of the hydrogeological basin. The aquifer of Acqua dei Faggi (located in southern Italy) is a compartmentalised system bearing a considerable hydraulic link among the fault zones (Celico et al. 2006). Such specific-site features enabled to test the physical-mathematical modelling of a hydrogeological domain made up of a poorly hydraulic conductive wide fault zone and to analyse the related filtration dynamics. A validation of the conceptual hydrogeological model was carried out by means of groundwater pouring off into a complex basin-in-series aquifer system, in order to show the competence of low permeability fault zones in the control of the spills, the piezometric gaps and the spring rate of water flow supply. The area study is the northern portion of the Monte Matese carbonate massif, whose permeability is due to a network of fractures and, subordinately, karst conduits as well. The hydrogeological system also includes a perennial source and some seasonal springs, located close to the low permeability fault zone. Two piezometers were drilled into the experimental site, up-and down-gradient with reference to a low permeability fault zone. Both devices were equipped with pressure transducers and data-loggers (Fig. 1).

Hydrogeological model vs matematical model

The schematic conceptual model performed by Celico et al. (2006) was applied to implement the mathematical model. This pattern describes low-permeability fault zones allowing groundwater to flow from an up gradient compartment towards a down gradient one. The up gradient sub-basin is fed by the zenithal recharge and includes a seasonal spring. The down gradient sub-basin is fed by the zenithal recharge and the groundwater coming from the up gradient compartment. The unsteady dynamics of field motion can be distinguished in a remarkable (greater than 80 meters), fast fluctuation of the piezometric values, and in the quick water flow supply from the spring causing a complex operation of the model. The schematic conceptual model was run by using the same hydrogeological parameter values acquired through field investigations. A physically based, finite-difference mathematical model was developed aiming at simulating the basic time trends, such as the long-terms ones of the hydraulic heads from the piezometers located up-gradient and down gradient with reference to the low-permeability fault (Fig. 2). This model was implemented with USGS finite-difference code MODFLOW (McDonald and Harbaugh 1988), which allows the computational domain to be divided in discrete and appropriate cells by means of finite-difference method and to solve for each node of the balanced block the differential equation of the flow in porous media, under the condition of darcian motion.

Results and discussion

The steady state model was implemented by means of an uniform assigned value of the vertical recharge, which was kept equal to the mean estimated infiltration on the whole hydrogeological system (600 mm/y) The calibration produced the following results: 1) hydraulic conductivity values of carbonate rocks and fault rocks are respectively about 10^{-3} m/s and 10^{-8} m/s; 2) since the calibration between the fault zone and the remaining modelled area produced a high contrast of hydraulic conductivity, the model was regarded as unable to simulate the high hydraulic head loss between the up -and down-gradient compartments.

With reference to the unsteady state, the effective porosities of the two compartments were calibrated considering the withdrawal of the piezometric levels during the summer period. Instead, the daily recharge was adjusted by referring to the rainy periods (inter-withdrawal). Therefore, the unsteady state model was calibrated by means of mean piezometric levels from a time span of about five years. The calibration was divided into two steps. The former- that is the high constrain of rainfall input- was excluded, aiming at obtaining the effective porosity value (0.1 %) which can be able to best replicate (least error) the withdrawal behaviour of the piezometric head line, coupled with the hydraulic conductivity valued resulting from the steady state calibration (Angelini and Dragoni 1997). The latter-namely "trial and error" step-led to evaluate a characteristic monthly recharge value, which can trace out the trend of piezometric levels all along a time span of about five years. The main results are the following: 1) hydraulic conductivity values of carbonate rocks and fault rocks are respectively about 10^{-3} m/s and 10^{-8} m/s; 2) the computation domain contains the whole aquifer with a piezometric surface showing an impressive terrace framework (about 60 m), due to the fault zone. A slow but uninterrupted filtration flux developed in the fault displacement zone, so that the up- and the down-gradient sub-basin are hydraulically interconnected. Therefore the model can validate the functioning of the tested basin-in-series aquifer system (Celico et al. 2006), as well as to properly simulate the large fluctuations of the water level measured into the piezometers. Particularly, the highest calculated hydraulic head trends for the up gradient piezometer, as showing a regular flatted line, clearly point out that groundwater from the up gradient compartment flows out partly at the seasonal spring. Hence, the mathematical model also completely simulates the typical seasonal activation of the spring located along the low-permeability fault zone (Fig. 3).

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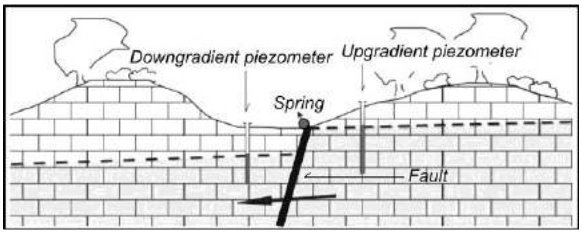

Fig. 1 – Acqua dei Faggi hydrogeological system; the arrow shows the mean flow direction.

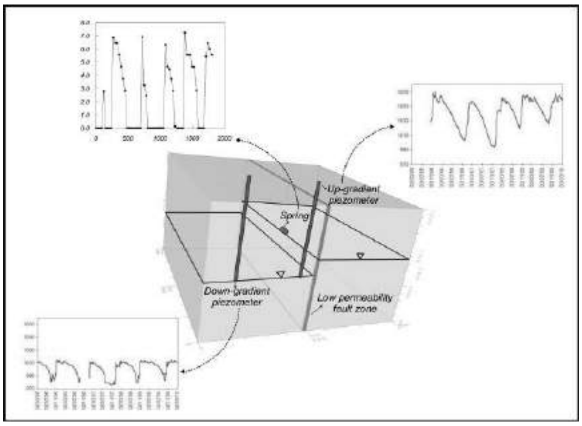

Fig. 2 – Schematic conceptual model for the groundwater flow of Acqua dei Faggi compartmentalised aquifer system (modified from Celico et. al. 2006).

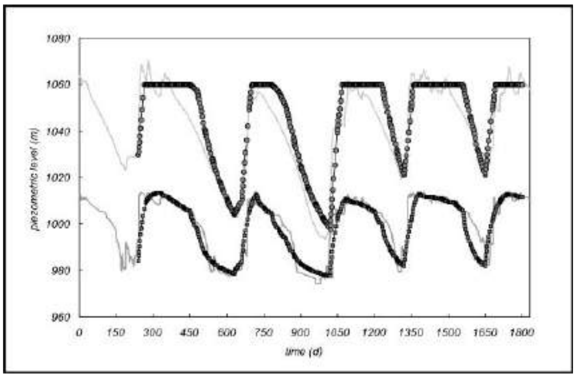

Fig. 3 – Piezometric observed values (straight line) vs calculated (dots) values for the up-and down-gradient piezometers.

[14] BORON RICH GROUNDWATER IN CENTRAL EASTERN ITALY: MULTIDISCIPLINARY APPROACH TO DEFINE THE SOURCES OF CONTAMINATION

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Keywords: Boron, statistical analysis, groundwater natural contamination, hydrogeochemistry.

Introduction

The presence of boron in limestone aquifers of the Apennine Mountains, in aquifers of the intramontane basins and in alluvial aquifers of the Adriatic alluvial plains was assessed.

Boron (B) is normally considered a minor constituent within groundwater. However, in many Mediterranean areas, contamination with B is a serious problem that limits the use of groundwater for public water supply and irrigation.

More than 5% of the 653 monitoring points within the study area show B concentrations that are above the limits (1000 µg/L) set by Italian legislation (D.Lgs. 152/06), with maximum values that reach 7600 µg/L.

B can have a hydrothermal origin in many Mediterranean areas or can be associated with salinisation of groundwater. B is also widely used in various industries, including those of ceramics, glass and detergents (Pennisi et al. 2006; Gimenez Forcada and Morrel 2008).

B presence within groundwater was assessed through hydrochemical and statistical factorial analysis. It was possible to identify 2 groups of B rich groundwater (Palmucci and Rusi 2013).

In the first group, B presence is attributable to natural contamination, while in the second one, anthropogenic pollution cannot be excluded.

Isotopic analyses ($\delta^{11}B$) in progress on 2 sample areas (Saline and Vomano alluvial plains), will be useful to distinguish more carefully contamination caused by anthropogenic activities from natural pollution.

Materials and methods

Groundwater chemistry was assessed through more than 2400 chemical analyses, undertaken between 2010 and 2012 on groundwater samples. In addition to the above, approximately 360 soil chemical analyses from 302 monitoring points were observed.

Groundwater chemistry was compared in relation to the location and geology and the analyses were classified according to Piper and Schoeller (Fig. 1).

The B concentration in groundwater was compared to the soil concentration.

Principal Component Analysis (PCA) was undertaken and its interpretation was useful to assess the genesis of the different groundwater's groups. In order to distinguish natural from anthropogenic origin, isotopic B ratio will be used.

Results

The analysis of B distribution showed that the highest concentrations are found in alluvial aquifers of fluvial valleys. Groundwater from limestone aquifers and from intramontane basins aquifers of the Apennine do not show boron contamination.

Survey of soil showed that detected concentrations are generally very low, and only 2% of samples highlights significant concentrations (> 1 mg/kg).

Hydrochemical analysis found a strong correspondence between the presence of B and chloride-sodium facies with high saline content, negative redox potential and low values for the rSO_4^{2-}/rCl^- ratio (Fig. 1). Within the assessed geological context and basing on the great distance from the coast, the genesis of these groundwaters can be correlated to the uprise of deep waters which is naturally enriched with these three elements (Desiderio et al. 2010; Palmucci and Rusi 2013).

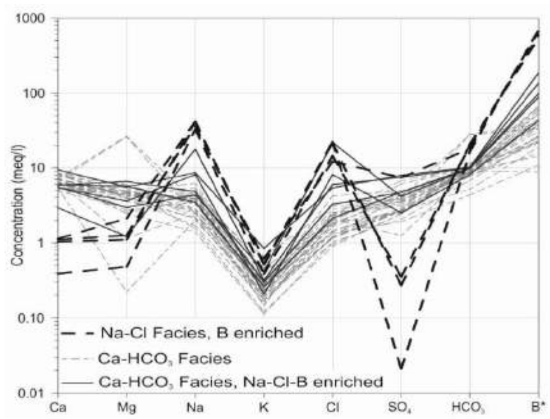

Fig. 1 – Modified Schoeller diagram. B indicates that the boron concentration was multiplied by 10^3.*

Principal Component Analysis confirmed the findings obtained from the hydrochemical analysis. The first principal component (PC1) is characterized by very high loadings of EC, Na^+, Cl^- and B as well as a significant negative loading for the redox potential (Fig. 2).

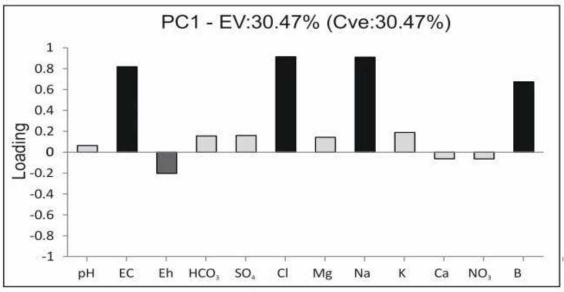

Fig. 2 – Loading plot for the PC1 component.

The presence of B in this component indicates that this element is strongly related to the presence of chloride-sodium waters characterized by low or negative redox potential and high saline levels. As these groundwaters are connected to the uprise of connate waters, the presence of Na^+, Cl^- and B is likely of natural origin. Both the hydrochemical analysis and the PCA have permitted identifying a group of samples characterized by high concentration of B, not associated with the presence of Na^+, Cl^- and high saline levels. For these samples the connection with the connate groundwater is less likely and it cannot be excluded that the anomalous presence of B within the groundwater is connected to anthropogenic activities.

Conclusion

Boron has an almost ubiquitous presence only in correspondence of alluvial aquifers of fluvial valleys where the highest concentration are reached. Analysis of soil samples excluded that the soil could be the origin of the B contamination in groundwater.

The hydrochemical analysis and the PCA have permitted identifying a group of samples characterized by high concentration of B, Na^+, Cl^-, high saline levels and low or negative redox potential, whose genesis can be correlated to the uprise of connate waters. For these samples the natural origin of B is the most likely. Furthermore, a group of samples, in which, the anomalous presence of B, is not connected to any of the markers that have been previously described (Na^+, Cl^-, EC, Eh) was identified. For these samples the anthropogenic origin of contamination cannot be excluded.

The execution of isotopic analyses will allow to discriminate more carefully the genesis of contamination.

Theoretical basis of the method are based on the different isotopic ratio that characterizes the two main chemical species in which B is present in nature ($B(OH)_3$ and $B(OH)_4^-$). The $^{11}B/^{10}B$ ratio of $B(OH)_3$, is about 20-27‰ higher than $B(OH)_4^-$. Dissolved B can be easily removed from the fluid and adsorbed by clay minerals (Spicvack et al. 1987; Williams et al. 2001). The borate anion ($B(OH)_4^-$) is more easily adsorbed due to its tetrahedral form. Thus, B adsorption by clay minerals, leads to $B(OH)_3$ enriched solutions that are enriched in heavy isotopes or rather with a strong positive isotopic ratio (Pennisi et al. 2006). The clearest example of B-isotope fractionation, linked to B adsorption onto clay minerals, is represented by sea water that shows a constant $\delta^{11}B$ value of +40‰.

B-isotope fractionation produces large variations in the $^{11}B/^{10}B$ ratio, thus $\delta^{11}B$ is an important parameter to characterize groundwater from different geological environments.

Connate waters, naturally enriched in B, have a strong positive isotopic signature, comparable to sea water, that is substantially different from the isotopic signature of anthropogenic pollutants. For these reasons, it is believed that the definition of the B isotopic ratio ($\delta^{11}B$) can identify with greater certainty the origin of the contamination.

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[15] INTEGRATED PLUME TREATMENT WITH PERSULFATE ISCO AND MICROBIALLY MEDIATED SULFATE REDUCTION (IBR): A FIELD EXPERIMENT

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Keywords: treatment train, ISCO, IBR, monitoring tools, CSIA, molecular biology

Introduction

The coupling or sequential use of two or more treatment technologies is believed to provide more efficient and extensive removal of a range of environmentally relevant contaminants including petroleum hydrocarbons (PHCs) (Tsai et al. 2009). Coupling of different remediation technologies combines the strengths of each individual technology to improve treatment performance. The sequential use of in situ chemical oxidation (ISCO) and intrinsic bioremediation (IBR) is an example of a treatment train approach. The notion behind a persulfate ISCO/IBR treatment train is that it could potentially combine the aggressive nature of persulfate ISCO in the source zone with the long-term efficiency of subsequently enhanced sulfate reduction in both the source zone and downgradient plume (Richardson et al. 2011). To design an effective and efficient persulfate treatment train, it is necessary to have a comprehensive understanding of all the relevant physical, chemical and biological processes occurring in the subsurface system. The primary objective of this research is to develop a better understanding of the characteristics of a coupled persulfate ISCO/IBR treatment train by executing a carefully monitored pilot-scale field experiment. Additionally, novels site characterization tools were used to assess the performance of the treatment system.

Methods

The pilot-scale field experiment was conducted at the University of Waterloo Groundwater Research Facility at the Canadian Forces Base (CFB) Borden, ON, Canada. A dissolved BTX plume over 170 days with maximum concentrations of approx. 15 mg/L was created using a diffusive source. An anaerobic aquifer system was fully developed prior to persulfate injection. The anaerobic aquifer is intended to provide a favorable condition for the acclimation and growth of indigenous sulfate reducing bacteria (SRB). A persulfate solution was injected at day 170 and 180, and the plume monitored during 391 days in total. Numerical modelling has been used to optimize the design of the persulfate injection system.

BTX concentrations, compound specific isotope and microbiological analysis were conducted to investigate the performance of the treatment train, the effect of the injected persulfate on the population and activity of sulfate reducing bacteria indigenous to the Borden aquifer and finally to differentiate concentration reduction processes (e.g., biodegradation vs chemical oxidation).

Results

The BTX plume was partially remediated. An average degradation of 50% because of the ISCO was estimated using BTX concentration and $\delta\ ^{13}C$ and $\delta\ ^{2}H$ results. The remaining fraction was degraded because of the mediated sulfate reduction processes for most part of the plume (Fig. 1). A detectable growth of indigenous sulfate reducing bacteria was shown by qPCR r and key metabolites concentration results. The coupling $\delta\ ^{13}C$ and $\delta\ ^{2}H$ indicated a different and specific trend for chemical oxidation and biodegradation processes for benzene only (Fig. 2).

Conclusions

Induced biodegradation under stimulated sulfate reduction condition following a persulfate ISCO treatment was successfully demonstrated. Compound specific isotope analysis and molecular biology methods are powerful tools in evaluating the performance of these type of combined remediation techniques like persulfate ISCO/IBR treatment trains.

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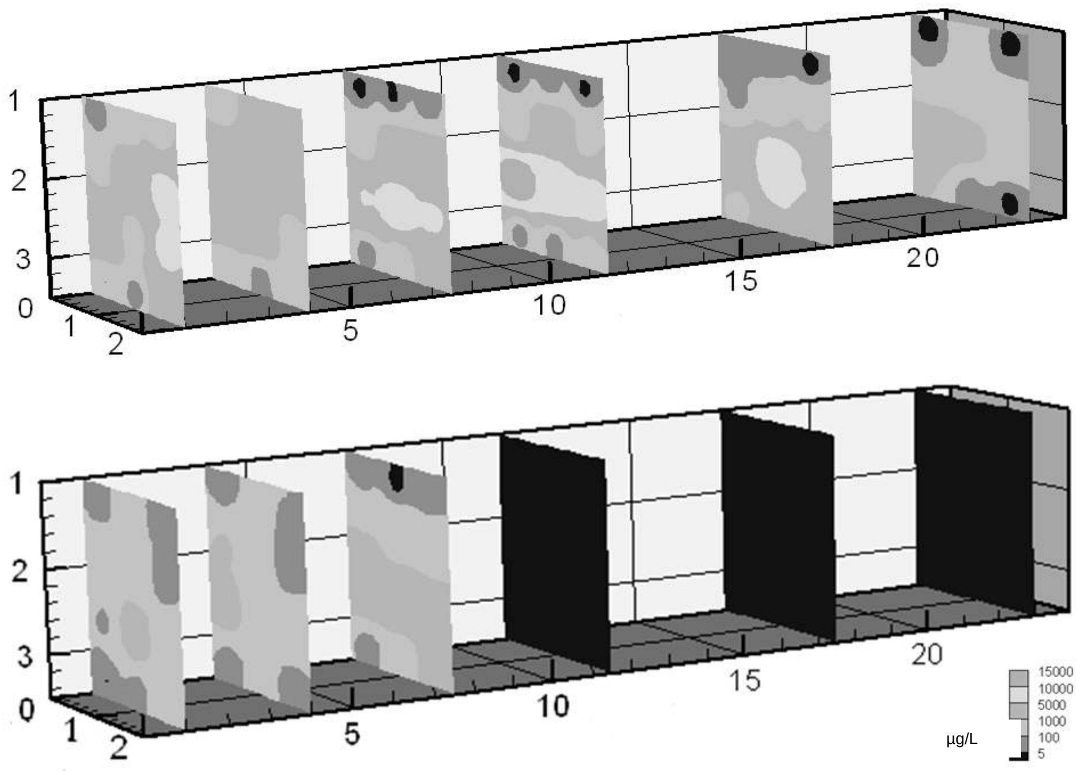

Fig. 1 – Benzene concentration in µg/L at day 170 (on top, before the injection) and day 391(below); the plume is moving from left to right. The persulfate was injected in between Row 1 and Row 2 (located at the left side).

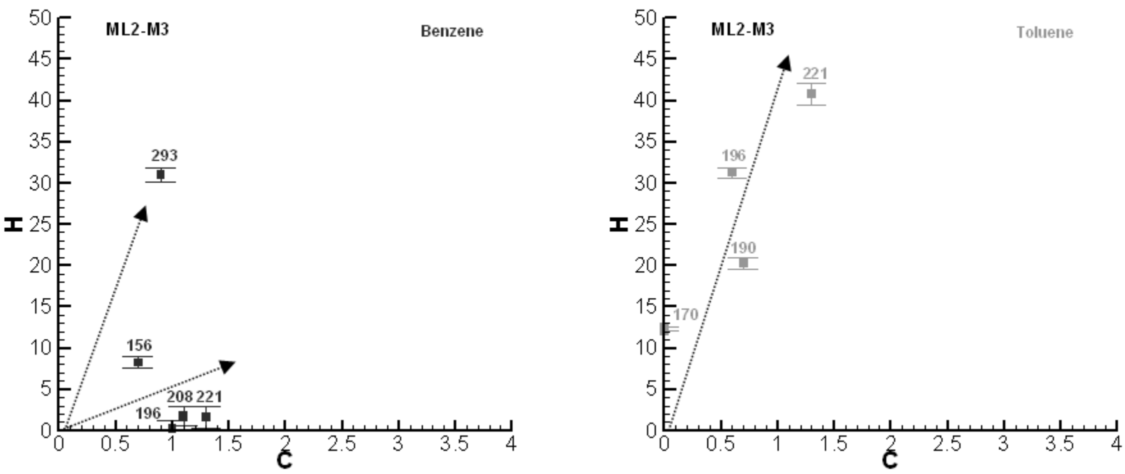

Fig. 2 – Δ δ ^{13}C and δ ^{2}H (‰) for Benzene (left) and Toluene (right) at Row 2 multilevel M3; the numbers at the top refers to the sampling date.

SESSION 2

Groundwater quality protection

Chairs: Fulvio Celico, Marco Doveri

[16] ENVIRONMENTAL TRACERS AS A TOOL IN GROUNDWATER VULNERABILITY ASSESSMENT

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Keywords: groundwater, vulnerability, environmental tracers

Introduction

Groundwater is subjected to different pressures such as exploitation, pollution, changes in land use and climate patterns. The availability and quality of groundwater is significant not only to its use for human consumption but also to maintaining surface water quality and to ecosystems dependent on groundwater. The management of groundwater resources must consider risks to groundwater users and to the environment caused by pollution and other anthropogenic pressures (EC 2010). Vulnerability of particular groundwater receptors to pollution depends on those physical properties of groundwater systems that control flow paths and rates of pollutant transport. However, the most common approaches to vulnerability assessment are not physically based and, in particular, do not take into account time scales of pollutant spreading. The environmental tracers appear in this context as a significant tool to investigate functioning of groundwater systems in a wide range of spatial and temporal scales. This paper discusses specific applications of tracer methods in the physically based assessments of vulnerability of groundwater receptors to pollution basing partly on the results of the 7th Framework Programme project GENESIS (www.thegenesisproject.eu).

Environmental tracers

In a broad sense, the environmental tracers can be seen as physical properties and dissolved constituents of water whose spatial and temporal differentiation are be used to infer properties of groundwater systems. These properties are related to either origin, movement and mixing of water or to origin, transport and transformations of solutes. Tracers provide also information on groundwater age – time elapsed since water entered the subsurface (Newman et al 2010). Applications of environmental tracers in hydrology and hydrogeology are well established and are described in a number of monographs (e.g. Cook and Herczeg 2000; Mook 2001; Kazemi et al. 2006; Leibundgut et al. 2009). Table 1 presents some commonly used environmental tracers and their typical applications.

Tracer	Typical applications
$\delta^{18}O$, $\delta^{2}H$ (H_2O)	Origin and mixing of waters; residence time of water in the unsaturated zone and small catchments; estimation of recharge rates
^{3}H	Identification and dating of young groundwaters; estimation of recharge rates
Freons, SF_6	Identification and dating of young groundwaters
^{14}C	Discrimination between young and older groundwaters
Water temperature	Quantification of groundwater – surface water exchange
^{222}Rn	Identification of groundwater outflows to surface water bodies
$\delta^{18}O$, $\delta^{15}N$ (NO_3^-)	Identification of sources; evidence for denitrification
$\delta^{13}C$ (organic compounds)	Identification of sources; characterization of degradation processes

Tab.1 – Typical applications of environmental tracers.

Applications of tracers in vulnerability assessments

The ability of environmental tracers to give information on the origin, flow paths and ages of groundwater makes them a useful tool in the physically based assessments of the intrinsic vulnerability. Firstly, tracers can be used to identify connections between recharge areas and receptors (Zuber et al. 2008) and to identify and quantify groundwater fluxes to surface water bodies and to groundwater dependent ecosystems (Bertrand et al 2012). Secondly, residence time of water or solutes provided by tracers is a pragmatic indicator of vulnerability. For example, occurrences of tritium or anthropogenic trace gases (e.g. freons) in groundwater indicate that they were recharged during the last few tens of years and are thus vulnerable to pollution. On a more sophisticated level, the tracer data and lumped-parameter or numerical models of transport are used to derive the residence time distributions which fully characterize responses of groundwater receptors to pollution (Eberts et al 2012). Knowledge of these temporal characteristics of pollutant transport is also important for the risk management because responses of groundwater quality to the undertaken or planned measures are characterized by time lags associated with spreading of pollution through groundwater systems and catchments (Witczak et al 2007).

Finally, stable isotope compositions of carbon and nitrogen are used to identify and characterize sources and transformations of organic pollutants (Nijenhuis et al 2013) and nitrates (Kendall and Aravena 2000) in groundwater. Such information is of great value in assessments of the specific vulnerability where retardation and decomposition of the reactive pollutants need to be addressed.

Conclusions

The environmental tracers are an indispensable tool in assessments of both the intrinsic and specific groundwater vulnerability. Main advantages of tracers over the more conventional methods are that they: (i) integrate information on the physical and biogeochemical processes occurring in the groundwater environment over a wide range of spatial and temporal scales, (ii) quantify time scales of groundwater flow and pollutant transport. Recent technological developments, including the advent of the cavity ring-down spectrometers for determination of stable isotope composition, will contribute to the further dissemination of tracer methods in the management of groundwater resources.

Acknowledgements

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[17] PLANNING ACTIONS FOR CONTROLLING SALTWATER INTRUSION COUPLING SEAWAT AND GLOBAL INTERACTIVE RESPONSE SURFACE: THE NAURU ISLAND CASE STUDY

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Keywords: response surface; groundwater; optimization; saltwater intrusion

Introduction

Several infrastructural interventions can be implemented to limit or avoid seawater intrusion in coastal aquifers, including scavenger wells and infiltration galleries. Their optimal design can be decided by solving a multi-objective optimization problem balancing freshwater availability and costs, simulating the effects of the options with a density dependent flow-transport model. The integration of these models within an optimization-based planning framework is not always straightforward due to computational limitations of the model and of the optimization algorithms. Combinations of optimal decision-making and high resource demanding groundwater models on coastal aquifers have been explored widely in literature (Ferreira da Silva and Haie 2007; Kourakos and Mantoglou 2008). In this study it is investigated the use of a new methodology, the Global Interactive Response Surface (GIRS) (Castelletti et al. 2010), to design solutions for preventing saltwater intrusion. GIRS procedure is used to iteratively build a non-dynamic emulator of a 3D groundwater model, relating the design options and the objectives and can be used in place of the original model to quicker explore the design option space. This approach is used to plan an infiltration gallery to control seawater intrusion, ensuring sustainable groundwater supply for a small Pacific island. GIRS is used to emulate MODFLOW-SEAWAT2000. Results show the applicability of the GIRS approach for optimal planning in coastal aquifer cases, comparing to classical ‘what-if’ expert-based analysis.

Global Interactive Response Surface Method

This work presents some results of the NAURU project, funded by EXPO 2015, which has the objective to improve groundwater resources development in Pacific small islands [1]. This paper is focusing on the design of an infiltration gallery using, as process-based model, MODFLOW-SEAWAT2000, a 3D density-dependent flow-and-transport model developed by USGS. Nauru Republic is a small limestone island located in Central Pacific area, that suffers of periodic droughts due to ENSO (El Niño-Southern Oscillation) effects. The fresh groundwater (GW) resource is very limited, represented by small lenses few meters thick. GW flows radially from the center of the island toward the sea with gradient of 0,02%. Due to huge hydraulic conductivity (>500 m/d) of the limestone, fresh water mixes very fast with saltwater. Consequently the thickest lenses (5 m) were found only along coast line where fine sand sediments having a lower K (10 m/d) could store fresh water for a longer period (Alberti et al. 2011). Salt concentrations distribution in GW were simulated through a calibrated SEAWAT model implemented for the half north part of the island where was found one of the main fresh water lens. Thanks to model results, infiltration galleries were selected as the most suitable technology for this case. The gallery is to be installed orthogonally to the main flow direction, considering three variables: the location Y (distance from the coast line), its length L and the pumping rate per unit of length q. Every option is simulated with SEAWAT over a 5 years horizon using constant pumping rate. Since total number of feasible alternatives is 15,000, an exhaustive search with SEAWAT is computationally expensive (at last 12 hours for a single simulation run). The three objectives (outputs) considered are the following: minimization of the cost for cubic meter of freshwater extracted (*unitary cost*), minimization of the average concentration exceeding freshwater threshold concentration (*water quality*) and minimization of shortages and surplus in freshwater supply with respect to water demand for civil use (*water quantity*).

In a planning project, an alternative is univocally represented by a vector of decision variables. The set of the efficient solutions can be obtained by solving a multi-objective minimization problem (MO) of a performance indicators (objectives) set of economic, water quality and quantity targets via a function relating inputs and outputs (I/O relation). This relation is reproduced accurately through a process-based model but its computational complexity makes it impossible to solve the MO problem. To overcome such limitations, in this work, Global Interactive Response Surface (GIRS) approach was tested. Based on the Response Surface (RS) method, originally proposed by Box and Wilson (1951) it performs in an iterative way the following steps: an initialization phase where initial input dataset is chosen; a learning phase in which indicators are computed via simulation of a set of alternatives with the process-based model to identify an approximate I/O relation (e.g. the response surface, RS) via interpolation of I/O simulated; finally a planning phase, where the MO problem is solved replacing original I/O relation (e.g. the process-based model) with the RS and then the Pareto front (e.g. the set of solutions for which no other alternative is better for all the objectives) is analyzed to select efficient solutions to be simulated at the following iteration. Procedure is completed by a termination test.

Results and discussion

GIRS methodology was applied with the goal of finding improved solutions at small additional computational cost with respect to those obtained via 'what-if' analysis by a field expert from Politecnico di Milano. The initial sample data set of input (decisions) and output (objectives) values was built using a subset of alternatives chosen with Latin Hypercube sampling technique.

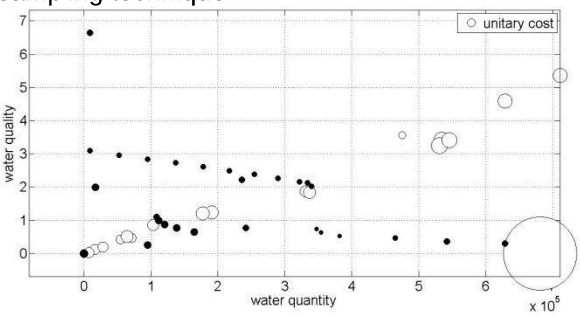

Fig. 1 - Performances of the alternatives obtained by the expert (white circles) and the GIRS methodology Pareto-efficient ones (black circles). Circle dimension represents cost objective.

Procedure was stopped at the third iteration as the variation of the hypervolume of the objective space dominated by the Pareto front from previous iteration was under a 2% chosen threshold (termination test). The response surface of the three objectives was obtained using feedforward neural networks, obtaining good performances for the water quality objective (R^2=0.99), the water quantity objective (R^2=0.7) and the unitary cost objective (R^2=0.7), and more importantly, simulating with SEAWAT only the 0,5% of the overall alternative set. The performance of the Pareto-efficient solutions computed using GIRS approach and those obtained by the expert are reported in Figure 1. GIRS approach was able to single out more solutions than the expert, whose solutions are Pareto dominated, and moreover mostly concentrated in the compromise region of the Pareto-front where generally solutions are not only efficient but also fairly balanced among the objectives.

Conclusions

In this paper the Global Interactive Response Surface (GIRS) approach combined with SEAWAT simulations, is adopted to optimally designing a horizontal gallery for controlling saltwater intrusion in the aquifer of Nauru. Results show that GIRS is able of obtaining a higher number of approximated Pareto-efficient solutions at small additional computational cost with respect to an expert running a 'what-if' analysis. Future research will explore the space for improvement by fully exploiting the potential of the GIRS methodology to emulate high-resource demanding models.

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[18] HYDROGEOLOGICAL AND HYDROCHEMICAL RESEARCHES IN THE UPPER VICENZA'S PLAIN: RESULTS ACQUIRED AND DEVELOPMENT PROGRAM FOR GROUNDWATER PROTECTION

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Keywords: unconfined aquifer, monitoring, groundwater protection

Introduction

The present study comes from hydrogeological experiences collected around Vicenza's area aquifers starting from the 80s (Sottani et al. 1982).

Vicenza's plain area holds precious and productive groundwater resources, widely used by the population (Bullo et al. 1994). The aquifers are intercepted by several public wells, thus feeding a network that is 9300 km wide and serves up to 1.050.000 users, other than thousands of private wells.

The studied area, where the majority of groundwater recharge takes place, is also peculiar from a hydro chemical point of view.

Vulnerability of alluvional deposits is in fact very high, mainly because of high permeability of gravel deposits. The presence of several industrial areas or farming activities on the surface represents an ever present risk of pollution (Altissimo et al. 1990).

Materials and methods

Systematic activities have been integrated into the monitoring program as part of the management of drinking water networks, along with the setting up of monitoring stations and scientific goals.

Initially, different monitoring networks were compared (Fig. 1) in order to determine the best distribution and monitoring network of wells according to hydrological structure of the plain.

Geostatistical analysis was also used in order to identify areas needing further attention.

Experimental activities were also carried out with in situ measurements of groundwater temperature and electrical conductivity. These measurements, performed by vertical logs, help to determine chemical/physical differences in a saturated environment.

Covering an area of 520 km^2 and counting almost 150 points, the final network was considered for sampling activities to analyze groundwater chemistry.

Quality measurements take into account natural elements like NA, K, SO_4, Cl and anthropic ones such as NO_3, VOC, etc. circulating inside the aquifers. Data coming from northern plain area in between Brenta and Agno-Guà rivers are meant to complete the historical database and to improve our knowledge of the aquifer nearby the northern Vicenza area.

Discussion

Interpretation of data allowed to trace a detailed map of groundwater deposit and flow for the whole area. The monitoring network has been analyzed so that the most significant hydro-geological factors are highlighted. Factors such as drainage axes and hydrogeological watersheds, other than local variation of hydraulic gradient connected to the deep structures. (Passadore et al. 2012).

The description of aquifer chemical/physical features made by using logs allowed the mapping of temperature distribution all over the province (Fig. 2). This search was key in pinpointing and measuring river dispersions (USGS 2003; Cox et al. 2007).

Following this first screening, a few detailed studies of these areas have been planned.

In the upper plain area, in fact, the riverbeds leakage is the main factor in contributing to the re-charging of groundwater. Moreover, the easily measurable temperatures have been used to analyze the effects of both natural and artificial re-charging.

Mappings show the peculiarities of the Vicenza area caused by different geological and hydrological conditions in main mountain basins.

Mappings also show pollutants groundwater flow that have been monitored for years (Fig. 3) thanks to this sensors network and logs.

According to law, these activities are considered essential in a dynamic management for prevention process for groundwater supply wells.

In general, these kind of detailed mapping is used in many different application, such as zoning background values, determining areas suitable for geothermal plants and groundwater protection zone.

Conclusions

This study aims to increase the knowledge of the hydrogeological structure and to improve the management of Vicenza's area aquifers.

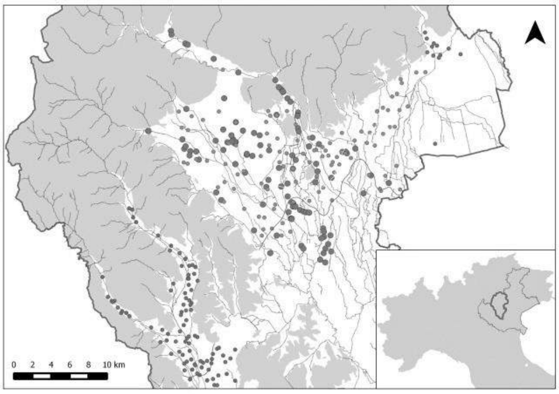

Fig. 1 - Domain of research and monitoring network.

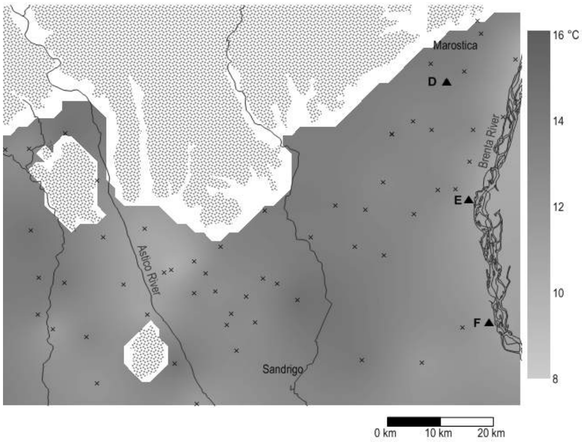

Fig. 2 - Temperature distribution.

The researches combine chemical analysis with hydrogeological and physical elements and highlight recharging and pressure values all over the province.

This combines approach proves a key screening tool to plan detailed further studies aimed at supporting aqueducts managers (protection of quantity and quality).

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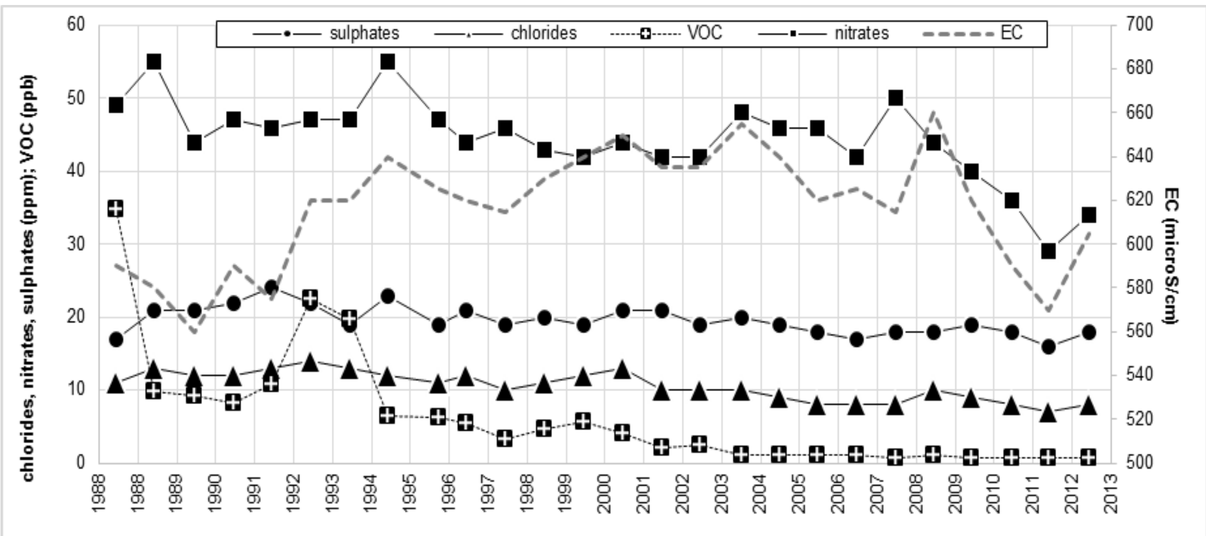

Fig. 3 - Hydrochemical trends example: data from 1988 to 2013 in one of the monitoring well (ID=TH24).

[19] THE ROLE OF PERCHED AQUIFERS AND DOME-IMPOUNDED GROUNDWATER IN DRINKING WATER SUPPLY IN THE CIMINO-VICO VOLCANOES (CENTRAL ITALY)

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Keywords: Cimino-Vico volcanoes; perched aquifer; dome-impounded aquifer; drinkable resources.

Introduction

The volcanoes of central and southern Italy constitute aquifer systems with average yield from 0.005 to 0.02 m^3/s per km^2. These aquifers are widely used for drinking water supply, irrigation, industry, water bottling and therapeutic purposes. The type of volcano, hydrostratigraphy and volcano-tectonic settings control the flow in the aquifer systems, originating complex circulations. Waters frequently show different qualities, which strongly influence their possible use for drinkable purposes, especially in relation with the geogenic contamination by arsenic and fluoride (e.g., Baiocchi et al. 2011; 2013).

This study examines the role of the groundwater flows at high elevation (HGW) in the Cimino-Vico volcanoes (central Italy), at present poorly understood. Hydrogeological and hydrochemical investigations were carried out on a surface area of 55 km^2 (Fig. 1) to examine the origin, the yield and the quality of the HGW.

Material and Methods

The study area is located within the Cimino and Vico volcanic complexes (Fig. 1). The Cimino volcano was active between 1.35 and 0.95 Ma and gave rise to rhyodacitic ignimbrites and domes as well as latitic and olivine-latitic lavas. The Vico volcano is a stratovolcano that was mainly active between 419 ka and 95 ka. It gave rise to ignimbrites, pyroclastic fall deposits and lava flows, which are phonolitic, tephritic and trachytic in composition (e.g., Sollevanti 1983).

The hydrostratigraphy of the area was reconstructed based on the interpretation of lithologic logs and specific surveys. Flow measurements of 10 springs and 15 stream sections were conducted in 2011 and 2012, using tanks or current meters. Water level, temperature and electrical conductivity were measured in 10 wells with depths from 5 to 100 m.

Hydrological budget was estimated based on the monthly values of precipitation and temperature of 9 meteorological stations. Actual evapotranspiration was determined by the Thornthwaite-Mather method. Effective infiltration was estimated for two representative basins (Fig. 1).

A total of 30 sources were sampled during the 2012 surveys. Temperature, pH and electrical conductivity were measured on the field, as well as alkalinity, determined by means of titration. Major anions (Cl^-, SO_4^{2-}, NO^{3-}) and fluoride (F^-) were determined by ion chromatography. Major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) were determined by atomic absorption spectrophotometry. As was determined by ICP-MS.

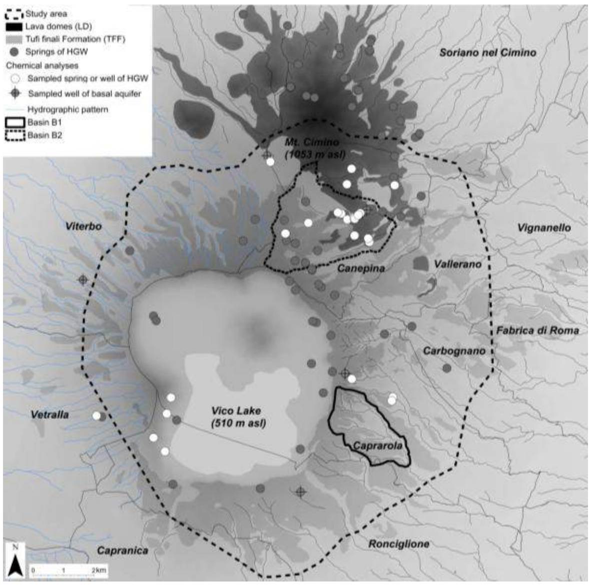

Fig. 1 – Location of springs at high elevation in the Cimino-Vico volcanic system.

Results and Discussion

Several springs and gaining streams were detected at altitudes between 560 and 800 m asl (Fig. 1), mainly falling at the edge of the last products of the Vico volcanic complex (Tufi Finali Formation; TFF) and of the lava domes of Cimino volcanic complex (LD).

In the first case, groundwater outflow is related to perched aquifers, having the basal aquifer in the area piezometric levels between 400 and 500 m asl. The origin of these springs is due to the presence of ash deposits and paleosols in the TFF and at its base, which locally reduces the permeability of the formation constituted by layers of pumice and scoria.

Springs at the edge of the LD had always been related to perched aquifers, but the detailed reconstruction of the hydrogeological scheme, together with the results of numerical models developed in this area (Di Luca et al. 2014), led to consider the presence of dome-impounded groundwater, as reported for other volcanoes (e.g., Takasaki and Mink 1985). The latter interpretation would be consistent with the significant increase of the hydraulic gradient of the basal aquifer at the transition between the lava domes and volcanics that surround them.

An estimation of groundwater resources was conducted with reference to two basins for which more data were available (Fig. 1). In the first basin B1 (surface area of about 4 km^2), a perched aquifer in TFF was detected, an effective infiltration (R) between 20 and 30 L/s was estimated and a total flow from springs linked to perched aquifer (Qs) of 2 L/s was measured. The resulting percentage of effective infiltration discharging to the springs (IFS = Qs/R × 100) is between 7-10%. In the second basin B2 (surface area of about 9 km^2) springs from LD are present, an effective infiltration (R) between 40 and 70 L/s was estimated and a total flow from springs (Qs) of 5 L/s was measured. Therefore an IFS index of 7-13 % results.

Subsequently, a total HGW of 20-30 L/s for the TFF and 10-20 L/s for the LD was potentially estimated, on the basis of the effective infiltration of the total surface areas of the TFF and LD falling in the study area and using the values of the IFS calculated for B1 and B2.

Waters were sampled from 5 wells of the basal aquifer, 13 wells and springs of the TFF perched aquifers and 12 springs of the DL. All the sampled waters exhibit a homogenous hydrochemical facies (Fig. 2): they are calcium-bicarbonate waters that are characterized by a temperature of 11 to 17 °C, a pH of 6.7 to 7.8, and a specific electrical conductivity between 183 and 531 μS/cm.

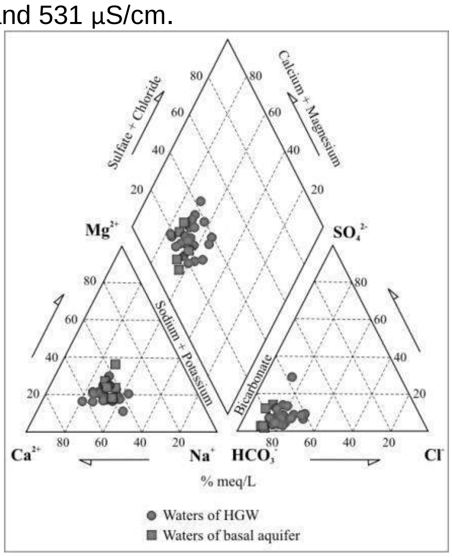

Fig. 2 - Piper diagram of sampled waters.

The waters only show differences in the concentration of the minor and trace constituents. A nitrate concentration lower than 10 mg/L characterizes most of the sampled waters; higher values (11-50 mg/L) have been found in 4 springs located in rural areas. The lowest arsenic concentration (2-10 μg/L) concern the spring and well waters of the TFF and DL, while the waters of the basal aquifer are richer in arsenic (15-38 μg/L).

Conclusions

The HGW of the Cimino-Vico volcanic system is related to the presence of a complex hydrostratigraphy, which implies a vertical heterogeneity of the hydraulic conductivity. The perched aquifers and/or dome-impounded groundwater flow to the surface by means of several springs with low discharges, flowing also directly into the upper branches of local streams. In the study area, 7 to 13 % of the total recharge feeds springs and streams at high altitude. The waters of these aquifers are of high quality, being characterized by low contents of As. On the contrary, the waters of the basal aquifer are characterized by geogenic contaminants often exceeding the maximum admissible concentration for drinking water (10 μg/L).

Even though the yield of HGW represent only a fraction if compared to the basal aquifer, the chemical characteristics can be of great interest for the local request of drinking water. New approaches to tap safe drinking water can be inferred from the promising results of the investigations.

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[20] REVIEW ON AVAILABLE DATA ABOUT NATURAL BACKGROUND LEVELS OF DISSOLVED ELEMENTS IN THE GROUNDWATER OF ROME (ITALY)

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Keywords: Rome, Groundwater, Natural Background levels, Pollution

Introduction

Natural background levels (NBL) of groundwater, are defined as the concentration of a given element, species or chemical substance present in solution of a groundwater body which is derived by natural processes from geological, biological or atmospheric sources. Substances need to be understood in the context of their geochemical setting. This may often be difficult where substances exhibit high NBL in relation to any presumed anthropogenic component (Hart and Müller 2006).

In this note a review about currently available data of NBL in groundwater of Rome (central Italy) is presented in order to plan further studies about all the municipality area.

Main Body

Establishment of natural background levels (NBL) for groundwater is commonly performed to serve as reference when assessing the contamination status of groundwater units (Griffioen et al. 2008).

Background levels in groundwater are the result of water–rock interaction, chemical and biological processes both in the vadose and saturated zone, relationships with other water bodies, atmosphere and rainfall composition. For this reason, spatial variation of background level of a substance present in solution in a specific groundwater body can be huge and a single value may be difficult to define (Preziosi et al. 2010).

Several studies have been carried out in Europe and in Italy (Molinari et al. 2012; Hynsby and Condesso De Melo, 2006) to evaluate thresholds of NBL in groundwater and soils and many of those were commissioned by government authorities in order to manage drinkable water supply and also the real pressure of contaminated sites and/or their identification.

In the Latium Region the only commissioned studies, right now, are related to specific evaluation of thesholds of NBL for water supply and for some important potentially contaminated sites (IRSA/ENEA 2010), and moreover there are several scientific published works by research institutes and universities (Vivona et al. 2007; Preziosi et al. 2010; 2014).

The area of Roma Capitale (Municipality of Rome) has a particular geological and hydrogeological setting. It is in fact strongly influenced by the coexistence of tectonic activity, volcanism of several volcanoes (the Vulsini, Cimini, Sabatini volcanic complex northward, the Colli Albani volcanic complex to the south) and eustasy. By a general hydrogeological point of view, the roman area is placed between three regional structures and the aquiclude of the Pliocene Clays (which can be considered the bedrock of this area, with more than 800 meters of thickness).

Going into details, main aquifers of Rome are located in the Colli Albani volcanic pozzolanaceous products and in the continental and alluvial prevolcanic and sinvolcanic sediments. Moreover Olocene valleys, filled by postvolcanic alluvial sediments, are interested by a confined aquifer into the gravels placed in the base of the alluvial sequence (Capelli e al. 2008).

Thus there are 6 hydrogeological units that can be indentified: the aquiclude of M. Vaticano clayey Pliocene formation, the volcanic aquifers of Sabatini Volcano (right of Tiber), the volcanic aquifer of Colli Albani Volcano (left of Tiber), the continental aquifers of Paleo-Tiber and of Ponte Galeria Formation, the alluvial aquifers of the Tiber basin and fan. Looking at hydraulic relationships between these units, the main groundwater circulations which can be identified are: the basal Tiber alluvial gravel body, the volcanic and prevolcanic aquifer's body in the orographic left of Tiber, the volcanic and prevolcanic aquifer's body in the orographic right of Tiber, and the alluvial fan aquifer's body.

In this complex geological and hydrogeological setting the presence of many natural elements (i.e. As, F, V, Mn, Fe) and compounds dissolved in groundwater is widely documented, sometimes and somewhere exceeding the law thresholds, due to the volcanic and mineral nature of soils and hydrothermal activity. It's important to consider that some elements, naturally contained in soils, may be mobilized by pollution phenomena by changing physic and chemical parameters like Eh, pH, etc. so that their concentrations in groundwater may have also significant, local, not natural increase.

The lack of a general NBL aquifer zonation is a real problem to manage the water supply and the contaminated sites pressure.

Even if the best solution for the future NBL thresholds evaluation should be to plan a study regarding the whole territory and every existing aquifer, looking at the existing studies inside or close to the Municipality territory (Fig. 1) it can be shown which is the area with no data and which must be investigated in a first moment in order to obtain a first NBL diffusion in the Roma Capitale territory. Is important to underline that all these existing studies have not analyzed the same species. Many data about groundwater quality which could be easily used for these purposes are currently, for example, available at Regional Environment Protection Agency (ARPA Lazio) and other local administrations. These data could be a useful support to a scientific hydrogeological study which should be a good opportunity for government administrations to work together in order to apply the best groundwater management practices.

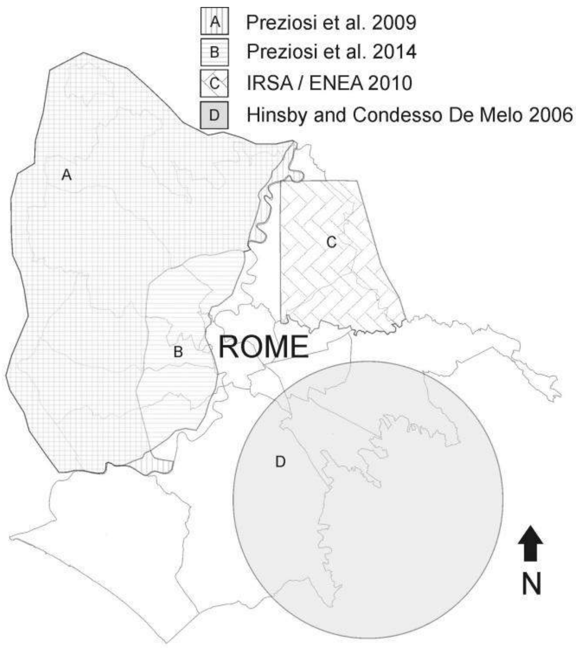

Fig. 1 – Location of the existing studies of NBL regarding the ROMA CAPITALE territory.

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[21] GROUNDWATER RESOURCES ASSESSMENT FOR A MONITORING NETWORK DESIGN IN THE UPPER BASIN OF SAMALÁ RIVER (SOUTHWESTERN GUATEMALA)

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Keywords: hydrogeology, monitoring network, Samalá River, Quetzaltenango, groundwater resources

Introduction

Guatemala is characterized by recent urban and industrial development with population growth rate nearly 2%. Therefore, accessibility to water resources represents one of the main social and political issues. The upper basin of Samalá River (Fig. 1), in Quetzaltenango Department, is one of the areas with the highest population and productive activities density. Groundwater is exposed to intense exploitation and contamination risk, thus needing qualitative and quantitative monitoring activities.

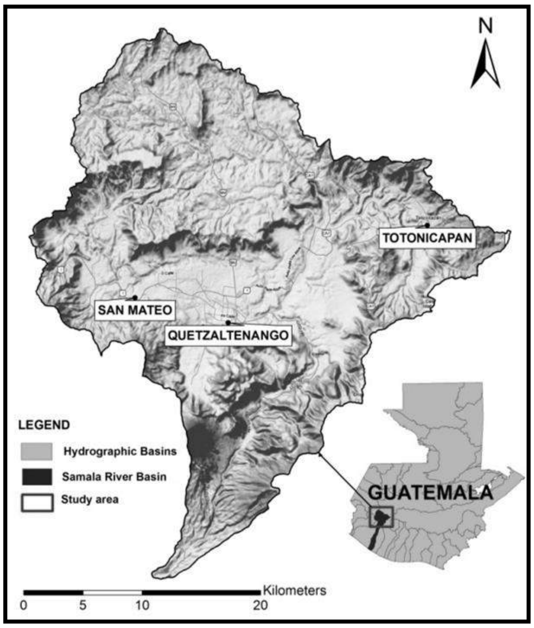

Fig. 2 - Study area location.

The present research aims to create a preliminary framework for the design of a groundwater monitoring network. Groundwater monitoring networks are designed in order to assess the qualitative and quantitative state of groundwater. Monitoring points generally include wells, piezometers and springs, selected after evaluating conceptual groundwater flow models within aquifer systems. Such points must be distributed in a more or less regular geometric pattern within the selected aquifers (De Luca et al. 1992). The monitoring network must be managed by local authorities; qualitative controls require an analytical protocol based on national water quality regulations. Groundwater monitoring network design in the upper basin of Samalá River consists in an early definition of the water qualitative-quantitative features, the analysis of groundwater resources exploitation and the preliminary location of water monitoring points. Preliminary geological and hydrogeological features have been yet defined by Rose (1987), INSIVUMEH (1988), Bennati et al. (2011) and Franchino et al. (2013). The bedrock, formed by Tertiary and Quaternary magmatic rocks, alternates highlands and lowered areas filled by thick layers of recent pyroclastic deposits. Those sequences generally host phreatic or just locally confined aquifers.

Materials and methods

Three field survey campaigns were performed in February 2011, May 2012 and November 2013. Field surveys and meetings with local authorities allowed to locate existing water supply sources, e.g. springs and drinking water wells (Franchino et al. 2013), among which the monitoring points could be chosen. Each water point was recorded with a synthetic description and with its geoposition, acquired through a portable GPS device. In order to assess groundwater qualitative features, the identified water points were sampled. Some physical-chemical parameters, e.g. pH, temperature, electrolytic conductivity, dissolved oxygen, were measured on the field with a multi-parameter probe. About 100 samples were characterized under the chemical point of view both in Italian and Guatemalan laboratories. The most abundant chemical species and metals were quantified through different analytical techniques (e.g. volumetric analysis for alkalinity, ICP-OES for metal and non-metal cations). Microbiological parameters (faecal and total waterborne coliforms) were determined through a membrane filtration method. Results were compared with Italian and Guatemalan drinking water quality regulations. In order to set the conditions for future development of the monitoring network, the study involved various local authorities (i.e. municipalities, university, municipal water service suppliers, local NGO).

Results and discussion

During the field campaigns over 70 water catchments were identified in 9 municipalities of the upper basin of Samalá River. They consist of wells, water tanks and springs of municipal water supply networks. Concerning groundwater resources exploitation, water supply is borne by farmers' and private citizens' associations in rural areas, while in urban centers it is managed by local municipal authorities that assure a higher coverage of served population. In highland sectors the most of water supply sources are springs, whereas in lowland areas wells are the mostly used ones. Quetzaltenango Valley (western-central sector) shows the highest density of wells because a great part of population and economic activities are located there. The main groundwater physical-chemical parameters are within an average range. Some parameters display a broad variation: temperature goes from 13°C in springs in distal sectors to 37°C in western area nearby San Mateo village (Fig. 1). Electrolytic conductivity ranges from 50 µS/cm in springs in northern area to 900 µS/cm in eastern sector in Totonicapán town (Fig. 1). The prevalent ion species are Ca^{2+}, Mg^{2+}, Na^{+} and HCO_3^{-}. This feature is generally related to cold and relatively young groundwater. Site-specific influences on hydrochemistry are associated to prevalent lythotypes (magmatic intermediate-acid rocks and acid pyroclastic deposits). Some samples from Quetzaltenango and Totonicapán wells show possible hydrothermal influence because of higher values of electrolytic conductivity, temperature and Cl^{-}-SO_4^{2-} concentrations. Microbiological analysis showed the presence of coliform bacteria (6÷35 colonies) in most of samples from the third campaign. According to Italian and Guatemalan qualitative standards, 20 samples did not comply with coliform bacteria rule. Another parameter out of regulation is the nitrate concentration in few samples. Both contaminants can be related to human presence and in particular to agriculture activity and wastewater discharge. However, the overall water quality data do not show significant contamination.

Conclusions

This study provides a framework about groundwater quality resources and sets the preliminary conditions to plan a monitoring network in the upper basin of Samalá River. Groundwater is the main resource for water supply and, although its qualitative status does not appear currently significantly compromised, strong human pressure on the territory could cause serious damages. Three field survey campaigns allowed to identify a large number of water supply sources that can represent monitoring points for qualitative controls. Further developments should include insights for monitoring station identification for quantitative controls and assessment for the installation of piezometers. Furthermore, an accurate conceptual groundwater flow model at a basin scale has to be defined.

Acknowledgements

This study is within cooperation projects carried out by Turin University in collaboration with Quetzaltenango city authorities. We would like to thank the University of Turin for economic support within the UNI.COO Program scholarship. We would also thank EMAX, CUNOC and Mancomunidad Metrópoli de Los Altos for their field support.

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[22] MINOR ELEMENTS HYDRO-GEOCHEMISTRY FOR CARBONATE AQUIFER CHARACTERIZATION (GRAN SASSO, CENTRAL ITALY)

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Keywords: carbonate aquifer, major and minor ions, flowpath

Introduction

This work, carried out in co-operation between the University of L'Aquila and ENEA, concerned the physical and chemical monitoring of waters sampled in several springs and streams selected within the structure of the Gran Sasso carbonate aquifer, in order to increase the data of the time series collected since the 1970's and also to investigate the behavior of some trace elements, never analysed in this kind of environment.

The Gran Sasso aquifer is characterised by Meso-Cenozoic carbonate rocks (marly-cherty-calcareous in its western part and calcareous in its central one) referring to basin-to-slope and carbonate platform-reef lithofacies, respectively. The Gran Sasso aquifer is surrounded by Miocene terrigeneous units (regional aquiclude) along its northern border through a regional overthrust and by Quaternary fluvial and lacustrine deposits, as regional aquitards, which lay upon or are in tectonic contact with the carbonate aquifer along its southern side (Fig. 1) (Adinolfi Falcone et al. 2012).

Main Body

The Gran Sasso carbonate aquifer accommodates a unique wide regional locally partitioned groundwater. At its border, the groundwater feeds springs with high discharge (more than 1 m^3/s each) and a steady regime, which are located at low altitude along its southern side. The groundwater also supplies other springs (mean discharge: 0.1-0.5 m^3/s each), located at high altitude along its northern and eastern sides. Total discharge from its springs is about 23 m^3/s. Six spring groups have been recognized across the entire aquifer based on local hydrostructural settings and hydrochemistry (Fig. 1). The Group 7 springs, which belong to the Sirente carbonate aquifer, are considered useful comparisons with the Gran Sasso springs (Gr 1-6).

In the hydrogeological conceptual model groundwater travels from the aquifer core to springs (Gr 6, primitive end member from which all the others evolve), moving from the centre (Campo Imperatore) to the boundaries of the massif and reaching remote springs (e.g. Gr 5) (Petitta and Tallini 2002).

As a general pattern, the Gran Sasso groundwater flows at three different levels and is influenced by aquitards, aquicludes and morphology: i) the upper level is the one of overflow springs, which occur at elevations above 1000 m (northern-side springs: Gr 1). The Gr 2 springs are fed by local minor porous perched aquifers overlying the carbonate bedrock and have a fluctuating and low discharge; ii) the intermediate level lies at an elevation of 600-700 m (L'Aquila plain: Gr 3 and 4); iii) the lower level, at an elevation of 250-350 m, is the one originating the large springs of the Tirino and Pescara River Valleys (Gr 5) (Fig. 1).

Four seasonal sampling surveys were conducted during 2011. The surveys were focused on the same springs monitored from 1970's at regional scale. Samples were collected and analysed for major, minor and trace elements. pH, EC, T were measured in situ with portable instruments, while the main ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, F^-) and content of La, Sr, U, Th, Cs, Mn, Fe, Zn have been lab-measured. Major anions (HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, and F^-) were measured in the laboratory within 24 hours of sample collection. HCO_3^- was determined by titration, F^-, Cl^-, NO_3^-, and SO_4^{2-} were analysed by ion chromatography. Major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}), Fe, Mn, Sr and Zn were determined by ICP-OESand ICP-MS was used for trace element analyses (La, U, Th, Cs). The PHREEQC software, version 2.17.5-4799 (Parkhurst and Appelo 1999), was used to compute saturation indexes of calcite.

The Gran Sasso waters have an alkali earth-bicarbonate nature and are mostly enriched with Ca^{2+}. The actual and dominant role of the Ca^{2+}-Mg^{2+}-HCO_3^- balance is explained by the origin of these ions from the dissolution of calcite and dolomite. Moreover, a single trend is noted from the most immature waters (Gr 6) to the increasingly mineralised ones which outcrop at gradually lower elevations.

It is worth stressing that the hydrochemical evolution of the Gran Sasso groundwater is controlled by its interaction with carbonate lithologies. CO_2 is absorbed by the soil upon recharge, successively it reacts with the carbonate host rocks, dissolving $CaCO_3$ and $CaMg(CO_3)_2$ (Petitta and Tallini 2002).

During decades the hydrochemistry has showed a constant trend and a slight seasonal variability in major ion concentrations and in physical-chemical parameters (Adinolfi Falcone et al. 2012). Lower concentrations have been recorded during the summer/autumn period when, after the completely snow melting, the dilution effect and the lower total dissolved solids (TDS) concentration should be evident. On 2011, the results do not show a clearly seasonal trend for both the major ions and the electrical conductivity. The Gran Sasso aquifer shows a homogeneous trend of enrichment in TDS, along the epicentral flowpath.

Saturation Indexes of calcite show lowest value during spring and summer seasonal sampling, according with the main discharge period after snow melting. Oversaturated values for the SI of calcite are exhibeted in winter and autumn seasons, when the infiltration supply is less abundant because of the solid precipitation.

Almost all the sampled waters during historical time series are undersaturated in dolomite and saturated or oversaturated in calcite. The fact that the waters are undersaturated in dolomite suggests a possible dissolution of dolomite in this system (Barbieri et al. 2005). The Mg^{2+}/Ca^{2+} ratio rises with the length of the groundwater pathways in a prevailingly calcareous aquifer.

As regards minor and trace elements, La, U, Th, Cs, Mn have concentrations just detectable in the samples as a whole, with values near their detection limits. Fe and Zn show values below the detection limit (10 µg/L) in all the samples analysed in this work.

The only exception is represented by Sr, that shows a regular increasing trend, like major ions, in the substitution processes with Ca.

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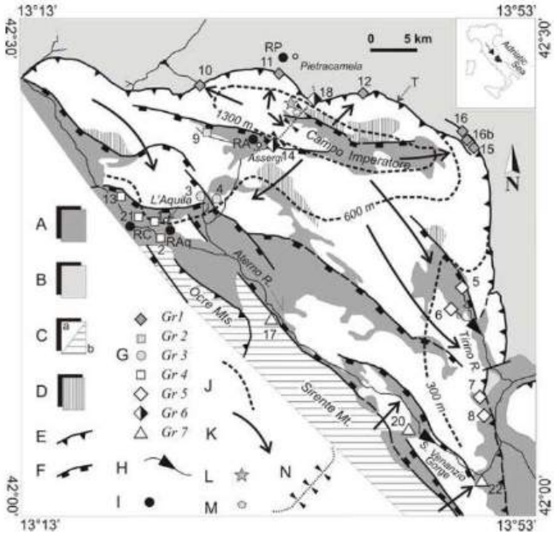

Fig. 1 – Hydrogeological map of the Gran Sasso carbonate aquifer. A - continental aquitard (Quaternary); B - terrigenous aquitard (upper Miocene); C - regional aquifer (Miocene – upper Triassic); D - overthrust; E - extensional fault; F - Paganica fault (PF); G - location of the groundwater sampled sites; H - linear spring; I - groundwater flow directions; K - Gran Sasso core aquifer; J - highway tunnels; L - epicenter of April 6, 2009 M 6.3 L'Aquila earthquake and its focal mechanism (modified from Adinolfi Falcone et al. 2012).

[23] MANAGEMENT AND PROTECTION OF WATER RESOURCES: INTEGRATED MODELING AND APPLICATIONS TO DRINKING WATER CATCHMENTS AREAS

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Keywords: hydrogeology, modeling, hydraulic contribution, Watermodel, Epiclès, nitrate, catchment

Introduction

The degradation of water resources by diffuse pollutions, essentially due to nitrate and pesticides is a matter of public health. Restore the quality of raw water catchments by working on the catchment areas is therefore a national priority in France. To consider catchment areas as homogeneous and work equally on the whole area would inevitably lead to a waste of time and money, with actions that may not be as efficient as wished. The variability of the pedologic and geological properties of the area is actually an opportunity to invest on smaller surfaces, simply because every action is not as efficient on every kind of pedologic or geological surface. That way, it is possible to invest in a few selected zones, where it could be efficient in terms of environmental results.

Main Body

The notion of Hydraulic Contributing Areas (HCA) is different from the notion of catchments area. Because the transport of most of the mobile and persistent pollutants is first driven by the water circulation, the concept of HCA is based on the water path from the surface of the soil on the catchment area to the well. The method used is a 3D hydrogeological model surface and groundwater integrated with a GIS: Watermodel©. The model calculates, for each point of the soil of the catchment area, the contribution (in m^3/h or %) to the catched flow.

In the case of the Orvanne valley (catchment area of 23 000 ha at Dormelles, county 77, France in the chalk aquifer (Cretaceous), the model (Fig. 1) financed by the Seine-Normandy Water Basin Agency showed that 95% of the water pumped at the Dormelles well came from only 26% of the total surface of the catchment area. Consequently, the action plan to protect the water resource will be targeted on 50 farmers located on this 26% of the global surface instead of the 250 farmers present on the 23 000 ha (Fig. 2).

Another modeling, under the Epiclès© software, allows the calculation of the under-roots nitrate concentrations for each farming plot regarding soil type, climate and farming practices.

Then, coupling Watermodel© and Epiclès© allows to model nitrate transfers from the soil to the catchment and the river, to set up the initial pollution due to actual farming practices and simulate also the efficiency of the farming actions plan by testing multiple scenarii and calculate the time needed to reach nitrate concentration objective at the well (Fig. 3).

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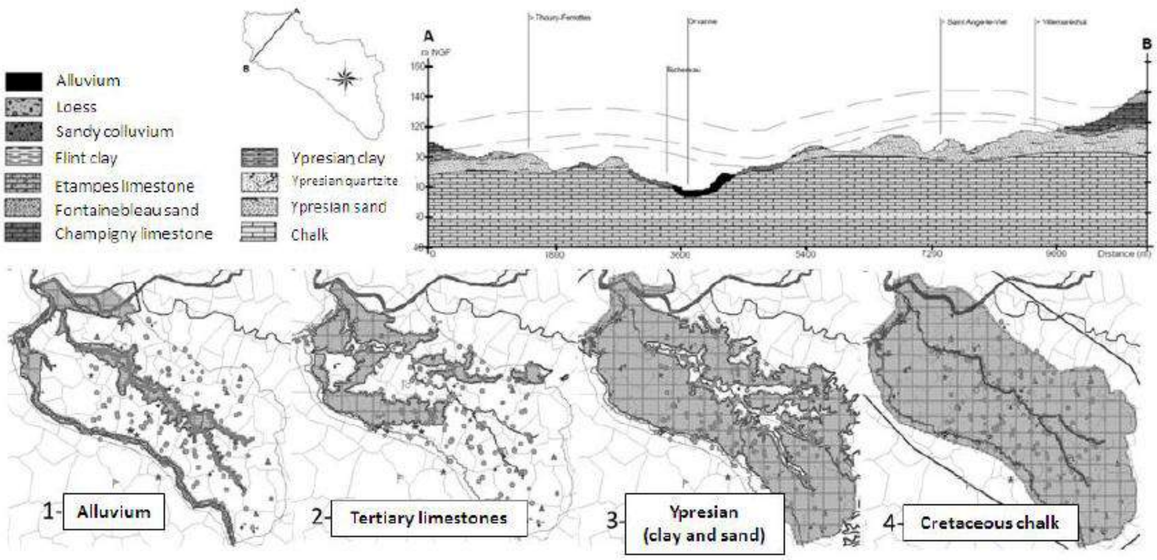

Fig. 1 – Model grid and geological section (NE-SW) of the Dormelles catchment area.

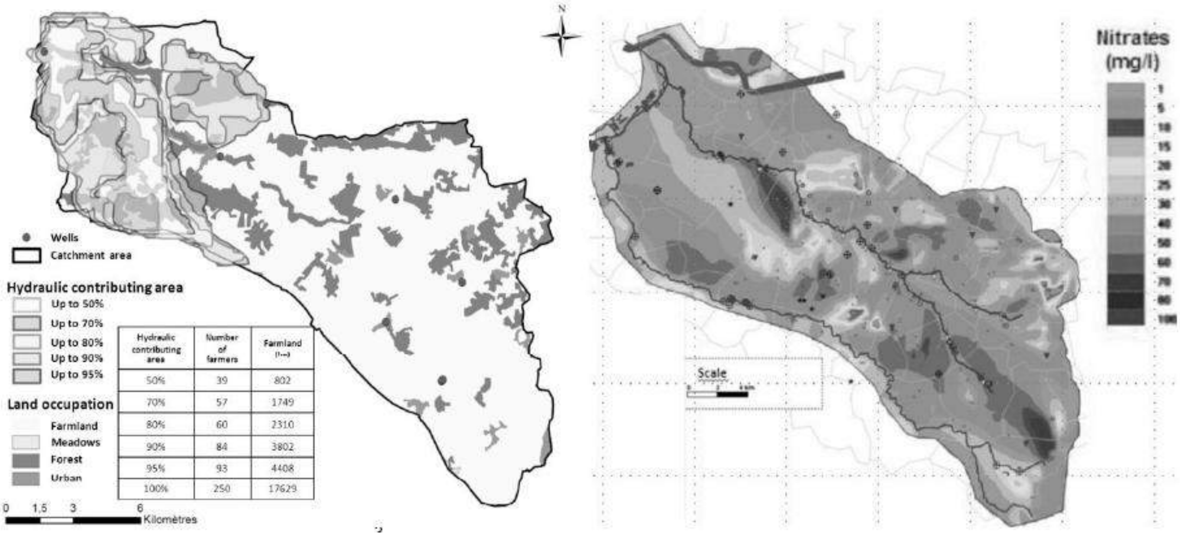

Fig. 2 – Soil contribution (in m3/h to the catched flow and nitrate concentration (mg/L) in groundwater.

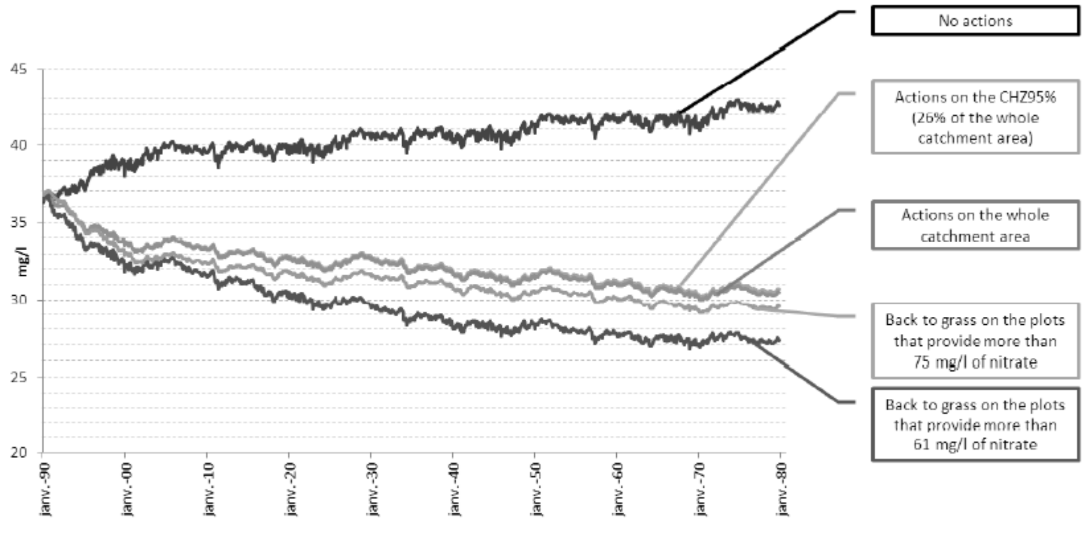

Fig. 3 – Tests of several scenarii of actions plan and translation in terms of nitrate concentration at the Dormelles well.

[24] HYDROGEOLOGY AND GROUNDWATER RESOURCES OF MT. MASSICO (CAMPANIA)

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Keywords: carbonate aquifer, hydrogeology, climate, hydrogeochemistry, Massico, Campania,

Introduction

The study deals with the definition of the relationship among groundwater of the carbonate Mountain of Massico (Campania) and the neighbouring alluvial and volcanic groundwater bodies. The research counted on a lot of piezometric, chemical and pumping data, prevalently acquired in the framework of the VIGOR Project (2012). This project (Evaluation of geothermal potential in the Italian Regions of Convergence), originated from a synergy between the Italian Ministry of Economic Development and the Italian Council for Research (CNR), supported the exploitation of low enthalpy geothermal resources of the Mondragone plain (southwestern margin of Massico).

Moreover, attention was given to the chemistry of groundwater due to the presence in the Massico groundwater body, and in the nearby area, of mineral and thermo-mineral groundwater (Corniello, 1988).

Hydrogeological outlines

The Massico Mountain is a northeast trending horst typified in the eastern and central sector by carbonate rocks (Trias - upper Cretaceous) while Miocene marly-arenaceous-clayey deposits (Vallario 1966) are present in the southern sector. A N-S fault determines the contact between the carbonate rocks and the Miocene deposits (Fig. 1). The Mt. Petrino, which is N of Mondragone town, is calcareous and in tectonic contact with the Miocene deposits (Billi et al. 1997).

The Massico is bounded along the margins of the Garigliano (NW) and the Volturno depressions (SE) by NE-SW faults, whereas southwestern margin, towards the Mondragone plain, is cut by a curved dipping fault (VIGOR Project 2012).

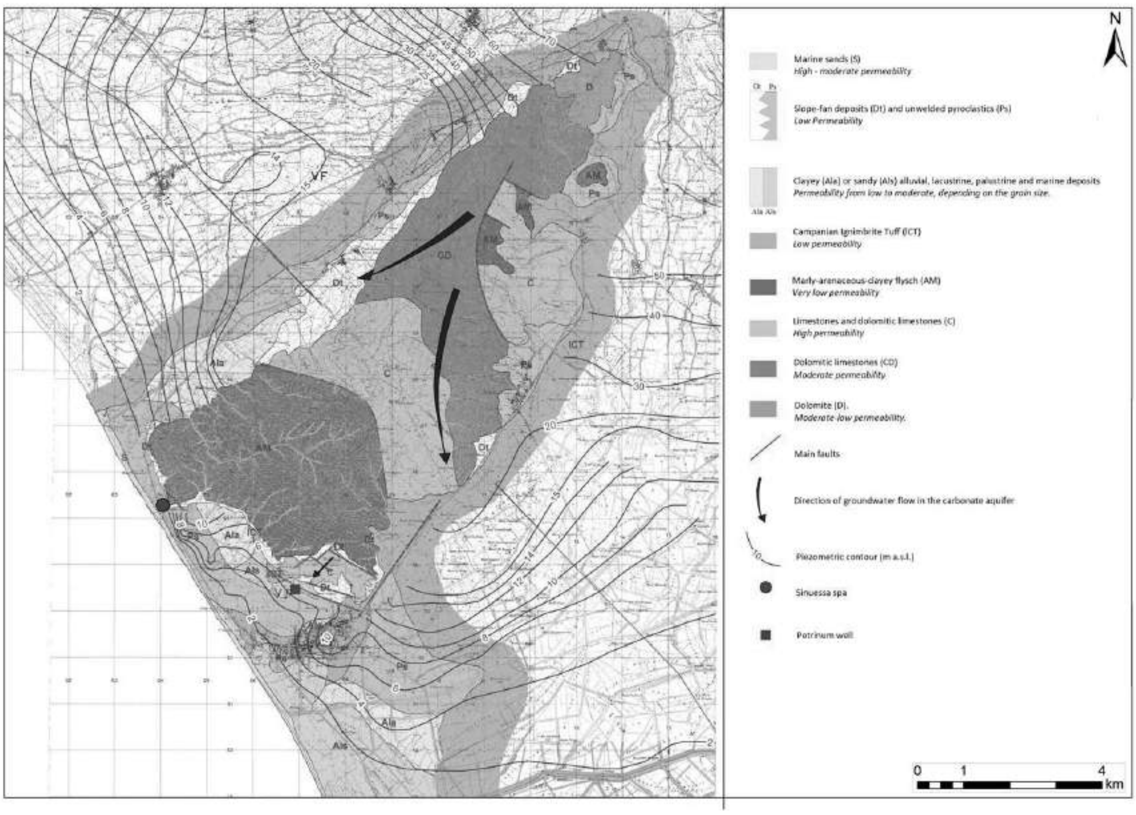

Fig. 1 - Hydrogeological map of the Mt. Massico.

These faults represent the contact between the rocks of the Massico Mountain (Mariani and Prato 1988; Billi et al. 1997; Bruno et al. 2000) and the Quaternary sediments filling the depressions (Corniello et al. 2010; Ducci et al. 2010), constituted by pyroclastic-alluvial deposits, characterized by the presence of a level of grey tuff, the so-called Campanian Ignimbrite (39 ky B.P. to 37 ky B.P.: Deino et al. 1994; De Vivo et al. 2001).
From an hydrogeological point of view, the permeability of the carbonate mountain of Massico is high and favors the recharge by rainfalls of the unconfined main groundwater body that feeds, in turn, the deposits of the plains through subsurface flow (indeed there are no springs at the foot of Massico).

Materials and methods
An accurate groundwater budget has been evaluated on the basis of climate data, starting from the year 2000. These data showed the irregular distribution of precipitation during the last ten years, verified in all the Campania region. The first seven years present a clear drought, if compared with historical data (rain gauge station of Roccamonfina of the old pluviometric network), while the last years have high levels of precipitation (Fig. 2).

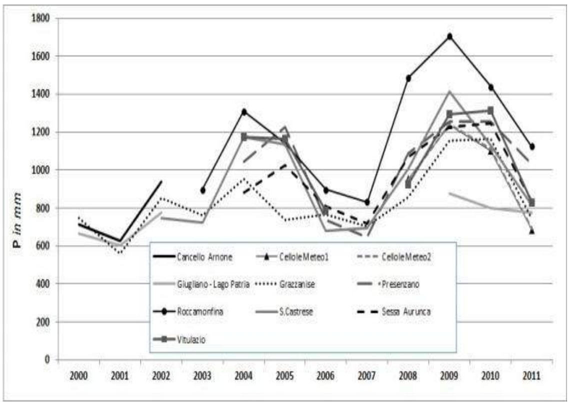

Fig. 2 - Rainfall at the rain gauge stations near the Massico.

Piezometric data has been used to evaluate the exits from the Massico groundwater body.
Hydrochemical patterns performed from new aquired chemical data have been used to differentiate different recharge areas.

Results and conclusions
The balance, computed for drought and wet years, allowed to evaluate that the mean subsurface flow is about 120 L/s towards the plain of the Volturno River and 180 L/s towards the plain of the Garigliano River.
The piezometric and chemical data have also permitted to exclude significant hydrogeological connections between the Massico and the Roccamonfina volcano groundwater bodies. Moreover, both approaches confirmed the lack of connection between the aquifer of the above mentioned Mt. Petrino and the remaining part of the Massico groundwater body.
Finally, thermo mineral waters, with temperatures between 35 and 50 °C, found in wells and springs, contributed to clarify the different groundwater flow directions. Thermal waters are everywhere sulfureous and CO_2 rich, but varying from calcium-bicarbonate composition to sodium-chloride type.

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[25] CONCEPTUAL MODEL OF THE GROUNDWATER FLOW IN THE JONIAN COASTAL AREA OF THE GULF OF TARANTO (SOUTHERN ITALY)

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Keywords: Salento, coastal aquifers, hydrostratigraphy, conceptual model.

Introduction

The Mediterranean region is characterized by a strong coastal development and a high concentration of water-demanding human activities in coastal areas, resulting in extensive withdrawals of groundwater which accentuate the saltwater intrusion phenomenon. The change of the natural equilibrium between fresh and salt water in the aquifers is one of the main processes responsible for the deterioration of groundwater quality in coastal areas. Therefore, a correct policy of exploitation of groundwater resources and appropriate monitoring activities are necessary.

The worsening of groundwater quality is a huge problem especially for those regions, like Salento (southern Italy), where the karst and fractured aquifer system represents the most important water resource because of the deficiency of a superficial water supply. In this framework, the first 2D numerical model describing the groundwater flow in the karst aquifer of Salento peninsula was developed by Giudici et al. (2012) at the regional scale and then improved by De Filippis et al. (2013). In particular, the estimate of the saturated thickness of the deep aquifer highlighted that the Taranto area (see Fig. 1) is particularly sensitive to the phenomenon of seawater intrusion, both for the specific hydrostratigraphic configuration and for the presence of highly water-demanding industrial activities.

The research program RITMARE

The city of Taranto and its surroundings are subject to a high risk of environmental crisis for the presence of important industrial activities and of highly vulnerable water bodies (the Mar Grande and the Mar Piccolo) which host the most important freshwater springs in Puglia. Moreover, the national government included Taranto in the list of the contaminated sites of national importance.

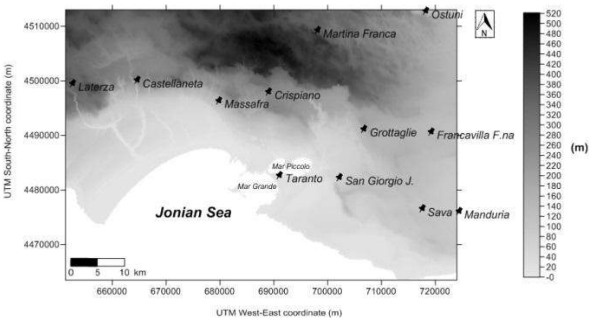

Fig. 1 – Location and DTM map of the study area. The DTM values are expressed in meters above the mean sea level.

These remarks motivate a research project which is part of the research program RITMARE (The Italian Research for the Sea), within which a subprogram is specifically dedicated to the problem of the protection and preservation of groundwater quality in Italian coastal aquifers, including the Taranto area. In this context, the operative unit 06 deals with the characterization of the study area with regard to groundwater and its relationship with the sea. For this purpose, the specific objectives are:

- the reconstruction of the groundwater dynamic in this coastal area (i.e. the preliminary identification of a conceptual model for the aquifer system and the subsequent modeling of groundwater flow in a multilayered system which is very complex from the hydrostratigraphical point of view);
- the characterization of the submarine and subaerial springs and of the water exchanges with the shallow coastal water bodies (e.g. Mar Piccolo) and the off-shore sea;
- the modeling of seawater intrusion in the coastal aquifer system.

This presentation is focused on the first objective, achieved firstly through the analysis of hydrostratigraphic reconstructions obtained from different data sets: well logs, published geological field maps, studies for the

characterization of contaminated sites.
The identified hydrostratigraphic structure is shown by three cross sections (see Fig. 2 and Fig. 3).

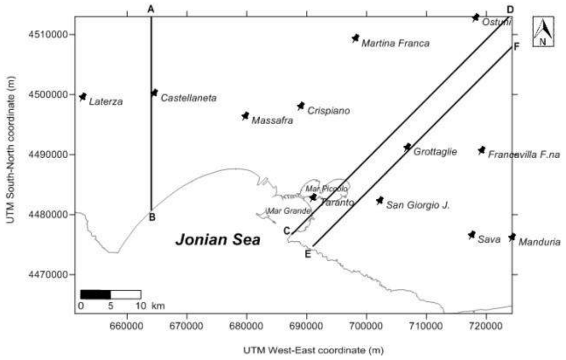

Fig. 2 – Location of the hydrostratigraphic sections AB, CD and EF.

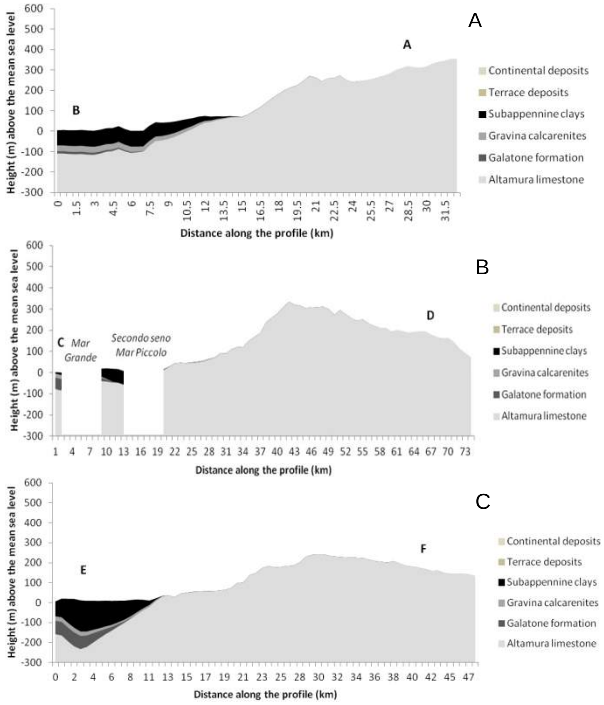

Fig. 3 – A-hydrostratigraphic section AB; B-hydrostratigraphic section CD; C-hydrostratigraphic section EF. See Fig. 2 for the localization.

Another important result is the reconstruction of a reference hydraulic head map for the karst aquifer under exam (see Fig. 4): such a chart is obtained by merging both well data and published hydrogeological maps.
These outcomes are merged with maps of land use, estimates of crop water requirements, data about groundwater extraction (for drinkable, industrial or irrigation use), data on source discharge, hydrometeorological data, in order to identify the conceptual model of the groundwater flow in the fractured/karst deep aquifer.

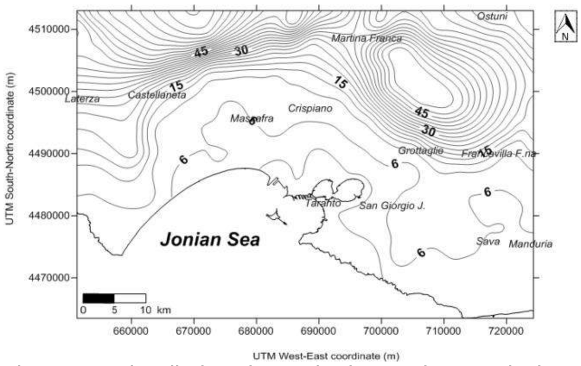

Fig. 4 – Hydraulic head map in the study area (values in meters; contour interval 3 m).

Acknowledgements

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The cooperation of the Ministero dell'Ambiente e della Tutela del Territorio e del Mare (MATTM) and of the ENI refinery of Taranto, which provided several data sets, is gratefully acknowledged.

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[26] THE IMPORTANCE OF DISTINGUISHING BETWEEN ANTHROPOGENIC POLLUTION AND NATURAL ORIGIN IN GROUNDWATER OF HIGHLY DETERIORATED AREAS

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Keywords: Groundwater quality, Groundwater Daughter Directive, Natural background levels, Statistical methods, “Terra dei fuochi” - Italy

Introduction

The adoption in 2006 of the Groundwater Daughter Directive (GWD, 2006/118/EC) laying down additional technical specifications on the protection of groundwater against pollution and deterioration (WFD - 2000/60/EC) clarified the criteria for good chemical status and introduced the concepts of threshold values and natural background level. The EU Member States have to determine appropriate threshold values (TV) for several potentially harmful substances, taking into account natural background levels (NBL) when necessary, in order to assess the chemical status of groundwater bodies.

In the framework of a common project between Italy (CNR) and Portugal (FCT), with the objective to define a methodology for NBL assessment at groundwater body scale, NBL methods have been applied to case studies in different geological and land use settings. Study sites are located in the so-called “Terra dei Fuochi” area, located in Campania, near Naples city, where the illegal dumping of toxic waste has been widely documented on the media, and in a highly contaminated industrial area in the surroundings of Rome.

Indeed, the examined groundwater bodies present very often high levels of contamination resulting in the “poor status” classification (**a** in Fig. 1).

Nevertheless, as for inorganic substances such As, Fe, Mn, F, this contamination may also be of natural origin (**a** + **b**, or **b** in Fig. 1); to declare the whole area as “poor status” involves an impracticable reclamation. For this reason, it is very important to distinguish the areas/levels of anthropogenically influenced pollution (a or and b in Fig. 1), on which remediation measures should be planned.

Hydrogeological setting

The Italian case studies are located in volcanic and volcano-sedimentary geological context. In the Regi Lagni-Volturno River Plain ($BRV_{sx.Volt}$), the main aquifer is located in the alluvial, pyroclastic and marine porous sediments underlying the “Campanian Ignimbrite” tuff which can be conceptualized as a single groundwater body (Corniello and Ducci 2013). In the Phlegraean Fields (FLE), water chemistry results from a complex interaction of water of meteoric origin, hydrothermal fluids and seawater. The Latium groundwater body is located in the volcano-sedimentary sequence of the southern Sabatini Mounts (Parrone et al. 2013). All GW bodies present high concentrations of substances such as As, F, Fe, Mn. Furthermore, intensive farming and widespread settlements determine very high nitrate concentrations and spot presence of PAH and BTEX.

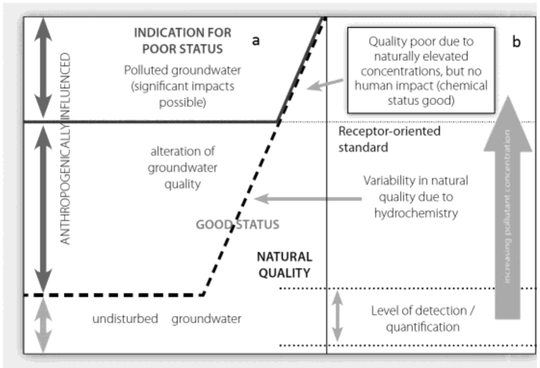

Fig. 1 – Groundwater quality status (modified from BRIDGE 2009).

Materials and methods

Today essentially two groups of methods are proposed, the first ascribed to the probability plots (PP method), the second based on the selection of the uninfluenced water samples corresponding the natural population (Pre-Selection method, “PS”). PPs are grounded on the principle that different sources generate different data populations which can be separated by statistical procedures (Wendland et al. 2005). The PS method proposes to select only those samples which are not, or very little, influenced by human activities, e.g. removing those with high nitrate or other markers of anthropic contamination (Hinsby and Condesso de Melo 2006; Wendland et al. 2008; BRIDGE 2009). In the residual data set one value is chosen as representative of the NBL, meaning that all concentrations exceeding that level should be ascribed to anthropogenic sources (Wendland et al. 2008; Preziosi et al. 2010; Baiocchi et al. 2011; Ducci and Sellerino 2012; Ducci et al. 2013).

Results

NBLs have been determined using both PS methods and probability plots. In $BRV_{sx.Volt}$ groundwater body (Fig. 2), iron and manganese, in reduced form, have high NBLs and TVs exceeding reference value, due to the reducing conditions present in the alluvial plain of Volturno. Instead, in the FLE groundwater body, arsenic and fluoride have high NBLs and TVs exceeding reference value, due the volcanic origin of the area. In the Latium case study, Mn and Fe show enhanced dissolution in the industrial area probably in relation to organic contamination, while As and F levels appear related to natural origin only. NBLs and site scale TVs were set accordingly.

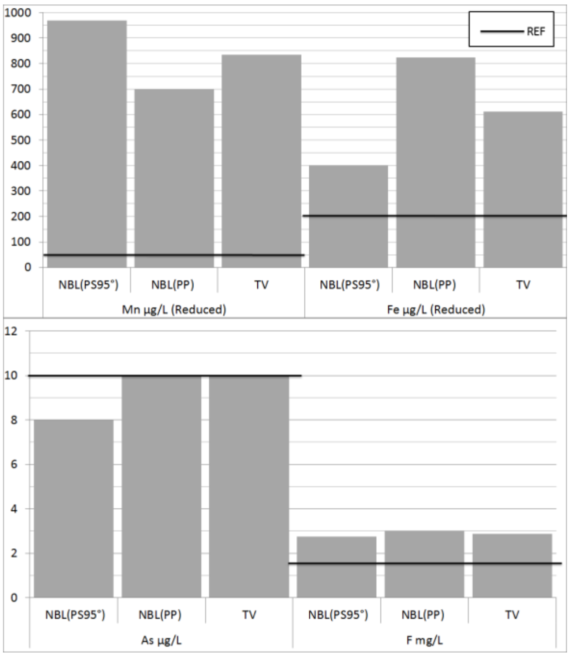

Fig. 2 – Campania case study results (Regi Lagni-Volturno River Plain).

Conclusions

The application of these methods has highlighted the importance of aquifer conceptual model in deriving NBLs. Results indicate that NBLs depend on the peculiar hydrogeological settings of the examined groundwater bodies, varying from alluvial-palustrine aquifer, with reducing conditions, to volcanic aquifers, characterized by thermal circulation in few dozens of square kilometers. The comparison among different case studies and methodologies shed light on the effectiveness of current NBLs methods and indicated the need of their application at the groundwater body scale in contamination studies, in order to manage an aimed reclamation.

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[27] REGIONAL DISTRIBUTION PATTERNS OF TDS AND HEAVY METALS IN GROUNDWATER AT DAMASCUS CITY AND ITS SURROUNDINGS, SYRIA

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Keywords: hydrochemistry, groundwater statistics, health, Damascus, Syria

Introduction

The majority of the population density is concentrated in the city of Damascus and the surrounding areas. The water quality is deteriorated by industrial facilities (Ministry of Irrigation 2006). The Neogene and Quaternary aquifer is the main water-bearing sediments in the study area (Fig. 1). Transmissivity varies between 100 and 2000 m^2/d (Fig. 2). The transmissivity is increasing in the northwest (1800 m^2/d) and in the central-eastern (2000 m^2/d) parts. In spite of the decrease in thickness of the Quaternary aquifer in the northwestern part, the transmissivity increases. This can be attributed to the high recharge at the highly elevated region (mountainous area). The latter is characterized by the high infiltration where the hydraulic conductivity increases (100 m/d). The discharge ranges between 3 and 31 L/s. The water table varied between 700 m and 540 m (Fig. 3). In general, the movement of groundwater is from northwest to southeast.

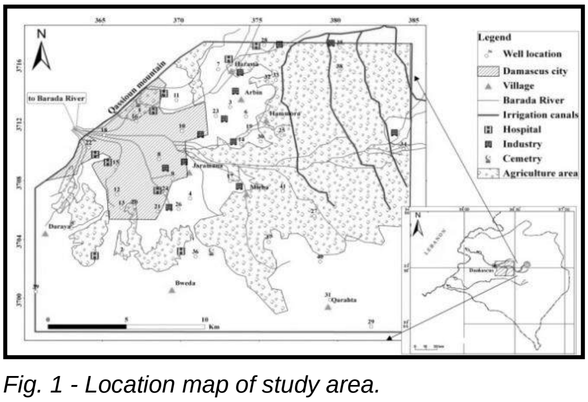

Fig. 1 - Location map of study area.

There are three closures; in the north, middle, and south of Damascus city. There are many lateral movements of groundwater. The decline of water table in 2009 reflects the increase in development and number of boreholes. In 2009, the number of wells reached about 700 wells in the study area. The annual yield, in 2009, was about 52 million m^3. The present thesis aims to detect the sources of pollution that may affect the quality of the groundwater used for drinking and irrigation purposes.

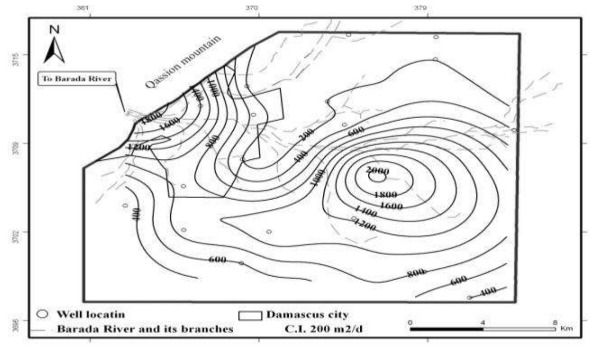

Fig. 2 - The transmissivity of the aquifer.

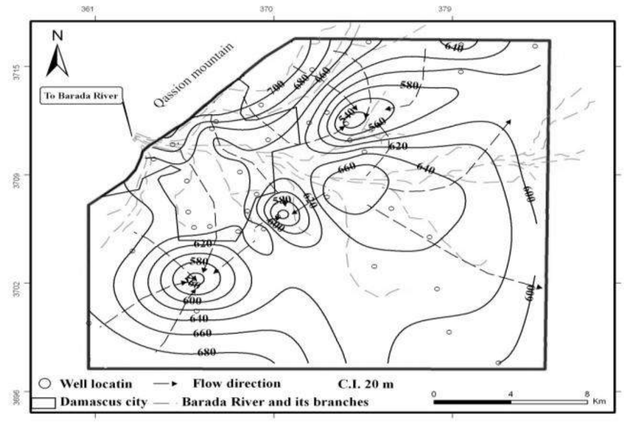

Fig. 3 - Water table map of the Quaternary and Neogene aquifer in 2009.

Methods

Forty one groundwater samples were collected from the Neogene and Quaternary aquifer. Two water samples were collected from the Barada River and rainfall. The Inductively Coupled Plasma- Mass Spectrometry (ICP-MS) was used to analyze As, Ba, Co, Cd, Cr, Cu, F, Fe, Mn, Ni, Pb, Sb, Se, Sn, Sr, V, Zn, Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}. Al^{+3}. HCO_3^-, SO_4^{-2}, Cl^- and NO_3 concentrations were determined using Ion Chromatography (IC).

Results and discussion (groundwater)

Total Dissolved Solid (TDS) and NO_3.

The TDS content varies from 225 to 1520 mg/L and decreases due the northwestern part (400 ppm) (Fig. 4). It is attributed to high recharge from mountainous area with high infiltration from the Cenomanian –Turonian aquifer. The southeastern part (highest TDS content), which encloses bedded limestone enhances the TDS concentration. The TDS content is intermediate in the northeastern part (800 ppm), caused by leakage of treated wastewater from the irrigation canals at Adra plant treatment. The hydrogeology also matches with hydrogeochemistry. The concentration of NO_3^- ranges between 10 and 150 mg/L (Fig. 5). It increases toward the northeast, southeast and southwest (Fig. 5). The groundwater can be used for drinking purpose except in the most southeastern part where NO_3^- content exceeds the MPL. The groundwater can be used for irrigation practices.

Trace elements

The concentration of Al varies from 106 to 1091 µg/L. Groundwater is mostly improper for potable uses with respect to Al and Cd concentrations (MPL is 200 and 3 µg/L for Al and Cd, respectively, WHO 2001 and 2006). The groundwater can be used for irrigation purpose with respect to Al (MPL is 5000 µg/L) but still offensive regarding Cd pollutant (MPL is 10 µg/L). The groundwater is generally not fitting for drinking purpose with respect to of Fe, Mn, and Ni (MPLs are 300, 400, and 70 µg/L, respectively). However, it is appropriate for irrigation with respect to Fe and Ni (MPLs are 5000 and 200 µg/L, respectively). The anomalous concentrations of Pb and Cr have been encountered in and around hospitals. The concentration of Cr is resulted from anthropogenic sources. The groundwater is essentially incongruous for drinkuing prurpose regarding the Pb and Cr contents (MPLs are 10 and 50 µg/L, respectively). Conversely, it can be accepted for irrigation (MPL 500 µg/L), but Cr remains a pollutant with values above its MPL (100 µg/L). The As, Sb and Se concentrations are below the detection limit (< 0.001 mg/L), also Sn and V are below the detection limit (< 0.005 mg/L).

Conclusions

The high concentration of some contaminants in the groundwater can be attributed to the absence of sewer system and dumping of municipal, industrial, agricultural and hospital wastewaters in the Barada River. Septic tanks distributed, the extension use of recycled wastewaters from Adra station, and cattle breeding are potential sources of pollution.

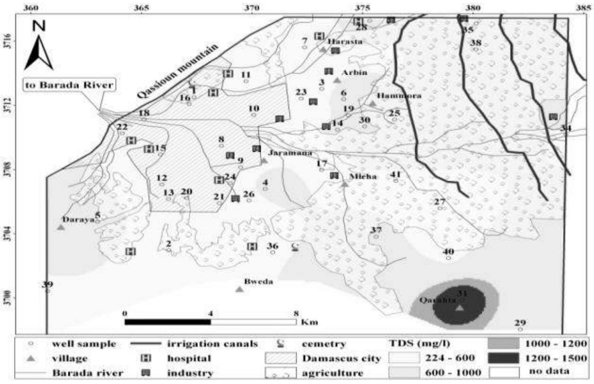

Fig. 4 - TDS distribution in the groundwater.

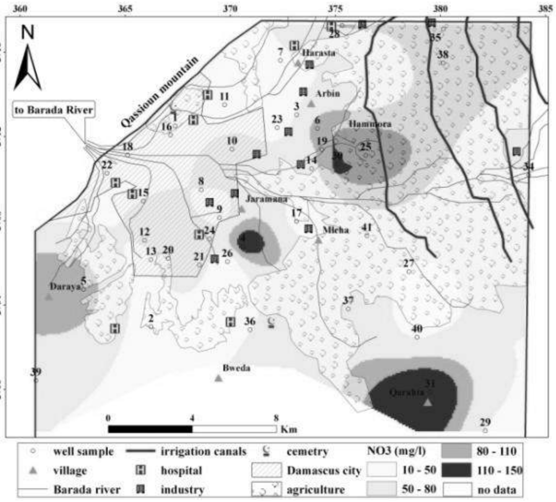

Fig. 5 - NO_3 distribution in the groundwater.

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[28] OBSERVATIONS AND ANALYSIS OF PERCHED GROUNDWATER CONDITIONS IN THE SOUTHERN BASIN OF MATESE MOUNTAINS (SOUTH ITALY)

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Keywords: Perched groundwater, Carbonate aquifer, Bauxite, Spring, Matese Mountains.

Introduction

In hydrogeological research data concerning perched groundwater flow are uncommon and often not widely documented. According to Freeze and Cherry (1979), perched groundwaters may assume many configurations and hydrodynamic conditions depending on recharge, hydraulic properties and relationship between aquifer and aquitard as well as on anthropogenic modifications. The most complex perched groundwater conditions may occur in limestone or dolomitic aquifers where a karst system is often combined with intercalation of low-permeability layers.

The interest in the assessment of the impact of perched groundwater on subsurface flow increased during last years in studies about groundwater management (e.g. Peleg and Gvirtzman 2010) or protection, especially to analyze the contaminant transport (e.g. Oostorm et al. 2013).

This paper presents field observations and analyzes factors that govern the perched groundwater behavior in the south-eastern sector of Matese Mts. (South Italy), where a number of temporary or permanent springs were recognized at a mean elevation of about 1200 m a.s.l. in the area known as Regia Piana.

The Matese Mts. are part of the thrust and fold belt of the Central-Southern Apennines originated during the late Cenozoic from the deformation of the continental margin of the Adria Plate (Carannante et al. 2009; Bassi et al. 2010 and referenced papers). It represents one of the most important hydrogeological unit of southern Italy (Allocca et al. 2007 and referenced papers), composed of 2500-3000 meters of Triassic-Cretaceous platform carbonates disconformably overlain by Miocene inner-ramp shallow-water limestones grading upwards to outer-ramp hemipelagic marls and finally into siliciclastic flysh deposits (Patacca and Scandone 2007).

Data and final remarks

The complex stratigraphic and tectonic setting of Regia Piana controls the groundwater flow and the formation of springs even at higher altitude. On this regard an important role could have bauxite deposits and paleokarst features due to relevant emersion phenomena during Cretaceous time (Crescenti and Vighi 1970; D'Argenio et al. 1987; Carannante et al. 1988).

Specific field activities was carried out in order to survey the most representative bauxite horizons, map the spring distribution, measure their discharges and chemical-physical characteristics and identify the perched groundwater conditions.

In the period June 2012- February 2014 monthly measurements of discharge, electrical conductivity, pH and temperature involved 10 springs in an area of about 10 km^2. A more complete chemical characterization of groundwater was performed on February and August 2013. Analyses concerned 34 parameters, including main 7 anions (HCO_3^-, Br^-, Cl^-, NO_3^-, NO_2^-, PO_4^{3-}, SO_4^{2-}) and most common metals (Al, Fe, Cr, Ni, Cu, Zn, Cd and Pb).

At the same time a geological survey at 1:5.000 scale was carried out.

The resulting hydrogeological map and one of the most significant hydrostratigraphic cross-sections are shown in Figure 1a.

The coupled processing of hydrogeological and hydrochemical information revealed a rather than complex perched groundwater system above the bauxite horizons due to the relationship between the detrital and carbonate aquifer as well as to the well-developed karst system.

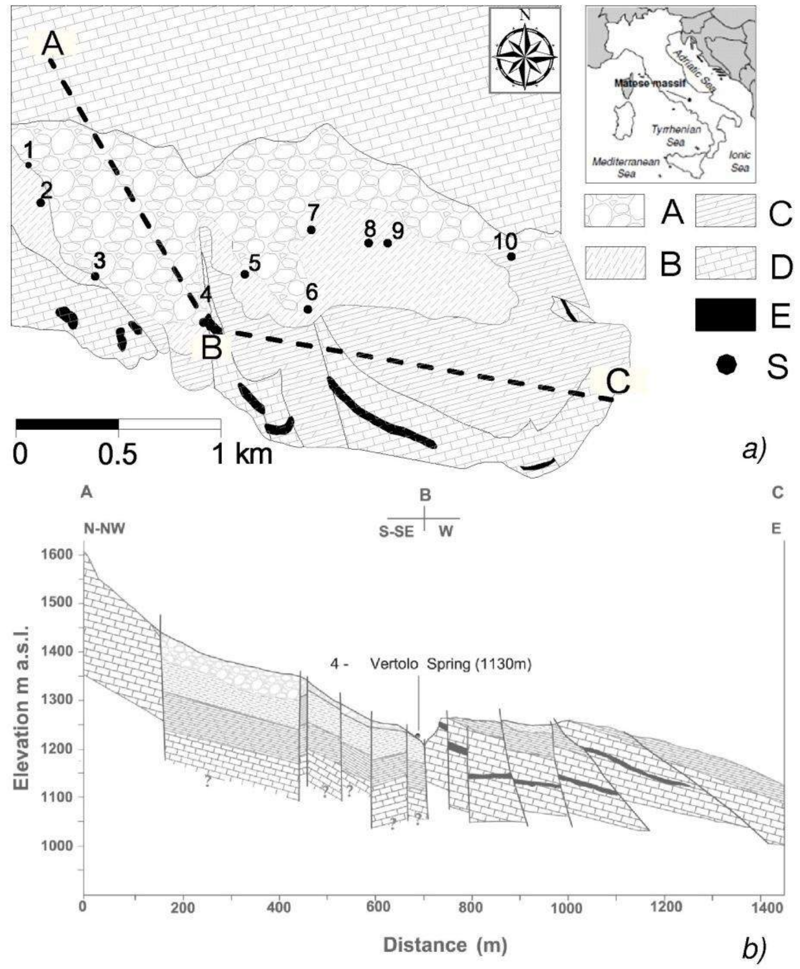

Fig. 1 - a) Hydrogeological map of Regia Piana (Matese Mts, South Italy) and b) Hydrostratigraphic cross-section of the study area: A) Detrital-Alluvial Complex; B) Clayey Complex; C) Marly-Clayey-Calcareous Complex; D) Calcareous-Dolomitic Complex; E) Bauxite Complex; S) Springs.

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[29] ALCOTRA – ALIRHYS PROJECT: CASE HISTORY OF GROUNDWATER QUALITY PROTECTION

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Keywords: Tenda spring, monitoring, water pollution, carbonate acquifer

Introduction

The doubling of the Tenda road tunnel that connects SW France to Piedmont (Italy) was planned to penetrate a complicated rock structure with several hydrogeological features including a carbonate-karst aquifer between flysch impervious complexes. The main problem of the project is the presence of a water flow that feeds into a spring at great local economic importance, that discharges into a railroad tunnel below. Therefore, if cement were used for tunnel consolidation it could alter the chemistry of the spring, making it unfit for human consumption. The aim of the work, performed by a research group of DIATI (*Dipartimento di Ingegneria dell'Ambiente, del Territorio e delle Infrastrutture*), was to identify the best indicators of the presence of such cement in water.

Methods and results

Fig. 1 shows the geological section of the Tenda pass. The aquifer is intercepted in the zone where the contact (permeability threshold) is situated, between the upper limestone formation and the upper flysch formation (Banzato et al. 2011). The area feeding the spring is a narrow, straight NW-SE band, which goes from the deep Cabanaira valley to the Val Grande di Palanfrè. Using monitoring data the pollution vulnerability of the springs, according to the VESPA method (Galleani et al. 2011), turned out to be low.

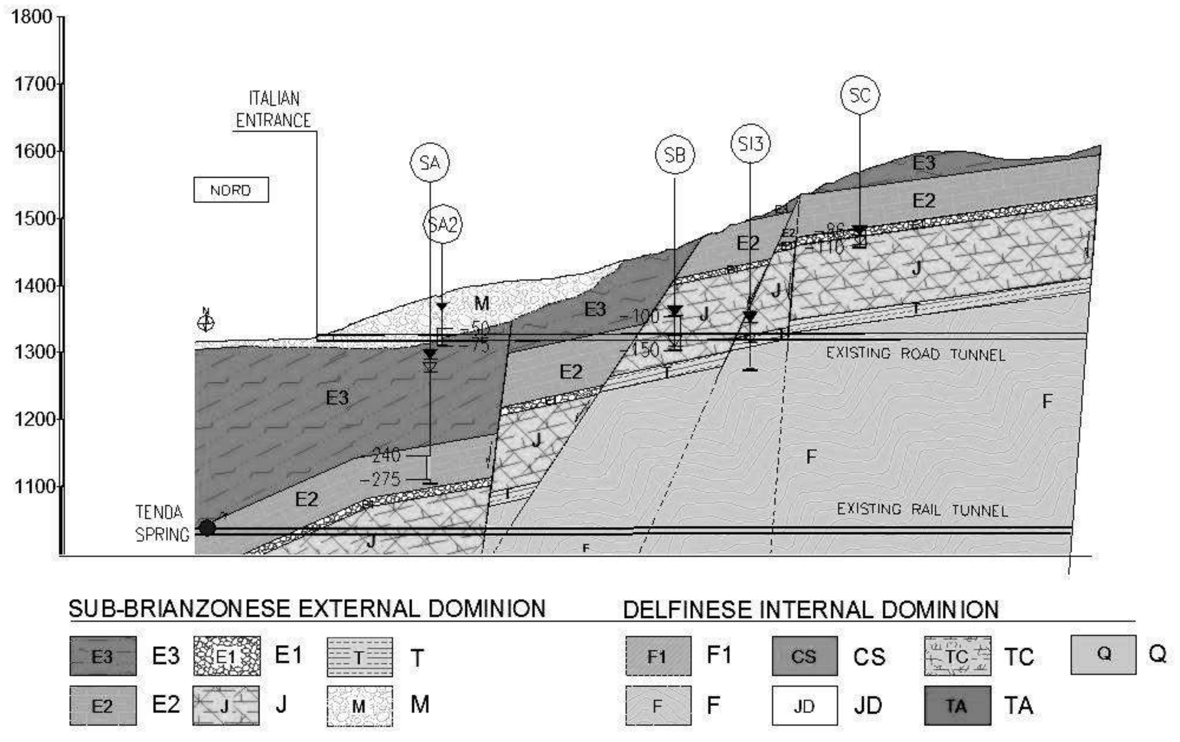

Fig. 1 - Geological section of the current road tunnel with positions of the main water flows. (Source: Cuneo Province)-modified and re-drawn. (M) Morainic deposit, (E3) Flysch, (E2) Nummulitic limestone, (E1) Polygenetic conglomerate, (J) Limestone, (T) Dolomitic limestone-dolomite. (Q) Several kinds of deposit, (F1) Rework flysch, (F) Sandstone-pelitic flysch, (CS) Marl limestone, (JD) Limestone and dolomitic limestone, (TC) Clay and carniole, (TA) Gypsum and anhydrite.

The vulnerability assessment was performed related to the spring recharge area without the preferential drainage route that the tunnel represents. The concentration of any cements in the water would not be attenuated because the terrain "filter effect" would be less significant. On this basis, in order to configure a possible alarm system, efficient indicators of the presence of cement in water should be identified.

Some tests were performed, in the laboratory, on the basis of following parameters:

- Turbidity
- pH
- Electrical Conductivity (EC)

Tests have shown that the EC is not a good indicator of the presence of cement in water, in fact by increasing the cement concentration in water, this parameter decreases first and then resumes the upward trend.

However, tests on turbidity and pH have given interesting results. As expected, the turbidity, by increasing the cement concentration in water, grows in a rather linear way (Fig. 2);

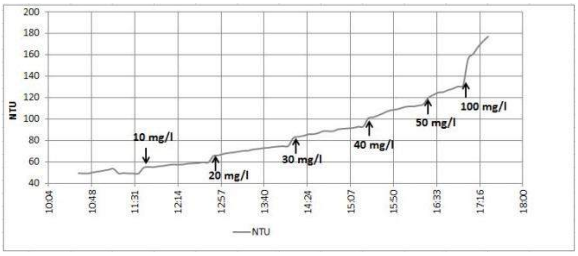

Fig. 2 – Turbidity trend with increasing cement concentration.

However it was found that the turbidity parameter only is not sufficient to detect the arrival of the cement because this parameter can also rise due to natural causes such as precipitation and snow melt (Fig. 3).

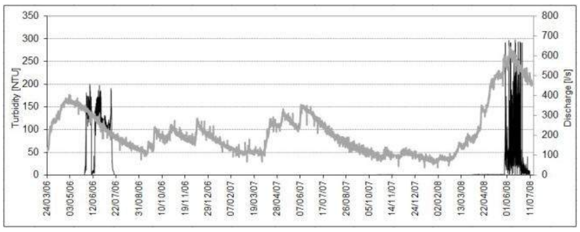

Fig. 3 – Turbidity trend after rainfall – Tenda spring.

The pH has also proved to be a valid indicator of the presence of cement in water (Fig. 4).

The results of the tests showed that turbidity (Fig. 2) and pH (Fig. 4) give strong indications of the presence of cement in water: a working solution could be the combined use of these indicators. The use of a double indicator allows errors related to natural variations on a single parameter to be avoided.

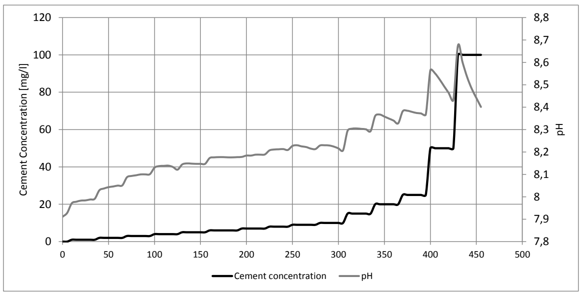

Fig. 4 – pH trend with increasing cement concentration.

Acknowledgements

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[30] STATISTICAL ANALYSIS OF GROUNDWATER NITRATE CONCENTRATIONS IN PIEDMONT PLAIN AQUIFERS (NORTH – WESTERN ITALY)

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Keywords: nitrate, groundwater, statistical analysis, Italy

Introduction

Nitrate contamination of groundwater is a worldwide problem (Almasri 2007). Many studies showed strong correlation between anthropogenic processes and nitrate concentration in groundwater (Joosten et al. 1998). Two kinds of anthropogenic contamination sources that contribute to nitrate pollution of groundwater can be recognised: point sources, such as septic systems and non-point sources, as the diffused use of fertilizers. Shallow groundwater in Italy generally shows a low quality due to nitrate contamination. Focusing on Piedmont Region (NW Italy) nitrate concentrations in the shallow aquifer are often high and in several areas exceed the maximum allowable concentration (50 mg L^{-1}) set by the Italian regulation. In these areas nitrate has been recognized as one of the most important pollutants of shallow groundwater (Lasagna et al. 2013), on the basis of its distribution and concentration. The aim of this study is to detect trends (or lack of trend) over time of nitrate concentrations in Piedmont plain shallow and deep aquifers. The purpose is to verify how Piedmont Region is responding to the EU Nitrates Directive, whose ultimate goal is "reducing water pollution caused or induced by nitrates from agricultural sources and preventing further such pollution". Research results can also create a premise for future studies and insights about nitrate pollution and nitrate attenuation processes in aquifers.

Materials and Methods

Data collection

The Regional Environmental Protection Agency (ARPA Piedmont) database was used to examine trends of nitrate concentrations. The wells included in the ARPA network belong to the shallow unconfined aquifer, consisting of the alluvial deposits unit (late Pleistocene mid-Holocene) and the deep confined aquifers of "*Villafranchiano"* unit (late Pliocene–early Pleistocene) and marine unit (late Pliocene–early Pleistocene) hereinafter defined respectively as "shallow aquifer" and "deep aquifers". A time series data from 2000 to 2012 was used, both for shallow and deep aquifers.

Statistical analysis

The Mann Kendall test (Mann 1945; Kendall 1975) was used in this study. It is a non-parametric statistical analytical test, which does not assume that the data follow any specific distribution. Non-parametric tests have greater power to detect differences or trends than parametric methods, when data do not follow a normal distribution (Frans and Helsen 2005). Since water-quality data are typically non-normally distributed, non-parametric tests are used to detect trends in water quality (Walker 1991; Yu and Zou 1993). The statistical analyses performed for this study were considered significant at a 95% confidence level. The Sen's slope estimator (Sen 1968) has been used to quantify the trend. A positive slope delineates an uptrend. Similarly, a negative slope defines a downtrend. The slope indicator (expressed in mg L^{-1} $year^{-1}$) has been evaluated for wells characterized by a statistically significant nitrate concentration trend.

Results

Time series analysis of nitrate concentrations in groundwater highlights that most wells (about 80%) do not show a statistically significant trend, both in the shallow aquifer (Tab. 1) and in the deep aquifers (Tab. 2).

Shallow aquifer	Total wells		No trend	Decreasing trend	Increasing trend
	N.	358	286	43	29
	%	100	80	12	8

Tab.1 – Trend of nitrate concentration in shallow aquifer from 2000 to 2012.

Deep aquifer	Total wells		No trend	Decreasing well	Increasing well
	N.	197	159	15	23
	%	100	80.7	7.6	11.7

Tab.2 – Trend of nitrate concentration in deep aquifers from 2000 to 2012.

Focusing on shallow aquifer (Fig. 1), 41 monitoring points showed nitrate concentration over 50 mg L^{-1} in 2012. The 78% of them do not display a trend, the 17% reveal an uptrend and only the 5% have a downtrend. Focusing on deep aquifers, only one monitoring point shows a nitrate concentration over 50 mg L^{-1} in 2012 and it is not characterized by a statistically significant trend. About the concentration change rate over time, the slope indicator shows that the uptrend and the downtrend slope in the shallow aquifer are about 5 mg L^{-1} $year^{-1}$, while slope values in the deep aquifer are about 1 mg L^{-1} $year^{-1}$.

Conclusions

Most of nitrate concentrations in Piedmont plain sector aquifers showed no statistically significant trends over time in the studied period both in the shallow aquifer and in the deep aquifers. Furthermore, the wells where currently nitrate concentration overcomes the maximum standard value (50 mg L^{-1}) do not show a substantial water quality improvement over time. This provides an understanding of water-quality conditions about nitrate concentration in Piedmont that reveals a need for a better management of nitrate fertilizers in agriculture. Strategies and development tools to limit nitrate concentration in groundwater in Piedmont are currently not able to respond in an effective way to EU Nitrates Directive.

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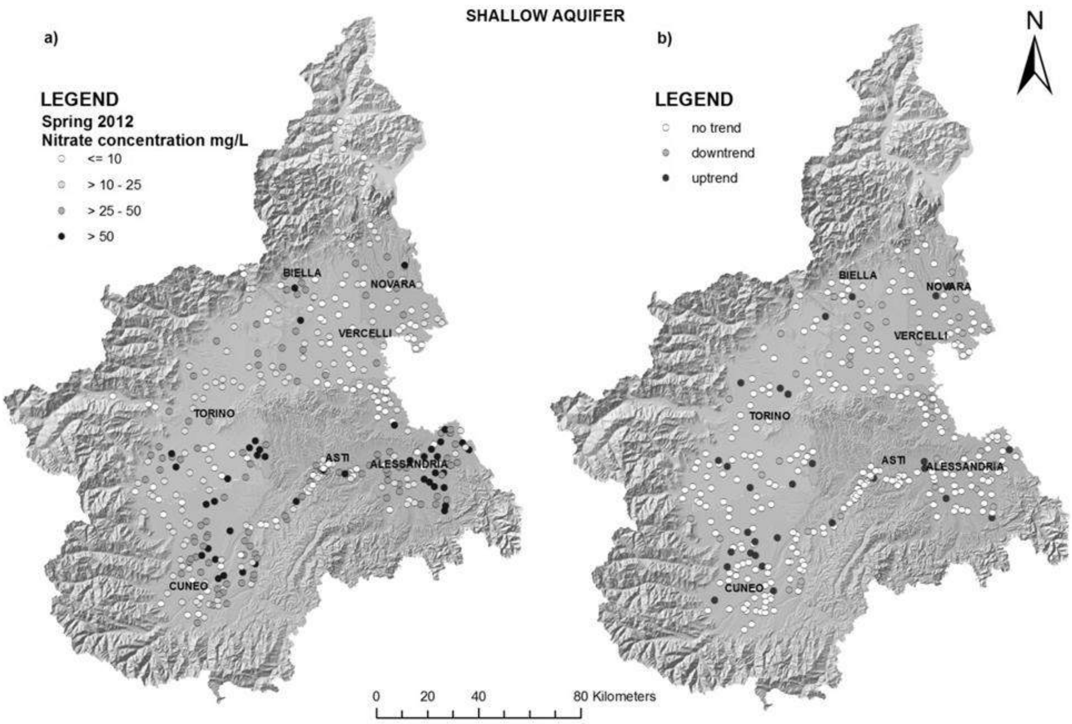

Fig. 1 – a) Nitrate concentration in the Piedmont shallow aquifer (Spring 2012); b) Nitrate concentration trend evaluation in the shallow aquifer for time series data from 2000 to 2012.

[31] PRELIMINARY ACTIVITIES FOR DEVELOPING THE GROUNDWATER MONITORING NETWORK OF ROME (ITALY)

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Keywords: Rome, Groundwater, Monitoring

Introduction

Groundwater quality monitoring network design is defined as the selection of sampling sites and (temporal) sampling frequency to determine physical, chemical, and biological properties of ground water. The main approaches to groundwater quality monitoring network design were identified as hydrogeologic and statistical. The various methods for network design available in the hydrologic literature have been evaluated by considering the spatial scale of the monitoring program, the objective of sampling, data requirements, temporal effects, and range of applicability (Loaiciga et al. 1992)

A number of specific factors must be considered when dealing with groundwater in urban areas. Urbanization significantly affects the natural water cycle, both in terms of quantity and quality. In particular, the main contributors to recharge and discharge clearly differ from those in natural systems. Moreover, water can affect underground structures and infrastructure characteristics of cities such as basements, public transport services (trains, underground railways, etc.), and utility conduits. As a result, urban groundwater is emerging as a distinct branch of hydrogeology (Vázquez-Suñé et al. 2005).

The area of Roma Capitale (Municipality of Rome) has a particular geological and hydrogeological setting. It is in fact strongly influenced by the coexistence of tectonic activity, volcanism of several volcanoes (the Vulsini, Cimini, Sabatini volcanic complex northward, the Colli Albani volcanic complex to the south) and eustasy. By a general hydrogeological point of view, the roman area is placed between three regional structures and aquiclude the Pliocene Clays (which can be considered the bedrock of this area, with more than 800 meters of thickness).

Going into details, main aquifers of Rome are located in the Colli Albani volcanic pozzolanaceous products and in the continental and alluvial prevolcanic and sinvolcanic sediments. Moreover olocenic valleys, filled by postvolcanic alluvial sediments, are interested by a confined aquifer into the gravels placed in the base of the alluvial sequence (Capelli et al. 2008; La Vigna et al. 2008).

Thus there are 6 hydrogeological units that can be indentified (Fig. 1): 1) the volcanic aquifers of Sabatini Volcano (right of Tiber); 2) the volcanic aquifer of Colli Albani Volcano (left of Tiber); 3) the continental aquifers of Paleo-Tiber of Ponte Galeria Formation; 4) the alluvial aquifers of Tiber; 5) the Tiber fan; 6) the aquiclude of M. Vaticano clayey Pliocene formation. Looking at hydraulic relationships between these units the main groundwater circulations which can be identified are: the basal Tiber alluvial gravel body, the volcanic and prevolcanic aquifer's body in the orographic left of Tiber, the volcanic and prevolcanic aquifer's body in the orographic right of Tiber, and the alluvial fan aquifer's body.

Main Body

In order to realize a groundwater monitoring network in the complex hydrogeological setting of the territory of Rome, the offices of the Environmental and Civil Protection Department of Roma Capitale are working to survey all the existing wells which are property of the municipal administration and which are more than 100 units.

All these wells are located in a random distribution but it should cover much of the Rome's territory. Moreover, as they were realized for the irrigation of public parks they generally are very productive wells because they were drilled until main aquifers.

The survey activity consists in two phases. The first is about the collection of all information about existing wells, the data entry in a database and in a geographic information system (GIS). The second phase will be the field survey in order to confirm the exact location using a GPS device, and to measure the hydrogeological data such as water table depth, groundwater temperature and electric conductivity, firstly manual and probably in the future with dataloggers.

When all the available wells will be surveyed, the Municipality of Rome will be able to use its monitoring network in order to detect:

1) fluctuations in groundwater levels caused by changes in land and water uses;

2) pollution problems caused by point or non-point sources in urban area;

3) characterization and quantification of the

components contributing to groundwater recharge and discharge;
4) specific characteristics of groundwater flow and solute transport models in urban areas;
5) geothermal energy potential of groundwater;
6) integration of data for sustainable urban water management.
Moreover all data could be used in order to realize a new Hydrogeological Map of Rome.

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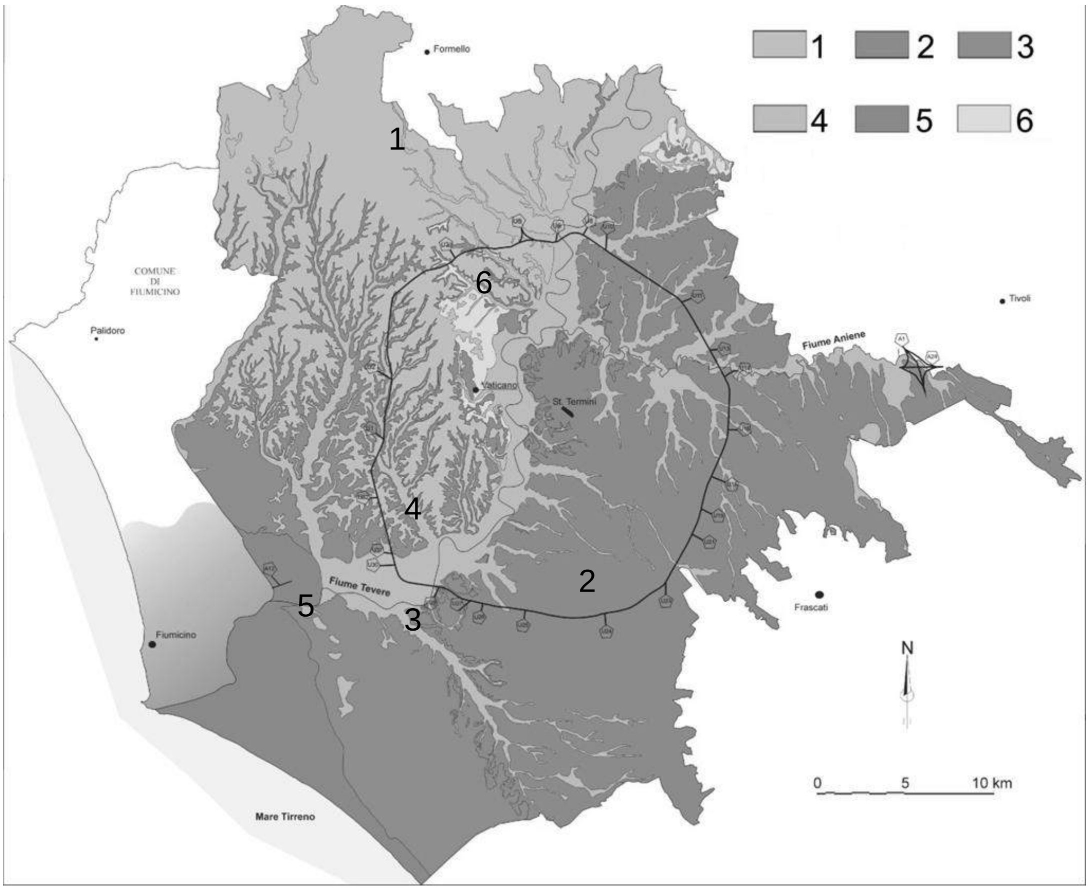

Fig. 1 – Hydrogeological Units of Rome (from Capelli et al. 2005). 1) Sabatini Mts.; 2) Alban Hills; 3) Ponte Galeria and Paleo-Tiber; 4) Recent and Present alluvia; 5) Tiber river delta; 6) M.Vaticano formation (aquiclude).

[32] PRELIMINARY CONCEPTS FOR FLUID FLOW BEHAVIOUR IN THE SHERWOOD SANDSTONE AQUIFER (GREAT BRITAIN): INSIGHTS FROM FIELD WORK AND LABORATORY ANALYSES

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Keywords: Sherwood Sandstone, Fluid flow, Contaminants, Sedimentary structures, Tectonic structures

Introduction

The Sherwood Sandstone Group (Triassic) consists of redbeds related to the rifting phase that preceded the opening of the Atlantic Ocean. The Sherwood Sandstone on-shore crops out over large portions of northern and central England and is the UK's second most important aquifer, supplying around 25% of abstractions in England and Wales (Monkhouse and Richards, 1982). In the North Sea, offshore Norway and in the Irish Sea the Sherwood Sandstone is also an important reservoir (McKie and Williams, 2009) for hydrocarbons and CO_2 storage. The cap rock both onshore and offshore is represented by the Mercia Mudstone Group. Onshore, the Sherwood Sandstone Aquifer is susceptible to contamination because of the widespread use of agrochemicals such as pesticides and fertilizers. Moreover, increasing industrial development around the cities of Liverpool, Manchester, Birmingham and Nottingham, where the Triassic sandstones form the bedrock, has increased the potential for aquifer contamination. Previous works on the Sherwood Sandstone have described separately the influence on fluid flow and contaminant dispersal of sedimentary structures (Pokar et al. 2006; West and Truss 2006) and tectonic structures (Wealthall et al. 2001; Hough et al. 2006). However, the combined influence of tectonic and sedimentary structures on fluid flow and contaminant dispersal remains largely unquantified (e.g. Hitchmough et al. 2007).

Methods

Geological field work at outcrop scale is being carried out on the west coast of England and in Yorkshire. The aim of this field work is to identify the heterogeneities that influence fluid flow, focusing on both sedimentary structures (e.g. bedding surfaces, bed-parallel laminations, cross-bedded laminations) and tectonic structures (e.g. veins, deformation bands, fractures, joints, faults). Samples have been tested for porosity and hydraulic conductivity parallel and perpendicular to bedding and tectonic structures and textures have been investigated by scanning electron microscopy (SEM).

Results and discussion

In northeast England the Sherwood Sandstone lithology is poorly lithified in outcrop and is characterized by bedding surfaces that dip regionally at about 2° to the east. Previous studies show that typical porosities 33-36% and the hydraulic conductivity is anisotropic with Kv/Kh varying from 0.03 to 1.7 (Pokar et al. 2006). SEM analyses show that the reason for this strong anisotropy is bedding-parallel and low angle sedimentary structures with clay minerals aligned parallel to the laminations. Consequently, the sub-horizontal sedimentary structures represent either strong barriers or baffles to fluid flow in orientations perpendicular to bedding, thereby encouraging lateral drainage parallel to bedding (West and Truss 2006). In these same rocks, deformation bands show a relatively low permeability of around 9 mD. SEM analyses show that such low permeability zones are due to porosity reduction and the presence of clay minerals and mica oriented parallel to deformation bands; such structures represent strong barriers to fluid flow.

Field work on the west coast of England (St. Bees Head area) has highlighted how the well-lithified Sherwood Sandstone of the East Irish Sea Basin is characterized by high-angle tectonic fractures and faults that define well-developed damage zones, which may represent preferential fluid-flow pathways. Where the Sherwood Sandstone is more lithified, deformation bands appear to be less common and tectonic features are dominated by open fractures. To aid development of a conceptual model for fluid flow in these rocks it is important to account for extension and uplift-related, sub-vertical, open joints, which tend to be strongly influenced by the mechanical units formed by the sedimentary structure. As a consequence, joints form strata-bound systems where they terminate at bedding surfaces (Odling et al. 1999). Bedding-parallel fractures establish communication between sub-vertical joints in adjacent units. Beds are characterized by bedding-parallel and low-angle-inclined laminations which form barriers for fluid flow. Consequently, tectonic joints may represent the dominant pathways for fluids and contaminants.

In the East Irish Sea Basin, as well as in the Triassic basins of Midlands (Rogers et al. 1981), the bedding surfaces attain regional tectonic dips of 10°-15° due to Cenozoic basin inversion. In the unsaturated zone in the Sherwood Sandstone of northeast England, West and Truss (2006) demonstrated how the presence of bed-parallel sedimentary barriers resulted in water movement parallel to bedding surfaces. This lateral drainage mechanism is also likely to be more important than has hitherto been recognized in the Sherwood Sandstone of the Midlands and the East Irish Sea Basin, especially where bedding dips regionally at 10°-15°.

Conclusions

Both tectonic and sedimentary structures can potentially influence fluid flow in the Sherwood Sandstone and consequently the dispersal of contaminants soluble in water. Sedimentary structures such as bedding-parallel and low-angle-inclined cross-bedded laminations can represent barriers or baffles to fluid flow and are potentially key drivers for flow behavior in all UK Triassic basins. Where the Sherwood Sandstone is poorly lithified and highly porous (e.g. northeast England) deformation bands can also represent important barriers for fluid flow. Where the Sherwood Sandstone is more lithified, sub-vertical and bedding-parallel joint systems are likely to represent important pathways for fluids. In addition, the movement of soluble pollutants may be enhanced in regions characterized by strata inclined at 10°-15° where Cenozoic inversion has tilted the beds, particularly in western England.

Acknowledgements

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[33] PROTECTION ZONES FOR DRINKING WATER: AN INTEGRATED APPROACH APPLIED TO SPRINGS AND WELLS LOCATED AT THE SW BORDER OF APUAN ALPS (TUSCANY-ITALY)

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Keywords: drinking water, aquifers, safeguard zones, protection zones, groundwater

Introduction

In many areas groundwater is the most important and safest source for drinking water (Zhu and Balke, 2008). In order to protect this essential resource the establishment of safeguard zones for drinking water abstractions is a very important task.

After the DIRECTIVE 2000/60/EC, Member States approached this issue by domestic legislation, in which, although with some technical differences, three zones are mentioned:

- an inner zone, that is the area immediately surrounding the abstraction point;
- an intermediate zone, which corresponds to the area surrounding the previous one and is generally delineated on the base of a reference travel time;
- an outer zone, that is the area around a source within which all groundwater recharge is presumed to be discharged at such source.

Several cases of study were also published (e.g., Derouane and Dassargues 1998; Pochon et al. 2008; Zhu and Balke 2008).

For the Italian law (D.Lgs. 152/2006; 12 December 2002 agreement) the above mentioned zones are named *absolute safety zone*, *respect zone* and *protection zone,* respectively. The first zone is simply defined by geometric criteria (radius at least 10 m), the second one is delimited on the base of a travel time (60 and 180 or 365 days), when the available data and the hydrodynamic context are favorable, otherwise by means of the "hydrogeological approach", as for the establishment of *protection zone*.

Due to their major importance in terms of safeguard, in Italy the respect zone has been delimited for several abstractions according to existing guidelines. Instead, for the delineation of protection zones (PZs) there are no official documents neither a significant number of study cases.

In the framework of a project funded by the Tuscany Region Administration, several studies were carried out in the areas surrounding abstraction points that are located in different places of the regional territory. Fifteen PZs were delimited by means of an integrated approach and a cooperation among our Institute (IGG), the Water Authorities (WAs) and the Integrated Urban Water Management Companies (IUWM-Cs). In this extended abstract the adopted approach is discussed and the results of its application on two groups of drinking water abstractions are presented.

Main Body

Methods

After a preliminary examination and elaboration of existent/available data, a survey program was produced and developed with the cooperation of the WAs and the IUWM-Cs. A general scheme about the integrated approach and the data used for the elaboration is reported in Fig. 1. Based on the hydrogeological context not all the data were necessarily required.

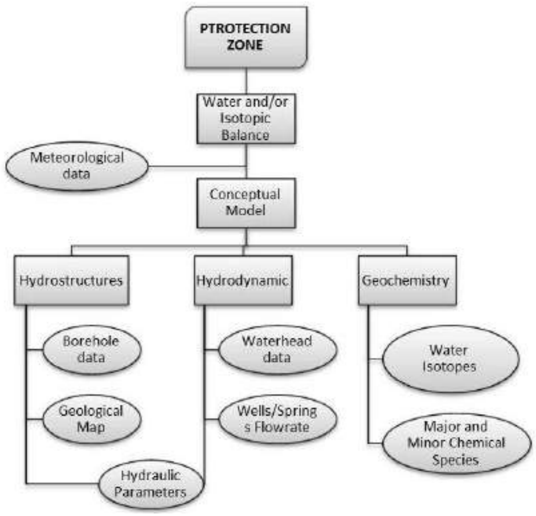

Fig. 1 – Scheme of the used data and the integrated approach (upward diagram flow).

Cases of Study

The examples discussed in this work regard the abstractions of the "Frati" well field (Fwf) and the "Stiava" springs (Ss), both groups located next to the southern border of the Apuan Alps (NW Tuscany). The Fwf is situated in the "Camaiore Basin" and it is made up by 32 wells; it drains about 300 L/s from an alluvial aquifer (gravel/pebbles, unconfined or semi-confined) whose substratum consists of permeable carbonate rocks, which widely outcrops on the nearby reliefs (Fig. 2). The Ss outflows from a sandstone formation that overlaps the carbonate complexes of the Apuan Alps, with an average flow rate of about 120 L/s.

Based on the scheme of Fig. 1, the study aimed at individuating the catchment basin for both groups of abstraction points and the main achieved results can be summarized as follows:

- the analysis of geological structures pointed out that in the area a general North-South groundwater flow is favoured by a combination of bedding and/or foliation attitude and fold axis plunges. The main fault system leads to the groundwater flow subdivision into different sub-basins and it also determinates an uprising of groundwater from the carbonate complexes throughout the sandstone formation (Ss origin). Moreover, the hydro-structures study highlighted a likely loss of groundwater from the "Camaiore Basin" towards the Ss, and some possible hydrogeological divides;
- a piezometric map was achieved for the alluvial aquifer that is exploited by the Fwf. The contours of hydraulic head show a feeding from the carbonate complexes, which outcrop in the surrounding area. Three major streamlines exist and they converge towards the wells field. After dividing the piezometric map into stream tubes, Darcy and Kamenskij equations were applied using the transmissivity values achieved by means of several pumping tests. In this way major and minor inputs at the system were identified. Based on the Ss discharge hydrograph and given the high variability of the flow rates (60-190 L/s) it is possible to state that the carbonate complexes are involved in the springs feeding, thus confirming the hydrostructural considerations;
- chemical and water-isotopes analyses were twice performed not only for the abstractions under study but also for about 15 water points (river, springs and wells) in their surroundings. Among these, six springs were opportunely selected to assess the relationship "altitude/$\delta^{18}O$‰", which is useful to achieve the recharge average altitudes of drinking water abstractions. By combination of chemical and isotopic data, the presence of some input and of their mixing products were verified. Chemical features suggested what kind of lithology is involved in water-rock interaction processes (e.g., Calcare Cavernoso for the SO_4 values, or Sandstone for the SiO_2 values), whereas isotopes indicated the average altitudes of infiltration for the different inputs. Taking into account these aspects and the mixing processes, it was possible to achieve indications both on the areas involved in the abstractions feeding and on their primary or secondary importance in terms of quantity.

Based on all the above mentioned information, two catchment areas were delineated for the Fwf and Ss, respectively. These polygons were additionally validated by means of water and isotopic budget: for each zone in which the same hydrogeological complex outcrops, both infiltration rate (http://www.sir.toscana.it/, for meteorological data; Piccini et al. 1999, for infiltration coefficients) and the average values of $\delta^{18}O$‰ (joining the average altitudes and the relationship "altitude/$\delta^{18}O$‰") were estimated.

After this validation, the final PZ was delimited for both the groups of drinking water abstractions (Fig. 2). As shown in the figure, for each PZ the results deriving from the integrated approach allowed also to individuate the subzones A and B, which respectively correspond to the chief zone and the secondary zone in terms of feeding.

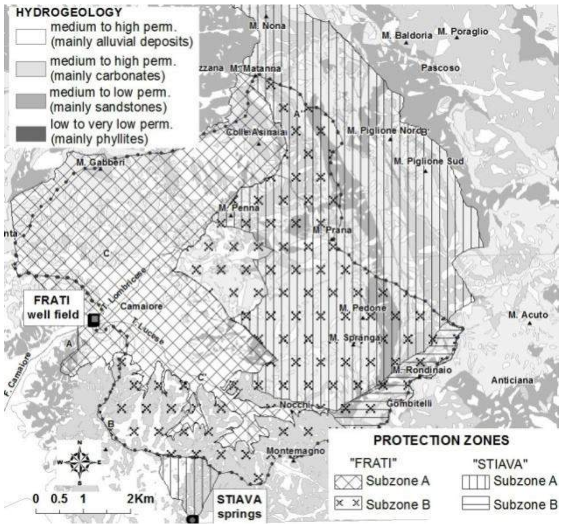

Fig. 2 – Hydrogeology and protection zones.

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[34] THE CURRENT STATE OF THE LOCAL GROUNDWATER SUPPLY SYSTEMS IN THE CITY OF BELGRADE, REHABILITATION AND PROSPECTS FOR UTILIZATION

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Keywords: urban hydrogeology, cadaster, Belgrade, groundwater quality

Introduction

Belgrade is the capital and largest city of Serbia, with a population of about 1.5 million, divided into 17 municipalities. It is located at the confluence of the Sava and Danube rivers, where the Pannonian Plain meets the Balkans. The city has an urban area of 360 km^2, while together with its metropolitan area it covers 3.223 km^2. Central Belgrade has a hilly terrain with two mountains, Avala (511 m) and Kosmaj, (628 m) south of the city. Across the Sava and Danube, the land is mostly flat, consisting of alluvial plains and loessial plateaus.

The population of Belgrade is supplied with drinking water from six water supply systems, a large number of local water systems, public fountains, and individual wells.

Only central and bigger local water supply systems are under permanent control. The majority of small local supply systems is in private ownership, and therefore, excluded from monitoring system. Also, there are no definite data about the total number of public fountains, individual wells and other water supply objects, nor on their characteristics, purpose or capacities. The biggest problem the is lack of knowledge about the water quality of those objects.

Goals and methodology

In the last 25 years, several times the city of Belgrade initiated to create the cadaster of the hydrogeological phenomena and objects that would determine their location and characteristics.

The main goal was to help solving the vital water supply problems in Belgrade and its municipalities.

Immediate objectives of this research were to develop maps of water objects (springs and wells), create a cadaster of the objects with chemical and microbiological analysis, determine the condition and maintenance level for tapped springs and wells and organize photo and video archive.

After completing these tasks, recommendations for necessary work on objects were formulated, with measures for protecting and arranging some objects which were estimated to be important for the water supply.

The basis for this investigation were two earlier studies, carried out in 1989 (Tošić 1990) and the other in 2006 (Group of authors 2007). In both studies, the basic cadaster of groundwater objects was formed. Data were correlated with available topographic and aerial maps of research area.

After cross referencing and correlatiing all objects from the maps with those already processed during earlier studies, field survey was started. It provided information on the state of the objects and about groundwater physical and chemical characteristics of groundwater.

In the end, a cadastre of water objects with a digital map and database was formed, aiming at systematizing and gathering all relevant data on the research area in form of layers.

Results and Discussion

By correlating new investigation results with previous data, it issues that the water quality of a number of springs and supply wells deteriorates in time, mainly because of urbanization and city development. On the one hand, most objects are properly protected and in poor condition, on the other hand, untapped aquifers are endangered by illegal landfills and wastewater discharge. Thus, groundwater quality is jeopardized by polluted sites, at a grade depending on local vulnerability and conditions.

On the basis of the water quality test carried out in the Belgrade area, it can be concluded that the water quality from public taps is highly variable. The majority of the public fountains under control do not meet the sanitary and hygienic standards for drinking water, especially in summer when bacterial and microorganism reproduction increases, or during the rainy period when the runoff and atmospheric water infiltrate into the aquifers

Conclusion

To summarize, more than thousand springs and wells are known in Belgrade. Most springs are located in the southern, hilly part of the town, whereas wells are common in its northern part. Unfortunately, there is a great amount of private wells for which we have no data. Most of the tapped springs were once used for domestic purposes. Nowadays, as a result of urbanization, most of the households are attached to

centralized water supply system, while springs and wells are abandoned. Only 6 out of 25 public fountains tapping ground water are regularly monitored and usually only the water of a half of them is suitable for drinking. A great amount of springs are used as waste water recipient in parts of town that have no sewage. Also, springs are used as a waste disposal sites. Wells are usually used for agriculture and cattle. In terms of chemical composition and water types of springs and wells, it can be said that, in general, water from the southern, hilly part of the town is of HCO_3-Ca composition, sometimes with increased concentration of SO_4 and Cl ions, due to the geology of the terrain. Chemical composition in the northern part of the area is usually of HCO_3-Na composition, as observed wells are located in alluvial planes of Sava and Danube, or in aquifers of the Pannonian basin.
The development of a vulnerability and hazard database and GIS map and photo and video archive represents the first step in an attempt to improve the present situation.

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We would like to thank dr Veselin Dragišić and mr Vladimir Živanović for their great help during the research.

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[35] APPLICATION OF A MULTI-COMPONENT METHOD FOR THE ASSESSMENT OF A SALTWATER UPRISING INTO AN ALLUVIAL CONTINENTAL AQUIFER (OLTREPO PAVESE PLAIN, ITALY)

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Keywords: saltwater contamination, multi-tracing method, alluvial aquifer, Oltrepò Pavese.

Introduction

The Oltrepò Pavese plain sector (Po Valley, Northern Italy) was already studied in the past for the occasional presence into the alluvial aquifer of deep salty paleo-waters, coming from the tertiary marine deposits and mixing with the fresh shallow water (Pilla et al. 2007a; Pilla et al. 2007b, Bersan et al. 2010; Pilla et al. 2010; Bersan 2011). These studies allowed to detect the three main hydrochemical facies of the Oltrepò Pavese groundwater: the Ca-HCO_3 waters, that are the most diffused, the Na-Cl waters, on which in particular the previous studies have focused, and the Ca-SO_4 waters.

Over an experimental site of about 8 km^2 a multi-component method on the Oltrepò Pavese groundwater was applied. It was based on a sampling realized at different depth for a few wells involved by saltwater contamination.

This kind of investigation pointed out interesting variations, both with depth and in time, not only for what concerns the Cl^- and Na^+ content of waters, but also for their HCO_3^-, SO_4^{2-}, Mg^{2+}, Ca^{2+}, NO_3^- and K^+ concentrations.

This study allowed to observe the complex relationship between shallow waters and deep mineralized waters, probably of different origins.

The origin of the Oltrepò Pavese saline waters is connected to the brines of the Po plain (Conti et al. 2000). Previous studies investigated the distribution of these waters into the alluvial aquifer, which is connected to the presence of discontinuities into the marine basement (Vogherese Fault, Marginal Fault, secondary discontinuities), and the possible mechanism at the base of their uprising. In particular, to define the distribution of these waters, both an hydrochemical study, that involved periodical sampling of waters and logs of electrical conductivity, and a geophysical study, that concerned 2D and 3D ERT surveys and a large scale VLF-EM survey, were carried out. The existence of isolated plumes of Na-Cl waters that pollute some limited sectors of the aquifer was pointed out. Moreover the three hydrochemical facies of the Oltrepò Pavese groundwater were detected: the Ca-HCO_3 waters, that represent the typical water of this area, the Na-Cl waters, which have a deep origin, and the Ca-SO_4 waters, identified on a few, restricted areas.

In this study 8 monofilter wells, 15 to 20 m deep and with a fully screened interval, were monitored, which waters are rich of Cl^- and Na^+; some of them also show an high content of SO_4^{2-} and a local presence of H_2S. A multi-component method was applied. Each well was sampled in different period of the year (July 2013, September 2013, 15 October 2013, 28 October 2013, January 2014) at different depth (every two meters) to define the chemical characteristics of waters along the vertical space. This kind of investigation is more complete than logs of electrical conductivity, a more expeditious technique that, however, doesn't allow to discriminate among the different ions present in the water.

A peristaltic pump was employed. The small dimension of the tube (Ø = 0.8 cm) and the low pumping rate allowed to avoid disturbances and mixing of waters during sampling. Moreover in situ measures of electrical conductivity, temperature, pH and RedOx potential were taken. Major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^{2-}, NO_3^-, HCO_3^- and Cl^-) were analyzed at the Hydrology, Hydrogeology and Hydrochemistry Laboratory of the Earth and Environment Science Department (University of Pavia). The software Wateq was employed to obtain log pCO2, TDS and saturation index for the main mineral phases.

Two areas were distinguished from data results. Area 1 is located northward, close to the Vogherese Fault. Area 2 is located southward, close to the Apennine margin and near the recharge area of the aquifer corresponding to the alluvial fans.

As expected, a vertical variation for Na^+ and Cl^- content of waters was detected. But in some cases, into the same well, it was also pointed out a different concentration relative to the other ions with depth, in particular the SO_4^{2-}. As their content increases with depth, a human contamination can be excluded. Moreover changes of ions concentration more or less evident in time were observed (Fig. 1).

The high content of sulphates in waters could be attributed to the local presence into the marine substratum of the alluvial aquifer of layers or lenses of Gessoso-Solfifera Formation, that

crops out along the low Apennine, rather than to the deep saline waters.
These results deserve attention and a more detailed investigations aimed at a better comprehension of the complicated relationship between shallow waters and deep mineralized waters, that are probably of different origins.

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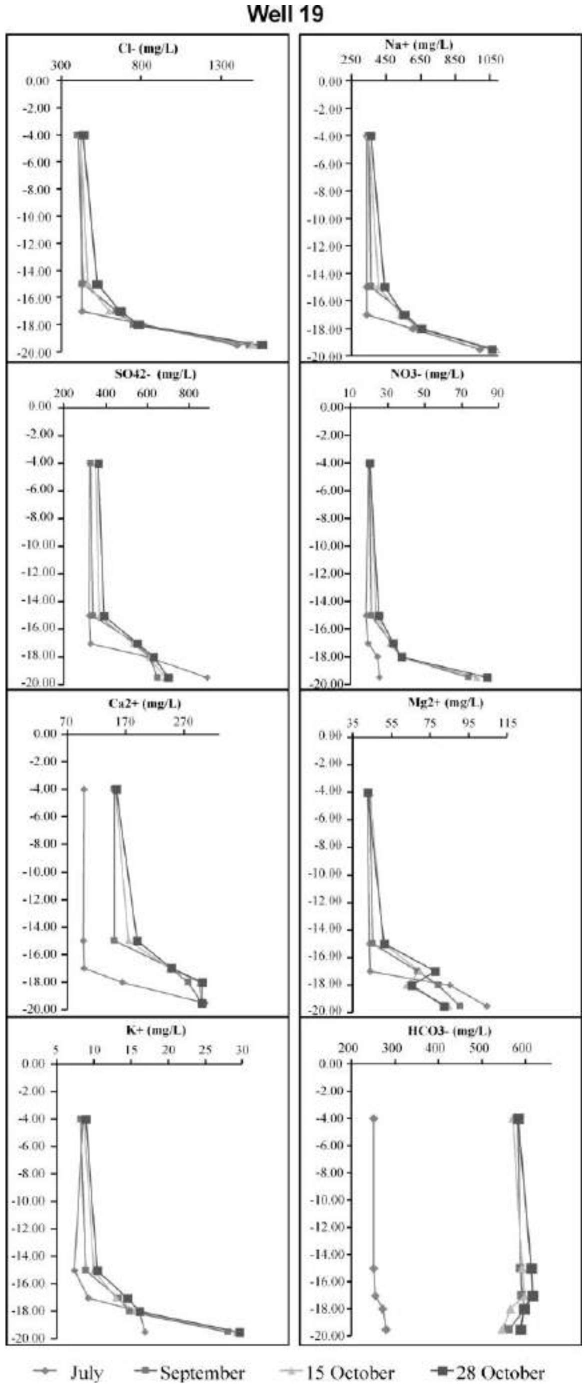

Fig. 1 – Variations in time of some ions for well 19.

[36] A MULTI-ISOTOPIC APPROACH TO EVALUATE ORIGIN AND FATE OF NITRATE IN GROUNDWATER HOSTED IN A NVZ SARDINIAN AREA

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Keywords: Nitrate Pollution, Groundwater, multi-isotopic approach, Arborea (Sardinia)

Introduction

Water pollution by agriculture nutrients, especially nitrate, has been recognized as one of the most relevant environmental problems in EU. Through the Nitrate Directive (ND, 91/676/EEC), the EU member countries identified Nitrate Vulnerable Zones (NVZ's), developed protocols of good agricultural practices and set up action programs for the management of farm wastes.

The understanding of the origin and fate of nitrate, as well as of the biogeochemical processes controlling nitrate attenuation in aquifers, is fundamental for preserving the quality of groundwater supplies, as well as surface waters affected by groundwater inflow.

The present study, framed within the KNOW project, aims to evaluate the integrated risk of aquifer pollution by agricultural origin in the dairy farming district of Arborea (W-Sardinia). The area, identified as a NVZ, is one of the most productive agricultural sites in Italy and the productivity of its diary system is one of the highest in Europe (Mura et al. 2013). Due to the complexity of the study area, the need to identify the potential sources of nitrate (organic and inorganic fertilization, sewage) in groundwater becomes more pressing (Nguyen et al. 2013). The research has been focused in a transect of 2.8 × 1.8 km, taking into account the nitrate seasonal dynamics, and integrating hydrogeochemical, hydrogeological and agronomic approaches (Pittalis et. al. 2013). Hydrogeochemical data were obtained coupling chemical and multi-isotopic approaches, in order to tracing the sources of nitrate pollution and evaluating the chemical reactions related to denitrification processes.

Material and Methods

The investigated area is located in the northern part of the Campidano Plain (Central-Western Sardinia, Italy). It occupies the northern part of the Campidano rift in which Quaternary deposits outcrop: littoral sediments (sands), lacustrine deposits (silt and clay), alluvial deposits along the rivers, continental deposits (gravel and sands).

Two Hydrogeological Units (HU) were identified:

- Sandy Hydrogeological Unit (SHU);
- Alluvial Hydrogeological Unit (AHU);

Groundwater from 13 wells were sampled bi-monthly since February 2013, along a transect located in correspondence of the sandy aquifer (SHU). Groundwater samples were stored at 4ºC in a dark environment. For each water sample, major anions, cations and metals have been analysed. Isotopic determinations were carried out for water stable isotopes ($\delta^{18}O$, $\delta^{2}H$), nitrogen and oxygen isotopic composition of dissolved nitrate ($\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$), sulphur and oxygen isotopic composition of dissolved sulphate ($\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$), and isotopic composition of dissolved boron ($\delta^{11}B$).

Results

In the Arborea area, nitrate concentrations in groundwater vary from 1 mg/L to 162 mg/L. The livestock effluents (mostly slurry) are used as organic fertilizers with formal restrictions on maximum rates (up to 170 kg N ha^{-1}) and time of their distribution (no spreading from November to February) as by the NVZ rules. Organic effluents represent more than 50% of the crop N input source and are considered the main source of nitrate pollution. In general, the pollution sources cannot be properly identified only considering the isotopic composition of dissolved nitrate (Fig. 1), although some samples appear characterized by a nitrate source from synthetic fertilizers. Preliminary results combining the use of boron and nitrogen isotopic compositions indicate that animal manure should be the dominant pollution source in this area.

Water samples with relatively low nitrate concentrations might be related to denitrification processes (Otero et al. 2009). Indeed, two types of processes that affect the SHU groundwater of Arborea area, have been observed: denitrification (Fig. 1) and sulphate reduction. The former process needs, however, to be further evaluated. In fact, in some surveys at more denitrified samples corresponded higher nitrate concentration.

The samples with the lowest concentrations of nitrate appear subjected to denitrification processes, because the isotopic compositions of dissolved sulphate for these samples, emphasizes the existence of sulphate reduction.

Conclusion

The case study site provides a number of potential insights about the dynamics of nitrate pollution. Results available so far indicate that nitrate pollution in the Arborea area can be attributed mainly to animal manure and secondary to synthetic fertilizers. Active natural denitrification is occurring in the area, although in some months is recorded an alteration of the process.

Further investigations are planned in order to characterize the seasonal variations in the chemical and isotopic composition of nitrate and to improve our current knowledge on both nitrate pollution sources and the quantification of natural denitrification rates.

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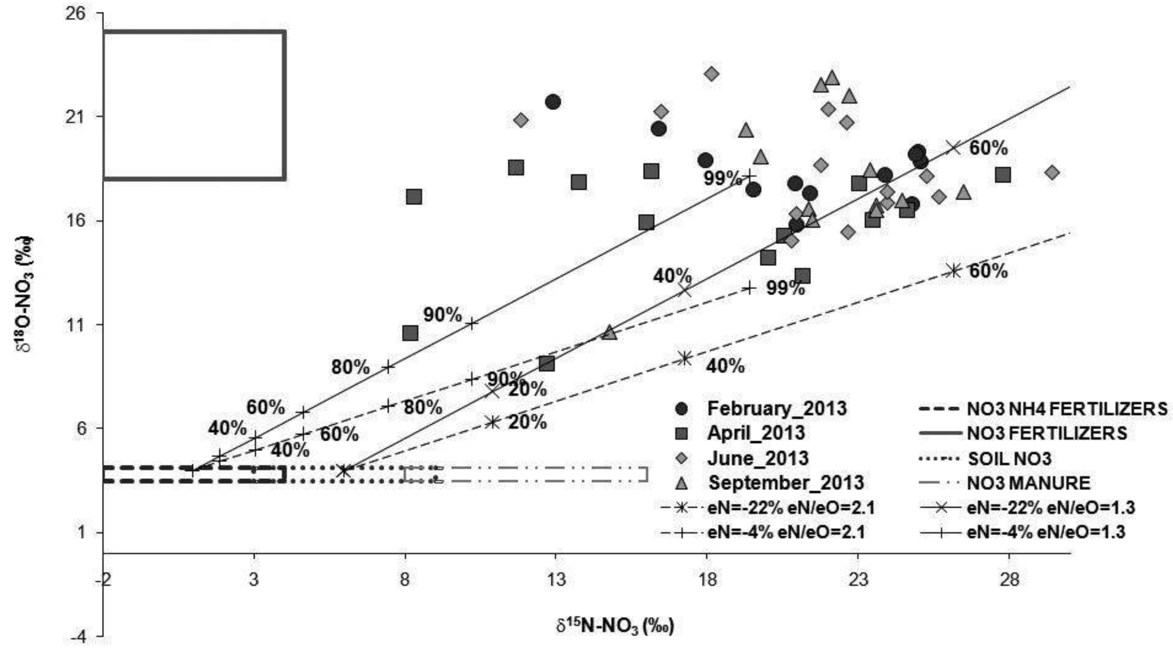

Fig.1 – Diagram $\delta^{15}N_{NO3}$ vs $\delta^{18}O_{NO3}$ and isotopic composition of the main nitrate sources (rearranged from Otero et al. 2009).

[37] HYDROGEOLOGICAL IMPACT OF FIRENZUOLA RAILWAY TUNNEL (ITALY): INFERENCES FROM THE CHEMICAL AND ISOTOPE COMPOSITION OF SUPERFICIAL AND GROUND WATERS

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Keywords: Chemical composition; Isotope composition; tunnel impacts; Northern Apennines; Mugello - Italy

Introduction

The Firenzuola tunnel is part of the new Bologna-Firenze high-speed railway, opened in 2009. This tunnel, located approximately 29,2 to 44,5 km northwards of Firenze, was excavated at an elevation of 300-350 m a.s.l, below the main apenninic watershed (mean elevation 1000-1100 m a.s.l.; Rodolfi et al. 2004).

The excavation of the Firenzuola tunnel caused a significant drop of groundwater levels, and the drying out of springs and creeks regionally, due to the seepage of surrounding groundwater into the tunnel (AA VV 2008). About 250 L/s of groundwater currently discharge into this tunnel during the low-flow season, but a maximum inflow of 900 L/s was estimated, along the whole tunnel, during the digging.

The main purpose of this study was to elaborate an integrated hydrogeological and geochemical model of the area impacted by the tunneling works, and possibly identify the main structures connecting the tunnel with streams and surficial aquifers.

Methods

Samples were repeatedly collected on a total of 46 water points during the period 2004-2009, and an additional point was sampled in 2011 and 2012. Temperature, pH, electric conductivity were measured in the field. The concentration of major (Ca, Mg, Na, K, Cl, HCO_3, SO_4) chemical constituents was determined in the ARPAT laboratories of Firenze, whereas the isotopic composition of water ($\delta^{18}O$, $\delta^{2}H$, ^{3}H) was measured in the CNR-IGG laboratories of Pisa.

Results and discussion

Three main types of waters were considered for this study: i) creeks and streams, ii) springs and wells; iii) tunnel seeps. All the sampled waters have pH values between 6.7 and 10, with the most alkaline values associated to tunnel seeps. Waters inflowing in the Firenzuola tunnel are generally more saline (up to 848 mg/L) than waters from springs (238-508 mg/L) and streams (314-574 mg/L). Surficial waters have a Ca-HCO_3 signature, whereas the chemical composition of tunnel inflows varies from Ca-HCO_3 to Na-CO_3–HCO_3 with increasing salinity. The prolonged interaction of meteoric waters with host rocks causes Na_{TOT} concentrations to increase and Ca_{TOT} to decrease in tunnel seeps (Figs. 1 and 2). Decreasing tritium contents (^{3}H <4 UT; Fig. 1) are good tracers of i) prolonged underground residence times, and ii) of the lack of mixing with meteoric waters (^{3}H >5 UT) rapidly infiltrating in the Marnoso Arenacea flysch.

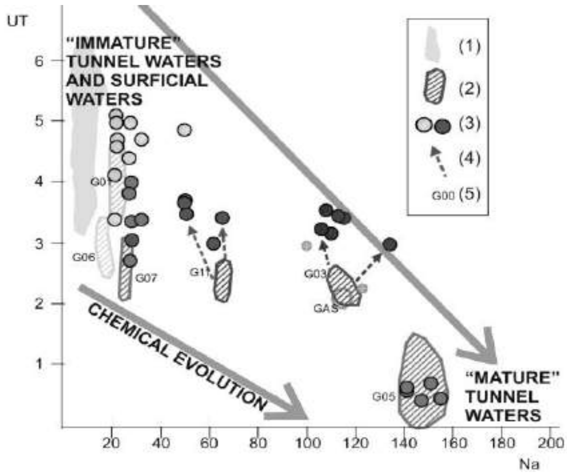

Fig. 1 – Tritium (UT)-Na correlation for streams and springs (1), 2004 (2) and 2007/08 tunnel seeps (3). Dotted arrows (4) indicate major variations over the period 2004 to 2007/08. Labels (5) identify tunnel water points (Gxx = Firenzuola, GAS = Allocchi).

A reaction-path modeling approach was applied to simulate water-rock interactions likely occurring in the Marnoso Arenacea aquifer. Numerical outputs indicate that most saline and alkaline waters sampled in the inner part of the Firenzuola tunnel (Southern sector, zone I of Fig. 3) can be produced by hydrolysis of the Marnoso Arenacea flysch.

The stable isotope composition of waters indicates that tunnel seeps have a common meteoric origin, compatible with precipitations falling in Central Italy (d-excess = 15).

By combining hydrogeological and geological information with data on chemical and isotope composition of waters, we derived a model of underground water circulation which considers two main hydrogeological sectors in the tunnel (Fig. 3). The northern sector of the tunnel is dominated by the rapid infiltration of meteoric waters, as testified by the direct drainage from Veccione stream (Vincenzi et al. 2013).

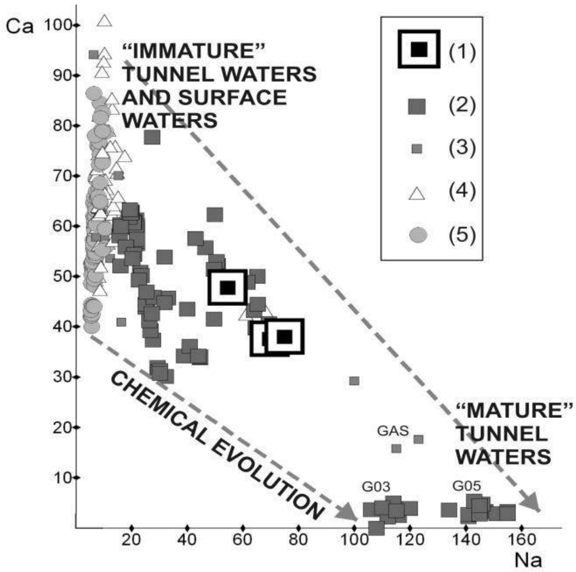

Fig. 2 – Ca-Na correlation diagram. 1) Firenzuola tunnel, southern entrance, 2012; 2) Firenzuola tunnel, 2004-2007; 3) Allocchi tunnel; 4) streams; 5) springs.

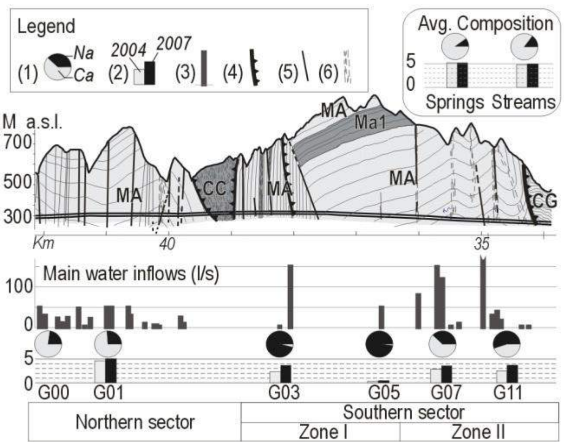

Fig. 3 – Projection of selected geochemical parameters over the geo-structural cross-section of the Firenzuola Tunnel. (1) Ca/Na ratio; (2) tritium content in 2004 and 2007; (3) inflow rates (L/s) during the excavation; (4) thrusts; (5) faults or main fractures; (6) fractured belts; (MA); Marnoso-Arenacea fm.; (MA1) marl-rich member of Marnoso-Arenacea fm.; (CC) Caothic Complex; (CG) Castel Guerrino fm.

The southern sector comprises two sub-zones: the first one (Zone I), adjacent to the olistostrome, is dominated by relatively ancient waters (likely older than 100 years; ^3H generally <2 UT), having high pH values, and Na-CO_3-HCO_3 composition. In this zone, the occurrence of marl-rich, relatively impermeable strata of the Marnoso-Arenacea fm. above the tunnel (MA1 in Fig. 2) prevents meteoric precipitation from infiltrating in the excavated area. The remaining zone (Zone II), is characterized by the occurrence of the same "old" waters of Zone I, locally mixed with waters rapidly percolated in the aquifer through well-defined fractures zones.

The occurrence of long residence water circuits, is further supported by: (i) the presence of low-^3H waters in the Allocchi tunnel, a railway tunnel excavated at the end of XIX century in the same flysch formation of the Firenzuola tunnel, not far (8 km) from the area of study; (ii) the measurable contribution of waters with prolonged residence times during the low-flow season in the water points sampled in 2011 and 2012 at the southern entrance of the Firenzuola tunnel.

Conclusions

Combined with geological and hydrogeological information, a detailed chemical and isotope survey of 47 water points (streams, springs, wells and tunnel seeps) during the period 2006-2012 contributed to the definition of an integrated hydrogeochemical model of an area impacted by the tunneling works for the Bologna-Firenze high-speed railway. Water isotopes revealed that waters of different age are drained by the Firenzuola tunnel, with the oldest groundwater component likely being older than 100 years. The chemical characteristics of tunnel seeps are controlled by the extent of interactions with aquifer rocks (Marnoso Arenacea flysch). More prolonged residence times and/or effective water-rock interactions lead to more saline, pH alkaline waters of Na-CO_3-HCO_3 composition.

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[38] LARGE SCALE PHYTO-TREATMENT FOR ECOSYSTEM RESTORATION: THE SAN NICCOLÒ EXPERIMENT

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Keywords: Groundwater dependant ecosystem, peatland hydrology, phyto-treatment, ecosystem restoration, paludiculture

Introduction

Since 1930, a large part of the Massaciuccoli Lake coastal marshy area (Tuscany, Italy) has been drained for agricultural purposes by means of a complex network of artificial drains and pumping stations. In the drained areas, peat soils, with values of organic matter up to 50% in some cases, are largely present (Pistocchi et al. 2012). Conventional agriculture (80%) characterises land use. As a consequence of land use, several environmental concerns arose in the last 50 years, mostly related to:

I. the eutrophication status of the lake caused by nutrient enrichment (N, P) in surface- and ground-water (Rossetto et al. 2010a) then pumped into the large water body. Indeed, from the 1970s, the lake, from an initial oligotrophic status, progressively converted to an eutrophic/hypereutrophic status;

II. the subsidence (2-3 m in 70 years) of the lake bordering areas due to soil compaction and increased mineralization, which left the lake perched above the drained area, now 0 to 4 m below the mean sea level (Rossetto et al. 2010b).

Setting-up a phyto-treatment system was identified as a solution to improve water quality and to decrease soil organic matter mineralisation, with the final aim of restoring the ecological functions and providing a way to maintain sustainable agriculture.

Materials and Methods

A pilot experimental field of 15 ha using three different phyto-treatment schemes has been set up (Fig. 1): constructed wetland (A), vegetation filters (B) and natural wetland (C). The (A) system is internally and externally banked (0.5 m) in order to force water flow to a convoluted pattern which results in a travel time lengthening. *Phragmites australis* L. and *Thypha angustifolia* L. constitute the natural succession vegetation. The (B) system is based on the plantation of seven different no-food crops managed according to a periodic cutting and biomass harvesting. The system is crossed by a dense network of ditches supplying water to the crops through lateral infiltration and partial submersion. The plant species used are: i) woody plants: *Populus spp.*, *Salix spp.*; ii) perennial grasses: *Arundo donax* L., *Miscanthus x giganteus* Greef et Deuter, *P. australis* L.; iii) turfgrasses: meadows of cool-season grasses and seashore paspalum. The (C) system consists in a rewetted area where the re-colonization of spontaneous vegetation takes place. Natural elevation changes help in creating areas of different slope in order to promote the colonization of different plant species.

Site investigation was performed and data on stratigraphy (from top: 1/2m thick peat layer, 1/3 m organic matter-rich silt, 1/3 m stiff blue-gray clay, up to 30m thick sand layer; Fig.1) surface- and ground-water quantity and quality were gathered and related to the local and regional groundwater flow. The inferred hydrological conceptual model revealed the area is set in a regional discharge area and the groundwater dependent nature of the wetland, with mixing of different origin waters (Fig. 1).

To assess the most effective phyto-treatment system a multidisciplinary approach is maintained, aiming at evaluating the status and changes in water and soil quality, below ground microbes, CH_4 and CO_2 soil emissions, plant communities and fauna biodiversity.

A complete hydrological monitoring protocol has been set in place starting by meteorological data acquisition and including estimation of processes controlling the outlet discharge, such as infiltration/exfiltration or evapotranspiration. The main objective is the water budget estimation in different times at each of the three schemes in order to gain information on nutrients load and transfer through the environmental matrixes.

The relationships between the surface water and groundwater systems are currently investigated by means of about 15 clusters of piezometers (each of them with boreholes at about 3m, 2m and 1m depth, Fig. 2) to gain information on infiltration and/or exfiltration processes and evapotranspiration. As the system is a coastal one, the presence and influence of saline water on phyto-treatment capabilities will be evaluated.

Three different monitoring schemes are used: 1) continuous monitoring with in-situ sensors (h, T, CES); 2) composite sampling with automatic samplers proportional to the flow regime; 3) instant discrete sampling for groundwater. As far as common ions and nutrients determination, isotopes will be used to infer answers to particular research questions.

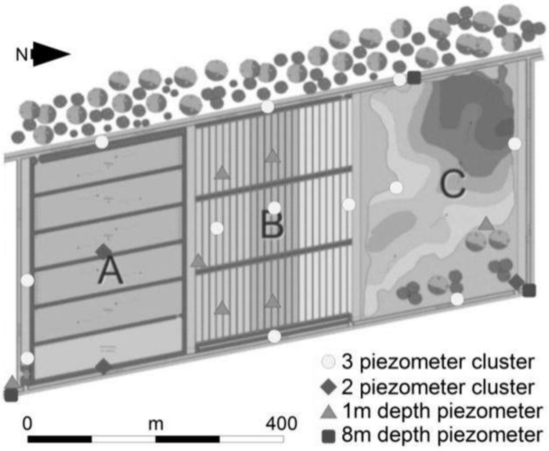

Fig. 1 - Aerial view (a) and sketch (b) of the pilot experimental field represented by three different phyto-treatment systems: constructed wetland (A), vegetation filters (B) and natural wetland (C).

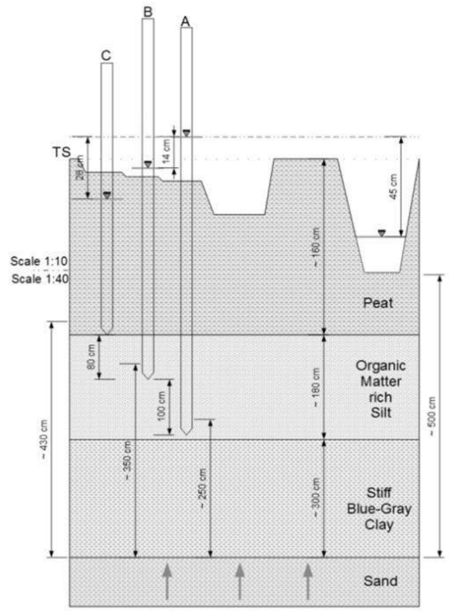

Fig. 2 - Hydro-stratigraphic setting and head potential distribution.

Main soil physico-chemical properties has been acquired in order to assess the experimental area status before rewetting. Measurements will be repeated time after time in order to evaluate the impact of the three different schemes on soil physico-chemical quality.

Molecular methods based on polymerase chain reaction (PCR) of DNA have been used to assess the genetic diversity of soil microbial communities. In the first part of the research activity, structure and composition of whole soil microbial community of the experimental field area has been assessed using DNA sequencing and high-throughput molecular tools.

The main greenhouse gases (GHG) fluxes from peatland, such as CO_2 and CH_4, are estimated in situ in order to assess the effect of rewetting and to improve the estimate of the peat mineralization coefficient.

The different plant species are monitored and harvested with the purpose of recording biomass production, shoot N and P uptakes and evaluating the technological parameters (e.g. ash, calorific value of biomass) for energetic purposes. The results will be used to choose the most suitable crop for phyto-treatment and energetic purposes. The effect of the three management system is going to be evaluated also in terms of biodiversity of the wetland fauna, such as aquatic birds and amphibians.

Conclusions

The experiment started in July 2013 and it is run routinely since December 2013. The three schemes are thought to be decreasingly managed as regard to water regime (from a strongly controlled system to a “quasi” natural rewetting), plant communities (from cultivated to native communities) and harvesting strategy. Successful results and social acceptance will constitute the basis for further enlargement of rewetted areas in the Massaciuccoli floodplain and other similar Mediterranean environments.

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[39] COMPONENT SEPARATION APPROACH TO ESTIMATE NATURAL BACKGROUND LEVELS: A CASE STUDY FROM THE LOWER PO PLAIN (NORTHERN ITALY)

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Keywords: Arsenic, Iron, Manganese, BRIDGE, Cremona.

Introduction

The EU Water Framework Directive (WFD 2000/60/EC) requires Member States to evaluate the “Status” of groundwater bodies, with the aim of achieving good groundwater status within 2015. In the case of naturally high concentrations of undesirable elements, the chemical status must be assessed against threshold values defined on the basis of Natural Background Levels (NBL). The EU research project BRIDGE (Müller et al. 2006) presents a procedure to derive NBL based on two different approaches: (i) pre-selection (PS) and (ii) component separation (CS).

This work presents an application of BRIDGE methodology on the aquifer system of Cremona, in the lower Po Plain (northern Italy), that hosts As, Mn, Fe and NH_4 rich groundwater. These species have a natural origin (Francani et al. 1994; Zavatti et al. 1995) likely related to reductive dissolution of Fe and Mn oxide-hydroxides coupled with oxidation of organic carbon of peat (Rotiroti et al. 2012b). The main aim of this work, which was developed in the framework of a scientific collaboration with the Province of Cremona, is to estimate the NBL for As, Mn, Fe and NH_4 in the Cremona area, using both PS and CS approaches, and then to compare the results.

Methods

The specific study area is located close to the confluence between Adda and Po rivers. It covers a 50 km^2 wide area around the town of Cremona. A subsoil depth of 200-250 m is considered. In the framework of the collaboration with the Province of Cremona, lithostratigraphic and hydrochemical data were collected and field measurements were executed. The interpretation of the lithostratigraphic data together with the measured hydraulic heads leads to the identification of five aquifer units (Rotiroti et al. 2012a): (i) phreatic (F), from 0 to 25 m, (ii) semi-confined (S) from 30 to 50 m, (iii) confined 1 (C1) from 65 to 85 m, (iv) confined 2 (C2) from 100 to 150 m and (v) confined 3 (C3) from 160 to 250 m. Aquifer F has a zone with reduced hydro-facies (F Red) and a zone with oxidised hydro-facies (F Ox) (Rotiroti and Fumagalli 2013), whereas the underlying aquifers have only reduced facies.

The hydrochemical data, collected from the archives of the Province of Cremona, consist of 1˙946 chemical analysis executed for 241 wells/piezometers from 1989 to 2010.

Three sites with possible anthropogenic influences on As, Mn, Fe and NH_4 concentrations (an oil refinery, a municipal solid waste landfill and a group of petrol stations) were identified in the study area. The influences can be occurred due to hydrocarbons and organic leachate spills, which were identified by the analysis of specific chemical parameters (i.e., total hydrocarbons and C.O.D).

Due to missing data, the PS approach was applied using simplified criteria, as described below: (i) subdivision of the dataset for each defined aquifer unit; (ii) exclusion of wells where possible anthropogenic influences could be occurred - for As, Fe and Mn, the data referred to the oil refinery, the landfill and the petrol stations were excluded in aquifer F, whereas only the data of the oil refinery were excluded in aquifer S; - for NH4, only the data referred to the landfill were excluded in aquifer F; (iii) calculation of a single value representing the whole time series for each sampled well (median) in order to guarantee that all wells contribute equally to the NBL estimation; (iv) subdivision of the aquifer F data in F Red and F Ox; (v) estimation of the NBL on the remaining dataset calculating the 90° percentile.

The CS approach was applied through a MATLAB code. The frequency distribution of the data (chemical concentrations) was modelled with a Maximum Likelihood Estimation (MLE) obtaining a Probability Density Function (PDF). The modelled PDF (PDF_{mod}) is composed of two components: a lognormal PDF (PDF_{logn}), representing the natural component, and a normal PDF (PDF_{nrm}), representing the anthropogenic component (Müller et al. 2006). This two components are multiplied by a mixture parameter (p) as follows (Molinari et al. 2014):

$PDF_{mod} = (p)\ PDF_{logn} + (1\text{-}p)\ PDF_{nrm}$.

Therefore, five parameters identify the PDF_{mod} and are estimated by MLE procedure: p, mean of PDF_{logn} (μ_{logn}), standard deviation of PDF_{logn} (δ_{logn}), mean of PDF_{nrm} (μ_{nrm}) and standard deviation of PDF_{nrm} (δ_{nrm}). The NBL is assumed to be represented by the 90° percentile of the PDF_{logn}, according to Molinari et al. (2014). Since the PDF_{mod} results sensitive to the initial value of p, the MLE is performed varying initial value of p (from 0 to 1, with increments of 0.01) by an iterative algorithm, and the solutions are evaluated considering the goodness of fit (in terms of R^2 and RMSE). Similarly to the PS method, the CS was applied to the median values of the time series of each sampled well, divided for each aquifer. CS was only performed in F Red and aquifer S, since they have a sufficient sample size for this analysis. Concerning F Red, a re-sampling scheme is here proposed due to the uneven spatial distribution of wells. The re-sampling was performed as follows: (i) creation of a regular grid with cells of 300 m (two times the average distance between wells); (ii) median averaging of the value (median of time series) of each well that is located in the same cell.

Results and discussion

Results presented here regard the example of As. Table 1 shows NBL estimation from PS. NBL results above the reference value (REF) of D.Lgs. 30/09 with the exception of F Ox and aquifer S. NBL estimation from CS is listed in Table 2. Concerning aquifer S, PS and CS approaches lead to similar values (9.6 and 9.64 µg/L, respectively). Conversely for F Red the two results show substantial differences (24.9 and 54.64 µg/L). This difference could be related to the uneven spacing of sampled well (i.e., higher density in the three sites with anthropogenic influences, where the 82% of wells are located; lower density elsewhere), that generates a small ratio (0.18) between the number of wells outside the three sites (27), used for PS, and the total number of wells (147), used for CS. After the re-sampling scheme, the ratio between points outside the three sites (decreased from 27 to 16) and total points (decreased from 147 to 43) increases to 0.37 and the derived NBL becomes 29.10 µg/L, closer to the value obtained from PS.

Conclusions

This work presented an application of BRIDGE method to estimate NBL for undesirable species in groundwater, focusing on CS approach. Both PS and CS approaches lead to comparable results, particularly for uniform data distribution, increasing the reliability of the estimated NBL.

	REF	F Ox	F Red	S	C1	C2	C3
N. of sampled wells		*12*	*147*	*40*	*13*	*7*	*22*
N. of wells after pre-selection		*12*	*27*	*19*	*13*	*7*	*22*
NBL (µg/L)	10	5.7	24.9	9.6	81.4	31.2	27.6

Tab.1 – Estimated NBL for As from PS.

		F Red	S
Original data	*N. of sampled wells*	*147*	*40*
	NBL (µg/L)	54.64	9.64
Data after re-sampling	*N. of points*	43	-
	NBL (µg/L)	29.10	-

Tab.2 – Estimated NBL for As from CS.

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[40] ASSESSMENT OF DRINKING WATER QUALITY AND HYDROGEOCHEMICAL CHARACTERISTICS OF PUBLIC WATER SUPPLY NETWORKS IN VITERBO REGION, CENTRAL ITALY

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Keywords: water quality parameters, trace elements, groundwater, geochemistry and WHO standards

Introduction

Groundwater is the primary source of domestic, industrial and agricultural purposes in Viterbo region, Central Italy. Unfortunately, in many countries around the world, including Bangladesh, India, China and many other ones drinking water supplies have been contaminated reducing the water quality (Guo et al. 2004). The contamination of major and trace elements in natural water is a risk to the health of millions of people (Khan et al. 2010). Drinking water quality is an issue of concern for human health all over the world (Edmunds and Smedley 2002). Therefore, knowledge of the variation and quality of major and trace elements allows a more efficient management of the water resources. Water quality is influenced by anthropogenic factors and natural processes including irrigation practices, climate, geology, volcanic activities and weathering/dissolution of different rocks and minerals etc. (Newcomb and Rimstidt 2002). Particular attention should be given to water quality issues and its management options all over the world, therefore WHO refers to "control of water supplies to ensure that they are pure and healthy" as one of the primary objectives of public health. The geochemical characteristics (i.e. major ions and toxic trace elements) of groundwater play an important role in classifying and assessing water quality. Concentrations of arsenic in some public supply networks of Viterbo area exceed the allowable limit of 10 µg/l. Recently, the government declared a "state of emergency" due to the presence of "high levels" of arsenic in drinking water (Ergul et al. 2013). The aim of this study is (i) to find out the main geochemical factors controlling the occurrence of major and toxic trace element concentrations in drinking water supply networks and (ii) determination of water quality parameters by comparing the results with different water standards. The results will be useful for effective management of water resources and development of appropriate treatment methods.

Methodology

In the present work, the existing monitoring data referred to over 200 sample coming from domestic water supply wells and springs have been employed for the identification of geochemical characteristics and water quality parameters. The main groundwater sampling survey was carried out from 2007 to 2012. For the identification of source of pollution, trace element concentrations (i.e. As, Li, Be, B, Al, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Se, Rb, Sr, Mo, and U) were measured from the most important seven public water supply wells using ICP-MS techniques. Physico-chemical parameters of water samples (i.e. water temperature, electrical conductivity, total dissolved solids and pH) were determined in the field employing PC 300 Waterproof Hand-held meter. The major cation and anion concentrations were determined by a Metrohm 761 Compact IC ion chromatograph. The identified chemical parameters were used to classify and assess the water quality for drinking purposes.

Results and Discussion

The summary statistics of physical and hydrochemical characteristics of groundwater coming from wells and springs are presented in Table 1. The results were compared with World Health Organization (WHO) standards. Na-HCO_3; Na-Ca-HCO_3 (no dominant type); and Ca-HCO_3 water types are predominant in the study area. The pH values of spring and groundwater samples ranges from 6 to 8.7 indicating slightly acidic to slightly alkaline nature and the values are in the range of WHO guideline limits (6.5 – 9.2). The total dissolved solids content (TDS) and electrical conductivity (EC) of spring and groundwater samples show differences and the values vary from 86 to 1478 mg/l and 65 to 1707 µS/cm, respectively. Water with a TDS lower than 1000 mg/l is usually acceptable for consumers (WHO 2006). Most of the samples show TDS values below 500 mg/l and can be considered as fresh waters, however few samples are classified as brackish water according to the WHO guidelines. The ionic dominance pattern of the water samples for cations and anions was $Ca^{++}>Na^{+}>K^{+}>Mg^{++}$ and $HCO_3^{-}>Cl^{-}>SO_4^{-}>NO_3^{-}$. The minimum required amounts of Mg and Ca in drinking water are 10 and 20 mg/l, respectively.

The maximum acceptable limits for Mg is 50 mg/l and for the Ca 75 mg/l. The Ca and Mg

		T °C	pH	χ 25°C μS/cm	Na mg/L	K mg/L	Mg mg/L	Ca mg/L	Cl mg/L	NO_3 mg/L	HCO_3^- mg/L	F^- mg/L	SO_4^{2-} mg/L	As μg/L	V μg/L	TDS mg/L
	Mean	17.1	7.0	448.7	23.7	19.4	10.6	43.9	21.7	14.9	209.8	0.8	17.3	15.1	15.4	361.5
	Median	16.7	7.0	373.0	20.0	20.0	8.0	27.0	15.0	13.0	164.0	0.7	9.0	11.0	12.0	290.3
Wells	Max	25.5	8.7	1707.0	144.0	71.0	45.0	221.0	275.0	87.0	992.0	3.2	295.0	57.0	76.00	1477.5
	Min	10.4	6.0	134.0	8.0	1.0	3.0	10.0	8.0	1.0	47.0	0.0	2.0	1.0	1.0	100.2
	SD	2.3	0.5	285.6	16.5	12.3	7.4	42.2	27.1	12.6	140.6	0.6	29.6	12.5	12.3	237.2
	Mean	15.4	6.9	340.9	18.7	15.4	7.	32.5	17.3	18.2	148.9	0.7	11.5	10.5	13.0	270.1
	Median	15.3	6.9	293.0	17.0	18.0	7.0	21.0	14.0	15.0	122.0	0.4	8.0	9.0	10.0	222.7
Springs	Max	21.4	8.1	894.0	55.0	39.0	18.0	132.0	54.0	100.0	416.0	2.7	53.0	45.0	51.0	715.4
	Min	9.9	6.2	65.0	8.0	1.0	3.0	7.0	8.0	1.0	46.0	0.0	3.0	1.0	2.0	86.0
	SD	2.1	0.4	188.9	8.3	9.2	3.3	31.1	9.0	18.6	90.2	0.6	9.5	9.1	10.1	155.6
WHO guideline values		N.S	6.5 9.2	1500	200	200	50-150	75-200	250	50	N.S	1.5	250	10	N.S	1000

Tab. 1- Descriptive statistics summary of the chemical analyses on the sampled waters. SD standard deviation.

concentrations in water samples range from 7 to 221 mg/l and 3 to 45 mg/l with minimum and maximum values, respectively. The SO_4^- concentration in water samples range from 2 to 295 mg/l and most of the samples are not exceed the permissible WHO guideline value of 250 mg/l. Bicarbonate values in water samples varies from 46 mg/l to 992 mg/l. The K and Na values of the water samples range from 1 to 71 mg/l and 8-144 mg/l and most of the samples fall within the guideline levels (<200 mg/l). Chloride concentrations in theinvestigated water samples are found in the range of 8-275 mg/l and few samples show Cl levels in excess of the permissible limit of 250 mg/l. The concentrations of the elements are summarized in Table 2.

Monitored Wells								
Trace Elements (μg/l)	MJ1	MJ2	Castagno	MBN1	MB3	MB2	MBV2	WHO limits (μg/l)
Li	9.85	9.03	33.2	66.8	66.16	16.22	30.4	N.S
Be	0.35	0.45	0.77	1.19	1.12	0.35	0.44	N.S
B	93.0	79.6	381.3	832.0	840.72	145.10	319.8	2400
Al	5.42	11.9	10.3	18.0	7.08	4.62	6.41	200
V	33.8	38.4	44.8	32.5	27.98	40.01	34.3	N.S
Cr	0.61	1.39	0.07	0.07	0.10	0.37	0.20	50
Mn	0.16	0.35	99.1	110.5	99.86	30.71	11.4	50
Fe	2.39	11.3	814.5	114.1	36.82	321.82	4.58	300
Co	0.29	0.28	0.81	1.84	1.82	0.38	0.93	N.S
Ni	0.00	5.96	0.06	0.92	1.91	0.01	0.00	70
Cu	0.43	91.5	0.74	2.47	0.46	0.00	0.00	50
Zn	0.01	16.6	71.5	2.76	1.03	13.05	0.00	5000
As	16.7	14.3	15.1	13.0	14.11	14.50	7.70	10
Se	4.60	3.3	2.70	3.49	4.19	4.00	2.90	40
Rb	30.9	34.5	101.3	169.6	165.6	73.72	124.2	N.S
Sr	324.9	273.4	532.9	1228.6	1082.6	199.54	586.4	N.S
Mo	2.34	2.17	2.65	1.35	1.10	1.30	0.70	70
U	6.26	2.71	6.76	12.8	10.65	3.38	7.63	30

Tab. 2 - Trace element concentrations of selected public water supply wells. N.S not stated.

Among the determined analytes, concentrations exceeding the WHO recommended drinking water limits were found for As (> 10 μg/l), F (>1.5 mg/l), and Fe (>300 μg/l). The total hardness of water samples range from 29.8 to 736.5 mg/l and fall between soft and very hard water category. Few water samples exceed the allowable limit for domestic uses (500 mg/l).

Conclusions

Physico-chemical parameters of most of the water samples are within permissible guideline limits and safe for drinking. However, As (>10 μg/l) and F (>1.5 mg/l) contents exceed the permissible limit for drinking prescribed by the World Health Organization in many drinking water wells. It was considered the weathering and direct dissolution of volcanic materials presented in the aquifer systems and/or past volcanic activity, probably causes high arsenic and other trace elements (i.e. Li, B, Mn, Mo, V, U, Fe and Sr) in groundwater. It is recommended that the appropriate treatment must be applied to the public water supply wells having elevated concentrations of these elements.

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[41] EFFECTS OF URBAN CHANGES ON GROUNDWATER VULNERABILITY

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Keywords: QuikSCAT, urban changes, spatial statistics, time-dependent groundwater vulnerability maps

Introduction

The Environmental European Agency in 2006 (EEA 2006) reported that the expansion of urban areas in many eastern and western European countries had increased by over three times the growth of population. This urban sprawl is one of the most important types of land-use changes currently affecting Europe. It has increasingly impacted the regional environment, the social structure and the economy.

The area of the Po Plain in northern Italy is one of the most populated areas in Europe and can be considered representative to identify which environmental, social and economic impacts could affect cities in their urban sprawl phase.

Recent studies (Masetti et al. 2008; Sorichetta et al. 2011) have shown that, in some areas of the Po Plain, nitrate occurrence in groundwater is strongly related to urban sources more than to agricultural activities. Moreover, a recent study on the relationship between historical changes in groundwater nitrate contamination and in land use (Stevenazzi et al. 2014) has shown that, in the Po Plain area of Lombardy region, expansion of urban areas involves a degradation of the water quality.

In this study we analyze three different variables, which can be used as a proxy of the evolution of urban nitrate sources (satellite scatterometer data, population density and land use data), and the correlations with trends in groundwater nitrate concentration. The main purpose is to analyze the reliability of these variables in groundwater vulnerability assessment of the Po Plain area of Lombardy region.

Method and results

In order to perform the vulnerability analysis, different variables have been considered.

Three different factors have been selected in order to represent urban nitrate sources and their evolution: land use changes derived from satellite scatterometer data from 2000 to 2009 (QSCAT-DSM data; Nghiem et al. 2009), population density changes given by two successive population national censuses (2001 – 2011) and land use changes derived from interpretation of aerial photographs (database DUSAF, 2000 – 2009; Lombardy Region). These factors represent the time-dependent variables.

Four factors represent the geological and hydrogeological conditions of the study area: soil protective capacity, groundwater depth, groundwater velocity and hydraulic conductivity of the vadose zone. These factors have not been considered time-dependent for the purpose of the study; even if groundwater depth is actually time-dependent on a seasonal scale, it has not been significantly changed in the decade 2000 – 2009.

Nitrates in Lombardy region are monitored by a network of about 500 wells (source Regional Environmental Agency – ARPA). We use data collected each half year from 2001 to 2011. Only those with a minimum of 8 observations monitoring the shallow aquifer have been considered for the analysis. The change in nitrate concentration has been calculated as the slope of the regression line interpolating concentration data. The slope identifies the rate of nitrate concentration change in mg/L per day.

Groundwater vulnerability assessment has been performed through the spatial statistical method Weight of Evidence (WofE), which has been demonstrated as a reliable method in environmental studies to evaluate groundwater vulnerability (Masetti et al. 2008, Sorichetta et al. 2011). WofE can be defined as a data-driven Bayesian method in a log-linear form that uses known occurrences representing the response variable as training sites (training points) to produce predictive probability maps (response themes) from multiple weighted evidences (predictors) influencing the spatial distribution of the occurrences in the study area (Raines 1999).

The correlation between each factor and the training points (TPs) is represented by positive and negative weights, and their derived contrast. The contrast (positive weight minus negative weight) represents the overall degree of spatial association between each class of a given predictor and TPs; therefore, it is a measure of the applicability of the considered class in predicting the location of TPs (Raines 1999).

Wells with rate of nitrate concentration change higher than the established threshold value of

0 mg/L per day, representing water quality deterioration, have been used as training sites in the WofE analysis.

The contrasts of the statistically significant predictors of each variable (either urban changes or geological conditions) enable to infer the influence of each variable has on groundwater contamination. The results of the contrasts of the three variables representing urban changes are presented in Fig. 1.

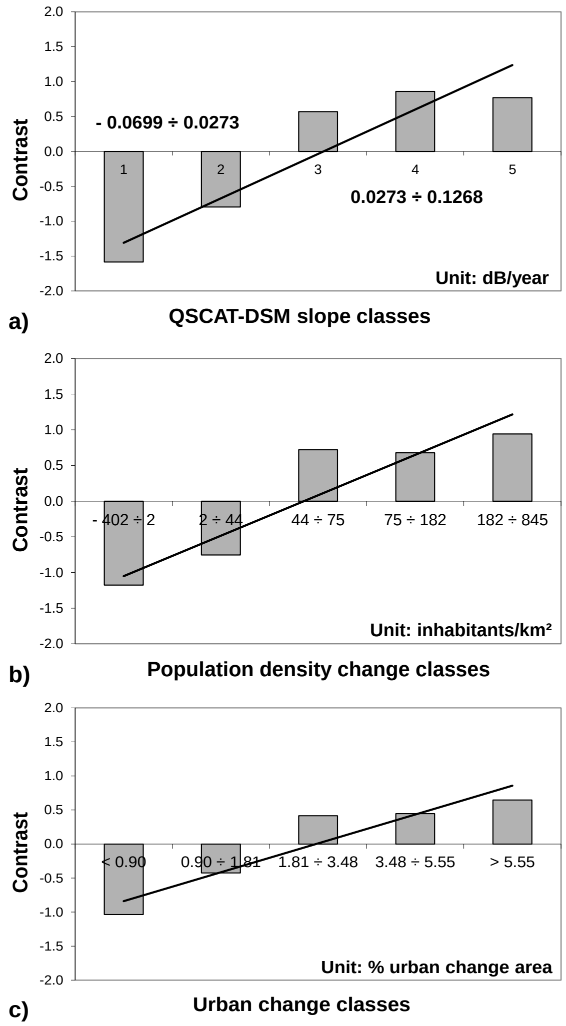

Fig. 1 – Contrasts of the statistically significant classes of the evidential themes representing urban nitrate sources changes.

The significant predictors representing urban changes show a direct relationship for all the three factors. These findings indicate that increasing nitrate concentrations are related to areas of urban development or population increase.

WofE technique has allowed observations of the individual role and the combined effect of both urban change and geological factors in the analysis of groundwater vulnerability related to the change of nitrate concentration in the decade 2000 – 2009 in the study area, and the development of time-dependent groundwater vulnerability maps. It has also allowed assessing the reliability of the three different factors representing urban changes. Among these, satellite scatterometer data are reliable for evaluating urban changes, across the decadal worldwide coverage continuously without a temporal or spatial gap.

Acknowledgements

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[42] THE USE OF GEOPHYSICAL SURVEYS FOR THE INVESTIGATION OF PALEOWATERS CONTAMINATIONS WITHIN THE OLTREPÒ PAVESE PLAIN AQUIFER (NORTHERN ITALY)

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Keywords: paleowaters, Vogherese Fault, geophysical surveys, VLF-EM, ERT

Introduction

The Oltrepò Pavese plain aquifer (Po Valley, Northern Italy) is characterized by the presence of Na-Cl rich paleowaters (Conti et al. 2000; Regione Lombardia and ENI Divisione AGIP 2002) that uprise from the Miocene-Pliocene marine substratum along the "Vogherese Fault", an important buried tectonic discontinuity (Bersan et al. 2010; Pilla et al. 2010). These deep mineralized paleowaters mix with the shallow fresh groundwaters (hosted in gravelly and sandy silty Quaternary alluvial deposits) polluting them and preventing their use not only for potable, but also for agricultural and industrial purposes. Given that saltwaters mapping cannot be undertaken on the sole basis of wells hydro-chemical monitoring as these are often insufficient or absent in some areas, a geophysical survey was carried out.

Methods

VLF-EM surveys were undertaken to achieve an expeditive mapping of the conductive bodies over the entire area (Torrese et al. 2009), involving 35 lines for a total length of 71 kilometers. Seventeen resistivity depth soundings (VES) were undertaken along a cross section of the "Vogherese Fault" to reconstruct the bedrock geometry and the different hydrogeological units (Torrese et al. 2009; Pilla et al. 2010). The geometrical complexity of the contaminated areas located in proximity to the fault, was also studied at the local scale within three selected experimental site, during a more detailed phase of investigations: 5 resistivity depth soundings (VES), 1 short spread 2D-ERT (Electrical Resistivity Tomography) surveys, four 3D-ERT surveys, a closely spaced grid VLF-EM survey were undertaken at a site together with a resistivity profile and 5 long spread 2D-ERTs that were undertaken along an approximately 3000 m long profile crossing the fault zone with a N-S direction and overlapping a significant length of the VLF-EM surveys.

Discussion of the results

A main NE-SW trend of high conductivity anomalies was revealed at a large scale by VLF-EM surveys. This trend can be correlated to the occurrence of the Vogherese Fault trace. Five NE-SW minor trends were also identified, suggesting the existence of secondary and sub-parallel discontinuities (Torrese et al. 2009; Pilla et al. 2010). 2D ERT surveys show that the marine deposits (3-6 ohm·m) at the base of the alluvial aquifer are characterised by morphological irregularities, which are likely to have been shaped either by tectonics (Vogherese Fault) and/or by the paleo-river's erosion. In the southern area of the plain the depth of the substratum varies between 10 to 30 m; this depth increases northward due to the Vogherese Fault (Fig. 1). Within the aquifer, coarser deposits (gravel or sand with silt and clay) show resistivity values ranging between 20 and 40 ohm·m; finer deposits (fine sand with silt and clay) show values ranging between 10 and 15 ohm·m (Fig. 1). ERT surveys show that the thickness of the clayey silty covering (4-10 ohm·m) ranges between 2 and 6 m in the area. Both the 2D and the 3D ERT surveys pointed out the existence of localised and restricted zones of the aquifer saturated with saline waters, showing resistivity values ranging between 3 and 8 ohm·m (Fig. 1).

Conclusions

VLF-EM surveys revealed that the distribution of the paleowaters plumes is controlled by the presence of tectonic discontinuities, like the Vogherese Fault and other secondary discontinuities and/or by fractures into the marine substratum. 2D-3D ERT surveys highlighted a spot spatial distribution of the saline contamination, suggesting the existence of isolated plumes of saltwater within the aquifer. The morphology of the bedrock, the spatial distribution of the structural discontinuities and the hydraulic conductivity of alluvial deposits are likely to be controlling the areal distribution and in depth geometry of these isolated plumes of saltwater within the alluvial aquifer.

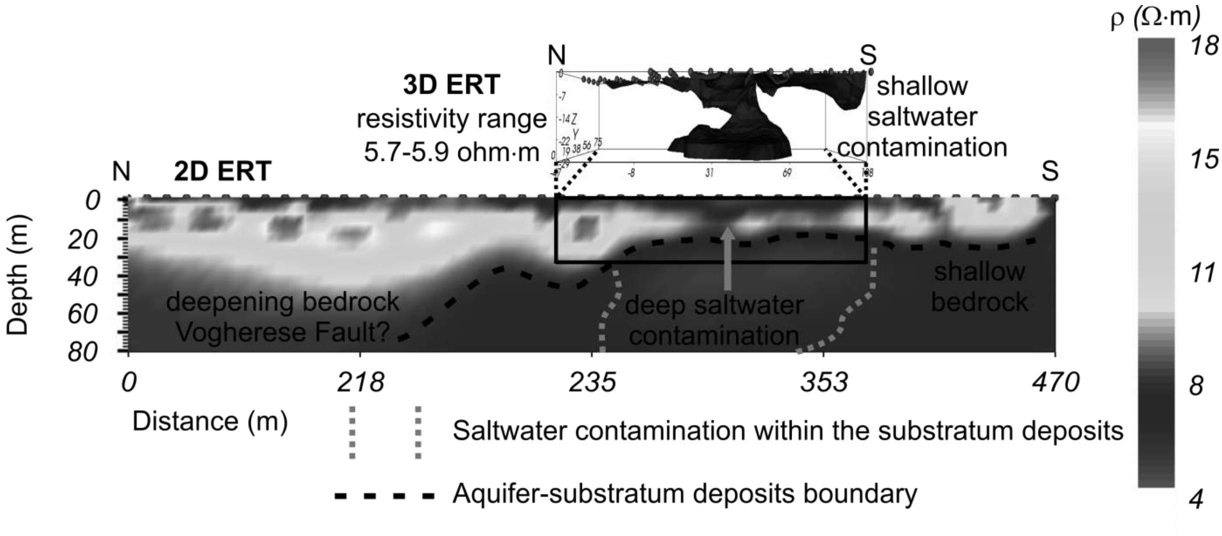

Fig. 1 - Example of 2D ERT and 3D ERT surveys showing Na-Cl rich paleowaters uprising from the Miocene-Pliocene marine substratum and contaminating the shallow fresh groundwaters hosted in gravelly and sandy silty Quaternary alluvial deposits. The 2D ERT survey that was undertaken along a 470 m long profile (obtaining an investigation depth of approximately 70 m) crossing the fault zone with a N-S direction shows that the depth of the substratum increases northward due to the Vogherese Fault; it also shows a deep saltwater contamination occurring within the substratum deposits uprising along tectonic discontinuities and a shallow isolated plume of saltwater occurring within the alluvial aquifer. A 3D resistivity block measuring 155 x 75 m in size with a maximum depth of 29 m was obtained by full inversion of two 3D ERT surveys: it allowed to achieve a detailed reconstruction of the shallow saltwater contamination of the fresh groundwater occurring within the alluvial deposits as shown also by the 2D ERT. The occurrence of isolated plumes of saltwater within the alluvial aquifer is likely to be controlled by the morphology of the bedrock, the spatial distribution of the structural discontinuities and the hydraulic conductivity of alluvial deposits.

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[43] THE PHREATIC AQUIFER OF THE ISONZO PLAIN (NE ITALY): HYDRODYNAMIC AND VULNERABILITY

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Keywords: hydrogeology, groundwater, intrinsic vulnerability, transboundary aquifer, water management, SINTACS method

Introduction

The Isonzo-Soča High Plain is located in the eastern side of the Friuli Venezia Giulia Region, across the border between Italy and Slovenia. It holds a significant phreatic aquifer that represents an important natural wealth, in terms of quantity, quality and ease of supply. The aquifer is used for various activities such as drinking, household, industrial, agricultural and farming purposes. The increasing interest of the resident population for this important resource has given rise to "GEP" and "ASTIS" Projects, funded by the Programme for the cross-border cooperation Italy-Slovenia 2007-2013. As part of these projects, the present research focuses on the characterization of the phreatic aquifer of the Isonzo-Soča plain in order to evaluate its intrinsic vulnerability. Moreover it aims to safeguard the groundwater resource and support the environmental protection and management policies.

Hydrogeological settings

The Isonzo-Soča Plain is constituted almost entirely by quaternary alluvial deposits of Isonzo-Soča, Torre, Judrio, and Versa rivers. It is divided in two areas: the High Plain to the North and the Low Plain to the South (Fig. 1).

The High Plain is delimited to the North by the Collio Hills, constituted by marlstones and sandstones of the Flysch Formation, and to the South by the limestones reliefs of the Karst Plateau. It is constituted mainly by coarse and very permeable sediments that hold a well-developed phreatic aquifer. The rivers dissipate a great amount of water during their way in the High Plain; for this reason Torre and Judrio rivers remain dry most of the year while Isonzo loses about 26% of its discharge (Zini et al. 2013). These river losses, together with rain and run-off waters coming from the hills and karst waters from the underground, feed the phreatic aquifer of the High Plain.

Towards the Low Plain, the phreatic aquifer joins with a multi layered aquifer system characterized by alternating gravel-sand and clay-silt deposits.

Due to the southward permeability decrease, the High Plain phreatic waters outflow in correspondence to a NW-SE wide area.

Ground water monitoring

Prior to the vulnerability assessment various investigations have been performed and integrated to the bibliographic data to better constrain the hydrogeological behavior of the system.

A monitoring survey (44 monitoring stations) was realized in order to elaborate the water table map in high flow conditions. Recovery and aquifer pumping test were performed to better define the hydrogeological parameters. Four seismic sections were realized to evaluate the alluvial thickness. In addition, major ions concentrations and isotopic composition were measured.

Consequently, isobaths of the bedrock, isopachs of the alluvial deposits, isophreatics and hydrochemical maps were elaborated.

Intrinsic vulnerability assessment

In order to evaluate the intrinsic vulnerability the SINTACS method (Civita and De Maio 2000) was used. It is a point count system model and considers the following seven parameters: depth to groundwater table, effective infiltration, unsaturated zone attenuation capacity, soil attenuation capacity, hydrogeological characteristics of the aquifer, hydraulic conductivity and topographical slope. Spatial knowledge of all these factors and their mutual relationship are needed to model the aquifer vulnerability. Furthermore, the method uses different weight coefficient multipliers for every hydrogeological environments.

First, the study area were discretized with a grid cell of 10 × 10 meters. A 3D model of the bedrock was realized using ArcGIS software and geostatistical interpolation, starting from

lithostratigraphic and seismic data.
A dedicated geodatabase was designed to express each of SINTACS parameters as a spatial thematic layer with a specific weight and score. SINTACS layers were prepared using bibliographic and survey data such as effective precipitation, water table, hydraulic conductivity, geology, pedology and digital elevation model.
The intrinsic vulnerability index was produced for each grid cell by taking the amount of each score parameter multiplied by its specific weight.

Results

The monitoring activities highlighted the large contribution of the Isonzo/Soča river in feeding the aquifer in the central and eastern parts of the plain. Conversely the western part suffers from the influence of the Torre river, while in the northern part the underground waters flow through the Classical Karst aquifer, feeding it.
The SINTACS vulnerability map shows that the Isonzo/Soča plain is rather vulnerable because of its hydrogeological characteristics: the most exposed areas occur in correspondence to the riverbeds and, in the South, to the contact between High and Low Plain, where resurgences of waters occur.

Acknowledgements

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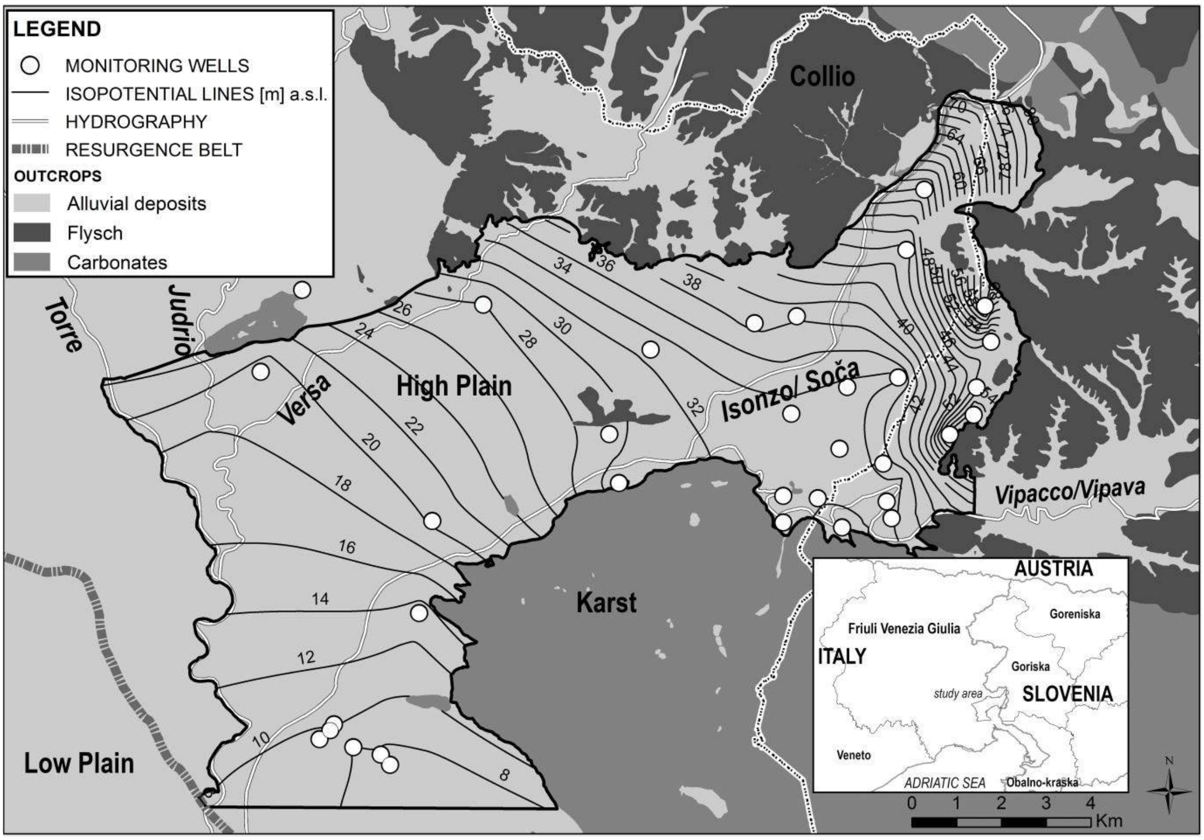

Fig. 1 – Hydrogeological map of the study area.

[44] COLLOIDS CONTAMINATION IN PERYTHIRRENIC VOLCANIC AQUIFERS (CENTRAL ITALY)

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Keywords: Volcanic aquifers, Colloids contamination, Water management, Hydrogeological model

Introduction

Perythirrenic volcanic aquifers of Central Italy are important resources for the local water supply. The optimal management of this resource is closely linked to the knowledge of the hydrological dynamics. The increasing urbanization, industrialization and agricultural withdrawals lead to several management problems such as the depletion of groundwater and deterioration of water quality.

Several authors focused their attention on natural contamination problems of volcanic aquifers exploited for water supply. Most of studies concern water quality studies focus on fluoride and arsenic occurrence due to geogenic contamination. On the contrary shallow aquifers water quality is often affected by anthropogenic activities, i.e. common contamination is due to nitrate in agricultural areas or heavy metal pollution close to industrial areas.

Arpa Umbria detected anomalous concentration in aluminum and iron in volcanic aquifer near Orvieto in January 2010. Analyzed samples did not fulfil guidelines for water human consumption (98/83/EC implemented in Italy with D. Lgs 31/2001), then the authorities forbid the use of public water for drinking use.

High concentrations in aluminum and iron were largely detected in shallow aquifer and sometimes in the basal aquifer due to localized water mixing. There are no evidence of human activities responsible of this contamination. Al and Fe are present in colloid form according to detected pH (6.5-7.5) and oxidizing Eh conditions. Another study area, characterized by similar volcanological and hydrogeological features and by the same colloids contamination in groundwater, was searched to understand similarities in the causes and processes of natural contamination of shallow aquifers near Orvieto. The second monitoring area was detected on the NE flank of Roccamonfina Volcano (Campania Region, Central Italy).

Main Body

A regional hydrogeological survey was performed in the Umbrian sector of Vulsini Mounts and in the eastern sector of Roccamonfina Volcano in order to identify the hydrogeological settings of these areas and to discriminate the presence of shallow aquifers.

A detailed monitoring site was detected in each study area: Rocca Ripesena (RR) promontory near Orvieto and Rianale Valley (RV) on Roccamonfina. A weekly monitoring was performed from March to July 2013. During this monitoring data about discharge rate and chemical – physical parameters (electrical conductivity, pH, temperature and Eh) of several springs were collected. Four aliquots of water were collected from each motoring point:

- Unfiltered and un - acidified sample
- Unfiltered and acidified (HNO_3 60%Ultrapur MERK) in field sample
- 0.45 μm filtered and acidified (HNO_3 60% Ultrapur MERK) in field sample
- 020 μm filtered and acidified (HNO_3 60% Ultrapur MERK) in field sample

Alkalinity were measured with titration using HCl 0.1N and metylorange. Major elements (Na^+, K^+, $Mg^{2+,}$ Ca^{2+}, $F^{-,}$ Cl^-, NO_3^- and SO_4^-) were analyzed by ion chromatography. Trace element analyses were performed with an Agilent 7500 ce ICP-MS ORS technology. Li, Be, B, Al, Si, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Mo, Cd, Ba, Tl, Pb and U were analyzed. Shallow aquifers are characterized by high concentrations in Al and Fe in unfiltered samples collected in both study areas. Al and Fe concentration decrease in filtered samples (0.45 μm filtration efficiency about 80%; 0.2 μm filtration efficiency about 99%). A linear relationship correlate Al and Fe (Fig. 1), then the enrichment in these elements depending to the same natural process.

A direct relationship was detected between rainfall and colloids concentration, it can be distinguish a first rainy period in which high concentrations of Fe and Al were detected and a second period characterized by lesser rainy events in which colloids concentration quickly decrease (Fig. 2).

Principal Component Analysis (PCA) has been elaborated on the whole database to point out the relationship between the water parameters and their chemical behavior in studied water systems. Chemical variables (analyzed parameters) governed by the same geochemical processes fall within the same factor. In the study areas the same processes were distinguished: the major component explains the enrichment of ions in solution related to chemical alteration of rocks whereas the second component explains a physical colloids mobilization which occurs independently from water mineralization (Fig. 3).

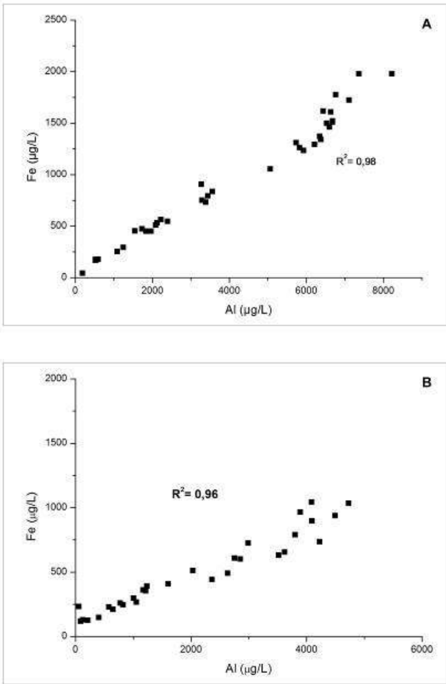

Fig. 1 - Fe-Al concentration in RR (A) and RV (B) springs.

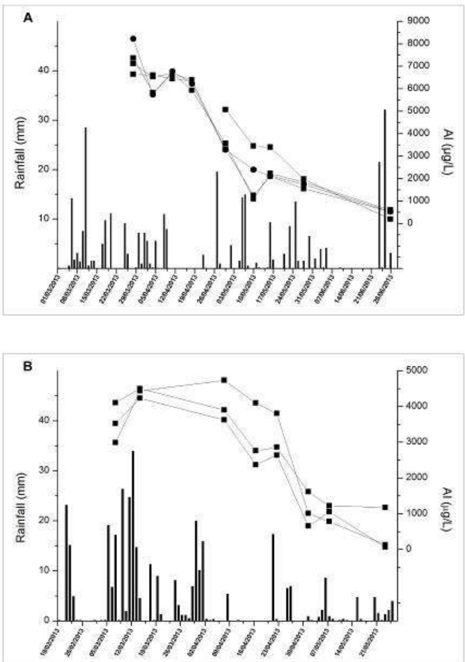

Fig. 2 - Variability in Al concentration compared to rainfall data in RR (A) and RV (B) springs.

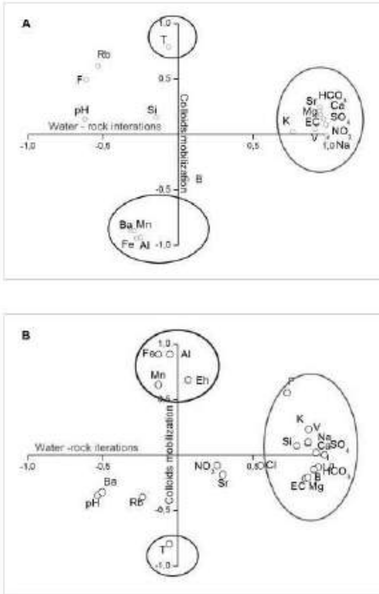

Fig. 3 - PCA of RR (A) and RV (B) springs.

All detected contaminate springs, both in Orvieto area and on Roccamonfina Volcano, were referred to a unconsolidated weathered pyroclastic aquifer constituted by deposits emplaced in a similar period (about 330 ka) and characterized by intense weathering. Furthermore study areas show a fundamental difference for water management: the basal aquifer in Orvieto district is characterized by a higher vulnerability than Roccamonfina one. The intermediate aquitard near Orvieto is constituted by lava characterized by variable permeability and irregular distribution in the whole area. On the contrary about 100 meters of low permeability pyroclastic flow deposits protect the basal aquifer from the shallow contamination on Roccamonfina Volcano. Identification background values of Al and Fe in shallow volcanic aquifers is fundamental for environmental management in order to discriminate natural processes from human pollution. Not well done drilling or wells could increase vulnerability of deep resource, therefore shallow aquifers should be isolated from the basal one through a correct cementation of borehole.

[45] INTERACTION BETWEEN KARST AND POROUS AQUIFERS, THE CASE OF MT. MIA TRANSBOUNDARY AQUIFER

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Keywords: hydrogeology, karst, transboundary aquifer, oxygen isotopes, tracer test

Introduction

The Mount Mia massif is located in the eastern side of the Friuli Venezia Giulia Region, across the border between Italy and Slovenia. It is an important karst hydrostructure bounded in the N, E and S by the Natisone River (Figure 1). Several springs are emerging at the toe of the massif mainly in the south-eastern side along the river. The two main springs, Poiana and Tologu, are tapped for the Cividale town water supply. The aim of the present paper is to assess the spring recharge area, its potentialities and vulnerabilities in order to quantify a possible increase withdrawal for the water supply.

The monitoring network

From a geological viewpoint, the Mt. Mia area is characterized by a succession of carbonatic shelf and scarp deposits Late Triassic to Early Cretaceous in age, overlayed by a clastic succession of carbonatic breccias and Flysch. The latter consists of an alternation of marls, sandstones, calcarenites, and limestone breccias, Late Cretaceous to Pleistocene in age (Buser 1979). The monocline NW dipping structure makes outcropping the older units in the Italian valley bottom, while the most recent terms outcrop on the Slovenian side. The older terms (Late Triassic – Early Cretaceous) are more karstified than the intermediate ones (in general breccias and calcarenites, Early to Late Cretaceous), whereas the alternating sandstones-marly Flysch (Late Cretaceous to Pleistocene) are not karstified and present a low permeability.

Geological and geomorphological surveys allowed to produce a permeability map where are inserted also all the monitored points, consisting in 7 springs and 1 surface point (Natisone River).

Springs were regularly sampled. Two of which Poiana and Tologu, were monitored through in continuous devices recording water level, electrical conductivity (EC) and temperature. In order to define $\delta^{18}O$ isotopic gradient of the area and consequently the linked watershed, rainfall dataset were collected (in the valley and at the top of Mt. Mia).

Results

From the realized analysis, emerge that groundwaters present similarities being characterized by a low mineralization typical of oligomineral waters. All the waters belong to the calcium-bicarbonate facies having affinities with magnesium one and highlight the same hydrochemical behaviour.

Analyzing the in continuous parameters, emerge that for the Poiana spring, the average EC calculated on three years of recorded data (2006, 2007 and 2008), has a value of 296 µS/cm varying between 238 and 309 µS/cm. Average temperature, calculated within the same period is of 10.5°C with variations between 8.2 °C and 12.8 °C.

At Tologu spring the average conductivity measured between 2006 and 2008 is approximately 293 µS/cm, ranging a minimum value of 230 and a maximum of 310 µS/cm. The average calculated temperature is instead of 10.5°C presenting an important seasonal variation ranging between 9.6°C during February and March till 11.3°C recorded in September.

In addition Natisone River has been monitored. Its average conductivity is of 285 µS/cm, reaching values oscillating between 270 and 310 at low water regime, considerably decreasing while flooding with minimum values reaching 120 µS/cm. Water temperature present a mean value of 10.5°C, with seasonal variations with minimum values of 3-4°C and maximum values more than 20°C.

From a chemical viewpoint, Natisone River and the tapped springs are similar but no information can be meaningful for the recharge definition; conversely $\delta^{18}O$ values were very useful.

58 water samples for each monitoring points were collected between 2005 and 2008 and isotopical analyses were carried out. The average results varies between -7.34 (Tologu spring) and 7.49 recorded on Natisone River.

Isotopic gradient calculated in 2006 is 0.13‰/100 and permits to assess the average altitude of recharge for the springs monitored. The above-mentioned height reaches an elevation that is higher respect to the summit of Mt. Mia.

For this reason a groundwater input from Natisone River is evident for the recharging of the springs monitored.

Dual tracer tests were conducted and the outputs evidenced the connection between Mt. Mia aquifer and the Natisone River hydrological basin.

For Tologu spring, emerges that, it is supplied by the Mt. Mia karst aquifer and by the leakages of Natisone River. During floods prevails the input from the karstic hydrostructure.

For Poiana spring instead, there is a clear prevalence of the inputs coming from the karst hydrostructure, which in turn benefits of the loosing character of Natisone River in correspondence of the north side of Mt. Mia.

Anyway, independently from the two springs, the comparison between rainfall and spring data (water level and EC values) highlights a quick circulation of the groundwaters evidencing a piston effect and consequently a typical karst character with a moderate effective drainage system (Type B – Galleani et al. 2011).

The fast circulation confirmed also through the tracer tests and the results of the monitored springs, highlight the presence of an aquifer highly vulnerable to pollution that need to be protected jointly by Italy and Slovenia being a transboundary aquifer.

Acknowledgements

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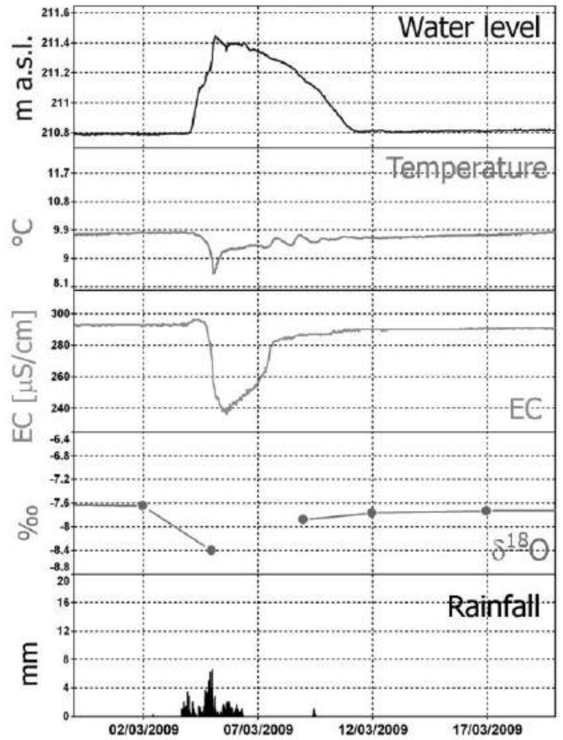

Fig. 2 - Tologu spring: comparison among δ18O, water level (m), and conductivity (µS/cm) during the flood event of 4-5 March 2009.

SESSION 3

Hydrogeology of mineral and thermal waters

Chairs: Fabio Fabbri, Stefano Lo Russo

[46] ORIGIN AND RECHARGE OF HUNGARIAN THERMAL WATERS BY CHEMICAL AND ISOTOPE DATA

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Keywords: thermal waters, Hungary, environmental isotopes, chemistry

Introduction

Hungary has one of the biggest thermal water reserves and geothermal energy potential of low and medium enthalpy in Europe. As a consequence of the abnormally thin lithosphere the heat flux (mainly 90 to 100 mW/m^2, Dövényi et al. 2002) in Hungary is above the average of Europe. The mean geothermal gradient of 50 ^{o}C/km is significantly higher than the world average (30 to 40 ^{o}C/km), producing groundwaters exceeding 30 °C even at low depth (about 400 m). 900 of the 1400 thermal wells (≥30 °C, Figure 1) in the country are in operation as production wells, their total abstraction is near 80 million m^3/a. 27% of them is used for heating green-houses and communal buildings, 34% for thermal- and medical spas and 25% for drinking water supply and mineral water bottling (Szanyi and Kovács 2011). Total thermal water resource of Hungary is estimated as 2 500 km^3, but its exploitable, dynamic part under debate being very indefinite. Basic problem is the origin and recharge conditions of thermal waters. Results of studies of these properties will be presented using chemical and isotope analyzes of the Hungarian thermal waters.

Results, discussion

The thermal water reservoirs in Hungary can be classified into two groups according to their geological settings: (i) karstic or fissured rock reservoirs in the Pre-Neogene crystalline basement (ii) porous sedimentary aquifers of the Neogene basement filling. Significant difference can be observed between the chemistries and isotopic compositions as well of the two groups reflecting their differing origin.

The dissolved solid content of lukewarm and warm karstic waters is low in the zones of more intensive flow: their total dissolved salt content does not reach the value of 1 g/L. At larger depth the surplus carbon dioxide makes these waters aggressive and able for dissolution again. Stable isotope studies (Deák et al. 2010) have proven that this CO_2 originates from the metamorphosis of buried rocks, and post volcanic or organic origin can be excluded. The chemical character of some karstic thermal water is shifted towards to alkali hydrogen-carbonate nature because of the contact with clayey formations present in carbonate rocks (Ca and Mg exchange to Na and K). δ^{34}S studies (Fórizs et al. 2010) have shown that in the case of Buda Karstic Thermal Water considerable amount sulphur originates from dissolution of marine sulphate minerals.

In confined thermal karstic reservoirs located at larger depth the NaCl concentration may increase: in some cases it can even reach the concentration of several 10 g/L corresponding to that of seawater.

Porous waters in the geothermal reservoirs usually below 500 m are of alkali-hydrogen carbonate character. The total dissolved salt content is generally 1 to 3 g/L, however it can reach the value of 10 g/L. Waters of higher salt content occur in the deeper, confined zones of the reservoirs. In such places waters are characterized by higher chloride content and their composition is similar to that of seawater.

The stable isotopic composition of greatest part of thermal waters plots on or close to the Global Meteoric Water Line (GMWL) supporting their meteoric origin. However the δ^{18}O and δD values are significantly lower than of the Holocene precipitation (δ^{18}O = -9.5‰, δD = -65‰; Deák and Coplen 1996) proving that these thermal waters infiltrated under a cooler climate than today (Ice Age). The δ^{13}C corrected radiocarbon ages being more than 10 thousand years support this observation. The isotopically lightest (δ^{18}O = -13 to -15‰ and δD = -90 to -110‰) waters are of 18 to 25 thousand years old thermal waters infiltrated at the Last Glacial Maximum. The ages are growing along the hydrodynamically determined flow paths demonstrating permanent recharge of resources. While there are some thermal water wells producing high TDS (10 g/L or more) water with undetectable ^{14}C content and with δ^{18}O shifted to positive direction from the GMWL. These water bodies are generally in high depth, and the shift in δ^{18}O value is probably caused by water-rock interaction, but the presence of fossil marine or semi-marine lake (Pannonian-lakes) water or dehydration water cannot be excluded. The residence time of these waters are assessed to be up to few million years. These resources are supposedly situated in closed reservoirs and not replenished.

Acknowledgements
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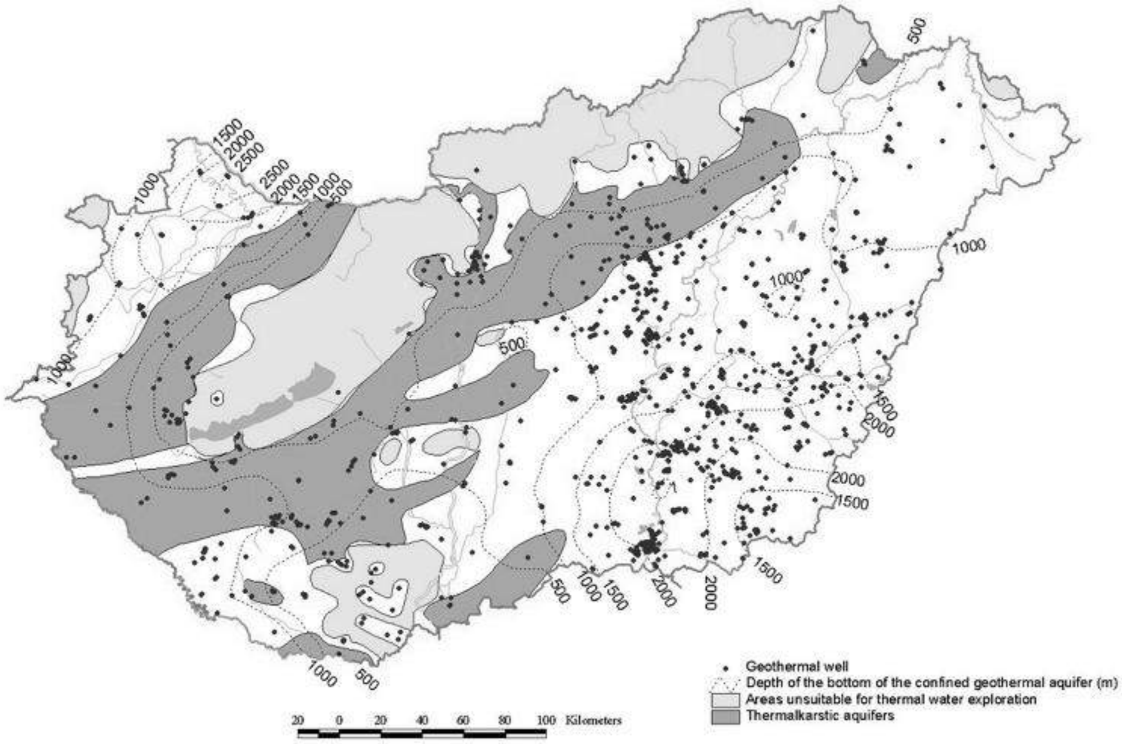

Fig. 1 – Geothermal reservoirs and wells in Hungary (Liebe 2001).

[47] BOREHOLE HEAT EXCHANGERS: HOW FLOW VELOCITY AND DISPERSION INFLUENCE HEAT TRANSFER

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Keywords: BHE, Flow velocity, Dispersion, Heat transfer

Introduction

Ground source heat pumps systems likely to use low enthalpy resources are gradually spreading, representing one of the most efficient and low environmental impact technologies for cooling and heating of buildings. Most common geothermal systems are made up of closed loop boreholes (Borehole Heat Exchangers or BHEs) buried into the ground, typically 100 m deep, where a thermal-carrier fluid is circulated into polyethylene U-pipes, extracting heat from the ground in winter and/or injecting heat into the ground in summer.

The energy performance of these systems depends on the heat transfer process between the BHEs and the ground. In many applications the ground can be considered as a purely conductive medium: in fact this hypothesis is at the base of many commercially available tools used to design BHEs, such as GHLEPRO or EED (Hellstrom 2001). Therefore some efforts have recently been carried out to include the effects of the presence of a groundwater flow into the BHEs modeling (Diao 2004). In this case the heat is transported not only by conduction but also by advection. Extending this problem could change the correct prediction of the energy performance of the BHEs and the investigation of the thermal impact, in terms of the temperature perturbation produced by the BHEs operation in surrounding aquifer. The aim of this work is the evaluation of these two aspects, varying the rate of groundwater flow velocity and dispersion coefficient using a numerical model realized through Modflow/MT3D (Angelotti 2014), already validated with respect to the Moving Line Source analytical solution (Molina-Giraldo 2011), demonstrating that both advection and dispersion play an important role in the heat transfer.

Main Body

A finite difference numerical model of a 100 m U-shape pipe in a saturated homogeneous sandy aquifer (thickness equal to 200 m) is created adopting Modflow coupled to MT3DMS (Fig. 1). This model is validated against the Moving Line Source analytical solution, both considering a null dispersion coefficient, resulting in a maximum discrepancy of 9% (Angelotti et al. 2014).

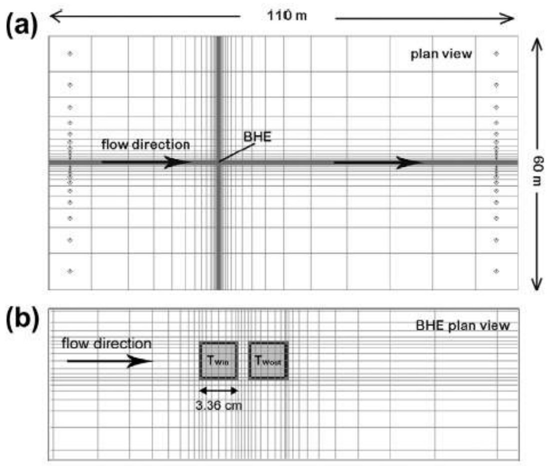

Fig. 1 – a) Plan view of the model and boundary conditions implemented in Modflow. b) Zoom on simulated BHE.

The boundary conditions given to the model consist of an initial uniform temperature in the medium, a constant unperturbed temperature at the physical boundaries of the medium and a constant hydraulic gradient across the horizontal section. By varying the hydraulic gradient and consequently the horizontal grid, the Darcy velocity of groundwater is varied (Tab.1). About the BHE, a given mass flow rate and inlet fluid temperature are given, according to the period simulated. Therefore the heat transfer rate of the BHE is not imposed, but depends on the temperature field in the aquifer.

Porosity, θ	0.35
Dispersivity, δ	0; 10 m
Effective thermal conductivity, λ_m	2.3 W m^{-1} K^{-1}
Thermal capacity per unit volume, C_m	2.72 MJ m^{-3} K^{-1}
Hydraulic porous medium conductivities, k	2 x 10^{-4}; 2 x 10^{-5}; 2 x 10^{-3} m s^{-1}
Darcy velocities, v	0; 10^{-7}; 10^{-6}; 10^{-5} m s^{-1}

Tab.1 – Porous medium thermal and hydrogeological properties.

Model simulations, considering heat extraction from the aquifer during wintertime and heat injection during summertime, regard the typical yearly operation of a BHE for a 2 years long period. For a given groundwater velocity,

different dispersivity values are assigned to the cells representing the modeled sandy aquifer, in order to evaluate the effect of this parameter on the BHE performance and temperature distributions.
In particular, the impact of different groundwater velocities on the energy performance of a typical BHE in a sandy aquifer has been assessed and shown by Angelotti et al. (2013). For $v \geq 10^{-6}$ m/s a significant increase (up to 90 % if $v = 10^{-5}$ m/s) in the injected/extracted energy is found, so neglecting the advection effect due to groundwater may lead to significant errors in the design of a BHE.
Only recently in the Moving Line Source problem the dispersion coefficient has been taken in account. For this reason, some simulations with significant dispersivity values over the whole model domain are run in MT3D for the first year period for the case of 10^{-5} m/s groundwater velocity. Heat contours show that, in a dispersive domain, the plume can spread around the BHE, producing thus a perturbation of temperatures in the transverse direction.
In particular, the 10 m longitudinal dispersivity configuration is deeper examined because of its relevant weight in literature values. When 10^{-5}m/s groundwater flow is present, total developed energy results to be higher than when dispersion is not set: the percentage difference is 97.8% for the heating period, whereas it is 94.7% for the cooling period (Fig. 2).

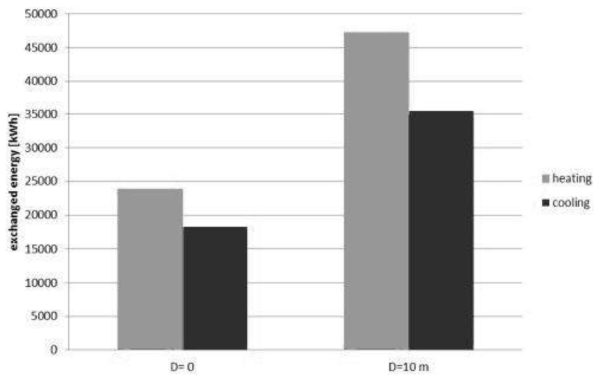

Fig. 2 – Exchanged energy in the case of groundwater flow $V = 10^{-5}$m/s, with null dispersivity and 10 m dispersivity.

Results regard also temperature distribution into the entire model domain. In fact three observation wells are set transverse to the downstream flux in order to observe difference between the cases with and without dispersion; hence a series of 41 monitoring wells is set along the downstream flux in order to look at the temperature variation with time (Fig. 3).
Results taken from the three monitoring wells show that observed temperature values, where dispersion is applied, are smaller for OBS1 than in the case without dispersion. Sensors far from the flow line register a lateral spreading of the heat if dispersion is applied, equal to that registered in OBS1. The 41 observation wells downstream the BHE show that, where dispersion is present, the BHE's disturbance can dissolve also laterally: it disappears almost 92 meters before than in the case without dispersion. These results demonstrate that, even if heat transfer simulations generally neglect dispersion, the effect of this phenomenon is really important and heavily influences the results, especially in terms of exchanged energy. Further efforts are then necessary in order to better define the sensitivity of a numerical model to dispersivity parameter and hence to highlight the most suitable value to correctly estimate the energy transport in the presence of groundwater flow.

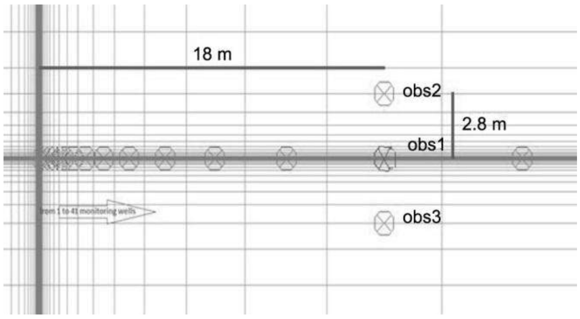

Fig. 3 – Plan view of positioned monitoring wells.

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[48] SOURCES OF BIAS FOR HIGH RESOLUTION TEMPERATURE PROFILES IN A COASTAL AQUIFER

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Keywords: temperature, aquifer, bias, tracer, infiltration.

Introduction

In literature there are an increasing number of studies focusing on temperature as a tracer to infer groundwater recharge in susceptible areas like the coastal aquifers (Taniguchi 2000; Taniguchi 2002; Vandenbohede and Lebbe 2010). To quantify the temperature behavior in the subsurface, analytical and numerical modeling techniques are usually employed (Rau et al. 2010; Anderson 2005). Although beside the thermal properties of the aquifer, these techniques needs reliable data inputs like surface temperature and high resolution groundwater temperatures. While the surface temperature are usually easily accessible and not affected by bias, the high resolution groundwater temperatures are more challenging to obtain, only few field site are equipped with multi-level temperature sensor probes directly installed in the ground (Taylor and Heinz 2009).

In this study open borehole temperature logging; pumping test temperature and packer isolated temperature in several coastal piezometers were compared to assess the sources of bias that could occur during temperature logging.

Materials and methods

The unconfined coastal aquifer is located in the Ferrara province (IT) and consists of littoral sands and shallow marine wedge deposits. The topography is below the sea level and the land is artificially drained by a network of canals. The thickness of the aquifer varies from 16 m to 22 m, and is characterized by saline and hyperhaline groundwater with shallow freshwater lenses of 1-2 m (Mastrocicco et al. 2012).

Eleven fully screened 2" piezometers of the Emilia-Romagna Region Geological Survey were selected to test three different methods to gain groundwater temperature profiles with 1 m vertical spacing: the first one is the open borehole log (OBL), which is the least expensive and fastest method; the second one is the classical temperature measurement during a pumping test with a flow cell using a straddle packer system with a screen length of 0.3 m (MLS); and the third one is an online measuring method consisting in accommodating a temperature sensor in a sampling window between the two inflatable packers to ensure that the measured groundwater temperature is taken at the desired depth. To purge the selected interval a the submersible pump is connected in line above the upper packer, this arrangement avoid the heating effect associated with electric engines (MLS-LTC). A Levelogger LTC Solinst, equipped with a spreading resistance silicon sensor to measure temperature (accuracy of 0.1 °C and resolution of 0.01 °C), was used in all the three methods to minimize the temperature bias induced by different sensor utilization. The temperature was logged every 10 sec and the mean value was taken after at least 20 screen volumes of sampling (about 12 L).

The last method was chosen as representative of the real aquifer temperature profile and compared with the other two techniques.

Results and discussion

The results obtained by the MLS-LTC were quite different from the ones obtained by OBL and MLS.

The mean error between the MLS-LTC and OBL for all the eleven piezometers was 1.50 °C. A quite common source of error during OBL is the equilibration time of the temperature sensor that in this case was minimized by waiting for 3 minutes with the Levelogger LTC submerged just below the water table before starting the log. Thus, excluding the sensor equilibration time, the source of bias was probably due to heat convection through the open borehole, since at the water table depth a quite large variation of temperature occurs during the year ($\Delta T \approx 20$ °C) and this thermal gradient can trigger a downward heat flux within the open borehole that is not representative of the aquifer temperature distribution.

The mean error is nearly double comparing the MLS-LTC against MLS temperatures, with a discrepancy of 2.34 °C. This large error is because the collected data were biased by external temperature and by heating of the submersible pump, which was amplified in low permeability formations since the pumping rate was lower. The lower flux of groundwater allowed heat exchange from the submersible pump and from external temperature (20-22 °C during the campaign).

Figure 1 shows the results obtained in piezometer P2, with the MLS-LTC profile always lower than the other two methods and the MLS displaying the highest temperatures, with the largest discrepancies in the silty sand formation.

In general, the regression coefficient (R^2) between the temperature profiles obtained with the MLS-LTC and the OBL method was high (0.96); while the R^2 between MLS-LTC and MLS was poor with a value of 0.69. Despite the quite high R^2 between MLS-LTC and the OBL, the temperature offset exemplified in Figure 1 could impair quantitative results from modeling such temperature profiles.

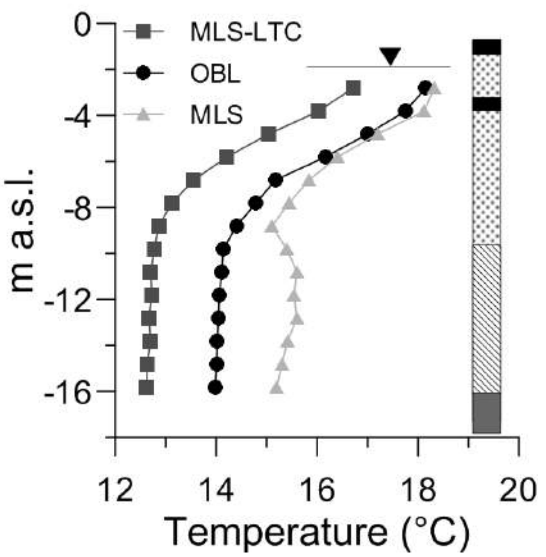

Fig. 1 - Temperature profiles collected at the piezometer P2 using open borehole logging (OBL), above ground measurement during multilevel pumping tests (MLS), and online measurement with a LTC logger within the packers (MLS-LTC). Shown is also relative stratigraphy: peat (black layers), dune sand (dotted layers), silty sand (backward slashes) and silty clay (grey layer).The water table is represented by the horizontal line and black triangle.

Conclusions

A comparative study was performed to assess if open borehole temperature logging or above ground temperature measurements from multi-level pumping test could be used to gain representative temperature profiles in unconfined coastal aquifers. But if precise temperature profiles are needed (e.g. modeling purposes), the only robust method is the online temperature measurement within an isolated portion of the well purged with a pump. This is the most reliable method that could be applied to existing long screen piezometers, if more expensive multilevel ground temperature sensor loggers are not available.

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[49] ONGOING ENVIRONMENTAL CHALLENGES IN THE ACQUE ALBULE BASIN (CENTRAL ITALY): TOWARD AN EFFECTIVE TIME-DEPENDENT GROUNDWATER CONCEPTUAL MODEL

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Keywords: conceptual model, groundwater management, hydrogeological hazard.

Introduction

The Acque Albule basin is located at the edge of the Lucretili and Cornicolani Mountains, about 20 km ENE of Rome (central Italy). The area is known since Roman times for the Thermal Baths of Tivoli and the Travertine rocks (*Lapis Tiburtinum*), by definition the ornamental building stone of Rome.

Just the long history of the area has meant that there are interferences and conflicts regarding the land use and its resources, overlapping in time, in an apparently inextricable way, as: the heavy anthropization (more than 900 inhabitants per km^2), the travertine mining activities and the water recreational-healthy-spa use. Groundwater is at the same time: an obstacle to be removed for mining production, a resource for healing and recreational activities, a matter of concern for buildings stability and land subsidence.

The man has heavily modified the natural groundwater flow over time, favoring the onset of new interactions between surface water and groundwater, modifying the water chemistry, and this is about to happen again since the quarry area will eventually closed and restored.

The basin is affected by serious geological hazards (active tectonics, subsidence, sinkholes, likelihood of flood) and linked risks.

Moreover, it is necessary to take into account the influence of natural inflows variability on the groundwater system (e.g. summer 2002 water crisis).

So it is mandatory to define a flexible and "evolutionary" groundwater conceptual model, which forms the development basis for management tools, critical issues addressing, best practice identification and potential impacts of alternative land use evaluation.

Results and Discussion

Since the mid-1800s, geological, structural, geotechnical, geophysical, hydrogeological and geochemical aspects of the area have been extensively studied by research institutions and public authorities, but not yet framed in a comprehensive management geological model.

From a hydrogeological point of view, almost all Authors (Boni et al. 1986; Capelli et al. 2005) agree in the overall scheme of the basin groundwater flow, which includes: a partially confined and unconfined aquifer in travertine, mainly supplied by the surrounding carbonate aquifers; an approximately north-to-south oriented groundwater flow, following the tectonic setting (pull-apart basin); a water mixing with warm gas enriched fluids, rising up from the deep buried carbonates which are in hydraulic continuity with the outcropping Lucretili and Cornicolani Mountains; a main point of groundwater discharge formed by Regina and Colonnelle springs (T: 23-25 °C, mean discharge: 2 m^3/s); and a basal flow boundary constituted by the Aniene River (and some neighbouring springs).

Only recently quantitative hydrogeological and geochemical studies have been performed by the implementation of numerical models and detailed field surveys (Petitta et al. 2011; Carucci et al. 2012; La Vigna et al. 2012a; La Vigna et al. 2012b; Brunetti et al. 2013).

These studies have substantially contributed to address several aspects concerning the mechanisms of groundwater flow, the interaction between the different aquifers, the mixing of different origin waters and water-rock interactions.

However, these works have mainly pointed out the deep and rapid change induced by human activities in recent years in terms of groundwater flow and water chemistry.

The groundwater flow in the partially confined travertine aquifer, containing a shallow relatively cold, slightly salty level and a deeper mineralized and warm layer, driven by the fault systems, has been altered. These changes effectively created new preferential pathways, canceled the natural vertical water stratification and drove back surface water from the nearby Aniene River.

In future, this hydrogeologic complex framework will be further modified with the inevitable restoration process of the quarry areas, which can lead to a new rising up of the water table affecting building foundations.

A fragmentary information distinguishes the Acque Albule basin knowledge, and, although plentiful, it is difficult to be fully validated and organized in a coherent way. Several piezometric

maps are available, but aquifer characterization is based on limited hydrodynamic data.
The relationships between the warm deep groundwater feeding Regina and Colonnelle lakes and the mining dewatering drawdown require additional investigation to be further detailed.
The existing numerical models are only steady-state and partially useful in defining the impacts. Heat flow models have not yet been fully implemented (La Vigna and Gnoni 2014).
A knowledge review has been undertaken to cope with land planning issues and to formulate a conceptual hydrogeological model, in which all the acquired elements converge, selecting and validating them with targeted field surveys.
Such studies should be aimed at investigating the travertine deposits hydrodynamics, complicated by depositional, karstic and tectonic patterns and by the uprising fluids flowpaths.
Above all, the changes induced by past, present and future human activities have to take into account by this model (Fig. 1).

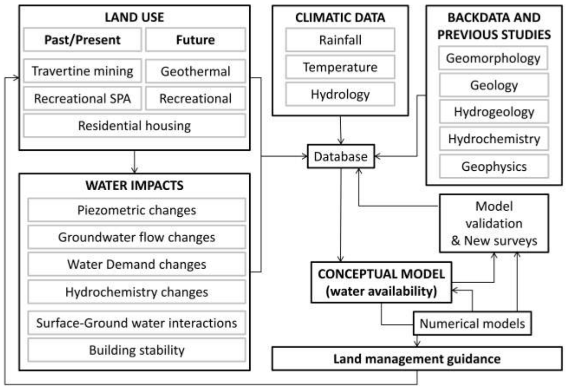

Fig. 3 – Conceptual model flow chart.

Conclusion

This ambitious project has to be supported by an open-access database that will help to continuously update the multidisciplinary available data.
The described complex framework requires a conceptual model to be provided with such a flexibility, to make it effective in following the evolution of the water resources uses, which have been proved to be very quick in the Acque Albule basin in recent years.
This model will lead to a dynamic management of the area, by providing useful information in terms of impacts, potentialities, shared planning, hazard and risk analysis.

Acknowledgements

Thanks go to CERI - La Sapienza for previous surveys and to E. Brunetti and V. Carucci for their useful suggestions.

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[50] A PHYSICO-CHEMICAL MODEL AS A WAY OF RECONSTRUCTION OF DEEP SOURCE THERMAL WATERS

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Keywords: thermal spring, physico-chemical modelling, chemical elements

Introduction

The major objective of the study was to determine the genesis of the Alginsky thermal spring with its for the Barguzin depression's hydrotherms so uncharacteristic sulphate-sodium composition of the water, where most common thermal outputs are of bicarbonate-sulphate and sulphate-bicarbonate sodium compositions. The main question is whether the generation of the water's chemical composition of this sodium sulphate thermal spring is due to granite or andesite.

The Alginsky thermal spring is located on the eastern side of the Barguzin depression at the base of the Ikat Range. Its source water temperature is 20°C, the water's chemical composition consists of sodium sulphate. Granitic rocks of Angaro-Vitimsky batholith are the prevailing type of basement rocks in the Alginsky spring region. However, bedrock exposures of young volcanic rocks with an age of approximately 8 million years (Rasskazov et al. 2013) have been found in this region, characterised by andesite composition, which is not typical for the volcanic rocks of the Baikal Rift System.

Modelling and results

At first, with the assistance of physico-chemical modelling of the Alginsky thermal spring water composition, the model validity was verified based on the chemical composition of water from this spring. The water's chemical composition was entered as a system of independent components and was calculated at a temperature of 20°C in and out of equilibrium with the atmosphere. The results of comparison of the Alginsky spring model solution with the real chemical composition (with macrocomponents) are presented in the Figure 1.

The closest values of the equilibrium chemical composition of the model water compared with the real water of Alginsky spring were obtained in case of calculations at a temperature of 20°C and at equilibrium with the atmosphere. Also, the model was verified at a temperature of 93°C without atmospheric equilibrium. Figure 1 illustrates that at a temperature of 93°C the value of pH is 8.1, which agrees with the pH-value of Alginsky spring's water. The concentration of dissolved components is also most closely corresponding to the composition of the hydrochemical analysis. Consequently, the model is valid and is able to describe the chemical composition of water solutions at the preset P-T conditions adequately (see the Table 1).

Checking assumptions about whether granites or andesites are the source of all chemical elements or if the formation of the analysed water requires participation of a juvenile substance source, was carried out in two stages. At the first stage of physico-chemical modelling there were provided investigations of interaction between rainwater and rock (andesites/granites) at different P-T conditions. In calculations the interaction degree between water and rock had changes. This interaction degree is expressed in terms of coefficients, reflecting the amount of rock interacting with 1kg of water. In experiments this coefficients were varying over the range 5 - 20 g/kg H_2O. The graphics illustrate that the most probable source of macroelements in water are granites rather than andesites (Fig. 2). There was obtained the closest model chemical composition at the interaction of granites with pure water at the temperature 93°C.

At the second stage of modelling there was considered the cooling-down process of the hydrothermal solution, obtained at a temperature from 93°C to 20°C. The obtained equilibrium composition of cooled hydrothermal solution is strongly distinguished from the real chemical composition of ground waters according to the concentrations of Si and Ca. The fact is that the solid phases of calcite and α-quartz with essentially less solubility were entered in the model. Because of this fact, in solid components α-quartz was replaced to amorphous and equilibrium calcite was excluded. In this case, the solution was obtained precisely to meet the chemical-analytical data. The only exception is the concentration of S. It is possible that such a high concentration of S in natural waters is connected with either endogenous sources or microbial activity. From this physico-chemical experiment it was concluded, that formation of waters of Alginsky hydrothermal spring is possible when atmospheric waters interact with granites (when temperature is 93°C and pressure reaches 840 Pa). In this case, a chemical composition similar to the concentration of basic macroelements of the analytical composition of Alginsky water was obtained due to the thermodynamic calculations (Fig. 3).

Thus, it was obtained a model, confirming that the Alginsky hydrothermal spring water's formation process doesn't require an endogenous source of macrocomponents, with the exception of sulphur. However, for supplying an identified concentration of microcomponents, such as U, Li, Rb, B, V, Mo, Sr, Cs, it is necessary to have an endogenous source (Fig. 3). The concentration of microelements in the model is often considerably less than it actually is in reality, although the graph for microelements illustrates that there is some tendency of repeating the balance of components' concentration in natural waters with the data of modelling, with the exception of Sr. Our findings are in correlation with the results of investigations of He isotopes (Polyak 2000), which showed the existence of mantle marks in hydrotherms of the Barguzin depression.

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chemical elements	real composition of the Alginsky thermal spring water (mole)	model composition of the Alginsky thermal spring water (mole)			
		20° C atmosphere pH=8,3	20° C no atmosphere pH=8,9	93° C atmosphere pH=2,6	93° C no atmosphere pH=8,1
Ca	1,08E-03	9,51E-04	6,55E-04	1,10E-03	1,06E-03
F	1,46E-04	1,00E-04	1,00E-04	1,00E-04	1,00E-04
Fe	3,04E-08	1,69E-13	7,01E-14	3,00E-08	1,20E-09
K	1,50E-04	2,00E-04	2,00E-04	2,00E-04	2,00E-04
Mg	1,31E-04	9,46E-05	7,99E-05	1,00E-04	9,39E-07
Cl	4,55E-04	5,00E-04	5,00E-04	5,00E-04	5,00E-04
Na	5,73E-03	5,70E-03	5,70E-03	7,08E-10	4,90E-03
P	1,06E-07	1,32E-09	3,25E-10	1,00E-07	1,29E-10
S	3,16E-03	3,20E-03	3,20E-03	3,20E-03	3,20E-03
Si	6,91E-04	8,41E-05	1,01E-04	7,00E-04	5,42E-04

Tab. 1 - Composition of the Alginsky thermal spring water.

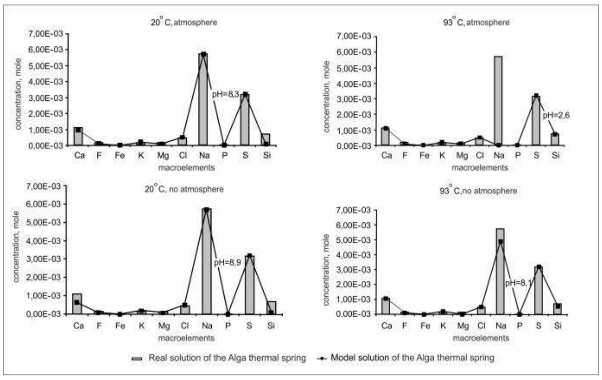

Fig. 1 – Results of the model test for adequacy.

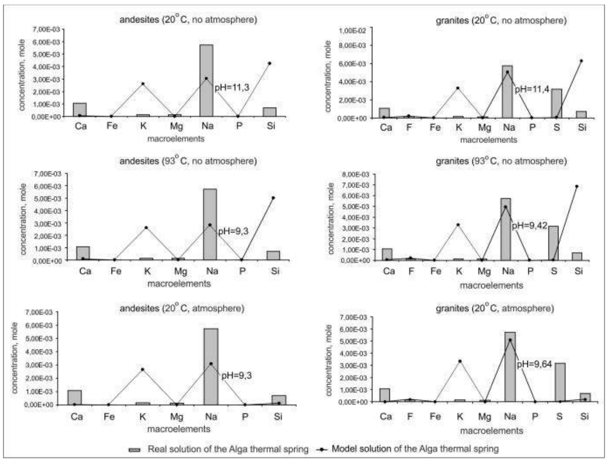

Fig. 2 – Graphic interaction of rainwater-granites (andesites) at different P-T conditions.

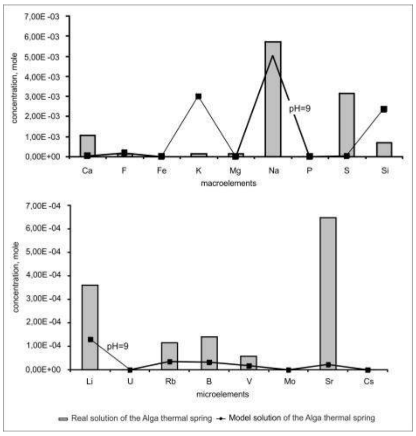

Fig. 3 – Physical and chemical model results for the hydrothermal solution cooling from 93 to 20°C.

[51] GROUNDWATER THERMAL-EFFECTIVE INJECTION SYSTEMS IN SHALLOW AQUIFERS

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Keywords: Groundwater Heat Pumps; Draining Gabions, FEFLOW; thermal plume; Italy.

Introduction

Urbanized areas have environmental features that may influence the development of low-enthalpy geothermal systems and the choice of the most suitable system type among the available. In this general context, the increasing implementation in several areas of the world of the open-loop groundwater heat pumps technology which discharge into the aquifer for cooling and heating buildings, could potentially cause, even in the short term, a significant environmental impact associated with thermal interference with groundwater, particularly in the shallow aquifers. An increased contact area between the dispersant system and the ground makes it possible to affect a greater volume of aquifer and, consequently, reduce the areal extent of the thermal plume that develops around the area of injection minimizing the time and the space needed for the disappearance of the thermal plume and the restoration of undisturbed temperature conditions. In order to investigate alternatives to traditional drilled water well for the re-injection and dispersion of water in aquifer downstream of the heat pump, we modeled with FEFLOW the possible reverse use of commercial draining gabions in various types of ground configuration, geometry and interconnection with systems of pre-fabricated vertical drains on a possible reliable test-site. The results highlighted that they can represent a good and efficient alternative for the groundwater dispersion in the aquifers.

Material and Methods

In this general context, the increasing implementation in several areas of the world of the open-loop groundwater heat pumps technology which discharge into the aquifer for cooling and heating buildings could potentially cause, even in the short term, a significant environmental impact associated with thermal interference with groundwater, particularly in the shallow aquifers (Lund 2011).

The discharge of water at different temperatures compared to baseline (warmer in summer and colder in winter) poses a number of problems in relation to the potential functionality of many existing situations of use of the groundwater (drinking water wells, agricultural, industrial, etc.). In addition, there may be cases of interference between systems, especially in the more densely urbanized.

Normally “traditional” drilled vertical wells are used both for the withdrawing and for the re-injection into the aquifer. In most of the plants in fact, the re-injection in aquifer water occur through a simple gravity disposal in a normal well that is thus defined in terms of "re-injection". Through the screens of this well column, the water discharged into the well interacts with the aquifer, being in natural motion, and disperses gradually transferring downstream the heat in the aquifer producing a thermal anomaly in the immediate surroundings (thermal plume). This thermal anomaly upon interaction with the undisturbed aquifer (heat exchange between water and the solid matrix and hydrodynamic dispersion) gradually tends to decrease up to disappear and, consequently, the water discharged goes back to the natural undisturbed temperature after a certain time and after covering a given travel in the aquifer. This project aims to investigate alternatives to traditional drilled well for the re-injection and dispersion of water in aquifer downstream of the heat pump in order to optimize the dispersion system in terms of simplicity of implementation and installation, costs of implementation and management, hydraulic effectiveness of the dispersion and containment of the spatial and temporal thermal plume. In particular, it will be studied the possible reverse use of commercial draining gabions. The study will examine, through a phase of experimentation on a suitable site, the effectiveness of systems for the dispersion of the water in the aquifer which are alternative to the wells. To evaluate the subsurface environmental effects of the GWHP system, modeling study was performed using the finite-element FEFLOW® package developed by Diersch, 2005. The conceptual model has been simplified in two layers, layer 1 corresponds to the unsaturated zone and the layer 2 represents the unconfined aquifer that is two meters below Level 1. All two layers has been simulated using physical properties appropriate to the hydro-geology of the formations. A plan view of the area covered by the computational grid (about 3,000,000 m^2; 595,062 elements and 396,968 nodes). The horizontal dimensions of the model grid are 1500 m (N–S) and 2000 m (W–E). The average mesh spacing in the modeling domain is

54 m. It was refined to 0.30 m in the central area close to the wells to provide enhanced estimation of thermal plumes. We have simulated in the transient condition for 10 days and then assuming a summer period. In particular, they have been assumed two scenarios. First scenario (case A) corresponds to the condition of including in the model the well while second scenario correspond of including in the model the alternative method to the well, such as a drain gabion (case B).

All two scenarios involve a particular interest with regard to the model simulations is the areal extent and sustainability of the subsurface thermal plume developed around the injection well and around the drain gabion at the maximum flow conditions set out in the summer during the cooling operations. The initial groundwater temperature for layers 1 and 2 was set at 14.4°C. This temperature is nearly constant throughout the year.

Rainfall infiltration was not included in the calculations due to a lack of infiltration data and the characteristics of the model surface, which is mostly covered by buildings and roads and was therefore considered essentially impermeable (Baccino 2010). The unperturbed groundwater flow is stable throughout the year, based on groundwater level monitoring. Therefore, for the case A, the Dirichlet boundary conditions were set by fixing groundwater levels on the upstream and downstream surfaces. Instead for the case B, the temperature and the discharge of the upstream surface (inflow) was set equal to the downstream surface (outflow) and was set based on a flux Neumann condition.

The numerical simulations of heat transport within the aquifer were solved using transient conditions. The maximum value of injection temperature and injection discharge are 21.4 °C and 420 m^3/d.

Results

The thermal plume of the case A is more narrow and long along the flow direction, while the thermal plume relative to the case B is more extended and wider (Fig. 1). The draining gabion therefore, is suitable for being considered as a recharge basin, this is why the isotherms are more extensive and less elongated along the flow direction.

Conclusions

In this paper, the results highlighted that they can represent a good and efficient alternative for the groundwater dispersion in the aquifers. Increasing the contact surface area for the dispersion in the aquifer therefore can be an effective way to significantly reduce the time needs for the dispersion of the discharged water, increase the volume of aquifer affected by the heat loss processes and consequently minimize the time and the space needed for the disappearance of the thermal plume and the restoration of undisturbed temperature conditions. The reduction in plan and temporal extension of the thermal plume would have several benefits minimizing the use of large areas around the buildings to develop the geothermal plants with direct economic benefits. This results are still under more investigation.

Acknowledgements

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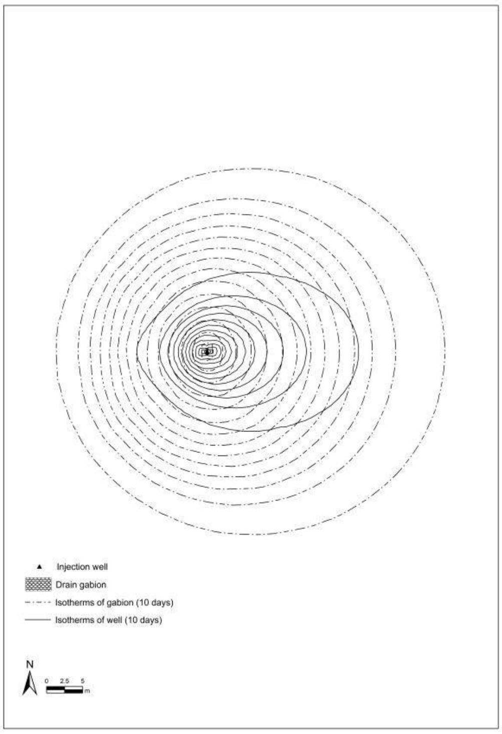

Fig. 1 – Plan view of the isotherms in case A and in case B.

[52] GROUNDWATER HEAT PUMP SYSTEMS: NEURAL NETWORK APPROACH

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Keywords: Groundwater Heat Pumps; Thermally conditions, FEFLOW; Neural Networks; Italy

Introduction

The market for geothermal heat pumps has grown considerably in the last decade (Fry 2009; Bayer et al. 2012) and is one of the fastest-growing renewable energy technologies.
Computational fluid dynamic (CFD) models are widely used in this field because they offer the opportunity to calculate the time evolution of the thermal plume produced by a heat pump, depending on the characteristics of the subsurface and the heat pump. Nevertheless, these models require large computational efforts, and therefore their use may be limited to a reasonable number of scenarios. Neural networks could represent an alternative to CFD for assessing the TAZ under different scenarios referring to a specific site. The main advantage of neural network modeling is the possibility of evaluating a large number of scenarios in a very short time, which is very useful for the preliminary analysis of future multiple installations. The neural network is trained using the results from a CFD model (FEFLOW) applied to the installation at Politecnico di Torino (Italy) under several operating conditions.

Material and Methods

The test site (Politecnico di Torino) is located in the urban area of Turin the capital of the Piemonte Region in northwest Italy (geographical coordinates 45°03'45''N, 7°39'43''E, elevation 250 m asl). The buildings connected to the existing GWHP plant are used for university offices and laboratories. Two 47 m-deep wells, one used for groundwater extraction and the other for injection, having the same technical characteristics are present at the site. The conceptual model was set up considering the structure and geometry of the different units of the domain. Several control points were included downgradient with respect to the injection well in order to check the evolution of the thermal plumes over the space (Fig. 1).
Control points 19, 21, 24, and 26 are placed along the line that connects the injection well with the piezometer, while control points 20, 22, 23, 25, and 27 are projections of previous control points along the groundwater flow direction. The horizontal angle between the two lines is almost 30°.Control points 19-23, 25, and 27 are located 10 m from the injection well while control points 24 and 26 are located 20 m from the injection well. In order to show the main effects of the thermal plume, in Table 1 three principal scenarios are analyzed and modeled using FEFLOW; appropriate FEFLOW time-varying functions (TVFs) for Q and ΔT were thus defined. The TVFs have been discretized considering a time step of one day, while the automatic computational time-step has been used for FEFLOW simulations. The first two scenarios are different because of a different maximum value of the re-injection temperature (3.3 °C in the first scenario and 11 °C in the second scenario). The third scenario is similar to the first one but a small value of the reduction in mass flow rate is considered, which means that when the heating/cooling load decreases, the heat pump is primarily operating by reducing the re-injection temperature change with respect to the extraction temperature.
The neural network model can be used to predict groundwater temperatures for installations that still do not exist or that can be caused by variations in the heat pump operation (e.g. use of large storage systems or variation in the control mode). For this reason, the network should be trained considering a large variety of CFD simulations, performed by modifying the boundary conditions that refer to the heat pump operation. In the case of complex phenomena, multiple neurons arranged into layers can be used. Usually, two layers are used: in the first layer, the hidden layer, the function associated with the neuron is generally non linear (e.g. a sigmoidal function), while in the second layer a linear or non linear function is applied (Hertz et al. 1991). The neural network developed is now applied to a real case. The goal is to compare the groundwater temperatures calculated with the neural network model and with FEFLOW. To use the neural network, an equivalent semi-sinusoidal function must be obtained for the cooling load. The reason for using the equivalent function is due to the expected applications of this kind of model, which is mainly focused on non-existing installations. Since this is not a posteriori simulation, data about the thermal request are not known, therefore it makes sense to consider approximate functions.

Results

The results deriving by the modeling of scenarios are compared by checking the groundwater temperatures at two control points downstream of the injection well. The groundwater temperatures in the three scenarios tend to converge at longer distances, where temperature gradients are small. Figure 2 shows a comparison between the temperature profile at the piezometer calculated using the neural network, the values simulated using FEFLOW and the measured temperatures. The results provided by the FEFLOW model are very close to the measurements. It is worth recalling that the input data for this model are the measured values of withdrawal mass flow rate and injection temperature. The results provided by the ANN model have similar trends and close values with respect to the FEFLOW model. There are two main sources of difference between the results: 1) the ANN model is a reduced and non-physical model which is originated from the physical model and therefore characterized by larger approximation and 2) the inputs are the semi-sinusoidal curves, which are obtained from energy equivalence, thus approximated. The temperature difference between the peak temperatures obtained with the two models is 0.34 °C, while the root mean square error in a period of 200 days is 0.46 °C. The largest temperature deviation is about 1 °C. It is worth remarking that the purpose of the ANN model is to predict the thermal impact of a possible installation, not in its vicinity, but in areas where other heat pumps operate or may be installed in the future.

Conclusions

In this paper, the use of a neural network model to predict groundwater temperature profiles at a specific site is proposed. The network is trained using simulations performed using a computational fluid dynamic model such as FEFLOW. In these simulations, theoretical profiles of the plant utilization have been considered; this allows one to characterize an application using a limited number of parameters, which is a desirable feature for the purpose of this model. Nevertheless the ANN model can be easily implemented into optimization procedures and used by people that is not expert on CFD modeling.

Acknowledgements

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Scenario	Maximum heating [kW]	Maximum cooling [kW]	Maximum temperature difference [°C]	Mass flow rate reduction [kg/s]
1	450	450	3.3	0.7
2	450	450	11	0.7
3	450	450	3	0.1

Tab.1 – FEFLOW modeling functioning scenarios.

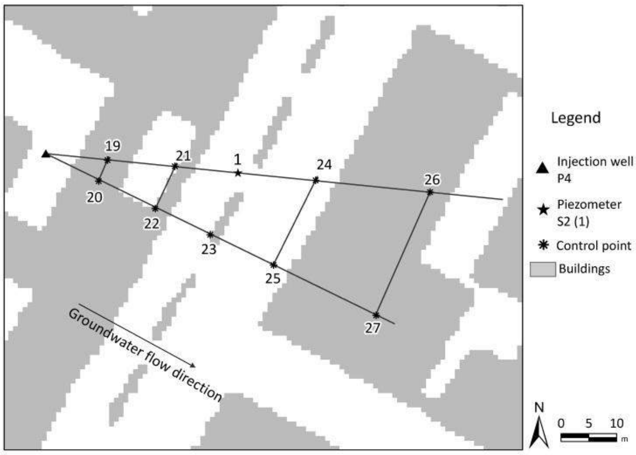

Fig. 1 – Plan view of the control points on the official cartographical map.

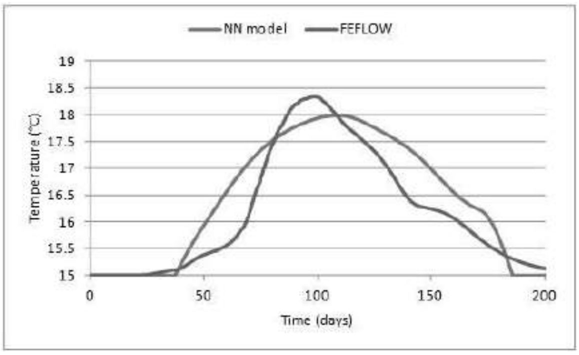

Fig. 2 – Comparison among the measured temperatures in the piezometer and those simulated with FEFLOW and calculated with the ANN model.

[53] SUSTAINABLE GROUNDWATER WITHDRAWALS IN THE GEOTHERMAL AREA OF VITERBO (CENTRAL ITALY)

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Keywords: sustainable groundwater management, thermal waters, multi-layered aquifers.

Introduction

This paper describes a possible approach to sustainable groundwater management of multi-layered aquifers in Viterbo area (central Italy), considering the results of previous studies.

It must be noted that the available legislation at local and national scale generally focuses on the quality of resources rather than on the best practices for their abstraction and management.

Hydrogeological model

In the geothermal area of Viterbo, two aquifers with different hydraulic and hydrochemical characteristics were recognized. The first aquifer (SA) is related to the regional flow of the Cimino-Vico volcanic system and its cold waters are used for irrigation and drinking water supply. The second aquifer (TA) is characterized by thermal waters (40-62 °C). The two aquifers are separated by an aquitard of variable thickness and locally fractured.

The interaction between TA and SA gives rise to mixed waters circulating in SA (Piscopo et al. 2006; Baiocchi et al. 2012). Results of numerical models and pumping tests (Baiocchi et al. 2013) highlighted that:

- an increase in withdrawals from TA could cause i) discharge and temperature decrease of the existing thermal springs and flowing wells, and ii) reduction of flow from TA to SA;
- withdrawals from SA would decrease the discharge of the thermal sources and increase the temperature of SA waters.

Method

The method adopted for the evaluation of sustainable withdrawals took inspiration from theoretical concepts and criteria reported in literature (e.g., Mandel and Shiftan 1981; Kalf and Woolley 2005).

Conceptual, numerical models and socio-economical analyses were interlaced to determine the maximum "acceptable" groundwater withdrawal, intended as the difference between potential yield and residual groundwater discharge from the system, taking into account the multi-purpose use of groundwater.

Results and discussion

A key point in definition of sustainable withdrawals is ranking the local uses of water resources.

Priority was herein given to withdrawals for drinking water and spas, and secondly to irrigation. Main constraints adopted were i) maintaining the water quality of TA and SA, and ii) ensuring a significant residual discharge to "historical" thermal springs and flow to streams fed by SA and TA.

The average annual water budget of the system resulting from conceptual and numerical models is shown in Table 1 by rounding each term to 5 L/s.

	Term	Value (L/s)
Inflows	Recharge SA (R_{SA})	300
	Recharge TA (R_{TA})	200
Outflows	From thermal wells and springs	75
	From streams (Q_{st})	35
	Towards the western boundary	390
Exchange	Flow from TA to SA (Q_{ex})	90

Tab. 1 – Groundwater budget of the Viterbo geothermal area (after Baiocchi et al. 2013).

In the case of TA, a residual discharge from untapped thermal springs (Q_{rs}) of 35 L/s was established in consultation with local stakeholders. Furthermore, the results of the modeling showed that it is possible to reduce of 40 % the flow exchange from TA to SA without inversion of vertical hydraulic gradient between the two aquifers, through the pumping from suitably located wells of the TA. If such is the case, sustainable TA withdrawals (Q_{susTA}) can be estimated as follows:

$$Q_{susTA} = R_{TA} - Q_{rs} - Q_{st} - 0.6\, Q_{ex} \qquad (1)$$

where terms are defined in Table 1. It results a value of Q_{susTA} of approximately 75 L/s.

In the case of SA, a discharge of 10 L/s (Q_s) from the cold spring tapped for drinking water must be granted and a flow to streams of 30 L/s (Q_{st}) must be safeguarded. Theoretical sustainable groundwater withdrawals from SA (Q_{susSA}) can be estimated as follows:

$$Q_{susSA} = R_{SA} - Q_s - Q_{st} \qquad (2)$$

where Q_{susSA} could be used for irrigation needs. This result is only theoretical, since pumping tests and numerical models highlighted a significant impact of withdrawals from SA on the equilibrium of the whole system.

Aquitard heterogeneity, different values of the vertical hydraulic gradient and location of wells tapping thermal waters impose to focus not only on the amount of the sustainable withdrawals, but also on their spatial distribution. To this end, two areas were distinguished (Fig. 1):

- A1 area includes: thermal springs, outcrops of travertine, zones of mixing between thermal and fresh waters, zones of reduced thickness of the aquitard;
- A2 area considers: drainage network fed by TA, heat flow map, hydrostratigraphic and structural setting.

Q_{susTA} would be applicable exclusively in A1 area. However, an excessive drawdown in TA wells must be prevented, since it would induce the capture of cold waters from the overlapping SA. This would affect the quality of thermal waters. Thus, further exploitation of TA inside A1 area needs a site-specific evaluation of the local vertical gradient and of any interference with "historical" thermal springs.

Q_{susSA} is applicable only in A2 area (with the exception of the safeguard area of the drinkable spring, Fig. 1). In this area, impact of withdrawals on the existing mixing between the two aquifers is moderate. Therefore a more reliable Q_{susSA2} can be obtained reducing the term R_{SA} of equation (2) into R_{SA_A2} *of* equation (3):

$$Q_{susSA2} = R_{SA\_A2} - Q_s - Q_{st} \qquad (3)$$

where R_{SA_A2} is recharge of SA that only accounts for direct infiltration above A2 area. Site-specific assessment should include temperature logs and pumping tests, in order to estimate hydraulic diffusivity of SA and local transmissivity of the aquitard.

Conclusions

Exploitation of the geothermal area of Viterbo is dependent on hydraulic conductivity and thickness of the aquitard that maintains the hydrogeological equilibrium between the two aquifers. A correct usage of groundwater resources should be based on the detailed knowledge of the local aquitard properties, in order to minimize mutual adverse effects in the exploitation of both aquifers. Effective methods to control this equilibrium include monitoring of vertical hydraulic gradient between SA and TA, residual discharge and temperature of natural thermal springs, temperature logs of SA wells.

These methods, applied herein at large scale, allowed a first quantification of the sustainable yield and a first spatial distribution of withdrawal for both aquifers.

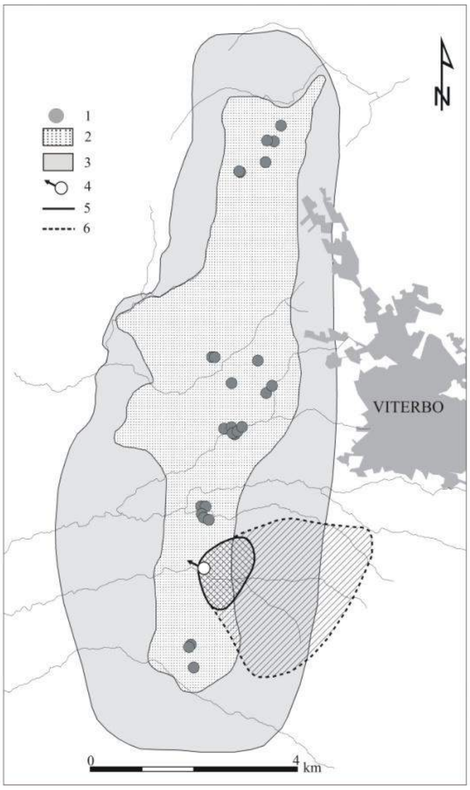

Fig. 1 – "Sustainable" areal distribution of withdrawals in the geothermal area of Viterbo: 1) thermal spring and well, 2) A1 area, 3) A2 area, 4) drinking water spring, 5) 90-day isochrones for drinking water spring, 6) 365-day isochrones for drinking water spring.

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[54] HYDROGEOLOGICAL INVESTIGATIONS AT "FERRARELLE" NATURAL MINERAL WATER SYSTEM (PIANA DI RIARDO-CASERTA): AN EXAMPLE OF MULTIDISCIPLINARY APPROACH

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Keywords: mineral water, hydrogeological budget, GIS.

Introduction

Management planning of natural mineral water system of high socio-economic interest, requires a multidisciplinary approach in order to ensure the sustainability of the resource.

This study is focused on "Ferrarelle" sparkling mineral water system (FMS) at Riardo plain. Over the last 30 years some studies highlighted several features of the hydrogeological framework at FMS (Allocca et al. 2007; Capelli et al. 1999; Celico 1983; Cuoco et al. 2010; Giordano et al. 1995). Sparkling FMS comprise water, CO2 and permeability. The last is linked to deep fractured carbonate rocks and overlying volcaniclastic deposits. Carbonate rocks deep fractures also allow CO2 rising to the land's surface with a partial pressure greater than the atmospheric one and with an increased rate of dissolution in water.

The aim of the study is the hydrogeological conceptual model development at FMS and subsequent hydrological budget by means of the identification of the geometry, extent, spatial relationships between geological structures and geological formations as well as by groundwater flow system definition.

Main Body

Riardo Plain (RP) is located east of the Roccamonfina volcanic complex (Rouchon et al. 2008) being enclosed south, east and north by Mesozoic carbonate ridge. The bedrock in RP is mostly composed of Mesozoic carbonate rock (i.e. limestone, dolostone) with overlying Pleistocene volcaniclastic and alluvial deposits.

Structural setting is made up mostly of tensional NE-SW and NW-SE trending fault system affecting carbonate rocks. The graben structures formed by Plio-Pleistocene tectonic activity are filled with volcaniclastic and alluvial Quaternary deposits. Moreover deep faults and fractures systems are the way for the CO2 rising up.

This geological framework hosts FMS, that has been exploited since the late 1800's for commercial purpose. During the years an higher mineral water exploitation led to the actual industrial activity and to the need of a better hydrogeological framework comprehension. For this purpose a research project was led by "Università degli Studi Roma Tre" for geological and hydrogeological aspects and by "Seconda Università di Napoli" for hydrogeochimical aspects. "Università di Pavia" conducted isotopic studies on the water.

Over the last two years several field hydrogeological surveys were carried out by "Università degli Studi Roma Tre". Groundwater levels and chemical-physical parameters were in-situ measured for more than 230 wells. Streamflow measurements were conducted over 33 cross sections. Water samples were collected and then major elements concentration analyzed for 53 of them.

Furthermore many data were collected by public and private sources. The geological field investigations also comprised the geological reinterpretation of all collected geological logs.

A structured database was created with actual an older data coming from previous studies, then a geodatabase was implemented in a GIS.

In order to construct piezometric levels and top of Mesozoic carbonate formation in the investigated area, data analysis and GIS elaborations were performed.

Results show a dynamic watershed within Riardo plain that separates two adjacent hydrogeological basins: Savone basin draining toward SW and Rio delle Starze basin draining toward NE.

In the first one the piezometric levels are similar both in deep wells and in shallow ones. Deep wells withdrawing from the carbonate-rock aquifer while shallow wells from volcaniclastic aquifer. In the available borehole cores coming from Ferrarelle s.p.a. mineral waters field, Miocene sandy-clayey formation is absent or strongly thinned. Geochemical analysis reveal the effect of groundwater interaction with volcaniclastic deposits even in highly mineralized samples caught in deep wells. The results force to think that volcaniclastic and carbonate-rock aquifer are hydrologically connected at the least at Savone basin.

Rio delle Starze hydrogeological basin point out the existence of two overlapping groundwater circulations in the south-eastern side of the basin (Fig. 1). The piezometric levels were consistent with the presence of low conductivity volcaniclastic deposits at least in that side of the

Rio delle Starze basin.

The estimation of hydrological budget is a fundamental tool in order to control and manage the water resource in every mineral water exploitation area. For this purpose all necessary FMS data were implemented in a GIS and a geodatabase including geologic data was achieved. Distributed hydrogeological budget method was applied (Capelli et al. 2005) by creating grids for every element computation.

Thermo-pluviometric time series data 2000-2012 were collected and then interpolated by radial basis functions-MF interpolation method on a monthly scale. Savone basin calculated hydrogeological budget, in which mineral water is exploited, is in equilibrium.

Moreover hydrological relationship between Riardo plain and surrounding carbonate ridges was investigated in order to define boundary conditions for FMS. Hydrogeological and hydrogeochemical survey reveal groundwater flow directed from northern carbonate ridge toward Riardo plain and from deeper aquifer toward southern carbonate ridge.

The groundwater flow system conceptual model proposed for the FMS area, represents the foundation to develop a numerical model.

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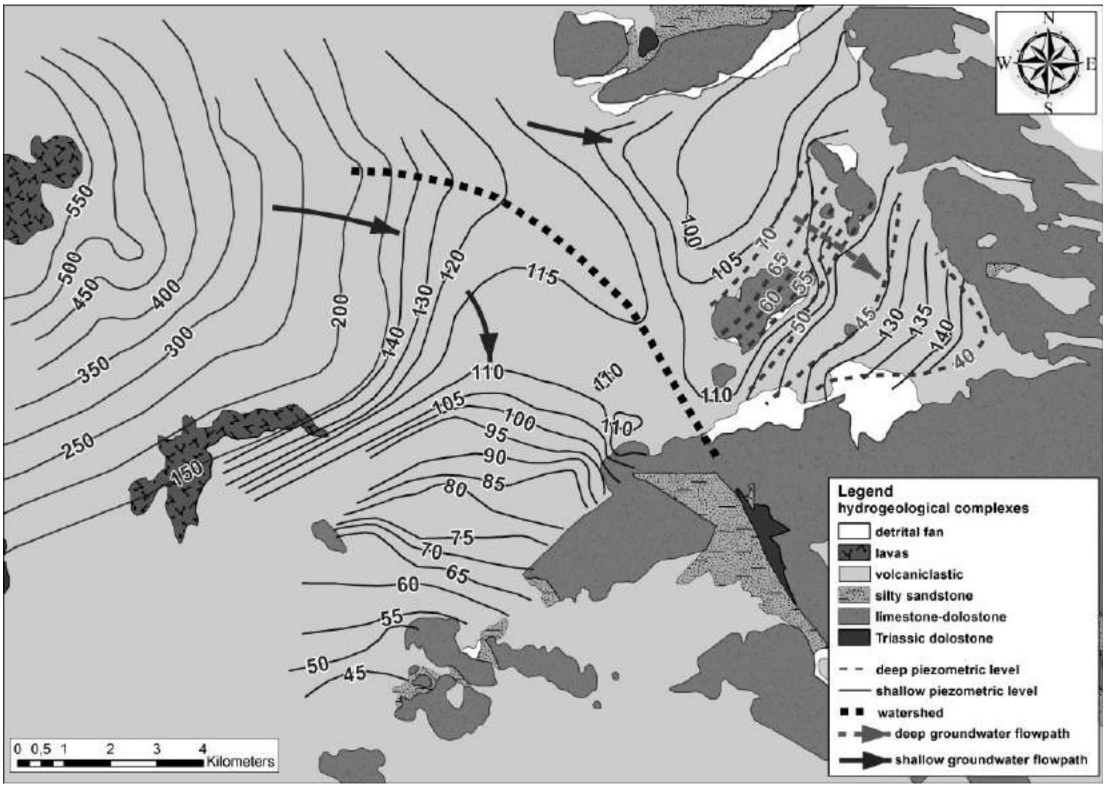

Fig. 1 – Hydrogeological complexes, piezometric levels and groundwater flowpaths in the study area.

[55] INFLUENCE OF WATER-ROCK INTERACTION AND OF UPRISING DEEP FLUIDS ON THE ARSENIC CONTENT IN THE GROUNDWATER OF VITERBO AREA

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Keywords: arsenic, Cimino-Vico volcanic district, hydrothermal fluids, water-rock interaction.

Introduction

Arsenic occurs frequently in groundwater of volcanic areas, due to the presence of the element as a natural constituent of volcanic gasses and geothermal fluids or to the interaction with rocks containing this element (Ballantyne and Moore 1988; Smedley and Kinniburgh 2002). In volcanic areas of Viterbo, the groundwater are hosted in three different type of aquifer: thermal waters, basal aquifer and perched aquifer.

The thermal waters, with $CaSO_4$ chemical composition show relatively high mineralization and high temperature (T=54–60 °C). They have arsenic concentration ranging between 176 and 371 µg/L.

The basal and perched aquifer (cold waters) with Ca–HCO_3 chemical compositions tending towards an alkaline-bicarbonate type show low salinity and low temperature (T=7–22 °C). The arsenic concentration rannges between 1.8 and 75 µg/L for the basal aquifer and between 1.7 and 12 µg/L for the perched aquifer (Angelone et al. 2009).

The occurrence of arsenic in groundwater is well documented (Cremisini et al. 1979; Aiuppa et al. 2006; Vivona et al. 2007; Angelone et al. 2009; Achene et al. 2010; Baiocchi et al. 2011). These studies show that several factors affect the mobility and distribution of arsenic in groundwater, such as temperature and water chemistry, composition of the rocks, volatile compounds originating from magma, as well as the regional and local hydrogeological characteristics.This paper reports the preliminary results arising from recent surveys carried out on volcanic outcrops either surrounding the Vico lake and emerging at the eastern margin of the Viterbo area, in order to evaluate the main causes of the anomalous arsenic concentrations in the groundwater of the Viterbo area.

Materials and methods

Based on literature information and on the geological maps of the studied area, a total of 60 samples were collected from the most representative outcrops of Cimino and Vico volcanics and characterizing the volcanic aquifer system.

Moreover, a few samples collected from cores drilled in a hydrothermal area have been considered in the present study.

Analyses of arsenic were performed using the inductively coupled plasma mass spectrometry (ICP-MS), after dissolution of the ground samples with a mixture of reagents (HNO_3, HF, H_2O_2) using a microwave oven (method EPA 3052). Data have been processed using a GIS software.

Results and discussion

The volcanics collected outside the hydrothermal area have arsenic content ranging between 29 and 108 mg/kg. The highest arsenic concentrations have been measured for the Ignimbrite A and for the pumices of Ignimbrite D (Locardi 1965) both belonging to the Vico volcanic district. On the contrary, the Ignimbrite Cimina pyroclastic formation (Puxeddu 1971) presents low arsenic concentration values and also a low variability of the data (Tab. 1).

Considerable differences in the arsenic content were measured for the same pyroclastic formation samples collected in different areas depending on the presence of uprising deep fluids. In fact, the Ignimbrite C (Locardi 1965) samples collected at the hydrothermal area showed higher arsenic content with respect to the ones located outside the active hydrothermal system (Tabs. 1 and 2).

Heat flow and structural setting (Fig. 1) maps have been compared with the distribution plot of the arsenic content in the rocks (not shown here) and in groundwater of the Cimino and Vico volcanic area (Fig. 2), to the aim of finding out a correlation among this occurrences.

The evaluation of these preliminary results showed that the areas with high arsenic content in the basal aquifer fairly match the areas with higher heat flow values. There is also the evidence that the heat flow rate have higher influence compared to the presence of a faults system. These evidences seem to confirm that there is a strong influence of the active hydrothermal system, both on rocks and groundwater As content, as reported in recent studies (Baiocchi et al. 2013).

Lithology	n° samples	District	min	max	mean
Ign. A	9	Vico	46	166	107
Ign. B	8	Vico	43	122	81
Ign. C	17	Vico	9	111	44
Ign. D	2	Vico	33	54	44
Pumices	3	Vico	78	138	108
Final Tuffs	8	Vico	23	57	42
Ign. Cimina	8	Cimino	14	42	29
Trachitic lava	2	Cimino	31	31	31
Leucitic lava	5	Vico	18	81	51
Tefritic-fonolitic lava	4	Vico	22	44	35

Tab. 1 - As content in the studied lithotypes (mg/kg).

Sample	Deep (m)	Lithology	As (mg/kg)
P1	7	Travertine	156
P3	12	Travertine	68
P4	19	Ign. C	437
P6	21	Travertine	224

Tab. 2 - As content in samples of the core extracted at the hydrothermal area of Viterbo (Bagnaccio).

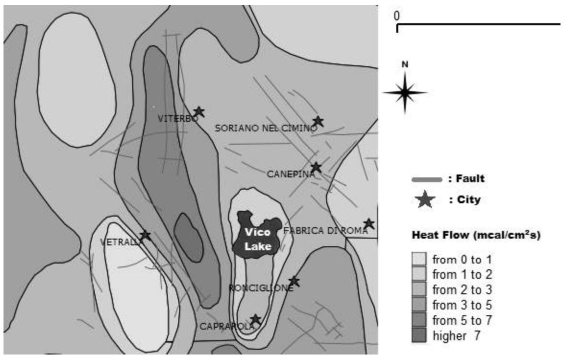

Fig. 1 - Heat flow and faults in the study area.

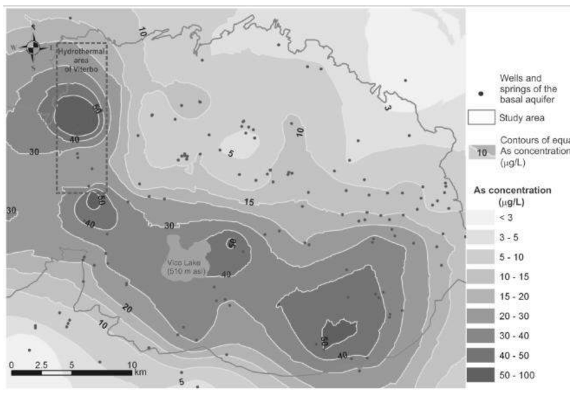

Fig. 2 - Arsenic concentration in the basal aquifer of Viterbo area (Baiocchi et al. 2013).

Conclusions

At this stage of our work, the uprising of deep fluids seems to be the leading factor contributing to the high arsenic concentrations found both in some rocks and in groundwater of the volcanic aquifer. On the contrary, the contribution of arsenic due to the leaching from rocks could be considered a secondary factor. In fact,at least for the Ignimbrites C (Locardi 1965) and the Ignimbrite Cimina, our preliminary studies, concerning water-rock interactions, showed a very low As contribution due to leaching mechanism, in the experimental conditions applied.

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[56] UPWELLING TIME OF THERMAL WATERS INFERRED USING RADIONUCLIDES: THE CASE STUDY OF THE EUGANEAN GEOTHERMAL FIELD (VENETO - NE ITALY)

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Keywords: radium isotope, groundwater age, thermal water, Euganean Geothermal Field.

Introduction

The Euganean Geothermal Field (EGF) is the most important thermal field in the northern Italy. The EGF extends on a plain band of 36 km^2 in the central Veneto (Fig. 1a). At present approximately 250 wells are active and the total average flow rate of exploited waters is 17×10^6 m^3/y. The temperature of thermal waters ranges from 65°C to 86°C with TDS of approximately 6 g/L (primary Cl^- and Na^+). Recently, Pola et al. (2013) proposed an updated conceptual model for the EGF system. According to this new model, the thermal waters are of meteoric origin and infiltrate 80 km to the north of the EGF in the Veneto Prealps. The groundwater flows southward within a Mesozoic carbonate reservoir and reach a depth of about 3000 m warming to approximately 100°C by the normal geothermal gradient. The regional Schio-Vicenza fault and the related highly permeable fractured damage zone represent the path for fluid migration in the middle part of the circuit. In the EGF area, the hot waters intercept a left stepover structure between faults of the Schio-Vicenza fault system and rise quickly to the surface through the local fracture mesh. A water residence time greater than 60 years, probably in the order of a few thousand years, was suggested by Gherardi et al. (2000). The quick upwelling is postulated because the water temperature measured in the wells (65-86°C) approaches the reservoir temperature (~100°C) inferred by geothermometers (Gherardi et al. 2000). This work constraints time scales of thermal fluid upwelling based on Ra and Rn isotopes of the decay chains of ^{238}U, ^{235}U and ^{232}Th. These radionuclides are characterized by different half-lives (from few days to thousands of years) thus they provide time constraints on different time scales (Porcelli 2008).

Methods

Twenty three samples of thermal waters were collected in 2012 from wells and springs (Fig. 1a). The depth of the wells varies from 310 m to 1027 m. Temperature, pH, Eh and conductivity were measured on field taking into account the pH and Eh variation during water cooling. Major and trace elements analyses were done at the chemical laboratory LHA (University of Avignon). Ra and Rn isotopes were measured using delay coincidence counting system (RaDeCC) and a Rad7 radon detector.

Saturation indexes (S.I.) of minerals in waters were calculated at sampling temperatures using the program Phreeqc (Parkhurst and Appelo 2013). In fact, Ra can be precipitated in Ca and Ba minerals (e.g., barite) or adsorbed in Fe-Mn hydroxides (e.g., goethite). These processes may affect Ra and Rn systematic, beside radioactive decay. In this study, the ratio between main Ra-Rn isotopes (e.g., ^{223}Ra/^{226}Ra, ^{222}Rn/^{226}Ra) were analyzed to determine the upwelling times of thermal waters. ^{223}Ra and ^{226}Ra are both produced after three alpha decays by U contained in aquifer minerals (^{235}U and ^{238}U respectively). Since ^{235}U/^{238}U in aquifer is constant, radium input into groundwater has the same ^{223}Ra/^{226}Ra equilibrium value (=0.046). ^{222}Rn is the decay product of ^{226}Ra (half-life=3.82 days) and reaches secular equilibrium activity (=1) with the aquifer in about 10-20 days.

Results and Discussion

The measured physical parameters and the chemical composition of the EGF thermal waters are comparable to the data reported by Gherardi et al (2000). The temperature varies from about 40°C (springs) to 85.5°C, regardless of the depth of the wells. On the other hand, the pH is slightly more acidic in this collection of samples (5.38-7.34) than the previous studies, probably related to the observed pH variation during the cooling of thermal waters. The more acidic waters (2 samples; pH< 6) are found in Montegrotto.

All samples are near saturation equilibrium conditions in respect to barite (S.I.~0), but are clearly oversaturated in respect to goethite (S.I.>0; Fig. 1b), except for the acidic samples (S.I.<0). In general both barite and goethite may remove radium from water, but goethite probably removes radium more effectively in the EGF water due to the higher S.I. value.

Most of the EGF thermal waters show a ^{223}Ra/^{226}Ra not in equilibrium with the aquifer. Two groups of samples can be distinguished on the base of the ^{223}Ra/^{226}Ra and S.I. of goethite (Fig. 1b). The same subdivision is depicted in the ^{226}Ra vs. ^{222}Rn diagram (Fig. 1c) with few samples plotting between the two groups.

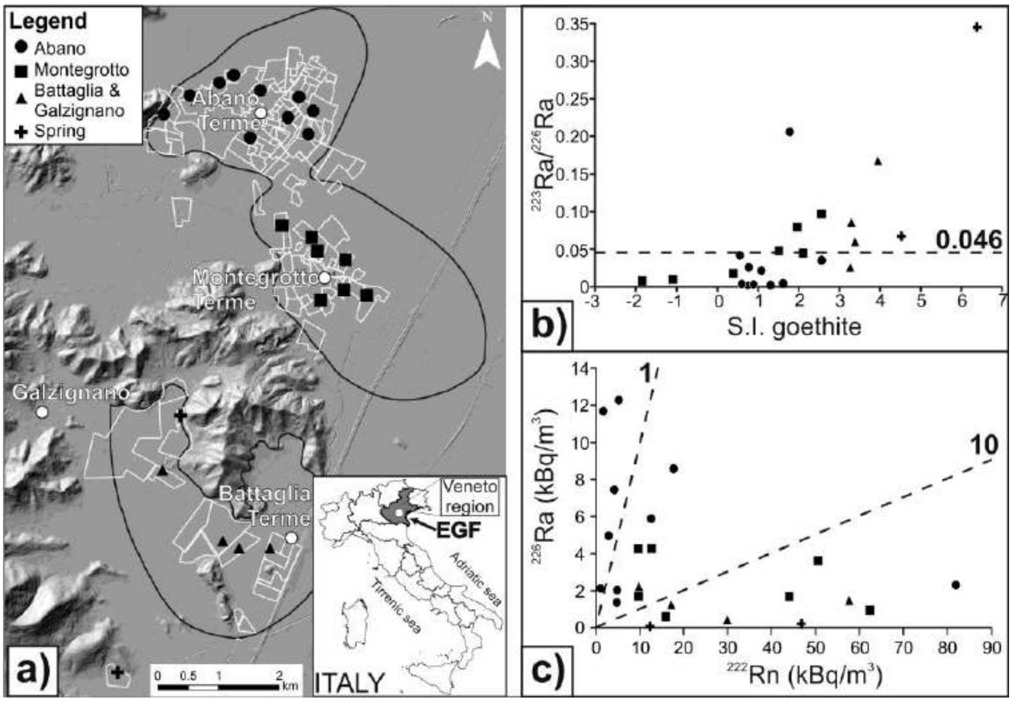

Fig. 1 – Map of the Euganean thermal waters samples distinguished on the base of the different municipalities (a). The same legend is used in the diagram of the ^{223}Ra/^{226}Ra vs. the saturation index of goethite (b) and in the diagram of ^{226}Ra vs. ^{222}Rn (c). Two group of samples can be distinguished: the first one (primarily Abano waters) is characterized by S.I.<1.6, ^{223}Ra/^{226}Ra<0.046 and ^{222}Rn/^{226}Ra≤1; the second one (primarily Montegrotto, Battaglia and Galzignano and springs) is characterized by S.I.>1.6, ^{223}Ra/^{226}Ra>0.046 and ^{222}Rn/^{226}Ra>10.

- **Group 1** waters (Abano samples, except for two affected by local lithological conditions) are characterized by $S.I._{goethite}<1.6$ and ^{223}Ra/^{226}Ra<0.046 (Fig. 1b). The ^{223}Ra/^{226}Ra lower than equilibrium arises from an high ^{226}Ra content that is shown also by the ^{222}Rn/^{226}Ra lower than the secular equilibrium value (Fig. 1c). The ratios suggest a two step processes: the waters should traverse an aquifer with minor or absent radium coating and then should pass through a zone where they assimilate ^{226}Ra shortly before sampling. In order to explain the ^{222}Rn/^{226}Ra<1, a short time (maximum 3 days) should have elapsed between ^{226}Ra sorption and sampling. Therefore, these waters could rise quickly to the surface through large fractures with minor water/rock interactions.
- **Group 2** waters (Montegrotto, Battaglia and Galzignano and springs samples) are clearly saturated in goethite (S.I.>1.6) and in general characterized by ^{223}Ra/^{226}Ra greater than equilibrium value indicating an active radium precipitation in goethite. The existence of an important radium coating is corroborated by high ^{222}Rn and low ^{226}Ra (^{222}Rn/^{226}Ra>10). The high ^{222}Rn content suggests in particular a slower groundwater upwelling in respect to group 1 waters governed by near porous-flow condition (e.g., meshed highly fractured bedrock).

Conclusion

The results of this work highlight the existence of different rising rates in the EGF. The thermal waters of Abano (group 1) rise to the surface quickly (maximum 3 days) through large fractures. Thermal waters of Montegrotto, Battaglia and Galzignano (group 2) rise more slowly through a finely fractured aquifer yielding an enhanced water/rock interactions.

Acknowledgements

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[57] STUDY ON THE HYDROTHERMAL SUIO-CASTELFORTE BASIN (Latina, ITALY)

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Keywords: Thermal-Springs, Ausoni Mts., Roccamonfina Volcano, Numerical-Modeling.

Introduction

Karst systems usually host a thermal basin, especially when in contact with volcanic masses. For hydro-geological purposes, the main goal lies in understanding circulation paths and defining water fluxes; on the other hand, it is important to define the heat transfer, in order to exploit the geothermal potentiality of a site. To permit subsequent thermodynamic considerations, a preliminary study on Suio spring site has been led, focusing on the hydro-geological features of the area. Taking into account geologic, structural, geomorphologic, geochemical and hydrological data, this work intends to give support to a first numerical-modeling of Suio spring.

Geological and Hydro-geological Setting

Suio thermal basin is located in the Southern Lazio, between the Roccamonfina volcanic unit (hereinafter referred to as RU) and the final sector of the Lepini-Ausoni-Aurunci unit (hereinafter LAAU), along the right side of the Garigliano river (Figs. 1A and 1B). The important Ortona-Roccamonfina structural line passes in correspondence to the volcanic area, to the East of the investigated area. From a stratigraphical point of view, LAUU belongs to the Lazio-Abruzzi platform series; more than 2000 m of meso-cenozoic dolostone and limestone, followed by terrigenous deposits, related to the orogenetic processes. LAUU is characterized by a main thrust that is shown along the NE boundary. Roccamonfina quaternary volcanism takes origin from the opening of the back-arc basin, with lava-banks followed by pyroclastic deposits. In this area, quaternary volcanism clutches the Garigliano river between the LAAU and the Roccamonfina edifice.

In the gorge, the Garigliano river is structurally controlled with a sharp change of direction from Apennine to counter-Apennine trend, moving from North towards South (Fig. 1B). Structural data collected by the authors in the mesozoic unit confirm the dominance of an Apennine-trend system on the E-W and N-S. An opening phase generates a Horst and Graben geometry; graben sectors host the RU.

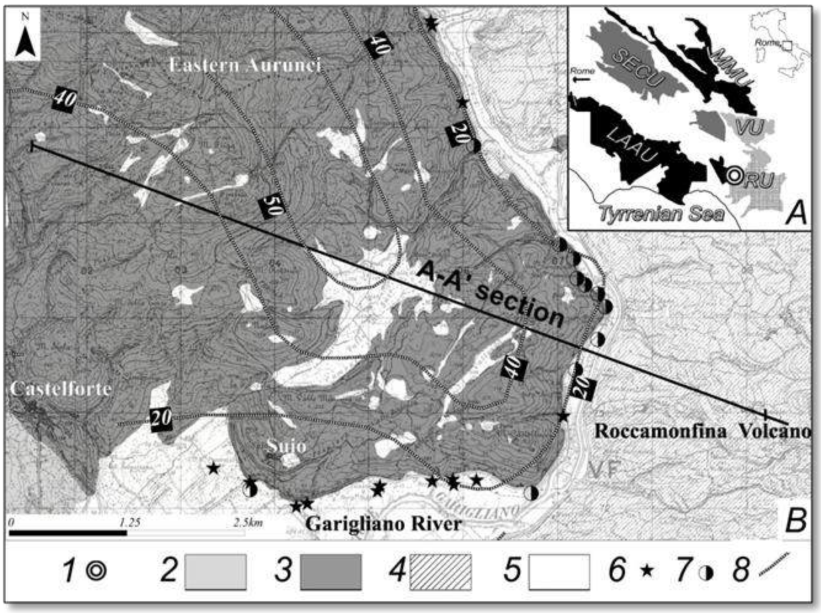

Fig. 1 - A) Hydro-geologic sketch of Southern Lazio hydro-structures. Legend: LAAU - Lepini-Ausoni-Aurunci unit; RU - Roccamonfina unit; VU - Venafro unit; SECU, Simbruini-Ernici-Cairo unit; MMU - Meta-Marsica unit. B) Hydro-geologic map of Suio springs. Legend: 1- Area shown in Fig. 1B; 2 - Carbonatic complex; 3 Terrigenous complex; 4 - Volcanic complex; 5 Alluvial-residual soil complex; 6 - Cold spring (T<25 °C); 7 - Hot springs (T>25 °C); 8 - Piezometric line. A-A' Section is shown in Fig. 2.

Proofs are represented by deep boreholes, made nearby Gallo village (Watts, 1987); here sin/post-orogenetic deposits (i.e. piggy-back sequence) are hidden under a thick blanket of volcanic material (about 800 m).

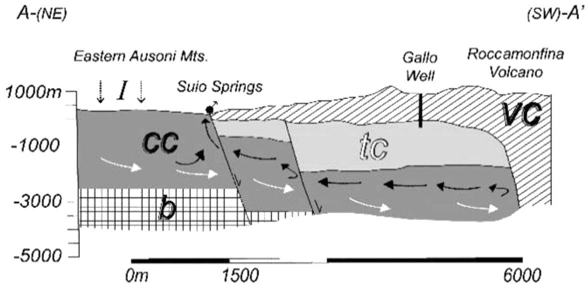

Fig. 2 - Schematic hydro-geological section A-A'. Legend: b - inferred basement; cc - calcareous complex; tc - terrigenous complex; vc - volcanic complex; I – Infiltration waters. Heat source establishes a convective loop that allows rising of thermo-mineral water (black arrows), in correspondence to Suio springs, starting from cold -karst water (white arrows).

Eastern Ausoni is the end sector of the LAAU and it can be considered an isolated hydro-structure, separated by way of two important lateral ramps at West and North-East.

Suio springs are one of the biggest delivery for Eastern-Aurunci underground-waters, with linear springs evaluated between 1 m^3/s and 5 m^3/s (Baldoni et al. 2012). Along the Garigliano river, linear springs are dominant and only a small amount of water comes out by punctual springs, with quotes ranging from 20 to 10 m (Fig. 1B). Nevertheless during the study activity, census of punctual springs has been very important, in order to understand physical and chemical features and their spatial distribution. Waters have mineral features with prevalence of SO_4^{-2}, HCO_3^-, Ca^{+2}, Mg^{+2}. Nearby the sharp turn of the Garigliano river (from Apennine to counter-Apennine direction) water temperature has the highest values, that can overreach 60 °C. With a temperature lower than 25 °C, cold mineral water are instead spread over the Garigliano gorges, along an E-W tectonic line.

In order to evaluate the geothermal potentiality of Suio reservoir, thermal-waters has been analyzed using the geo-thermometer method. The performed analysis allowed to estimate an average reservoir-temperature about 150°C, according with D'Amore et al. (1995).

Discussion data and conclusions

Temperature differences of mineral waters could be related to structural features. Cold-mineral water arises from E-W tectonic elements that are older than the Apennine and counter-Apennine trend, accountable for thermo-mineral water.

For thermo-mineral water, we propose a conceptual model in which carbonatic-karst complex is directly in contact with volcanic conduit, through a hydro-geologic section (Fig. 2). Following Nunziata and Gerecitano (2011), the magmatic chamber has been included, estimated with a depth ranging from 4 to 5 km. The hydro-geologic section shows a water-circulation path inside the carbonatic complex; in Fig. 2, with an average temperature of 200°C, the heat source establishes a convective loop that allows the rising of thermo-mineral water (black arrows), starting from cold-karst water (white arrows).

Starting from the hydro-geologic section of Fig. 2, numerical simulations have been performed, in order to verify the conceptual model and to compare the simulation results with the measured spring-data (well-temperature gradient).

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SESSION 4

Climate change and groundwater sustainability

Chairs: Daiela Ducci, Francesca Lotti

[58] CONSIDERATIONS ON CLIMATE CHANGE, THE HYDROLOGICAL CYCLE AND WATER RESOURCES

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Keywords: hydrological cycle, water resources, climate change

The researches of the last few decades confirm the ongoing warming of the atmosphere. Despite many uncertainties and various criticisms, the initial statement of the 5th IPCC report, synthesizing the most recent researches on climatic change, appears to be basically unquestionable: "*Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased*" (IPCC 2013). No matter how much the warming is due to anthropogenic or to natural causes, no matter if during the Holocene there were, or there were not, similar conditions during some time interval, and in spite of the uncertainties about the "exact" amount of this warming, the important point is that the atmosphere warmed, we are living in this time and the atmosphere will keep warming during the next decades on the average (Fig.1).

The ongoing climate change will bring numerous and dramatic environmental problems, including alterations to the hydrological cycle, which is already heavily influenced both by climatic change (Fig. 2) and by direct anthropogenic activity (Dragoni and Sukhija 2008, and references reported therein).

Groundwater will be vital to alleviate some of the worst drought situations, as it is today and it was in the past. What is new, compared with the past, is the global dimension of the environmental change and its permanency and, thus, its gravity. Compared to the climatic changes of the past, the present change is taking place in a world where many vast areas are densely populated, with high water demand.

The main problem regarding the building of future scenarios of the water yield of groundwater systems is due to the uncertainties about the future rainfall: unfortunately, the present General Circulations Models (GCMs) and the Regional Circulation Models (RCMs) are unable to give a narrow range of future climatic scenarios. This situation is not a surprise considering the large uncertainty about precipitation change occurred during the last century and the fact that, even at present, the rainfall over about 75% of the Earth (oceans and some of the continental areas) is very badly known (Fig. 2 and Strangeways 2006). The situation is worsened by the fact that both GCMs and RCMs give future scenarios on the basis of a range of future greenhouse gases emissions while, at the same time, neither the physics of climate is entirely known, nor other important climatic factors, as for example the future status of vegetation at the global scale.

The speech, besides discussing the uncertainties of our knowledge about past, present and future climates, and the ways to try to overcome the uncertainty problems, considers the main areas in which hydrogeological research should focus in order to mitigate the likely impacts. Some considerations about how to approach the research regarding climatic change and groundwater are put forward. In particular, the thesis uphold is that the impact of climatic variations on groundwater should be always evaluated by means of very focused site specific studies, especially in mountain regions, as the geological setup of these areas is in general much more complex than the geological set up of flat areas. This often implies the presence of strong hydraulic gradients, sharp variations of hydraulic conductivity and porosity, fracture flow and anisotropy. The presentation shows, by means of theoretical considerations and actual cases, how in these conditions the flow patterns, the discharge of the springs and the water supply under a changing climate depend on the groundwater recharge as well as on the geological structure.

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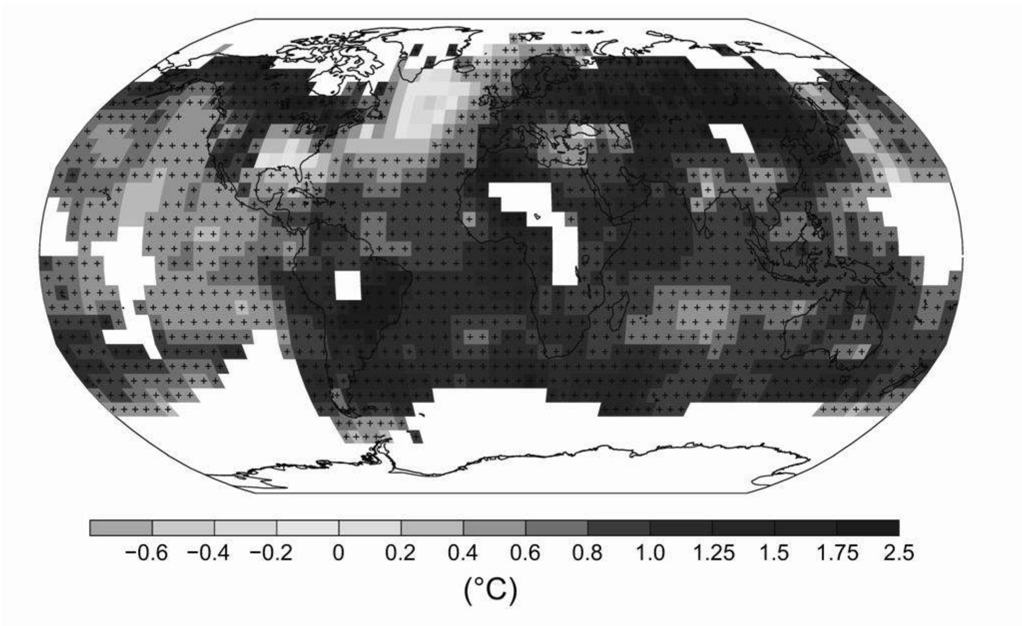

Fig. 1 – Map of the observed surface temperature change from 1901 to 2012 derived from temperature trends determined by linear regression from one dataset. Trends have been calculated only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period. Other areas are white. Grid boxes where the trend is significant at the 10% level are indicated by a + sign. (Simplified from IPCC 2013).

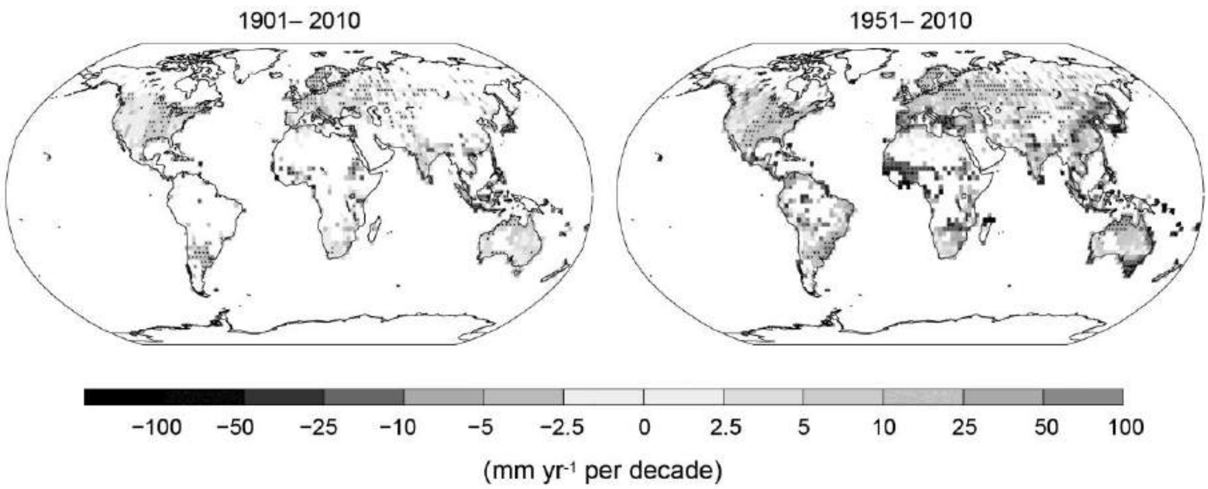

Fig. 2 – Maps of observed precipitation change from 1901 to 2010 and from 1951 to 2010 (trends in annual accumulation calculated using the same criteria as in Fig. 1). (Simplified from IPCC 2013).

[59] THE EFFECTS OF AN INFILTRATION BASIN ON GROUNDWATER: QUANTITATIVE ASPECTS (RIVER ARNO - LONATE POZZOLO - VA)

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Keywords: infiltration, recharge, vadose zone, infiltration basin, Ticino

Introduction

The main issue of this work is an hydrogeological characterization of an infiltration basin located in Lonate Pozzolo (VA) along the shaft of the Arno river (Fig. 1). The basin was built in 2000 in order to mitigate the flood risk. The bottom of the basin was dredged in 2011 due to a clogging phenomenon (IRER 2009; 2010). The evaluation of the hydrogeological implications and of hydraulic efficiency in the period of analysis is the main target of this work.

Fig. 1 – Geographical position of the infiltration basin (Lonate Pozzolo - Va).

Methods and results

Potentiometric levels have been monitored starting, on a hourly bases, from 2009 in two piezometers located up and downgradient respect to the infiltration basin (Pz1 and Pz3 in Fig. 2). The monitoring period covered both the situation of clogged basin (almost impermeable bottom conditions) and after the bottom dredging (highly permeable conditions).

In the same period, rainfall has been monitored through three different gauges stations surrounding the basin.

The basin is located in an area characterized by a surficial aquifer with a high transmissivity, about 1×10^{-2} m^2/s. Depth to water is about 30 m. The first period of monitoring confirmed the high hydraulic conductivity of gravel and sand composing the aquifer. By comparing rainfalls and potentiometric responses, recharge time has been estimated in the order of 36-40 hours.

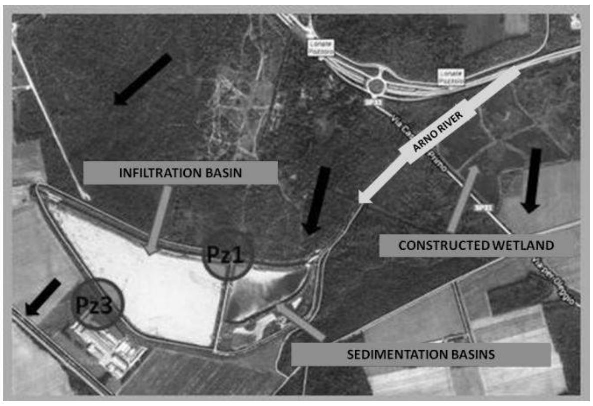

Fig. 2 – Satellite image indicating the location of the hydraulic plants; black arrows show the direction of groundwater flow.

The Water Table Fluctuations (WTF) method and infiltration modeling have been chosen to perform the first estimation of recharge amount (Scanlon et al. 2002; Delin et al. 2006). WTF provides an estimate of groundwater recharge by analysis of water-level fluctuations in observation wells and here it has been used in order to quantify the increment of recharge due to the infiltration (U.S.G.S. 2002; Healy and Cook 2002).

Table 1 shows the increase of recharge amount after bottom dredging. Percentage express the recharge amount related to rainfall amount.

GROUNDWATER RECHARGE	
Impermeable conditions	***Permeable conditions***
15 %	***700 %***

Tab. 1 – Results of estimation of groundwater recharge (WTF method).

The results obtained by the application of the WTF method have demonstrated the strong influence of the basin on the aquifer. A water-permeable bottom gives a groundwater recharge fifty-times higher compared to the case of clogged bottom. Values higher than 100% clearly indicate the effect of local recharge of the basin which acts as a sort of area of concentrated and augmented recharge for the surficial aquifer.

Infiltration modeling has then been implemented with a numerical model software based on Finite Element Method (SEEP/W).

The model allows to analyze both partial and complete saturation soil conditions. In this work it has been used to enhance the knowledge of infiltration dynamics.

Infiltration modeling has been carried on in two phase: calibration at impermeable conditions and sensitivity analysis in permeable conditions. The calibration has been realized by comparing calculated and measured data in order to find out the most reliable value for saturated hydraulic conductivity (2.52×10^{-4} m/s) of soil composing the surficial aquifer. A sensitivity analysis has been performed for the permeable bottom case in order to analyze different scenarios with different boundary conditions (Fig. 3).

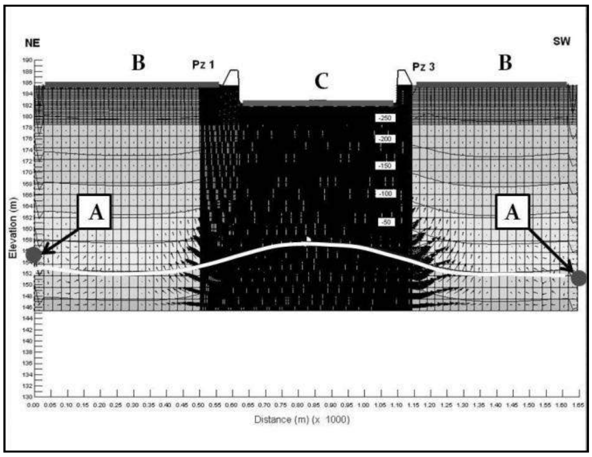

Fig. 3 – Sketch of the results of numerical modeling A- initial piezometric level; B- rainfall; C- hydraulic head at the basin bottom. The white line represents the groundwater level at peak time.

Conclusions

The five years monitoring results and numerical modeling have shown the great impact that an infiltration basin can have on aquifer recharge. When an infiltration basin is completely active it can locally increase recharge amount more than fifty times respect natural conditions. An estimation derived from numerical modeling has given that in ordinary rainfall events more than 1,000,000 m^3 can infiltrate from the basin to groundwater. Finally this aspect must accurately taken into account when considering the impact on groundwater quality. The good results achieved through numerical modeling could be used for further development in modeling mass transport.

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[60] MULTIDISCIPLINARY APPROACH ON HYDROGEOLOGY OF CARBONATE AQUIFERS OF CENTRAL APENNINES FOR EVALUATING OF THE INFLUENCE OF METEORIC RECHARGE

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Keywords: karst aquifers, central Apennines, multidisciplinary approach, recharge

Introduction

The peculiarities of karst aquifers make them strategic resources for water sourcing (Bakalowicz 2005; Civita 2008; Doveri et al. 2013; Goldscheider and Drew 2007) which, however, are not easy to investigate because of difficulties due to the inadequacy of classical investigation methods together with their inaccessibility.

For this reason, a multidisciplinary study was carried out to compare, analyze and validate the results obtained by the different techniques of investigation. Final result is the characterization of fractured aquifers and of their baseflow, as well as the evaluation of the influence of the recharge variability on groundwater regime.

This study includes two areas of the central Apennines, representative of the Umbria-Marche and Lazio-Abruzzi geological domains.

The upper basin of Aso river is located in the south-eastern area of “Sibillini Mount National Park”, surrounded by some of the higher reliefs of Sibillini Mounts. Here the pelagic Mesozoic–Cenozoic Umbria-Marche succession outcrops, involved by the Olevano-Antrodoco-Monti Sibillini Thrust (Pierantoni et al. 2005) characterized by an asymmetric, east-verging anticline with box-fold geometry.

Groundwater of the Aso River has been evaluated between 1400 L/s (Boni et al. 2010; Nanni et al. 2010) and 1800 L/s (Mastrorillo et al. 2012); about 530 L/s of those (Foce spring) are tapped for drinking use by a tunnel drainage.

The Sagittario river is located in the Northern Montagna Grande (Eastern Marsica, Abruzzi) where the Cavuto spring group represents the main discharge of Basal aquifer, with an average flow rate of 1800 L/s (Boni and Ruisi 2005). Mesozoic and Cenozoic carbonate deposits, belonging to different palaeogeographic domains (from platform to slope-to-basin) represent the aquifer, in contact with synorogenic flysch deposits by significant tectonic lines predominantly N-S and NNW-SSE oriented.

Methods

The analysis and elaboration of geological-stratigraphic and structural data allowed to define the major regional carbonate aquifers, to locate structural elements affecting groundwater flow and to identify stratigraphic elements leading to the presence of local or regional flow.

The hydrogeological analysis is based on the direct measurements of discharge, on the baseflow recession analysis, on the evaluation of annual changes in piezometric levels and on the implementation of vertical log with Flowmeter. The results obtained have allowed to evaluate the flow rate and the seasonal and annual variability, also related to climate change, and the intrinsic characteristic of the aquifer systems; in addition, it was possible to determine vertical component of groundwater flow and to detect interactions with adjacent aquifers and to differentiate separate flow coming from shallow aquifers. The chemical and isotopic data were useful to individuate a sole circulation or to confirm the presence of separate groundwater flows. Furthermore, the isotopic data allowed to define the average elevation of recharge area of main springs, while the results of chemical analysis have provided information about the different circulation systems drained by nearby springs which have or not similar chemistry.

Finally, in the investigated areas, the detailed analysis of temperature, rainfall and snow data (in terms of thickness variation of snowpack or amount felt on the ground) and, then, of Effective Rainfall, allowed to shed lights on the meteoric inflows and its relations with the variability of the groundwater regime.

Aso River Valley

The total amount of base flow of the Aso River in 2009-2012 has been evaluated in about 1900 L/s, ranging between about 2200 and 1500 L/s. The hydrogeological and geochemical approach made it possible to distinguish three regional groundwater flows inside the “Basal”, “Maiolica” and “Scaglia calcarea” aquifers. The flow of the river mainly supported by Foce and linear springs of the Basal aquifer (more than 70%), whose recharge area has been evaluated in about 40 km^2 by geological-tectonic and isotopic results: drainage occurs mainly in a direction NNW-SSE, from South to North.

Shallow alluvial-detritic aquifer of “Gardosa Plain”, connected with Basal aquifer, supplies the spring of Aso and Foce lake: in the wetter

years, when the rise of the groundwater table feeds a flowpath from Basal to shallow aquifer. Isotopic data confirmed the recharge area, evidencing differences between Basal and perched aquifers and related springs.
Recharge of the Basal aquifer is due to melting snows and subordinately to rainfall: the delay between the beginning of the snowmelt and discharge increase was estimated on about one month. The baseflow recession analysis shown that the Aso river is fed by Basal groundwater flow of SE part of the Sibillini Mountains.
Maiolica and “Scaglia calcarea” aquifers also contribute to the discharge of Aso river with, respectively, 240 L/s and 290 L/s (referred to the 2009-2012 period): the recharge areas outcrop northwards and their extension depends on the variation of meteoric inflow.
Influence of the snow on the recharge of aquifers of Sibillini has also been confirmed by the negative rainfall gradient (-41,3 mm/100 mt), because as the altitude increases the rains are replaced by snow, and by a coefficient of Lauscher over 50% above 1300 meters asl.
The Effective Infiltration has a great variability depending on the areal extension, the local relief and annual climatic variations: the mean value for 2008-2012 period is about 1020 mm/year, ranging between 630 and above 1400 mm/year. The water budget has provided a mean net infiltration of 990 mm/year, ranging between 735 and 1220 mm/year, comparable with those obtained from the analysis of climate data.

Sagittario River Valley

Measurements of discharge in the Sagittario river were carried out in 2009-2010, between San Domenico dam and Cavuto spring group, where the flow rate is strongly influenced by the presence of hydrodiversion. In fact, the volumes of water released immediately and about 1,5 km downstream of the dam, evaluated in about 50 and 320 L/s, move through the soil surface into the ground, leaving partly the riverbed dry. The Cavuto spring group, whose average base flow in 2009-2010 has been evaluated in 1860 L/s, is fed both by meteoric recharge due to rainfalls and snow, but also by approximately 225 L/s of groundwater that infiltrate directly into the riverbed. The baseflow recession analysis shown that α increases with time ($\alpha_2>\alpha_1$): this has been interpreted as temporarily flooded caves in the northern karst region.
Indeed, analysis of climatic data referred to 2002-2012, returned a wide range of effective rainfall with an average value of about 670 mm/year; instead, for 2009-2010 the average value is 925 mm/year, reflecting that these two years have been characterized by particularly high recharge rate. In addition, the water budget carried out by assuming an area of 53 km^2, identified on the basis of geological-structural setting, allowed to determine an average value of Effective Infiltration for the 2009-2010 of almost 970 mm/year, very close to that calculated by the “Indirect Method”.

Conclusions

The study conducted in the carbonate basins of the rivers Aso and Sagittario, showed that this approach made it possible the analysis and validation of the results obtained by the different techniques of investigation. In particular, the detailed evaluation of the annual and multiannual range of the “Effective Rainfall”, is essential for validating the Conceptual Hydrogeological Models by comparing different budget analysis methods.

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[61] THE SID&GRID MODELING ENVIRONMENT FOR SIMULATING GROUNDWATER FLOW: CASE STUDIES

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Keywords: SID&GRID, hydrological modeling, groundwater modeling

Introduction

During the last decade several regulations recommended the implementation of innovative technologies to manage water resources. In the meantime, nowadays a huge amount of hydrological variables are monitored, but still widespread semi-quantitative or analytical approaches reduce the content of information that might be derived from such data. Physically-based and distributed hydrological models may constitute a comprehensive and dynamic tool as: i) they assimilate the available data in a single picture; ii) they can be improved as new data are gathered; iii) they provide information in space and time to water managers; iv) they allow to evaluate several kind of impacts by means of scenario simulations.

GIS's being able to store, manage/analyze and visualize large spatial datasets are perfect candidates for advancing and facilitating the widespread use of modeling environments. However, currently the integration between GIS and hydrological modeling is mainly achieved through files exchange between the two systems. Such a procedure increases model setup and analysis time and causes data isolation, data integrity problems and broken data flows between models and the pre- and post-processing environment.

The above-mentioned background motivates the need for developing coupled GIS and hydrological modeling environments, as the SID&GRID tight-coupled GIS hydrological model, based on open source and public domain codes, in order to pre-process data, to run simulations and to analyze results (Rossetto et al. 2010). The code is now freely available along with a dedicated manual and tutorials at the web page: http://sidgrid.isti.cnr.it

Case studies

A series of case studies were developed by authorities and companies involved in the project, on order to test and evaluate the application of SID&GRID on real world problems. ARPAT and Regione Toscana tested the code functionalities developing a model for a contaminated site: a comparison with results obtained by benchmark commercial software was also provided (Fig. 1). The good agreement proves that input data for MODFLOW code are equivalently written by SID&GRID and commercial platform. ASA SpA converted an existing groundwater flow model, also developed in a commercial GUI, of a coastal plain in the Province of Livorno (Fig. 2). Ingegnerie Toscane srl, along with Studi Associato Georisorse, implemented a groundwater flow model for the Empoli alluvial plain (Fig. 3). Autorità di Bacino del Fiume Serchio, Autorità di Bacino del Fiume Arno and Provincia di Lucca collaborated with the scientific partners of the project (Scuola Superiore Sant'Anna, Università degli Studi di Firenze and ISTI-CNR) to implement a groundwater flow model of the Lucca plain (Fig. 4).

Results of the above-mentioned case studies demonstrate the reliability and flexibility of such modeling environment and the possibility to use it among governing authorities, agencies and water utilities as a common framework for the management of the groundwater resource.

Acknowledgements

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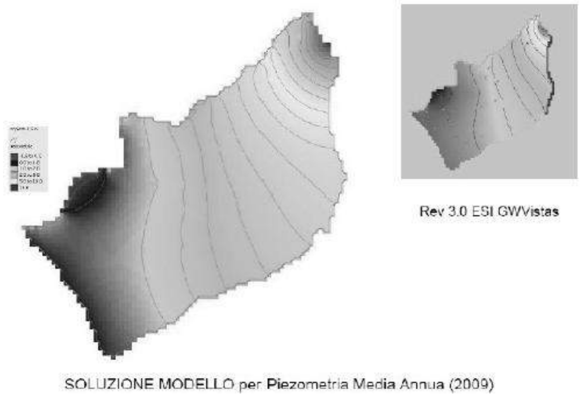

Fig. 1 – SID&GRID vs. commercial one simulation results in ARPAT and Regione Toscana test case.

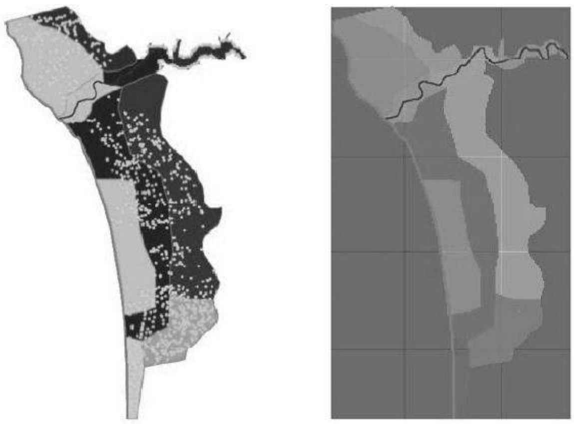

Fig. 2 - Polygon import for assigning hydraulic properties in the ASA spa model.

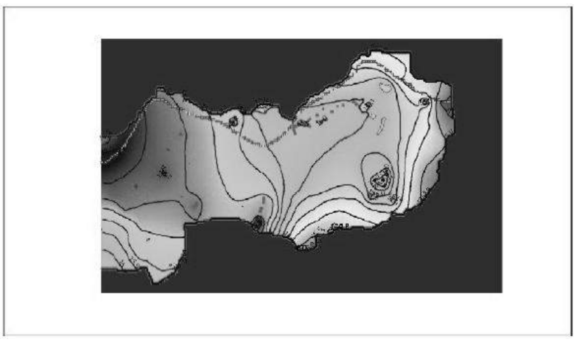

Fig. 3 – Empoli aquifer steady state groundwater flow (Georisorse and Ingegnerie toscane case study).

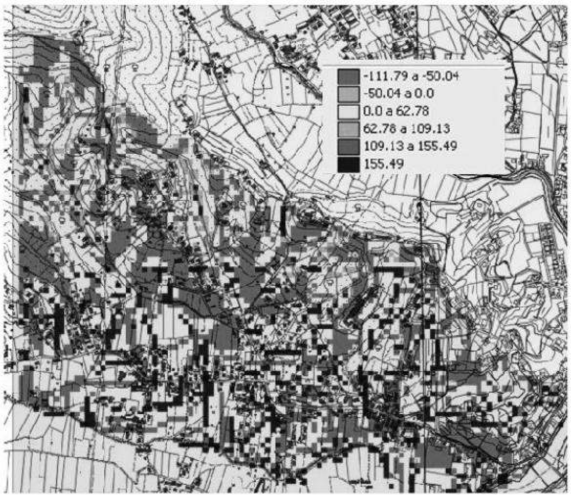

Fig. 4 - Simulated run-off on Lucca hills during a storm event.

[62] CHARACTERIZATION OF SUBSURFACE THROUGH JOINT HYDROGEOLOGICAL AND HYDROGEOPHYSICAL MODELS

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Keywords: heterogeneity, hydrogeophysics, geoelectrical prospecting, mathematical modeling, joint inversion.

Introduction

The characterization of the subsurface heterogeneity and the monitoring of the dynamics of groundwater are of paramount importance for protection of groundwater quality, design and check of the effectiveness of remediation plans. Invasive direct tools, mostly based on the drilling of piezometers and boreholes, geotechnical and geognostic surveys often provide information with accurate vertical resolution, but require horizontal interpolation or correlation. Hydrogeophysics provides a useful complementary technique, both for hydrostratigraphic characterization and for monitoring. Some attempts of joint inversion of geophysical and hydraulic data have been proposed (Fowler and Moysey 2011; Hinnel et al. 2010; Jardani et al. 2013; Lochbuehler et al. 2013; Pollok and Cirpka 2010; Straface et al. 2011). The goal of this paper is to describe an interpretative tool that profits from DC geoelectrical and hydraulic collected data, which are used in a joint modeling of hydrogeological and geophysical processes for the application of an approach similar to the Kalman filter (Kalman 1960; Evensen 2009).

Methods

The subsurface is considered as subdivided into regions occupied by geological materials, that we call hydro-geo-facies, HGF, as they share the same geoelectrical and hydrodynamic characteristics. In particular electrical resistivity and hydraulic conductivity are related to texture, soil saturation and pore water conductivity, by phenomenological laws that include specific parameters (Archie,1942; Slater, 2007)

The spatial distribution of HGFs could be estimated starting from a collection of lithological data (e.g., boreholes), possibly with a stochastic simulation that permits to obtain an ensemble of equiprobable realizations. On the other hand soil saturation distribution can be obtained by hydrological measurements. From this information, hydraulic conductivity and electrical resistivity fields could be reconstructed.

Two original computer codes, both based on conservative finite differences schemes, have been developed to solve the hydrological (YAGMOD) and the geoelectrical (YAELMOD) forward problems.

A straightforward use of these models is a Monte-Carlo approach, where different sets of parameters for the phenomenological laws are tested and a ranking of these sets can be obtained from the comparison of model forecast and measured data.

A more advanced interpretative tool applies an iterative procedure that repeatedly solves the hydraulic and electrical forward problem for different stress condition of the aquifer, as a basic step to match experimental data with model outcomes. The estimated HGF parameters are modified at each step, by the application of an approach based on the Kalman filter.

Discussion and conclusions

The specific goal of this presentation is to assess the sensitivity of some of the model features on the results and on the capability of the interpretative tool. As an example, Figure 1 shows the comparison between the results obtained from two different simulations. The geometrical and physical characteristics of the simulation correspond to those of a well field 20 km east of Milan; the HGFs distribution has been reconstructed from lithostratigraphic logs with SISIM, by using SGEMS (Remy et al. 2009). Then two forward hydraulic problems have been solved with different boundary conditions (BCs): (1) (Dirichlet BCs) linearly varying prescribed hydraulic head along the vertical borders; (2) (mixed BCs) prescribed head at the vertical planes orthogonal to the *x* direction and no flow for the vertical planes orthogonal to the *y* direction. The BCs for the hydraulic problem substantially affect the hydraulic head, whereas they have a minor influence on the apparent resistivity for a dipole-dipole array. This is a very important issue, in order to evaluate whether the tool can be applied and can be useful for water resources management in a sustainable development.

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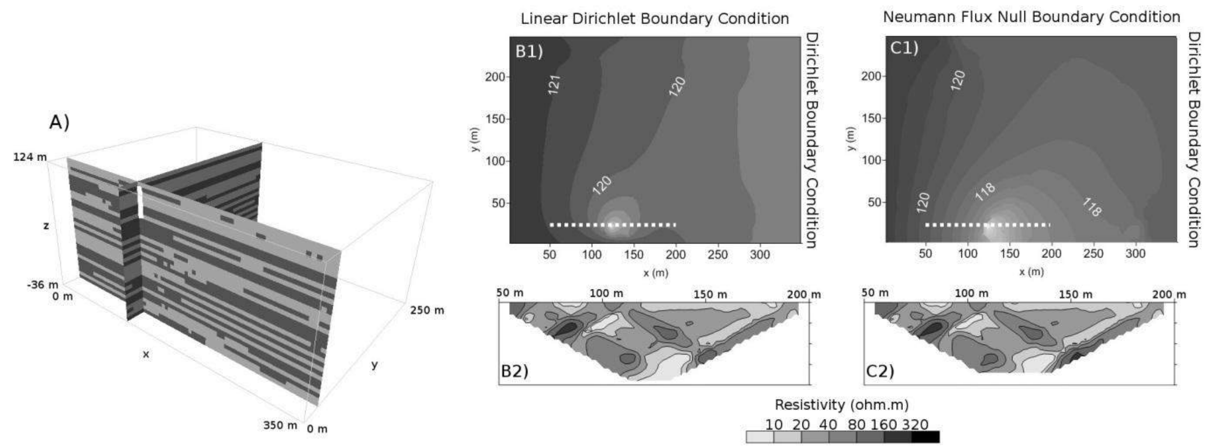

Fig. 1 - Comparison of two different simulations. A) Geometry of the volume domain: the distribution of HGFs (fine material in light grey, coarse material in dark grey) is shown on two vertical sections, crossing at the pumping well position (white vertical bar). B) Results for the first simulation (Dirichlet BCs): B1) Elevation (in meters) of the water table (contour interval 0.5 m); B2) pseudo-section of apparent resistivity along the section indicated by the white dotted line in plot B1. C) Results for the second simulation (mixed BCs): C1) Elevation (in meters) of the water table (contour interval 0.5 m); C2) pseudo-section of apparent resistivity along the section indicated by the white dotted line in plot C1.

[63] STATISTICAL ANALYSIS OF RAINFALL, RIVER HEAD AND PIEZOMETRIC LEVEL DATA OF CENTRAL-ADRIATIC ALLUVIAL AQUIFERS

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Keywords: auto-crosscorrelation, spectral analysis, rainfall, river head, piezometric level.

Introduction

The statistical and hydrogeological analysis of the relationships between rainfall, river and piezometric level historical data can be useful to characterize the aquifers and to manage the groundwater resources. For this purpose measurements acquired every three days, relative to 1986-2009 period, concerning the Pescara river alluvial plain (Fig. 1), were analyzed with several statistical methods. The alluvial bodies of the Pescara river (Desiderio et al. 2001) is mainly silty-sandy. The plain aquifer is supported by Plio-Pleistocenic clayey deposits. The three wells (Fig. 2) are located in the medium-low alluvial plain. Autocorrelation and spectral univariate analysis, cross-correlation and bivariate spectral analysis have been implemented with the purpose to evaluate memory effect, the delay of the piezometric level response to rainfall and river head/discharge impulse, and the periodical components of the time series (Mangin, 1984; Larocque et al. 1998; Polemio and Dragone 1999).

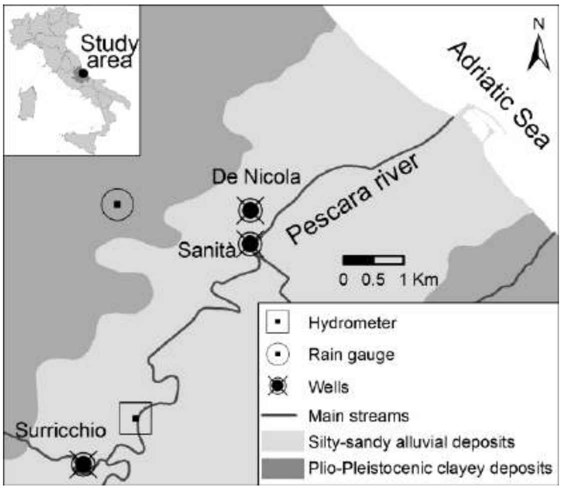

Fig.1 – Schematic geological setting of the study area and sites location.

Materials and methods

Rainfall, river and piezometric level data are due to the courtesy of Hydrologic Service of Abruzzo Region. The wells are characterized by a low - very low depth of the water table. In Fig. 3 behavior differences between piezometric level diagrams of the three selected wells are visible: in Surricchio diagram is self-evident the presence of a multi-year periodical cycle; the seasonal periodic structure describing the dry-wet season alternation can be observed in Sanità and De Nicola diagrams. River and rainfall data of Pescara Santa Teresa and Spoltore sites show that apparently the variability is mainly due to the seasonal effect.

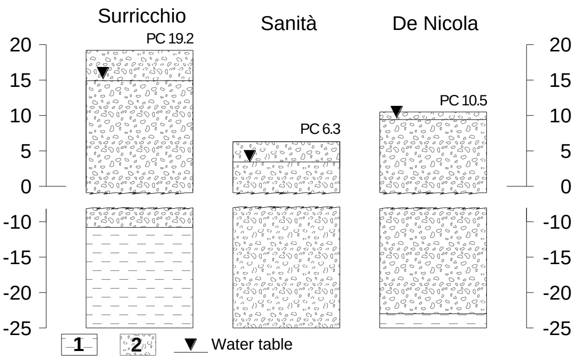

Fig. 2 - Schematic hydrogeological settings of observed wells (1. Plio-Pleistocenic clayey deposits, 2. Silty-sandy alluvial deposits).

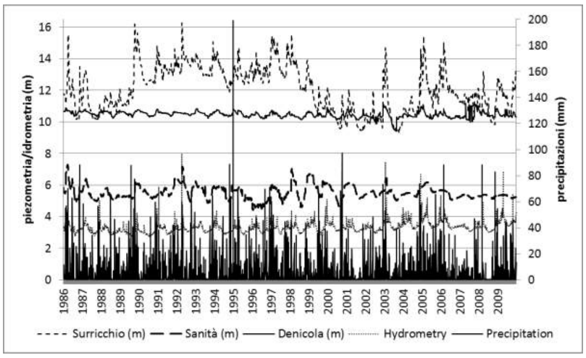

Fig. 3 – Rainfall, river and piezometric level diagram from 1986 to 2009.

Piezometric level autocorrelation

In all sites it is possible to point out that the daily piezometric level depends strongly from the level of the previous day. Especially the correlogram of Surricchio well shows the lowest gradient, reaching the decorrelation threshold value (Auto Correlation Function = 0.2) after more than 180 days. It means that this site is characterized by a longer "memory effect" respect to De Nicola and Sanità sites (Fig. 4).

Rainfall-piezometric level cross-correlation

In all sites the response time, “lag”, of the piezometric level to the rainfall impulse is weakly correlated (Fig. 5).

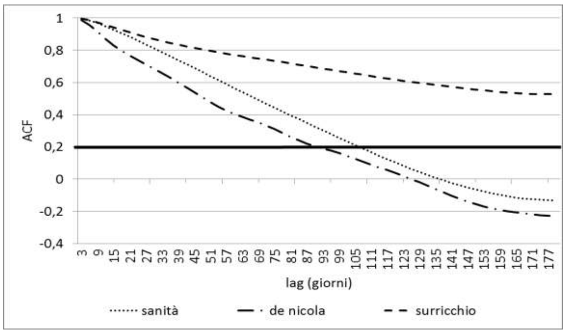

Fig. 4 – Autocorrelation results for the time series of Sanità, De Nicola and Surricchio wells.

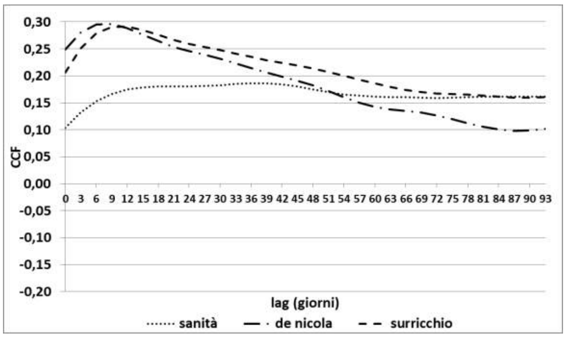

Fig. 5 – Cross-correlation rainfall-piezometric level.

Surricchio and De Nicola have a similar behavior and strongest maximum cross-correlation coefficient (0.29). They present a quick response to rainfall (12 and 9 days respectively). Sanità well has the weakest maximum CCF (0.18) and the curve form describes a site with a gradual response (18-39 days) and longest outflow.

Hydro-piezometry cross-correlation

The response of piezometric level (Fig. 6) to the river head impulse is of 9 days for Sanità, 6 days for Surricchio and immediate for De Nicola (3 days); Sanità has the strongest CCF (0.45) with a long-time descendent gradient. Surricchio and De Nicola site instead are characterized by weaker maximum cross-correlation (0.21 and 0.29) and a more rapid return to initial conditions (60 days).

Univariate and bivariate spectral analysis

Spectral densities of rainfall, river head and piezometric level present a peak in correspondence of f=0.0083, confirming the existence of the annual cycle. River time series points out the existence of a second spectrum peak in correspondence of f=0.00134 detecting a six-year periodicity; also Surricchio and Sanità wells show, in addition to the annual cycle, a 12-year and a 6-year long periodicity.

The bivariate spectral analysis, expressed by the cross-amplitude function, also identifies for the two wells the 12 and 6 years multy-year repetition behavior. These periodicities can now be better focused also in the raw data graph represented in Fig. 3.

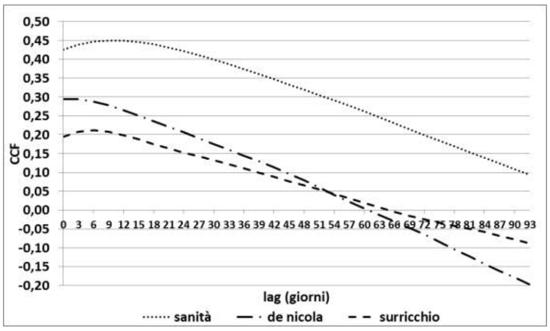

Fig.6 – Cross-correlation river head-piezometric level.

Preliminary considerations

Piezometric level and river head data show a strong memory effect with similar decreasing autocorrelation; cross correlations give us the chance to point when the “rainfall input” affects less the “piezometric level output” than the “river input” that reaches the wells trough the underground aquifer system inducing its fluctuation. The spectral analysis of all parameters identifies the presence of the annual cycle and it detects also multy-year periodicity. The studied groundwater resources are also influenced by the hydrometry behavior of the close Pescara river. The deepening of the hydrogeological framework will permit to verify these purely preliminary statistical considerations to proceed eventually to their validation. The used methodology for the Pescara river alluvial plain is being used for other central-Adriatic aquifers.

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[64] THE WBT METHOD: WATER BALANCE APPROACH TO ESTIMATE LONG-TERM WATER INFLOW INTO TUNNELS

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Keywords: water balance, water inflow into tunnel, effective infiltration

Introduction

In underground projects estimation of expected water inflow during and after construction is always requested. An estimation of this value is usually given by analytical approach (Goodman et al. 1965; El Tani 2003; Perrochet and Dematteis 2007; Preisig et al. 2013) and/or numerical calculations (Anagnostou 1995; Molinero et al. 2002; Zangerl et al. 2003), considering hydrodynamic parameters of the rock mass such as permeability, water head, and storage coefficient. The knowledge on those parameters is very often poor along the tunnel alignment, because of the little number of boreholes and hydraulic tests. The geological complexity, and depth of the tunnel, increase uncertainty on the distribution of the hydrodynamic parameters. In those cases the estimation of water inflow should always be verified by an inverse hydrological water balance. The hydrological water balance could be described by the relationship I=P-R-ETR, where I is the infiltration, P the rainfall or snow melting, R the runoff, and ETR the evapotranspiration. The calculation of the infiltration amount in the basins overlying the tunnel allows to obtain a rough estimation of theoretical maximum water inflow. The runoff is obtained from hydrological measurements in waterways, or can be indirectly estimated considering the parameters of the basins conditions at surface such as the energy of the slope, rock exposure, land use and type of vegetation. The influences of both geological and structural underground conditions, although it can significantly affect this value, are not taken into account in the inverse hydrological water balance.

The present work proposes a new classification method called WBT (Water Balance approach to estimate long-term water inflow into Tunnels). The WBT method integrates classical hydrological water balance with geological, structural and spatial-geometric parameters of the massif crossed by the tunnel. The result is the estimation of the long-term groundwater inflow into tunnel.

Main Body

WBT method consists in:

a. define the hydrogeological basins overlying the tunnel;
b. carry out the hydrological water balance in each basin, to obtain the average annual effective infiltration on the whole area of the basin under passed by the tunnel, expressed in m^3/s;
c. subdivide the tunnel in sectors. Each sector is the projection of the basin limits on the tunnel alignment in plan;
d. assign to each sector a rating from 0.5 to 3 according to geological underground conditions, as defined in Table 1 (overburden, permeability, high permeability channels, sector length, basin area);
e. summarize, for each sector, the contribution of each parameters of Table 1, to obtain the WBT rating. The WBT rating is further classified in Table 2 to define the reduction of effective infiltration. The reduction range indicated in Table 2 is estimated, and will be refined with the calibration on real data, still in progress;
f. apply to each sector the reduction indicated in Table 2 to the average annual effective infiltration calculated at point b). This is the long-term water inflow estimation into the tunnel according to WBT method.

WBR rating	Contribution of effective infiltration to the tunnel	Reduction of the water balance effective infiltration value
4-6	Low	40-70%
6,5-9	Good	10-40%
9,5-12	Very good	0-10%

Tab.2 – Reduction of water balance effective infiltration value depending on WBT.

The method has been implemented and is being validated in an ongoing twin tube excavation (8 km each tube) in the Chilean Andes.

In the first 2.5 km, 3 out of 16 identified hydrological sectors were crossed. For these three sectors, the calculated WBT rating ranged from 7 to 7.5, so, to estimate the expected long-term inflow into the tunnel, was applied the 20% reduction on the infiltration value of the hydro geological balance. Therefore, from an initial infiltration value of 110-120 L/s, a stabilized inflow value of 88-96 L/s after the application of

the reductions according with WBT ratings was obtained. Those results are under control and verification by means of monitoring the groundwater inflow discharge into tunnel. This will allow the calibration. Currently, the flow rate recorded in the tunnel for these three sectors, is equal to 90-95 L/s.
The first results of WBT application demonstrate a good response. The quickly application and the ease of retrieval and control of the input data, makes WBT an interesting and innovative method, which complements and improves the hydrogeological studies applied in tunneling. WBT should be understood as a complementary method to classical analytical and numerical approaches. In order to check and verify by a different way the forecast of water inflow into tunnels.

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PARAMETERS DEFINITION	EFFECTIVE INFILTRATION RATING		
1) Overburden The greater is the overburden, the lower is the contribution of effective infiltration to the tunnel	High > 500m	Medium 100 to 500 m	Low <100m
Rating	*1*	*2*	*3*
2) Permeability The lower is the mean permeability of the massif, the lower is the contribution of effective infiltration to the tunnel	Very low to Medium	Medium to High	High to very High
Rating	*1*	*2*	*3*
3) High permeability channels Fault zone, main joint, karstic layer connecting the surface with the tunnel, increases the contribution of effective infiltration to the tunnel	No fault zone or karst	Minor fault zones or main joints	Major fault zone, master joints and/or karstic terrains
Rating	*1*	*2*	*3*
4) Sector lenght The longher is the lenght of the sector (projection of the basin limits on the tunnel alignment in plan), the the bigger is the potential of inflow into the tunnel	< 50 m	50 to 500 m	> 500 m
Rating	*0,5*	*1*	*1,5*
5) Basin area If the tunnel has an elevation higher than the lower point of the basin, then the bigger is the percent of the upper area of the basin, the higher is the contribution of effective infiltration to the tunnel	Low rate (< 30%)	Low rate (30% to 60%)	High rate (> 60%)
Rating	*0,5*	*1*	*1,5*

Tab.1 – Classification parameters affecting the contribution of effective infiltration to the tunnel and WBT ratings.

[65] DETAILED GEOLOGICAL CHARACTERIZATION TO DEFINE GROUDWATER FLOW IN GOLE DI POPOLI (CENTRAL EASTERN APENNINE)

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Keywords: Gole di Popoli, groundwater flow, groundwater/surface-water relations.

Introduction

In this work geological and hydrogeological framework of Gole di Popoli, in the central eastern Apennine (Abruzzo), was reconstructed in detail.
The study area is located into the Morrone hydrostructure (Conese et al. 2000). In this sector, very important and hydrogeologically complex carbonate and alluvial aquifers are present (Massoli-Novelli et al. 1998; Rusi 2007). Furthermore, there are high and constant discharge streams, hydroelectric establishments, national roads and railroads, an important industrial area and a polluted site of national interest (SIN).
The purpose of this work was to identify groundwater flowpaths in order to define different aquifers and understand the relations between groundwater, surface-water and rainfall recharge.

Materials and methods

An accurate geological interpretation was performed by means of boreholes and Vertical Electrical Survey (VES) that allowed to elaborate 32 hydrogeological cross sections.
At the same time, a groundwater level survey was performed twice a week for about 4 years in 19 monitoring points. A total of 84 surveys were executed.
The measured hydraulic head fluctuations were related to hydrometric daily data of Pescara River and to daily rainfall data of Bussi Officine rain gauge, in the 2008 - 2013 period.
In addition, multiparametric logs were performed in some of the monitoring points in order to evaluate the chemico-physical parameters (T, EC, pH, Eh) of groundwater.

Results

The Gole di Popoli are a deep gorge into the Morrone carbonate structure, filled up with 100 meters of Quaternary continental deposits.
From bottom to top, they consist of heterometric gravels from surrounding slopes, travertine deposits, later eroded and filled up with silty clayey lacustrine deposits. Locally, gravelly sandy alluvial deposits are found.

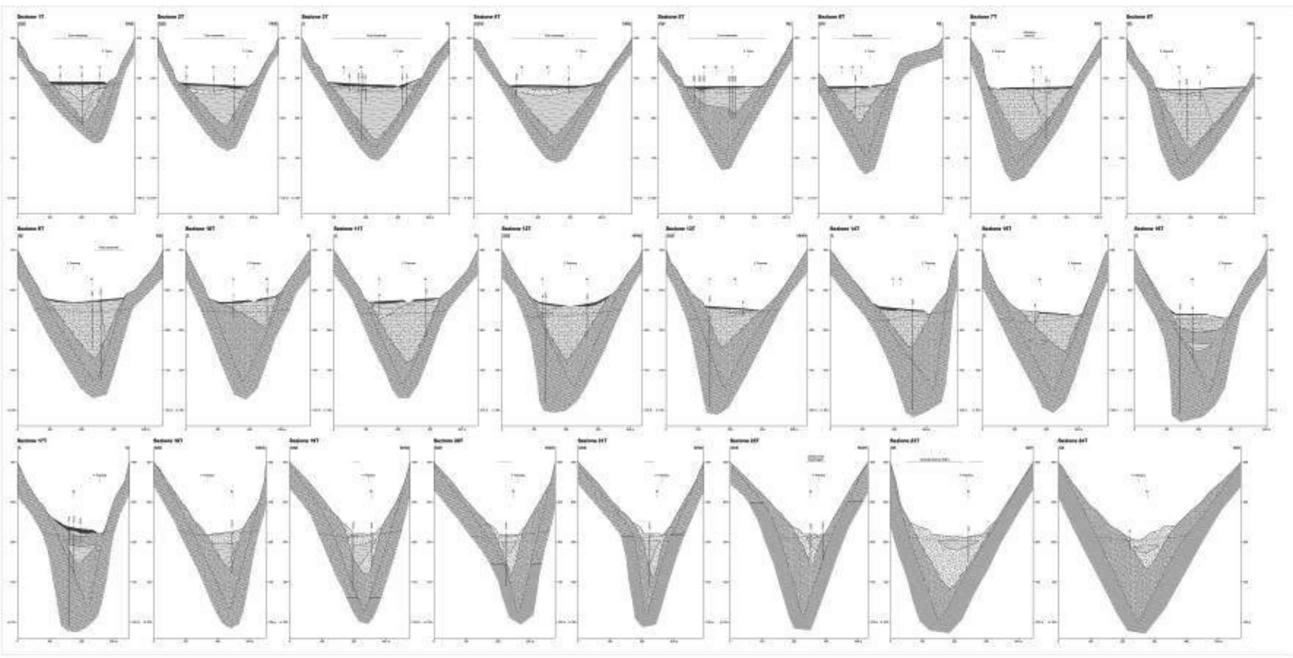

Fig. 1 - Hydrogeological cross sections' miniatures of Gole di Popoli (vertical exaggeration 2.5 X).

Moving downstream, heterometric gravels and gravelly sandy alluvial deposits become prevalent; they lie on a calcareous and/or clayey marly bedrock (Fig. 1).
The analysis of hydraulic head fluctuations compared with others hydrological parameters (hydrometric and rainfall data) and the knowledge of piezometers' stratigraphy and completion allowed to identify different groups of monitoring points characterized by a homogeneous behavior.
The first group, filtering in correspondence of heterometric gravels and fractured limestone, highlights a direct connection between the Morrone carbonate aquifer and the Quaternary continental deposits aquifer.
There is a strong correlation between the hydraulic head peaks and Pescara river exceptional flood events. These peaks can be explained by a hydraulic connection between groundwater and surface-water (Fig. 2). The correlation with rainfall is less evident (Fig. 3).

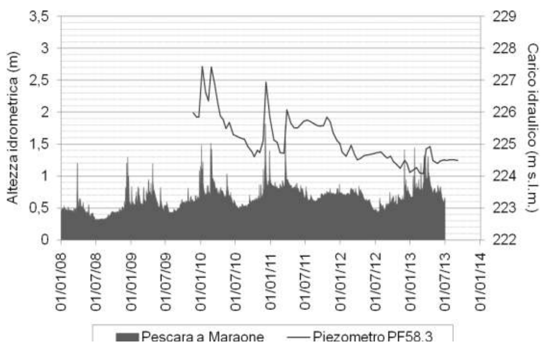

Fig. 2 - Comparison between PF58.3 hydraulic head and Pescara river hydrometric fluctuations.

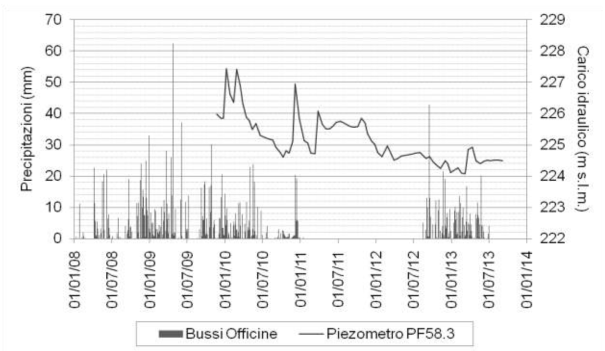

Fig. 3 - Comparison between PF58.3 hydraulic head fluctuation and Bussi Officine rain gauge daily rainfall data.

The hydraulic head trend of the second group is strictly comparable with Pescara River hydrometric fluctuations.
Stratigraphy in this monitoring points group is characterized by gravelly sandy alluvial deposits, that allows to suppose that a shallow alluvial aquifer is present.
The third group is composed by monitoring points installed in silty clayey lacustrine deposits. They show hydraulic head fluctuations comparable with daily rainfall trend, that highlights a fast recharge by rainfall.
Chemico-physical parameters measured by multiparametric logs, performed in one of these monitoring points, show a very high electrical conductivity values (approximately 3000 µS/cm) indicating slow flow.
Contrariwise, the parameters measured in the first group of monitoring points are typical of carbonate aquifers (Desiderio et al. 2010).

Conclusions
The detailed reconstruction of hydrogeological framework by means of available data allowed to individuate 3 different groundwater flowpaths: the first one is related to a Quaternary continental deposits aquifer supplied by the Morrone hydrostructure, occasionally hydraulically connected with Pescara River; the second one is a shallow alluvial aquifer supplied by surface-waters; the last one is a slow flow aquifer in silty clayey lacustrine deposits quickly recharged by rainfall.

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[66] WATER SUPPLY AND ENVIRONMENTAL PROBLEMS IN RIVER HEADWATERS: THE CASE OF THE SOURCE AREA OF THE TIBER RIVER (CENTRAL ITALY)

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Keywords: Tiber river, hydrogeological budget, climate change, river headwaters.

Introduction

This work reports the results of a study of Mount Fumaiolo (1407 m asl). This hydrogeological system, covering an area of about 11 km^2, is the source area of the Tiber, Savio and Marecchia rivers (Fig. 1). The basin of the Tiber, ca. 17340 km^2, is the second largest river basin in Italy, while its average yearly discharge (ca. 240 m^3/s) is the third largest. Due to the Tiber river's highly irregular hydrological regimen, its basin is subject to frequent droughts and floods, and the Tiber constitute a real flooding hazard for the city of Rome. For these reasons the Tiber has been much studied, focusing on floods, droughts and large groundwater systems (cf. for example, Calenda et al. 2005; Di Matteo and Dragoni, 2006; Romano and Preziosi 2013; Barbetta et al. 2014). As far as we know, there are no recent studies focusing on the hydrogeological setup of the river source area, characterized by many small springs, among which the larger are connected to drinking water aqueducts. These springs, often not shown on official maps, feed small watercourses which, during dry periods, maintain particular habitats for amphibians. The springs are fed by small, perched aquifers, whose discharge is quite sensitive to climatic conditions: due to prolonged drought periods that have occurred in the central-northern Apennines in recent decades and to the exploitation of the main springs, the habitat of these amphibians is in danger, and their survival is endangered (Stagni et al. 2005). The Mount Fumaiolo plateau is a well defined hydrogeological unit, resting on very low permeability rocks. Thus, the points where groundwater flows out of the system are known, and the plateau is potentially very suitable for studies about continuous water balances. In this framework, the preliminary results here presented seem to be of some importance, also considering the ongoing climatic change (Dragoni 1998; Di Matteo et al. 2006; Di Matteo et al. 2013).

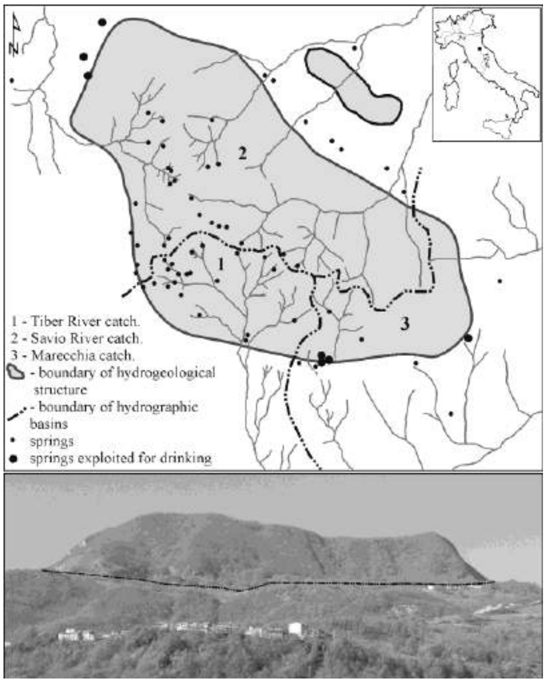

Fig. 1 – Map and panoramic view of the Mount Fumaiolo massif (photo taken from SSE). The plateau is made up of San Marino and Monte Fumaiolo formations, resting on low permeability formations.

Geological and Hydrogeological setup

The area is characterized by the outcropping of Epi-Ligurian units (Conti 1989): the Monte Fumaiolo FormatioN and the San Marino Formation, which are mainly composed of calcareous sandstones and marly-sandstones with medium to high permeability. The Epi-Ligurian units are deposited over the Ligurid nappes (Ricci Lucchi 1986), characterized by mudstone having low permeability. The main aquifer is hosted in Epi-Ligurian units which extend for about 11 km² (Fig. 1).

Hydrogeology

The hydrogeological system feeds about 50 springs, most of which have a mean annual discharge lower than 5 L/s (Maccari 2005). Considering the data available from aqueducts and a set of measurements in the 2004-2005 period, a groundwater mean total discharge of 175 L/s is estimated. In spite of the lack of continuous measurements of the small springs, a water budget was attempted considering storage variation to be nil (Tab. 1). The results, to be considered no more than a fair approximation, are consistent with the recharge and runoff values accepted for similar formations.

P (Precipitation, measured)	+1320	+1320
Etr (Evapotranspiration)	-530	-600
ΣQ (spring disch., measured)	-500	-500
R (surface runoff, as difference)	-290	-220
ΣQ/P	0.38	0.38
R/P	0.22	0.17

Tab. 1 - Water balance of Monte Fumaiolo. Figures are in mm and rounded off to 10 mm. ETR has been computed with the Turc and Thornthwaite methods (columns 2 and 3 respectively), obtaining similar results.

The depletion curves of the small springs, fed by small perched aquifers hosted in the heteropic Monte Fumaiolo formation, follow the Maillet equation. Interestingly enough, some of them show a variation of the depletion coefficient, which can be interpreted in terms of a reservoir feeding two springs located at different altitudes, according to the Chapman equation (1999) and to the findings of Cambi and Dragoni (2000).

Conclusions

In the present climatic situation, the Mt. Fumaiolo plateau produces about 175 L/s of high quality groundwater; of this quantity, about 120 L/s provide drinking water distributed by aqueducts. The other springs have a certain environmental importance, because they maintain humid habitats necessary for the survival of various endangered endemic species of amphibians. The issue of amphibian decline has aroused a strong interest in the recent years (Stagni et al. 2005; Larocque et al. 2013), and should be kept in mind in areas like the one here considered. Finally, the Mt. Fumaiolo plateau appears to be an excellent place for studying groundwater recharge processes and the depletion of springs in complex situations.

Acknowledgements

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[67] STEP DRAWDOWN TESTS AND SLUG TESTS: PERMEABILITY DISTRIBUTION IN AN AREA OF THE MIDDLE VENETIAN PLAIN (VENETO REGION, NORTHEAST ITALY)

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Keywords: Venetian plain, well test, step drawdown test, slug test, well performance test.

Introduction

This article presents the results of a hydrogeological investigation conducted near Scorzé (Treviso, Italy), where several step drawdown tests and slug tests were conducted to characterize a confined aquifer. The studied area, which covers 94,000 m^2 in the provinces of Venice, Treviso and Padua, is located in the middle Venetian plain (Fig. 1).

Fig. 1 – Veneto Region, with the study area circled.

The study area is characterized by the presence of a multi-layered aquifer system composed of ten confined aquifers ranging from 15 to 310 m in depth (Cambruzzi et al. 2010). In this system, permeable fluvio-glacial deposits are interbedded with marine layers of lower conductivity.

The investigations focused on the first confined aquifer, which is currently the most exploited by both public and private water companies. This aquifer is an alluvial gravel aquifer, with a thickness of approximately 30 m and a depth ranging from 15 to 60 m bgl. This aquifer is recharged from rainfall, irrigation and groundwater-river interactions at the large unconfined aquifer located in the high Venetian plain toward the N-NE. The groundwater flows from the recharge area to the sea, and the hydraulic head ranges from 24.8 to 7.3 m asl. Moving away from the recharge area, the first aquifer becomes progressively artesian, with the hydraulic head above ground during the year or periodically in the rainy season. This condition has favored extensive groundwater exploitation in the recent past, with more than one hundred wells for private supply drilled in the study area.

Materials and Methods

In November 2013, a well test program consisting of 4 step drawdown tests (SDTs) and 6 slug tests (STs) was conducted to evaluate the hydraulic conductivity (K) of the first confined aquifer. The SDTs were performed in private artesian wells, while the STs were carried out in private sub-artesian or non-artesian wells.

In the SDTs, the wells were pumped in four steps with an increase in discharge rate, with each step being approximately 10 minutes in duration. The calculated well performance equation allowed the linear aquifer loss to be distinguished from the quadratic well loss. Transmissivity values were estimated using the experimental relationship between the specific capacity (considering only aquifer loss) and the transmissivity developed in Fabbri and Piccinini (2013) and obtained under similar hydrogeological conditions.

The STs were performed through a sudden introduction/extraction of a known volume (slug) into/from the wells and subsequent measurement of the water level response. For each test, the procedure was repeated 3 times, and 6 recovery curves were obtained and elaborated. A metallic tube connected at the top of the well was used as a casing vertical extension in the sub-artesian wells to avoid water outflow. The results of the STs exhibit typical oscillatory (underdamped) responses due to the presence of inertial effects in the wells related to the presence of a high-K aquifer. Taking this into account, the ST data were analyzed by the solution proposed by Butler (1998) in the presence of an underdamped water-level response (Fig. 2).

ID well	Test	Type well	K (m/s)
16412	SDT	artesian	$4.8x10^{-4}$
20297	SDT	artesian	$8.5x10^{-4}$
20489	SDT	artesian	$1.6x10^{-3}$
20090	SDT	artesian	$1.3x10^{-4}$
16541	ST	sub-artesian	$2.7x10^{-3}$
new5	ST	non-artesian	$1.6x10^{-4}$
20535	ST	sub-artesian	$1.5x10^{-3}$
16166	ST	non-artesian	$3.0x10^{-3}$
21143	ST	sub-artesian	$2.0x10^{-4}$
6067	ST	non-artesian	$1.2x10^{-4}$

Tab. 1 – K values derived from the hydrogeological tests.

Results

The transmissivity values obtained from the SDTs varied from $2.8x10^{-3}$ m^2/s to $3.4x10^{-2}$ m^2/s; thus, the K values ranged from $1.3x10^{-4}$ m/s to $1.6x10^{-3}$ m/s (Tab. 1).

The hydraulic conductivities obtained from the STs varied between approximately $1.2x10^{-4}$ m/s and $3.0x10^{-3}$ m/s (Tab. 1).

The SDTs carried out in the artesian wells gave comparable results to those of the STs performed on the sub-artesian or non-artesian wells. They both ranged over one order of magnitude. These values are also comparable to those obtained by Cambruzzi et al. (2010), which were derived from pumping tests realized in two public supply wells screened in the first confined aquifer.

Conclusions

Slug tests offer a quick and inexpensive method to assess the hydraulic conductivity of the localized area surrounding an investigated well. The advantages of STs are a lower cost, as they require less equipment and manpower, and short test duration in permeable aquifers. However, STs cannot be performed in artesian wells, where the hydraulic head rises several meters above ground level. In such conditions, the well performance test offers an effective alternative method to estimate transmissivity as well as the hydraulic conductivity near the investigated well.

In this study, the results from both STs and SDTs performed in a confined aquifer in the middle Venetian plain were compared with each other and with those of pumping tests conducted in the same aquifer. The K values estimated from the STs and SDTs ranged over the same order of magnitude, from 10^{-4} to 10^{-3} m/s and were consistent with the values derived from pumping tests. Furthermore, STs and SDTs both constitute a useful tool for inferring the distribution of K values over a large area, where it can be difficult to perform a classical aquifer test.

The first confined aquifer represents one of the most important water resources in the provinces of Venice, Treviso and Padua. Our hydrogeological characterization confirms earlier results, demonstrating its high permeability and good lateral continuity.

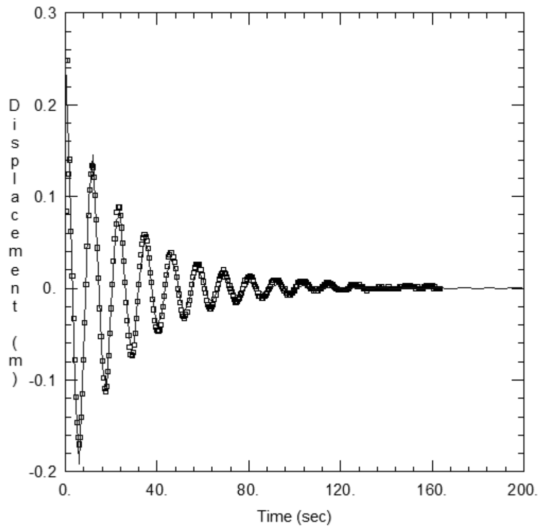

Fig. 2 – Type curve solution for a slug test in a gravel confined aquifer.

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Fabbri P, Piccinini L (2013), Assessing transmissivity from specific capacity in an alluvial aquifer in the middle Venetian plain (NE Italy). Water Science & Technology, 67(9): 2000-2008.

[68] RUNOFF VARIATION AS A CONSEQUENCE OF CLIMATE AND LAND-USE CHANGE IN THE PROVINCE OF PESARO-URBINO (MARCHE REGION, ITALY): IMPLICATIONS IN WATER RESOURCES MANAGEMENT AND RIVERS' ECOSYSTEM PROTECTION

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Keywords: net precipitation, runoff coefficient, minimum flow or DMV, carbonate aquifers, water management

Introduction

The paper presents the analysis of precipitation and temperature variations during the 1980-2010 period within the Province of Pesaro-Urbino and its effect on the water cycle, in terms of runoff and net infiltration changes. The aim is to develop a preliminary assessment of how runoff in the main catchments changed over the time, compared to a previous time-series (1950-69), representing the climate during a period of high socio-economic development, when most of the local water-supply infrastructures were designed and realized.

The assessment is meant to suggest up-to date criteria to public regulators, especially intended to set new minimum flow constraints to specific river sections (DMV: minimum flow need for ecosystem, required by law), where impact of surface water withdrawals are more evident.

Methods

Mean yearly evapotranspiration was calculated using different algorithms (i.e. Turc 1954; 1961; Schreiber 1904; Budyko 1958; 1974), while monthly analysis of water surplus was carried out by means of the Thornthwaite method. That helped to identify the regime variations of both input and output parameters of the soil water budget. As for the runoff, a preliminary comparison between the classical Kennessey method (Kennessey 1930) and the USDA Curve Number method, implemented on the WinHelp code (Waterloo Hydrologic) helped to indirectly asses the variations of average surface runoff; besides, it was possible to calculate the water budget of the main hydrogeological settings of real catchments and/or aquifers within the Province.

Due to the scarcity of updated hydrometric data, the comparison was limited to some recent river discharge measurements taken from Regione Marche, besides original measures performed by the authors (Farina and Severini 2013).

Results

The analysis highlights an average precipitation decrease of 11.7% between 1950-69 and 1980-2010 time series, calculated over the whole set of rain-gauge stations. The majority of stations in the mountain area show a precipitation decrease in the 12-21% range. The analysis also shows an average indirect runoff decrease of -33% between the two periods, estimated by the Kennessey method, depending to the Index of Aridity reduction (De Martonne 1926) and the expansion of forest land in the mountain area. Experimental data, although limited to the 2007-2010 period, show an important decrease of average year discharge in the Candigliano basin, (about - 40%) compared to the historical dataset (22 years 1924-1979 period). Analysis of the runoff regime in the Candigliano basin shows that most of the reduction, compared to the historical data available, occurs in late-autumm to winter months, and it is strongly related to high flow events typical of the water-surplus winter season (De Angelis 2006). Summer base-flow is less affected by the decrease, due to a significant groundwater discharge from the carbonatic aquifers outcropping in the same catchment (Boni et al. 1986).

Discussion

The decrease of average runoff is clearly related to the total and net precipitation reduction over the Province of Pesaro-Urbino. Nevertheless a significant influence of land-use variation in the mountain areas is deemed probable. The expansion of woodland observed during the past decades has a great influence on the formation of runoff, both regarding soil-water consumption during the dry season, and rainfall interception, both resulting in a significant runoff reduction. That is particularly evident in strongly sloping, less permeable catchments, particularly subject to erosion and runoff. The increase of woodland's water demand and consequent evapotranspiration also causes a decrease of net infiltration, especially in areas with deeper soils. On a year average, actual runoff reduction

isn't caused by water use, being water surplus much higher than water demand. Summer runoff depletion caused by withdrawals can be quite easily recognized in specific sectors of the rivers valley, where local critical situations were identified (Farina and Severini 2013).
Minimum flow requirements are subject to regulations by Marche Region Water Protection Plan or "PTA", (Regione Marche, 2008), were residual flow, that must be assured downstream of diversion points (such as dams, canals, pumping plant, etc.) is to be calculated via a parametric formula. The Specific Runoff set by PTA seems not to match the actual runoff conditions, being based on historical climatic and hydrometric data, that have changed over time. Minimum flow thus calculated is in many cases higher than the natural flow actually measured in the same gauging station. Therefore, to set an update minimum river flows a modification of the hydrological part of the parametric formula may be suggested. The alternative of a mixed hydrological-biological approach, such as that of the PHABSIM method (Hardy et al. 1997) seems applicable to major water diversion points.

Conclusions

The study showed a significant reduction of yearly average stream flow in the Province of Pesaro-Urbino, due both to climate change and land-use variations in the past decades. The decrease could not be precisely quantified, but it ranges from -30 to -40%, compared to the historical data collected in the past century (mostly from 1924 to 1979). The lack of flow-gauging stations doesn't allow to obtain a more stringent verification of the estimates. The availability of surface water, on which the local water-supply system is mostly based, is a critical issue in Summer periods, when different water uses and environmental constraints come to conflict.
The adaptative process is recently leading to reach a new equilibrium between surface and groundwater, with particular regards to carbonate aquifers, so far basically underexploited: the latter may be allocated to feed the system in Summer periods, while referring to the existing surface water supplies during the water-surplus period.
As for the minimum flow, a revision of the PTA's parametric formula is suggested: a preliminary value of Specific Runoff of 1.0 $L/s/km^2$ is suggested for most rivers of the Province, except for the Bosso-Burano sub-catchments, where the present value of 1.6 $L/s/km^2$ seems suitable.
Further studies are required, both to focus on the weight of specific environmental factors (such as actual water quality), ecology of the fish population and its adaptation capabilities.

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[69] DESIGN OF ARTIFICIAL AQUIFER RECHARGE SYSTEMS IN DRY REGIONS OF MAGHREB (NORTH AFRICA)

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Keywords: Artificial aquifer recharge, Water Harvesting, Desertification, Maghreb Regions

Introduction

North Africa arid land of Maghreb suffers scarce water conditions. Erratic behaviour of rainfall events over brief intervals often produce short and intense floods events which converge into ephemeral wadi beds. Since often this intermittent surface water is not optimally managed, most part of it is lost, providing scarce benefits for households living in villages of such semi-desert areas.

The present research is developed in the frame of WADIS-MAR (www.wadismar.eu). This is one of the five Demonstration Projects implemented within the Regional Programme "Sustainable Water Integrated Management (SWIM)" (www.swim-sm.eu), funded by the European Commission and which aims to contribute to the effective implementation and extensive dissemination of sustainable water management policies and practices in the Southern Mediterranean Region. WADIS-MAR Project concerns the realization of an integrated water harvesting and artificial aquifer recharge techniques in two watersheds in Maghreb Region: Oued Biskra in Algeria and wadi Oum Zessar in Tunisia. These areas are characterized by water scarcity, increasing water demand, overexploitation of groundwater resources, and are highly exposed to climate change risk and desertification processes. The situation is quite critical since groundwater withdrawal is bigger than the rate of recharge, with consequent groundwater deterioration and/or an imbalance in the groundwater budget.

Integrated (Sustainable) Water Resources Management (IWRM) promotes a coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of the environment. IWRM strategies are based on the four Dublin Principles presented at the World Summit in Rio de Janeiro in 1992. In arid and semi-arid areas, the optimum course of action for sustainable water resources management is, in most case, a combination of surface and groundwater use, with a range of storage options. Water harvesting techniques might catch water during rainfall events in order to recharge an aquifer, thus impeding the quick runoff out of a catchment area. An alternative or supplementary activity to it is the artificial aquifer recharge, consisting in a process of induced groundwater replenishment (Murray and Harris 2010; De Vries and Simmers 2002). The successful operation of an artificial recharge (AR) facility depends largely on an effective management. Among several technical aspects, before developing an AR facility, the viability and feasibility of the project should be assessed to verify that: (i) artificially recharged water does not cause geochemical reactions to occur in the subsurface that adversely impact aquifer water quality; (ii) water quality analyses of the possible sources of water for AR and water currently present in the aquifer to be recharged must be obtained; (iii) adequate permeability, thickness, and lateral extent occur to achieve the desired performance standards for the AR facility.

Main results and discussion

A multidisciplinary research effort, including geological, hydrogeological, hydro-chemical, multi-isotopical, geophysical and hydrological investigations, was aimed at selecting suitable zones for the artificial aquifer recharge in both target areas. For each study area, a schematic

3D hydrogeological model was built based on previous maps (both geological and hydrogeological), subsurface data (well-logs), photo-interpretation and remote sensing.

Algeria: the study area is located in a flat region between the chains Saharan Atlas mountains and the Aures hills, it is crossed by the Oued Biskra according to a NS direction. The area is characterized by the superposition of several folding events occurred from Middle Eocene to Pleistocene that strongly influence the geometry of the main aquifers (Buttau et al. 2013; MdH 1980). The main hydrogeological complex are: "Nappe des sables" (deposits of Miocene and Quaternary); "Nappe de Tolga" (limestone, lower-middle Eocene); "Nappe du Maestrictien et du Campanien" (limestones); "Nappe du Turonien" (limestones); "Nappe du Continental Intercalaire" (sandstones and limestones, Albian-Barremian). The mean annual rainfall of the area as a whole is about 200 mm.

We decide to recharge the infero-flux aquifer hosted in the alluvial deposits of the Oued Biskra. The depth to the water table ranges from 20 to 30 m and the thickness of the saturated zone from 40 to over 75 m. Extraction for drinking and agriculture occurs at 15 boreholes, whose depths range from 35 to over 50 m. Total well yields average is 4.5 M m^3/year. Groundwater flow originates dominantly from the NE and moves toward south. The average trasmissivity of this aquifer is 10^{-2} m^2/s. Preliminary results from NO_3 and SO_4 isotopes coupled to chemical data evidenced the existence of a source of contamination near the town of Biskra, probably related with wastewater or fertilizers, which needs to be better characterized previous to the definitive design of the recharge system. Based on the collected data, three types of AR methods i.e. recharge basins, vadose-zone wells, also called dry wells, and recharge tranches, are suggested to catch and infiltrate flash flood waters from the ephemeral streams. We estimate an average of 1.5 M m^3/year.

Tunisia. The study site Oum Zessar belongs to the region of SE Tunisia (province of Médenine). It stretches from the mountains of Matmata (Béni Khédache) in the SW, crosses the Jeffara plain (via Koutine) and the saline depression (*Sebkha*) of Oum Zessar before ending in the Mediterranean (Gulf of Gabès). The study watershed receives between 150 and 240 mm of annual rainfall. The groundwater system of the region can be subdivided into shallow and deep aquifers, and two hydro-litho-stratigraphic provinces may be differentiated: a) the northern Jeffarah, limited to the south by the monoclinal of Djebel Tebaga de Medenine of Permian age. That province is characterized by a large coastal aquifer made essentially of Senonian limestone and Mio-Pliocene sand; b) the southern Jeffarah with the occurrence of Triassic sandstone upstream of the Medenine fault, and with Lower Miocene sand downstream of the fault (Yahyaoui 2007). Increasing values of ^{15}N and ^{18}O from nitrate in some wells in the sourthern Jeffara, indicates that denitrification processes are occurring pointing out that natural attenuation decreases the nitrate pollution. We decided to concentrate our effort on the aquifer of the Triassic sandstone. The renewable resources are estimated to 150 L/s and the salinity varies between 1 g/L and 3 g/L. The analysis of $\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$ indicates that the origin of this salinity is natural, mainly related to the water-rock interaction with the triassic evaporites. The water from this aquifer is used mainly for drinking water and irrigation. In 2010, the rate of overuse reached 160%, which resulted in some tendency of piezometric level decline (Yahyaoui 2007). Based on the collected data and the hydogeological feasibility, dry wells with a recharge chambers are designed to catch and infiltrate flash flood waters from the ephemeral streams in 4 intervention sites. We estimate overall an average of 2.0 M m^3/year. Artificial aquifer recharge is a long-term phenomenon; indeed, its effects in term of efficiency, have to be examined on a large time and spatial scale. This issue will be the topic for the continuation of the research.

Acknowledgements

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[70] DETERMINING A SITE-SPECIFIC SUSTAINABLE YIELD THROUGH NUMERICAL SIMULATIONS

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Keywords: sustainable yield, alluvial aquifer, numerical model.

Introduction

The present study deals with hydrogeological investigations and numerical modeling of an industrial site, intentionally left anonymous, with the aim to quantify the sustainable yield that can be withdrawn from the wells at the service of production activities. It represents a practical application of the theoretical concept of sustainable yield (e.g., Kalf and Woolley 2005) through the use of numerical models (Baiocchi et al. 2013a; 2013b; 2014).
Reconstruction of the hydrogeological scheme showed the presence of two aquifers and four hydrostratigraphic units (Fig. 1).

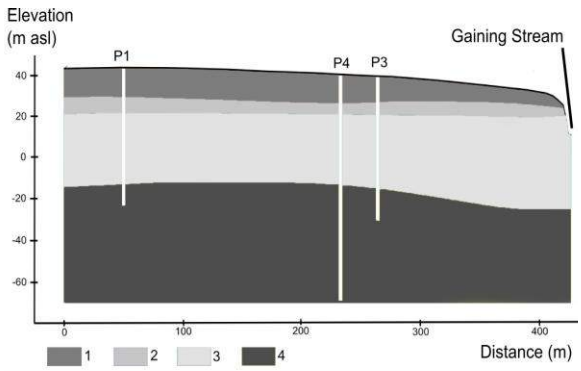

Fig. 1. Hydrostratigraphic cross section (SW-NE). 1: Sandy unit; 2: Aquitard; 3: Pyroclastic-sandy unit; 4: Clayey-sandy-marly unit.

The most superficial unit includes the sandy coverage of the pyroclastic formations and hosts the first unconfined aquifer of limited thickness. The pyroclastic-sandy unit constitutes the confined or semiconfined aquifer (35-38 m of thickness). This aquifer is bounded above by a more or less constant fine ash deposit with lower relative permeability (aquitard), which separates the two aquifers. The aquitard between the two aquifers can allow water exchanges along the vertical direction due to the possible local fracturing. The clayey-marly unit constitutes the base of the aquifer, having a relatively low permeability.
The considerable incision of the nearby riverbed represents the local natural discharge both of the shallow and pyroclastic-sandy aquifer (Fig. 2).

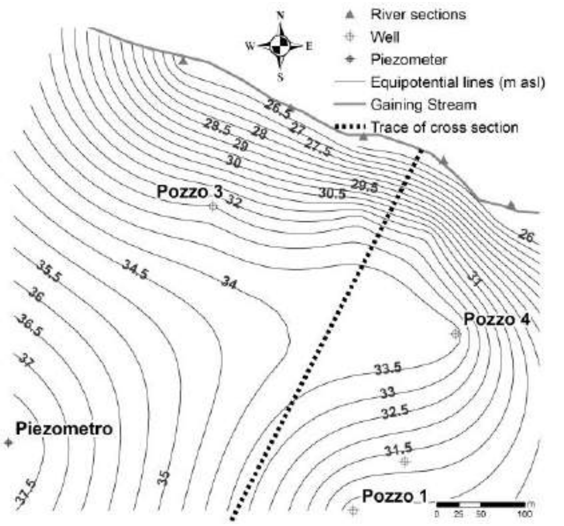

Fig. 2. Potentiometric surface of the pyroclastic-sandy aquifer.

Materials and methods

A multi-well pumping test was performed: four wells were monitored functioning both as pumping and observation wells. During the test, sudden interruption and/or changes in the pumping flow rates took place, resulting in partial recovery of the dynamic heads (Fig. 3). Given the variability of the conditions during the test, only a few traits of the curves could be interpreted with analytical methods.

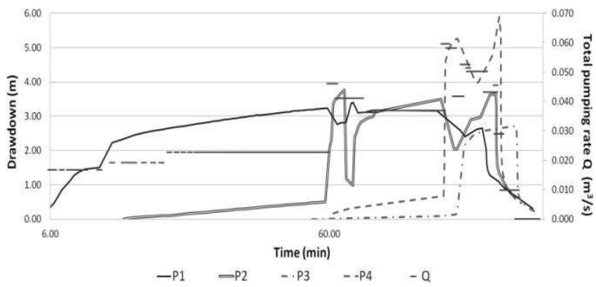

Fig. 3. Drawdown vs time of monitored wells, partial and final recoveries.

A numerical model was implemented using the MODFLOW-2000 code and calibrated on steady and transient conditions.
Observations consisted of the static heads of the four wells plus one external piezometer, the aquifer discharge towards the nearby river, and pumping tests response. After a first trial&error calibration, inverse modeling was applied through the *pilot*

points technique (Certes and De Marsily 1991; USGS 2010).
Three different pumping scenarios were simulated. Potentiometric deformations and lines of equal drawdown after two years of simulation are shown in Figures 4 and 5.

Discussion and conclusions
The evaluation of the sustainable yield was carried out at the scale of the site, taking into accounts the effects of the wells "capture", the depressions induced by simultaneous pumping from the four wells, the impact on the residual output towards the river and the resources stored by the aquifer.
One of the constraints for the amount of tapped water is the relationship between the pumping rate and the discharge into the nearby river, according to the concept that defines the sustainability of withdrawals on the basis of the residual outflow from the "captured" system.
Considering the results of the numerical model and the local hydrogeological scheme, a total pumping rate of 60 L/s would account for only 6% of the minimum discharge of the stream (about 1 m^3/s), and can be reasonably assumed as the site-specific sustainable discharge.

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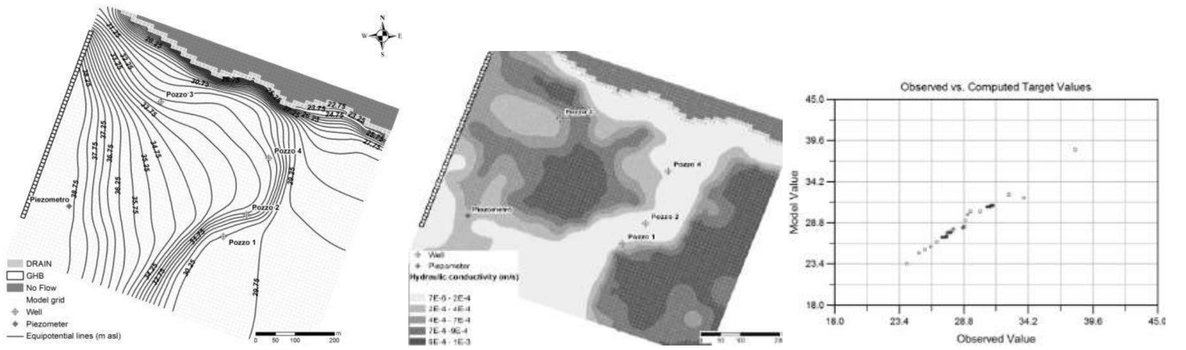

Fig. 4 - Simulated potentiometric maps (equipotential lines in m asl), distribution of hydraulic conductivity (m/s), and scatter plot of PP calibration.

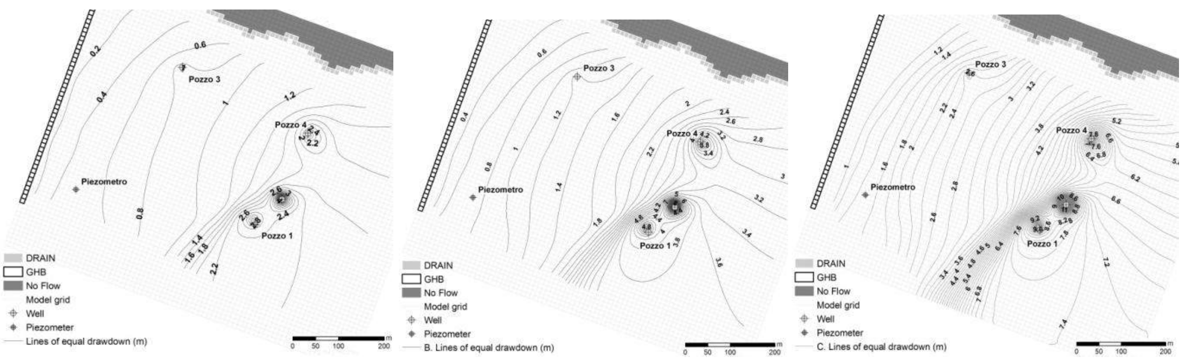

Fig. 5 - Lines of equal drawdown (m) for three pumping scenarios. Total pumping rate from left to right: A = 60 L/s; B = 90 L/s; C = 180 L/s.

[71] HYDROSCRUTURAL REGIONAL SETTING OF THE DOLOMITIC GROUP "PALE DI SAN MARTINO"

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Keywords: Fractured aquifer, groundwater flow, recharge areas, springs.

Introduction

Regional hydrogeological studies in mountainous regions, such as the Dolomitic Group Pale di San Martino, are very scarce due to a series of overlapping factors including logistic field issues, the lack of observation wells or meteorological stations at high altitude and last but not least the characteristics of the main aquifer, which is fractured, karsified and displaced by tectonics. Joints, veins and faults of various sizes create complex hydrogeological groundwater flow conditions and therefore affect the secondary permeability of the rock volume. In addition, mountain block recharge can be restricted by geological structures such as folds (Wilson and Guan 2004) also, faults can either act as conduits or barriers for the fluid circulation depending on the fault core's maturity (Storti et al. 2003).

The visible effect on the earth's surface of the underground rock structure and composition is the location of groundwater discharge points, mainly springs, which are characterized by their individual and particular regimes as a result of groundwater origin. In detail, spring's locations and regimes can be related either to the presence of faults or to the trend of the basal aquiclude, or both. In these hydrogeological systems it becomes mandatory to understand the quantitative and qualitative links between the structural elements and the outflow points in order to build an effective hydrogeological model.

Main Body

A regional multidisciplinary survey was carried out in the dolomitic Group Pale di San Martino, involving a combination of structural mapping (1:50,000 scale) and hydrogeological measurements. Based on the publicly available geological data and using a GIS system the study area was divided into 6 different areas of relatively homogeneous hydrogeological properties or HRUs (hydrogeological response units) (Fig. 1)

- Metamorphic Unit. *Aquiclude*
- Igneous Unit. *Aquifer*
- Werfen, Bellerophon, Val Gardena sandstones Unit. *Aquiclude*.
- Carbonate rocks and dolomites Unit. *Aquifer.*
- Fluvio-glacial sediments Unit. *Aquifer*.
- Volcanic Unit, *Aquifer.*

All the regional structural elements reportedly present in the area were added to the map as well as springs and other outflow manifestations. Thanks to this preliminary desktop review it was possible to create a sketch design of the main flow directions and to focus the field survey on the uncertainties identified. During the field activities all the structures that potentially affect the permeability of the aquifer were mapped including lithological contacts, primary structures, faults, joints and folds. Where significant rock outcropping were encountered scan line and scan area mappings were also performed in order to estimate the fracture density. During the field survey the springs and other outflow elements were geographically mapped using a GPS device. Groundwater chemical characteristics (pH, Temperature and electrical conductivity) were measured on-site as well as the discharge rate of the springs. The most relevant hydrological elements (main spring location and discharge) combined both with the structural setting and with the trend of the lithological boundaries led to the definition of a preliminary hydrogeological model.

The hydrostructure is mainly characterized by dolomitic rocks (Triassic) hosting the main regional aquifer, and is underlain by mixed-clastic carbonate and evaporitic sediments (Werfen and Bellerophon - Upper Permian). The last two formations together with the Val Gardena sandstones assume the hydrogeological function of the regional aquiclude. Apart from the lower basement, the hydrostructure is also laterally confined by four main shear zones, a northeast-southwest thrust on the southern portion of the area, a backthrust with the same trend on the northern part of the structure and two transpressive shear zones on the eastern and western border of the structure (northwest-southeast direction). Since these regional deformation surfaces separate rock types with different hydraulic conductivity they define lateral boundaries for the groundwater circulation. Given the aquifer boundaries, it became mandatory to follow the aquifer – aquiclude contact (Dolomites-Werfen formation) on the field and to link it with the location of the main springs in order to confirm the hydrogeological model.

The aquifer - aquiclude boundary's elevation is found at approximately 2000 m asl (above sea level) in the northwest portion of the area and it decreases to 1700 m asl to the southwest border (hanging wall of the thrust). In the eastern part of the hydro-structure the boundary is found at lower altitudes ranging from approximately 800 m to 1100 m asl. It has been observed that the elevation of the aquifer – aquiclude boundary matches the location of the main springs almost perfectly. Nevertheless the outflow points are also located preferentially along the valleys, which are in turn a reflection of underlying tectonic discontinuities. For instance, the springs with highest discharge in the hydrostructure (Sorg. Acque Nere, Fonti di S.Martino) are located at the southeastern border of the structure at the approximate altitude of the aquifer - aquiclude boundary but also in one of the major valleys which is characterized by compressive tectonics (Val Canali). Due to the relevant amount of Quaternary sediments (up to 100 m of thickness) the contact between the aquifer – aquiclude is frequently hidden, therefore the groundwater origin of the springs is not always clear. Given the complex hydrogeological setting and in order to better understand the relationship between the underground flow paths, the discharge points and the recharge areas our intentions for the future is to expand the study in the isotopic research field.

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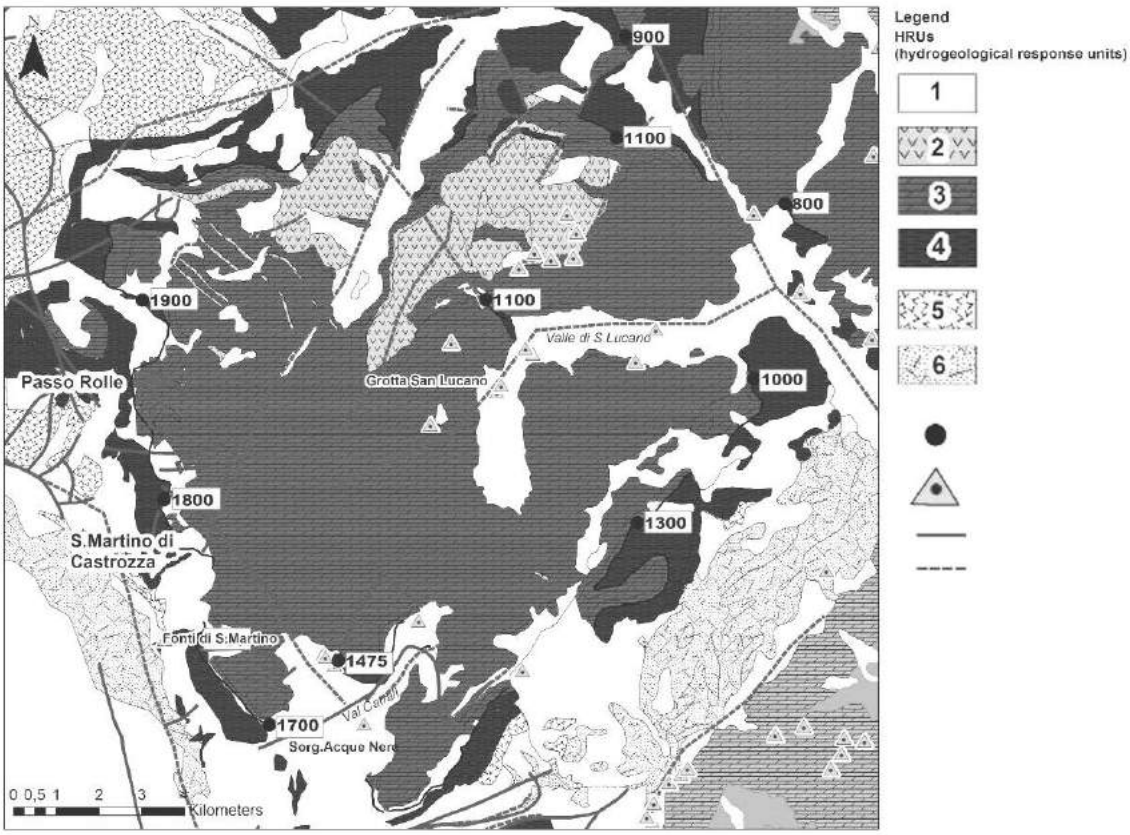

Fig. 1 - Hydro-structural map of the study area: 1.Fluvio-glacial sediments (Quaternary) 2.Volcanic Unit (Upper Triassic) 3.Carbonates and dolomites (Triassic) 4.Werfen, Bellerophon, Val Gardena sandstone Unit (Upper Permian) 5.Igneous Unit (Lower Permian) 6.Metamorphic Unit (Ordovician). Black dot: aquifer-acquiclude boundary elevation in meters (Dolomites-Werfen); Triangle: location of main springs; Solid line: fault traces; Dashed line: presumed fault traces.

[72] HYDROLOGIC RESPONSES TO SEISMIC EVENTS: TWO CASE STUDIES IN ITALY

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Keywords: near-field, static stress, dynamic strain, sponge effect, undrained conditions.

Introduction

In the past it has been studied countless hydrological changes caused by earthquakes (Wang and Manga 2010), it is impossible to list all studied cases in literature but here two Italian cases of near-field hydrologic responses to earthquake are argued: discharge increase observed at the Caposele Spring in consequence of the November 23th,1980 Irpinia earthquake (M_w 6.9), groundwater level increase observed in near-field four monitoring wells in consequence of the May 20th and 29th, 2012 Emilia earthquakes (M_w 5.8 and 5.8 respectively).

The aim of this work is to understand the mechanisms that involved the two aquifers and generated hydrologic anomalies.

Concerning the first case study, a numerical model of the Mt Cervialto aquifer (which feeds the Caposele Spring) has been performed, simulating pre- and post- seismic period.

In conclusion a conceptual model has been presented to explain probable mechanisms involved for each case study.

Methods

Discharge data from Caposele spring from 1964 to 1999 have been analyzed in order to understand the hydrogeological changes due to the Irpinia earthquake occurrence. The spring is located about 5 km away from the earthquake epicenter, the discharge raised a value of 7.2 m^3/sec in only one month, value never reached before.

The Caposele spring hydrograph has been analyzed before and after the Irpinia earthquake using the baseflow recession analysis. The recession curve, and α value contains valuable information concerning storage properties and aquifer characteristics.

Furthermore, in order to evaluate the hypothesis of changing in aquifer hydraulic characteristic, a numerical model of the Cervialto Mountain has been performed, simulating pre- and post-seismic period. Then output data have been compared with observed discharge data.

For the second study case, data from 19 monitoring wells draining aquifers at several depths (from 1 up to 45 m depth in the Po Plain) have been analyzed to understand the hydrogeological response to the Emilia earthquake 20th and 29th mainshocks.

Figure 2 shows the groundwater levels from October 2011 to October 2012, used for the analysis of changes during the earthquake event. The data of residual 14 piezometric dataloggers are not reported because variations due to Emilia earthquake are not observed.

Results

For the first case, recession analysis results on the spring hydrograph show that the recession constant is average decreased after the earthquake occurrence, this suggests that something in the aquifer structure (hydraulic characteristic) may have been changed, caused by the seismogenic fault dislocation (static stress) and/or by the seismic waves passage (dynamic strain).

The numerical model results show pre-seismic period model simulation convergence with the observed data of the Caposele spring discharge, while the post-seismic period model simulation doesn't correspond with observed discharge Caposele spring data.

For the second case, the Po Plain water well levels available data show step-like increase in the shallow aquifer groundwater level time series (Fe8100, Fe8000, Mo4301and Mo8000) in consequence of the two mainshok of the Emilia earthquake, while a slight increase after the May 20th mainshok in the deep aquifer monitoring well (Bof800) is observed (see Fig. 2).

Conclusions

The explanation of the hydrologic variation observed at the Caposele spring has been realized under the hypothesis of the "sponge effect", it consist in a rapid expulsion of fluid from the aquifer reservoir after the earthquake occurrence, due to cracks closing in consequence of the seismogenic fault dislocation (change in static stress) and to the fractures cleaning caused by the passage of the seismic waves (dynamic strain) (see Fig. 1). This explanation is supported by Muir-Wood and King (1993). The numerical modeling results have been affected by the difficulty of simulation of hydrological effects due to earthquakes, especially on a wide aquifer with no control point as the Cervialto Mountain. It is important to highlight that the principal goal of the numerical modeling is not to forecast the future behavior of the Mt Cervialto aquifer, but to use this instrument to understand the mechanisms involved in the aquifer structure with the earthquake occurrence.

In the second case, the hydrological variations observed at the Po Plain monitoring wells are within the characteristics reported in the common scientific literature relating to undrained consolidations phenomena, linked to earthquakes occurrence. Their amplitudes are function of their relatively small distances from the earthquake epicenter and to their location in an area subjected to compressive strain.

Acknowledgements

We wish to tank ARPA Emilia Romagna for providing water well levels data of Ferrara and Modena Provinces, Francesco Fiorillo for providing Caposele spring recession constant data from 2000 to 2009, Alessandro Gargini for useful advices on the hydrological anomalies due to the Emilia earthquake, and Vincenzo Piscopo for the stimulating discussions on Caposele spring.

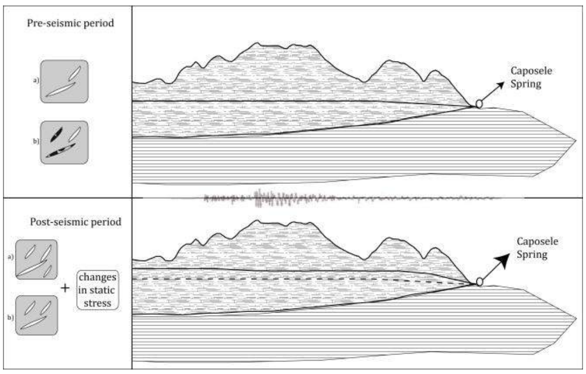

Fig. 1 – Conceptual scheme of groundwater changes caused by the Irpinia earthquake in the Mt Cervialto aquifer: the changes are explained with an increase of permeability in the carbonatic aquifer (new fractures creation and cleaning of sealed fractures) and variation in static stress conditions due to the epicenter close to.

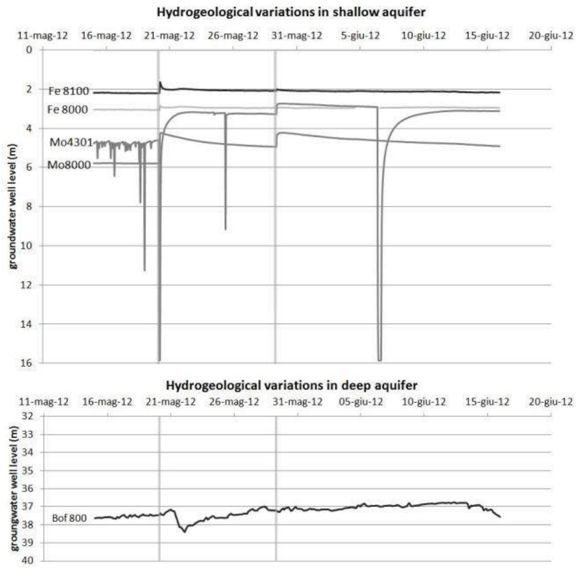

Fig. 2 – The shallow aquifer response to the Emilia earthquake (Fe8100, Fe8000, Mo4301and Mo8000) shows an increase in the groundwater level corresponding to the mainshocks. The deep aquifer response to Emilia earthquake (Bof800) shows no evident response to the mainshocks. Vertical lines represent the occurrence of the Emilia earthquake mainshocks (May 20th and 27th, 2012).

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[73] VULNERABILITY OF GROUNDWATER IN FRACTURED AQUIFERS, UNDER CLIMATE AND LAND USE CHANGE IN NORTHERN APENNINES

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Keywords: vulnerability, groundwater, climate change, Northern Apennines.

Introduction

We dedicate our research for assess vulnerability of groundwater under climate and land use change, in fractured and fissured aquifers from Northern Apennines of Italy. The work is included in the CC-WARE, South East European Project “Integrated transnational strategy for water protection and mitigating water resources vulnerability” (Marcaccio et al. 2014). In addition, the research examines the role of ecosystems services in the peculiar thematic, and quantify their possible mitigating action against climate change and land use in the future. This will provide guidelines for appropriate regulation of land use in recharge areas of groundwater bodies.

CC-WARE project methodology

From methodological point of view, the analysis of the problem involves the definition of indicators characterizing the hazards of climate change to 2050: aridity index, standard precipitation index, real and potential evapotranspiration. The indicators of vulnerability quantifies the quantity and quality indicators of groundwater resources (Cervi et al. 2014). We use in specifically following types of indicators: Physical vulnerability (related to climate change and land use); Socio-Economic Vulnerability (related to changes in the exploitation of water resources and land use); Adaptation / Mitigation (related to the role of ecosystem services, which are closely related to land use change).

Physical vulnerability index has become with VESPA index (Galleani et al. 2011) a method approach for assess the vulnerability of water resources, both in the present as in the future. It is based on the cross-correlation between variations in flow rate, electrical conductivity and temperature of groundwater resources. These parameters are sensitive to climate change and can be monitored in continuous with multiparametric probes. The time evolution and the futures variation of the considered parameters can be obtained by numerical flow groundwater models of aquifers, having as input climate scenarios that predict changes in precipitation and real evapotranspiration, until 2050. Furthermore, these model could be able to evaluate, thought correct simulations, the effect of the land use changes on the groundwater recharge processes.

Test areas

Three springs have been identified in Emilia Apennines (Ronchetti et al. 2014). These springs draining three different fractured aquifers: i) Fontana Magnano Spring, that it drains the ‘Prignano sul Secchia groundwater body’ (Regione Emilia Romagna 2010) and it is located in the municipality of Palagano (MO); ii) Fontana Grossa Spring, that it drains the ‘Villa Minozzo groundwater body’ (Regione Emilia Romagna 2010) and it is located in the municipality of Toano (RE); iii) Mulino delle Vene Spring, that it drains the ‘Monte Fuso groundwater body’ (Regione Emilia Romagna 2010) and it is located in the municipality of Carpineti (RE).

First results and conclusions

In the test sites, there are active since April 2013, three automatic groundwater monitoring systems, that monitor at the hourly frequency the flow rate, the electrical conductivity and the temperature of groundwater (Fig. 1).

The results of continuous groundwater spring monitoring are highlighted below. At Fontana Grossa, the groundwater flow rate was max in September 20, 2013 and register 1.19 L/s and min in May 16, 2013 with 1.08 L/s. The average flow-rate is 1.17 L/s. Groundwater temperature was max in October 31, 2013 and register 9.70°C. The min temperature register was 9.00°C, in 3rd decade of January, 2014. The average temperature is 9.46 °C. Groundwater EC was max in December 29, 2013 with 0.70 mS/cm and min in January 19, 2014, with 0.51

mS/cm. The average EC is 0.63 mS/cm.

At Mulino delle Vene, the groundwater flow rate was max in December 31, 2013 and register 82.18 L/s and min in November 17, 2013 with 0.45 L/s. The average flow is 19.58 L/s. Groundwater temperature was max in March 23, 2013 and register 12.10°C. The min temperature register was 11.90°C, in December 10, 2013. The average temperature is 11.99°C. Groundwater EC was max in March 16, 2013 with 0.82 mS/cm and min in March 12, 2013, with 0.65 mS/cm. The average EC is 0.76 mS/cm.

At Fontagna Magnano, the groundwater flow rate was max in January 18, 2014 and register 3.98 L/s and min in December 19, 2013 with 0.18 L/s. The average flow is 1.10 L/s. Groundwater temperature was max in September 10, 2013 and register 7.60°C. The min temperature register was 4.90°C, in December 19, 2013. The average temperature is 6.50°C. Groundwater EC was max in October 7, 2013 with 0.34 mS/cm and min in January 18, 2014, with 0.22 mS/cm. The average EC is 0.32 mS/cm.

For each spring from test site, the groundwater is monthly sampled for determine the main concentrations of trace cations and anions, the dissolved oxygen and the water stable isotopes (hydrogen and oxygen).

In conclusion, the activities and the analysis carried out within the project CC-WARE, will help to assess the groundwater vulnerability in fractured aquifers of the Northern Apennines chain, with respect to the future climate changes and land uses evolution. Furthermore, we think that our findings could be useful to analyse the role of the ecosystems services in mountain regions and for the protection and conservation of the groundwater resources.

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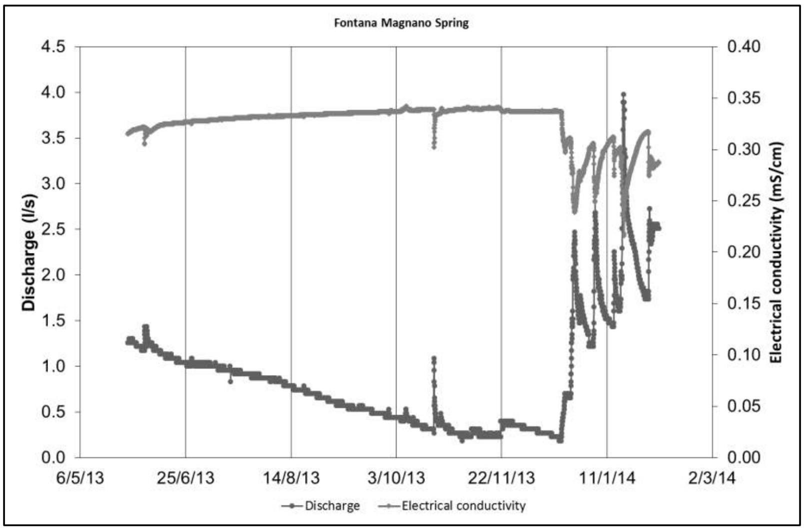

Fig. 1 - Continuous groundwater monitoring.

[74] ESTIMATION OF GROUNDWATER VOLUMES IN THE ADDA-OGLIO AREA (NORTHERN ITALY) BY 3D RECONSTRUCTION OF HYDROGEOLOGICAL PROPERTIES

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Keywords: heterogeneity, alluvial, gravitational groundwater, groundwater volume, Po Plain

Introduction

The reconstruction and characterization of subsurface is a remarkable aspect in groundwater management, since a detailed reconstruction can highlight groundwater flow paths along the sedimentary bodies. In this paper, we would like to overcome the strong subdivision into aquifers and aquitards, introducing the concept of textural changing inside an aquifer. This concept is translated into a 3D reconstruction of textural and hydrogeological properties of the aquifers of the chosen study area, located between Adda, Oglio and Po rivers including Bergamo and Cremona Provinces (northern Italy). This hydrogeological reconstruction is used in order to estimate the volumes of gravitational groundwater located in the subsurface: the studied territory represents a very important area, considering the high groundwater consumption by drinking supply and anthropogenic activities. The area is composed of heterogeneous deposits shaped by both marine transgression phenomena and erosive processes carried out by rivers and glaciers. These deposits are classified into four different aquifer groups, called A, B, C and D (Regione Lombardia-ENI AGIP 2002) from the youngest to the oldest: aquifer group A is the shallowest and most exploited over the whole study area, whereas aquifers B, C and D are almost exclusively exploited in the North. The proposed procedure allows us to characterize the aquifer groups located within the study area, reconstructing the textural distribution and calculating the main hydrogeological properties. The parameterization of hydrogeological properties, such as effective porosity, allows us to estimate the potential quantity of water stored in subsurface deposits. This hydrogeological reconstruction will be followed by a flow model, currently under development, aiming to a better understanding of the hydrogeological dynamics within the study area.

Materials and methods

Groundwater volumes estimation begins with the collection of different types of data, collected from several different sources: aquifer limits were taken from the study by Regione Lombardia-ENI AGIP (2002); water well data and geological maps were collected from previous hydrogeological studies (Forcella and Jadoul 2000). These data were used to build a preliminary conceptual model of the regional hydrogeological structure. Spatial data were elaborated using GIS software, whereas water well data were homogenized and codified in a specific database, called TANGRAM (Bonomi et al. 1995) for further extraction of hydrogeological properties. These information were integrated with data taken from other geological studies along with oil well data taken from VIDEPI project, in order to reconstruct the deeper portions of the study area. Once defined the geometries of the main geological/ hydrogeological bodies, a 3D computational grid, spanning from ground level to the top of Pliocene deposits and enveloping all aquifer groups (from A to D), was created and a geostatistical analysis was carried out. The spatial correlation between textural (lithological) terms, porosity and hydraulic conductivity was separately estimated in order to reconstruct the hydrogeological features of both shallower and deeper aquifers, using kriging interpolation. Piezometric and hydrometric data from ARPA Lombardia referred to September 2005 was used to reconstruct the piezometric surface: this reconstructed water table combined with the computational grid allows us to subdivide the underground volumes into saturated and unsaturated portions for each aquifer group. In order to estimate groundwater volumes, the resulted porosity distribution from kriging interpolation was used. Firstly, the total saturated volume of each aquifer group was calculated and within this volume the “real” groundwater volume was subsequently estimated: zones with effective porosity percentages above 10% are considered as potential locations of gravitational groundwater water whereas zones with low effective porosity values (below 10%) are considered as aquicludes (unexploitable). Finally, the estimated available groundwater volume was calculated for every porosity class (from 10% to 25-28%) by multiplying the aquifer volume located in each porosity class for the porosity value of that class. In deeper aquifer groups, this calculation was done using effective porosity values equal to 1/10 of that of shallow aquifers, since S values (storage) are lower compared to those of the shallow portion of the study area, due to hydraulic confinement. Aquifer D was not entirely considered for water volumes calculation, since it is traversed by a saltwater/freshwater interface. Therefore, the volume calculation was made only for the freshwater portion.

Results and discussion

Interpolations results show high percentages of coarse sediments (mostly gravel and conglomerate) rapidly decreasing from North to South (maximum values up to 70-40% respectively for the shallower aquifers and for the deeper ones). On the other hand, the medium textured sediments (sand and sandstone) increase southward (from about 10% to 50%). Fine textured deposits (clay, silt, peat and marlstone) show a strong increase with depth both in the northern part (from 20% to 40%) and in the southern part (from 30% to 50%). From the interpolation results, it is possible to notice that there is a general decrease of grain size from North to South, according to the decrease of depositional energy of the main rivers located within and near the study area. The upper aquifers are composed of coarse deposits, whereas the lower aquifers are composed of finer deposits, according to the different depositional environments (continental and marine). These textural reconstructions also allow us the creation of three-dimensional representations regarding the main hydraulic characteristics of the deposits (Fig. 1). The estimated gravitational groundwater volumes of each aquifer group are shown in Figure 2. It is possible to notice that the aquifer which includes the greatest amount of gravitational water is the aquifer A, with approximately 51 billion of m^3, as expected. As a result, aquifer A is composed of coarser deposits, which makes it the most exploited one, with approximately the 90% of active wells inside the study area. The other aquifer groups are mainly composed of finer deposits, such as sandy clay and silt (with effective porosity under 10%), and most of the groundwater remains bonded to the grains, so the stored gravitational groundwater shows very low values. These aquifers (B, C and D) are exploited by the remaining 10% of active wells.

Conclusions

This study underlines the ability of the proposed automated procedure to obtain 3D reconstructions of the main hydrogeological properties, with a good detail level, based on a continuously updated hydrogeological database. The application of the procedure allow us to perform quantitative assessments of groundwater volumes and for further implementation in flow models.

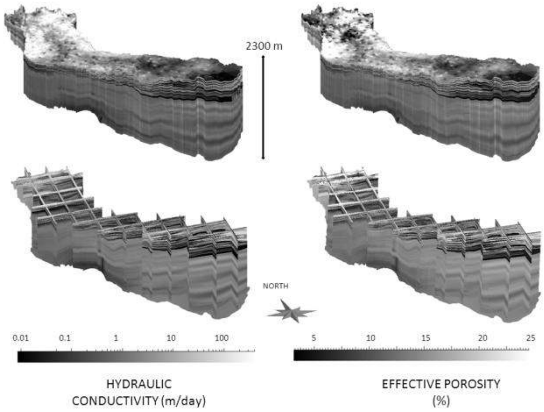

Fig. 2 - Distributions of both hydraulic conductivity (shown in logarithmic scale) and porosity, representing the main hydrogeological properties of the subsoil.

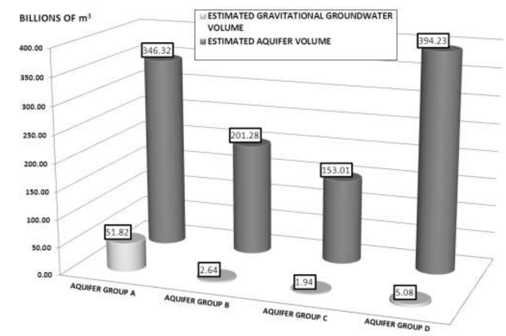

Fig. 3 - Relationship between estimated aquifer volumes and gravitational groundwater volumes for each aquifer group.

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[75] PUMPING AT CONSTANT HEAD, WHAT WE CAN INFER ABOUT THE SUSTAINABLE YIELD OF A WELL

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Keywords: Sustainable yield, Well yield, · Groundwater management, Numerical modeling

Introduction

Determining the yield of a production well remains one of the main challenges in hydrogeological studies. Starting from the results of a 3-year-long monitoring of a continuously exploited well functioning at constant head and variable discharge rate (Piscopo and Summa 2007; Cozzolino et al. 2010), a new pumping style has been examined using numerical models. In particular, the new pumping style is intended to be used in systems where low yields are expected and the investigations commonly performed are likely to be economically unpractical. The object is to control the impact of pumping on the aquifer, in accordance with the concept of *sustainable yield* (e.g., Alley et al. 2002; Devlin and Sophocleous 2005).

Different numerical model settings were used to examine the new pumping style, that was calibrated on the monitored discharge data of the well during the recession periods (Baiocchi et al. 2013).

Matherial and Methods

Available data are the well stratigraphy, a step-drawdown test and daily measurements of well discharge (from March 2004 to February 2007) (reported in Piscopo and Summa 2007; Cozzolino et al. 2010). The well, located in the Campania Region, is 162 m deep and taps Cretaceous limestones with varying degrees of fracturing that underlie low-permeability Miocene flysch and Quaternary detritic, alluvial and lacustrine deposits. Previous studies revealed that the well, if kept at constant head and therefore at variable discharge rate, behaves as a spring (Piscopo and Summa 2007; Cozzolino et al. 2010). Analyzing the recession curve of the well discharge, the extent of aquifer depletion and the original volume of water stored in the aquifer that feeds the well can be determined.

In the present study, an additional analysis of the pumping impact on the residual natural discharge of the system was carried out, using numerical simulations. This is necessary to prove the sustainability of the well yield.

Based on the results of previous works (Piscopo and Summa 2007; Cozzolino et al. 2010), the aquifer was modeled as an equivalent porous medium, using the MODFLOW2000 code (Harbaugh et al. 2000). The model covered an area of approximately 25 km^2 and included two layers: layer 1 represented the confining unit (i.e. the Miocene flysch and Quaternary deposits), layer 2 represented the confined carbonate aquifer (Fig. 1).

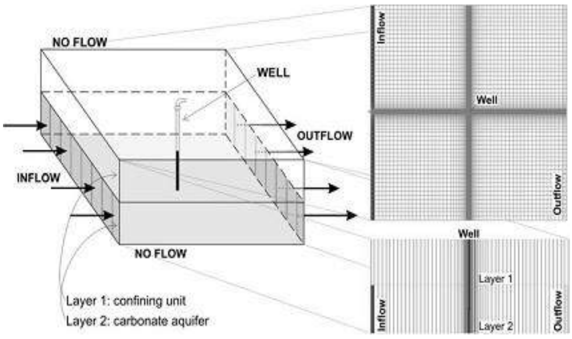

Fig. 4 – Sketch of the model showing grid, layers, and boundary conditions.

The natural inflow of the aquifer was simulated using an imposed flux placed along the first column of the carbonate aquifer. The natural outflow was simulated using the drain function along the last column of the carbonate aquifer. The other two sides of the box model are no-flow boundaries.

The well, placed in the central cell of layer 2, was simulated in two different ways: by the drain function when functioning at constant head and by the well function when functioning at constant discharge.

Results and Discussion

A first steady state model, calibrated on the step-drawdown test, allowed to estimate the aquifer transmissivity (2.28×10^{-4} m^2/s).

A second transient state model was calibrated using 2005 discharge data of the well during the recession period (Fig. 2).

A third model validated the previous according to 2006 discharge data of the recession period. Results of these models allowed to determine the aquifer storativity (4.25×10^{-4}).

The calibrated model permitted to evaluate the ratio between the total volume of water pumped from the well (V_P) and the total volume of residual natural outflow (V_{Dr}) by integrating both the curves of the well and natural outflow during the recession period. This ratio was 0.52 for the

2005 depletion period (214 days), assuring a significant residual outflow discharge.

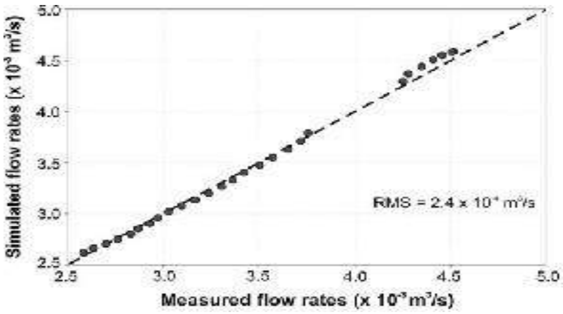

Fig. 5 - Comparison of the observed and simulated discharge rates of the well during 2005 recession period.

Subsequently, the calibrated model was used to simulate different cases of pumping at constant discharge *(P_{cd})* during the 2005 recession period. The trend and rate of the natural residual outflow were analyzed and the V_P/V_{Dr} ratio and drawdown in the cells near the well *(Δh)* were determined, as shown in Tab.1. This simulation allowed the evaluation of the residual outflow from the aquifer and the control of the drawdown in the well.

P_{cd} (× 10^{-3} m^3/s)	V_P/V_{Dr}	Δh (m)
3.5	*0.47*	*27.59*
4.0	*0.58*	*32.30*
4.5	*0.70*	*37.01*
5.0	*0.84*	*41.84*
5.5	*1.00*	*46.93*
6.0	*1.18*	*52.42*

Tab. 2 – Simulated variations in V_P/V_{Dr} and drawdown in the well (Δh) for increasing steps of constant discharge (P_{cd}) during the 2005 depletion period.

Other simulations were conducted to simulate the percentage of water pumpage coming from the aquifer storage *vs* time, varying the aquifer's hydraulic diffusivity (transmissivity and storativity ranged from 2×10^{-4} to 1×10^{-3} m^2/s and from 4×10^{-4} to 1×10^{-3}, respectively). In agreement with previous studies (e.g., Bredehoeft 2002; Zhou 2009), the capture of the residual outflow becomes evident only later in time for low-diffusivity aquifers, as this case (hydraulic diffusivity of 0.54 m^2/s).

Conclusions

Analyzing the discharge of a well functioning at constant head can be a valuable method for determining the impact of pumping on the residual outflow of the tapped aquifer.

The V_P/V_{Dr} ratio represents an index for the sustainability of groundwater withdrawal. This index is independent from the knowledge of the aquifer's recharge. Because the trend of the well discharge during the recession period depends on the hydraulic diffusivity of the aquifer, important information on the aquifer response can be acquired by a single well. A classic single-well pumping test does not supply the same amount of information.

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[76] CLIMATE CHANGE AND MEDITERRANEAN COASTAL KARST AQUIFERS: THE CASE OF SALENTO (SOUTHERN ITALY)

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Keywords: groundwater management, MODFLOW, SEAWAT, climate change, coastal karst aquifer

Introduction

Second half of the 20th century was characterized by an increase of groundwater discharge. Numerous aquifers are overexploited in the world and in particular in the Mediterranean area. Problems tie to overexploitation, as piezometric decline and increase of seawater intrusion, are amplified in karst coastal aquifers where the whole effect could be a groundwater quality and quantity degradation.

Focusing on Mediterranean countries, most part of coastal aquifers of Spain, France, Portugal, Slovenia, Croatia, Greece, Albania, Turkey, and Italy are karstic and affected, to different degrees, by seawater intrusion due high pumping extraction rates and low recharge. (COST 2005; Polemio et al. 2010).

Climate change may particularly aggravate these requirements, especially in the Mediterranean areas, due to the combined effects of semiarid condition climate, or reduced recharge and consequent increase of discharge (Cotecchia et al. 2003; Polemio 2005; Polemio et al. 2009).

The general purpose of this paper is to prove the capability of large-scale numerical models in management of groundwater, in particular for achieve forecast scenarios to evaluate the impacts of climate change on groundwater resources of karst coastal aquifer of Salento (Southern Italy).

The computer codes selected for numerical groundwater modelling were MODFLOW and SEAWAT. Three forecast transient scenarios, referred to 2001-2020, 2021-2040 and 2041-2060, were implemented, on the basis of calibrated and validated model, with the aim to predicting the evolution of piezometric level and seawater intrusion. The scenarios were discussed considering the effects of climate change, sea level rise and change of sea salinity.

Numerical model of study area

The study area, located in the Southern Italy (Fig. 1), is a portion of Salento Peninsula (about 2300 km^2) discretized into 97,200 cells, each one of 0.6 km^2.

Vertically, to allow a good lithological and hydrogeological discretization, the area was divided into 16 layers, from 214 to -350 m a.s.l..

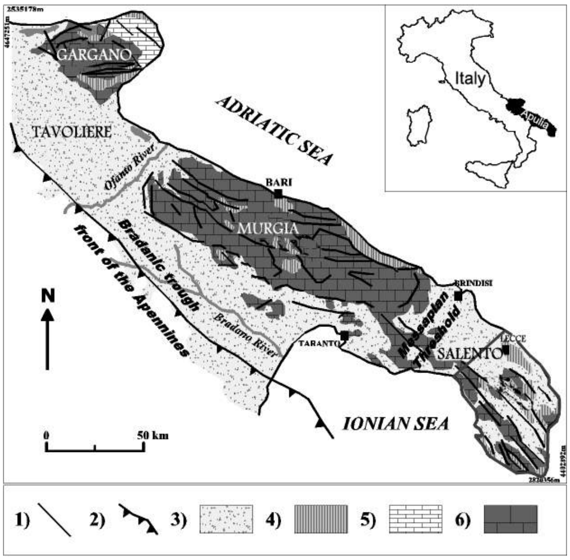

Fig. 1 – The study area.

Boundary conditions, thickness, and geometry of layers were defined on the basis of the aquifer conceptualization based on the 3D knowledge of hydrogeological complexes. (Fig. 2). The level of well discharge was almost low and negligible in thirties. A first simulation using data of thirties was done. This type simulation was defined on the basis of steady-state conditions to define natural conditions of flow and of seawater intrusion. Two new transient scenarios were done, from 1980-1989 and 1989-1989 periods also used to validate model. Model input data, calibration and validation phases are described in details by Romanazzi and Polemio (2013).

Climate changes and predict scenarios

In addition to overexploitation, in the next decades climate change may particularly aggravate these scenarios, due to these combined effects of temperature increasing and precipitation decreasing. Became so most important define new management tools, as numerical models, for a sustainable use of the groundwater resource. These models permit, for example, to test different recharge scenarios, on the basis of the effect of climate change, for a new sustainable groundwater management. Climate change hypotheses, referred to temperature and precipitation, were deifned on the basis of the model developed by Giorgi and

Lionello, called MGME, or Global Multi Model Ensemble, in relation to the defined scenario A1B (Giorgi and Lionello 2008). In the SEAWAT model also the variation of salinity and sea level rise were considered. An increase of salinity and sea level rise, respectively about 0.005 g/L and 0.05 meters for year, were implemented (Tsimplis et al. 2008). On the basis of annual step, transient piezometric and salinity scenarios of 2000-2020, 2021-2040, and 2041-2060 were elaborated. The results show a dramatic piezometric decrease and an important seawater intrusion increase. Figure 3 shows salinity variation map (layer -50 to -100 m a.s.l.) at 2060,referred to thirties (Fig. 3).

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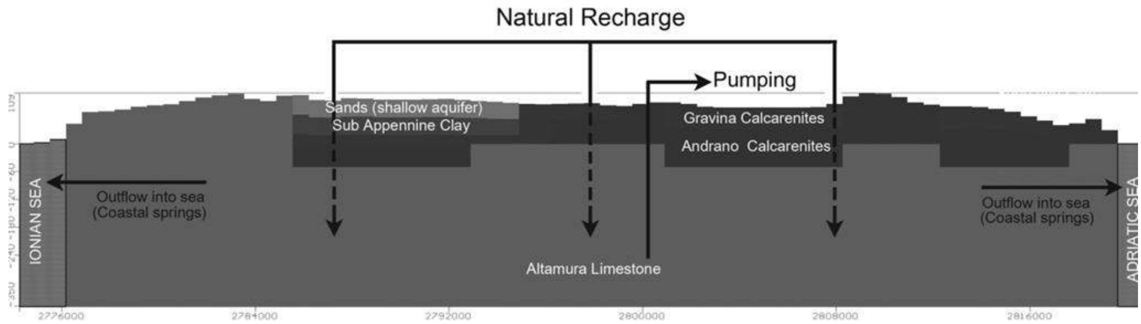

Fig. 2 - Conceptual model of Salento study area. Schematic generic section W-E.

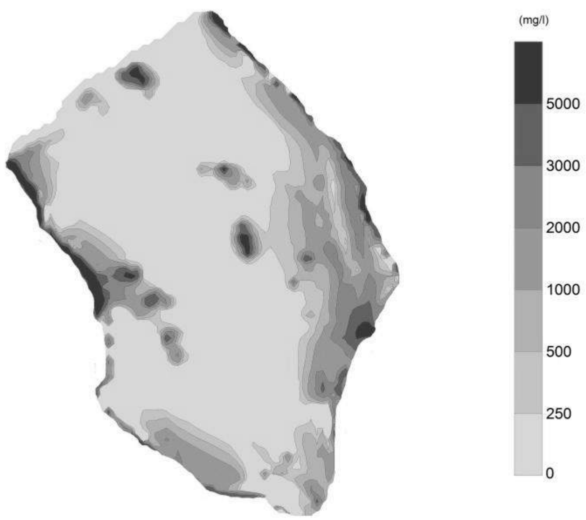

Fig. 3 - Salinity variation map (layer -50 to -100 m a.s.l.) at 2060 (referred to Thirties.

[77] BOTTOM-UP INTEGRATED APPROACH FOR SUSTAINABLE GROUNDWATER MANAGEMENT IN RURAL AREAS

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Keywords: Bir Al-Nas, Groundwater Management**,** IWRM, Cap Bon**.**

Introduction

Groundwater resources represent the largest volume of all unfrozen fresh water on Earth. However the knowledge and understanding of this precious resource is very little, if compared to surface water, especially when considering the general public and policy makers. Nonetheless groundwater abstraction for human needs significantly increased in the past sixty years (Foster and Chilton 2003), playing a major role in agricultural production and the support to rural livelihoods (especially in developing regions; Giordano and Villholth 2007).

For this reason it is of paramount importance to promote groundwater protection and to raise awareness on both its relevance and vulnerability to anthropic pressure. This, on the one hand, implies the implementation of science-based management practices, clearly resulting from sound hydrogeological and hydrogeochemical investigations, but also to start considering the social impacts of scarce and/or polluted water.

Indeed, groundwater resources if carefully managed can significantly contribute in meeting the increasing water demand, sustaining agricultural needs and adapting to global climate change (WWAP 2012).

Based on these assumptions, a bottom-up integrated approach for sustainable groundwater management in rural areas is proposed as a replicable example of a methodology for tackling groundwater issues.

The Bir Al-Nas approach

The need of including groundwater into Integrated Water Resource Management (IWRM) has been widely recognized (Foster and Ait-Kadi 2012), although the complete implementation of integrated approaches still remains challenging and characterized by dominant sectorial approaches.

However, the pressure of population growth, with the associated increase of food, water and energy demand, urge scientist to act in a holistic way when dealing with emerging water pollution and water scarcity issues.

As these problems calls for a prompt action, the Bir Al-Nas approach (Bottom-up IntegRated Approach for sustainabLe grouNdwater mAnagement in rural areas) is proposed as a way to better address management strategies tailored on the real needs and issues of local populations. In Arabic *bir al-nas* means the "well of people" and emphasizes the effective inclusion of the social dimension into hydrogeological investigations.

The overall objective is meant to be achieved through an integrated hydrogeochemical and social analysis, finalized to obtain robust and reliable information for providing advices and supporting integrated management practices for rural development (Fig. 1).

The key aspect of the Bir Al Nas approach is the implementation of socio-economic assessment into hydrogeological investigations evaluating the impacts of human activities on groundwater quality and quantity. In practical terms this is done through:

- A Stakeholder analysis prior the hydrogeochemical and hydrogeological study. This analysis allows for the identification of the main actors involved in the studied water issue, their power relations and possible existing conflicts.
- The direct engagement and confrontation with final water users while performing the monitoring activities. This represents a moment for knowledge and information sharing that can facilitates a better understanding of local issues while also retrieving direct information on groundwater use.

The main rationale behind this approach it that is possible to get people with different interests willing to cooperate and solve water issues only if they fully understand why it is necessary and how they will benefit (GWP 2013).

The Bir Al-Nas approach is currently being tested in the Cap Bon Peninsula, which is one of the main agricultural regions of Tunisia (Ben Hamouda et al. 2011), also interested by groundwater salinization and aquifer overexploitation issues.

The final outcomes are expected to be on the one hand an increase of the awareness of groundwater issues from the rural community, eventually resulting in a more proactive behavior in terms of groundwater protection. On the other hand, from the scientists' perspective, the engagement of farmers and well's owners will favor both the comprehension of local issues and needs, and help bridging the gap between science and society.

Acknowledgements
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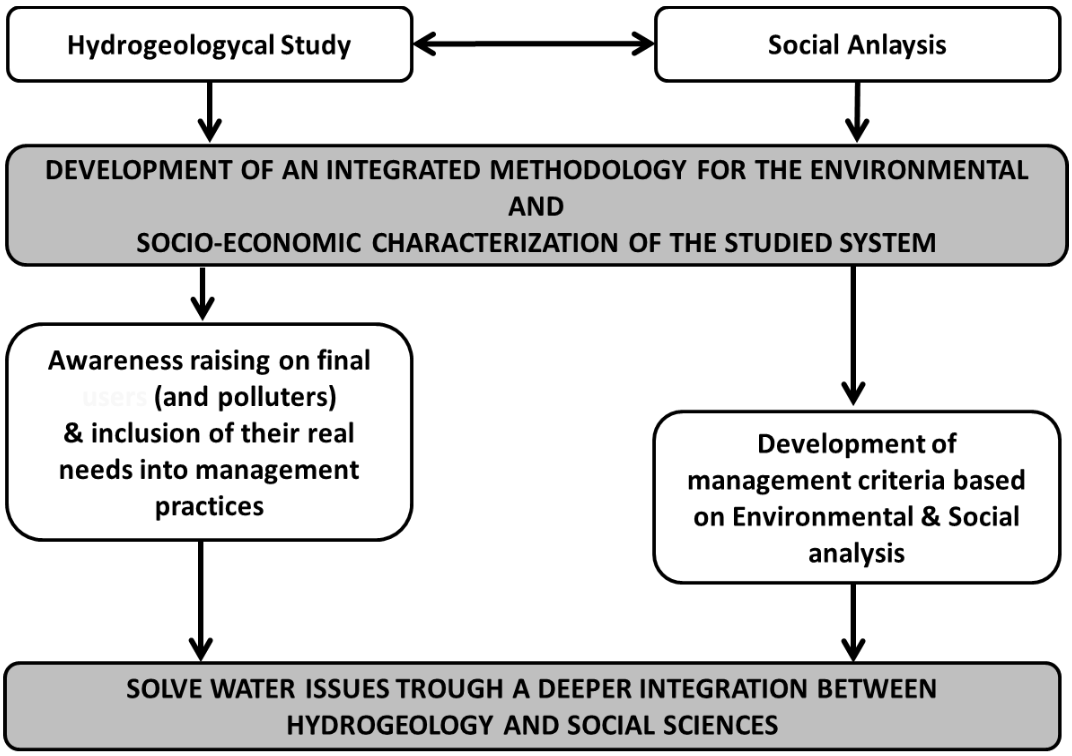

Fig. 1 - Conceptual scheme of the Bir Al-Nas approach..

[78] THE MULINO DELLE VENE SPRING SYSTEM: HYDROGEOLOGICAL FEATURES AND GROUNWATER BALANCE

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Keywords: spring monitoring, groundwater, northern Apennines, climate change, fractured aquifer

Introduction

In the northern Apennines of Italy, as a consequence of both the geological setting of the mountain chain and of the hydrogeological features of the rock masses, the groundwater resources are limited and not well distributed over the territory (Gargini et al. 2008). This scenario will get worse in term of groundwater quantity and quality, if we consider the decreasing trend in effective rainfall as a result of the future climate changes (CCWARE 2014). To better understand the future effects on groundwater resources, it is important to assess the present groundwater resources and to define the aquifers discharge behavior. This work describes the Mulino delle Vene Springs System (MVSS), located in the Reggio Emilia Province, which represents the total discharge area of an aquifer hosted within an epi-Ligurian fractured sandstone formation. The aims of the research are: a) to estimate the total groundwater discharge from the MVSS to the Tresinaro stream, during the depletion period; b) to characterize the discharge and the behavior of the main springs; c) to assess the effect of the last 9 years effective rainfall variation (period 2004-2013) on the main springs discharge.

Test site

The MVSS is located in the upper valley of the Tresinaro stream, at the mean altitude of 425 m a.s.l. (Fig. 1). It discharges from a slab of fractured sandstone (member 4 of the Pantano geological formation, epi-Ligurian Unit, C1 in Fig. 1), with an outcropping area of 5.5 km^2 and maximum thickness of 150 m. The sandstone slab is confined in depth by clayey and marly formations (C2, C3, C4, C5 in Fig. 1), characterized by low permeability (Papani et al. 2002). The MVSS is composed by 3 main springs (S1, S2, S3), while others emerges as small pools. The main springs (S1 and S2) outflow directly from open fractures, the other one (S3) takes origin from the quaternary slope deposits. Only one small spring (S3) is used for domestic purposes, the other ones flow directly into the stream. All the springs flow along an area with side 100 m and located in the left side of the Tresinaro, immediately above the actual stream bed (Fig. 2).

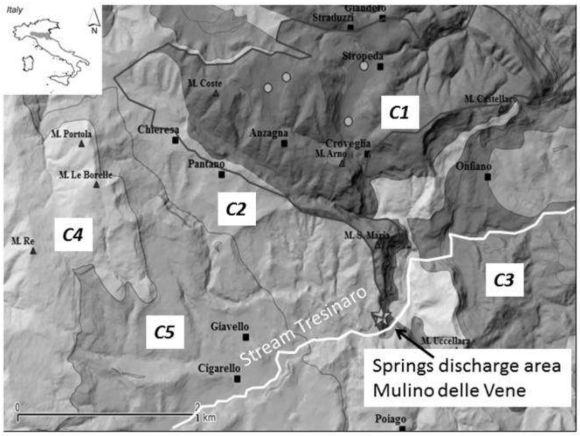

Fig. 1 – Map of the area with the location of springs, the hydrogeological boundary (dark line) and the different hydrogeological units (the permeability degree decreases from C1 to C5).

Fig. 2 – Picture of the Tresinaro stream; view immediately downstream the Mulino delle Vene Springs System area.

Methods

In 2004, S1 and S2 were equipped with 2 stream gauges and discharge data were collected every 2-4 months until April 2012. Since April 2012, the same measures have been conducted monthly. The mean annual discharge of the two gauged springs has been obtained through the sum of the two single discharges (as S1+S2). Furthermore the depletion coefficient of the springs have been estimated with Maillet method. The monthly effective rainfalls for the period 2004-2013 have been calculated using the Thorntwaite's formula and the rainfall and temperature datasets recorded at the weather station of Carpineti (RE) (ARPA-EMR 2014). To assess the MVSS discharge amount out of the 2 gauged springs, measures of the flow rate of the Tresinaro river, upstream and downstream of the MVSS discharge area, were carried out in October 2012 using mechanical current-meter.

Results

In the observation period, the mean annual discharge (as S1+S2) is 33 Ls^{-1}. The minimum and maximum observed annual discharges are respectively 12 Ls^{-1} (year 2007) and 57 Ls^{-1} (year 2013). The recession coefficients of S1 and S2 springs are the following: for the first part of the recession limb 0.006 d^{-1} and for the second part of the recession limb 0.0028 d^{-1}.

In the observation period, the mean annual effective rainfall is 480 mm. The lowest observed value is 155 mm (year 2012), while the highest is 740 mm (2013).

The discharge measures which were carried out along the Tresinaro stream in October 2012, are 6.6 Ls^{-1} (upstream) and 26.7 Ls^{-1} (downstream). During the same month, the S1 and S2 discharges are respectively 5.83 and 0.005 Ls^{-1}.

Discussion and conclusion

The S1 and S2 are among the most productive springs of the Emilia Apennines. Only the high discharge variation plays negatively for a possible drinking purposes. During the drought period, which normally fall in October, S1 is in the order of 5 Ls^{-1} while S2 can even dry out. By considering the drought period occurred in October 2012, a groundwater amount of about 14 Ls^{-1} didn't pass through the 2 stream gauges and outflowed to the Tresinaro river. The discharge measures conducted in the Tresinaro stream during the recession period of MVSS show a strong increase in the flow rate immediately after the springs locations. The increase in the flow rate is 20 Ls^{-1}; where 6 Ls^{-1} are due to the discharge of S1 and S2 and the remaining 14 Ls^{-1} are related to others springs and groundwater that discharges directly in the stream. This fact lead to affirm that a significant amount of groundwater has been not evaluated in the balance of the years 2004-2011. However, it can be reasonably assumed that this last amount is proportionally related to the S1+S2 discharge.

In the period 2004-2013, the S1+S2 mean annual groundwater discharge is changed, resulting strongly influenced by the annual effective rainfall. Drought years, as the 2007 and the 2012 (with effective rainfall equal to 150-250 mmy^{-1}), have been characterized by mean annual discharge in the order of 15 Ls^{-1} (Fig. 3).

In consideration to the future climate change scenarios, which generally forecast a decrease in the total amount of effective rainfall, the groundwater resources of the Mt. S. Maria sandstone will undergo to a slight decrease and, consequently, the MVSS will reduce their total annual discharge.

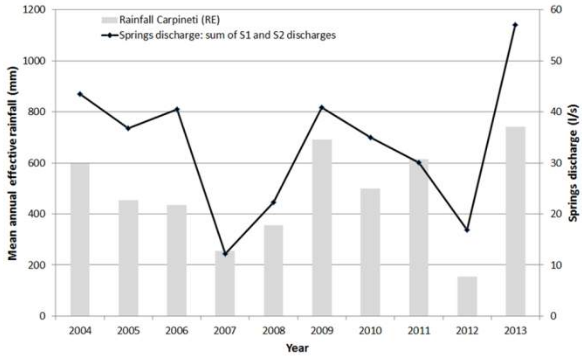

Fig. 3 – Mean annual spring discharges versus annual effective rainfall.

Aknowledgement

This work has been partially supported by CC-Ware EU-Project, Local Coordinator ARPA Regione Emilia Romagna.

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[79] THE SERCHIO RIVER WELL FIELD TEST SITE (LUCCA, ITALY) WITHIN THE MARSOL FPVII PROJECT: MANAGEMENT OF INDUCED RIVERBANK FILTRATION (IRBF)

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Keywords: Managed Aquifer Recharge (MAR), Induced Riverbank Filtration, water scarcity, Mediterranean region, Decision Support System for MAR

Introduction

Southern Europe and the Mediterranean region are facing the challenge of managing its water resources under conditions of increasing scarcity and concerns about water quality. Already, the availability of freshwater in sufficient quality and quantity is one of the major factors limiting socio-economic development. Innovative water management strategies such as the storage of reclaimed water or excess water from different sources in Managed Aquifer Recharge (MAR) schemes can greatly increase water availability and therefore improve water security.

The aim of the MARSOL project (co-financed by the EU under the FPVII-ENV-2013) is to demonstrate that MAR is a sound, safe and sustainable strategy that can be applied with great confidence and therefore offering a key approach for tackling water scarcity.

For this, eight field sites were selected that will demonstrate the applicability of MAR using various water sources, ranging from treated wastewater to desalinated seawater, and a variety of technical solutions. Targets are the alleviation of the effect of climate change on water resources, the mitigation of droughts, to countermeasure temporal and spatial misfit of water availability, to sustain agricultural water supply and rural socio-economic development, to combat agricultural related pollutants, to sustain future urban and industrial water supply and to limit seawater intrusion in coastal aquifers.

Results of the demonstration sites will be used to develop guidelines for MAR site selection, technical realization, monitoring strategies, and modeling approaches, to offer stakeholders a comprehensive, state of the art and proven toolbox for MAR implementation. Further, the economic aspects of MAR will be analyzed to enable and accelerate market penetration; as well as the legal aspects to shed light on the current legislation, both at the national and EU level, and draft a regulatory approach to assess the feasibility of proposed MAR schemes. The MARSOL consortium combines the expertise of consultancies, water suppliers, research institutions, and public authorities, ensuring high practical relevance and market intimacy.

The Serchio River Well Field Test Site

Along the Serchio River (Tuscany –Italy) a series of wells is set for an overall amount of 1 m^3/s pumped groundwater providing drinking water for about 300,000 people of the coastal Tuscany (mainly to the town of Lucca, Pisa and Livorno). Water is pumped enhancing riverbank filtration into a high yield (10^{-2} m^2/s transmissivity) sand and gravel aquifer by artificially rising river head and setting pumping well fields along the river reach.

However, being it un-managed aquifer recharge, concerns arise both for quality and quantity of the abstracted groundwater. It happens in dry climate extremes (i.e. 2002/2003 or 2011/2012) that Serchio River flow falls below minimum environmental flow (MEF). Long term contamination of river water had been causing contamination of groundwater, as in 2002/2006, when pesticide contaminated surface water was polluting the well fields causing several problems to water supply. Such problems were overcome by setting in place derogatory regulations and then through dissemination and stakeholder activities reducing pesticide presence in surface water (EU LIFE SERIAL WELLFIR project 2004-2007). Although widely adopted, it emerged that IRBF is also not soundly disciplined at the regulatory level and this might raise concerns regarding the legal aspects, in particular within the EU framework.

Within the framework of the MARSOL project an experimental site at a well field is going to be set in operation (Fig. 1) to demonstrate the feasibility (by a technical, social and market point of view) and the benefits of managing IRBF versus the un-managed option.

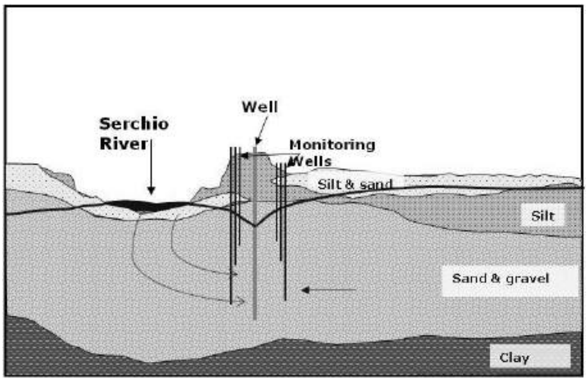

Fig. 1 – Hydrostratigraphy and monitoring concept at the S. Alessio well field.

The Serchio experimental site will involve merging existing and proved technologies to produce a Decision Support System (DSS) based on remote data acquisition and transmission and GIS physically-based fully distributed numerical modeling to continuously monitor and manage well fields, reducing also human operated, error-prone, activities. The DSS along with the installed sensors, data transmission and storage tools will constitute a prototype whose potential market exploitation will be tested.

Site characterization will be completed taking advantage of the MOSAIC on-site investigation platform for subsurface survey (http://www.ufz.de/index.php?en=16349). A set of sensors will be installed and operated to monitor by a quantitative and qualitative point of view hydrologic variables in the river water, in the aquifer, the unsaturated zone and the wells. Data will be continuously acquired and remotely transmitted to a server where they will first be checked for consistency and then sent to a database for processing in a dedicated modelling environment included in the DSS. Hydrogeochemical analysis for selected species will be performed both on surface-/ground-water and pore water.

The DSS combining and integrating measurements and the modelling environment will be developed and equipped with an alert system to inform water managers about the scheme performance and reaching limits of infiltration rates against river MEF or water quality indices. The hydrological and mass transport model will be implemented and calibrated at the demo site. A calibrated and time-variant water budget will be produced at the end of this task.

Fig. 2 – S. Alessio main well field control station. Groundwater from five wells is sent to a single pipe.

Conclusions

The developed DSS including the GIS integrated modelling environment will be applied to the Serchio IRF well field to demonstrate the benefits of switching from unmanaged artificial recharge to Managed Aquifer Recharge (MAR). Applications will involve estimating induced infiltration rates and travel time from surface water to the well fields, optimization of groundwater exploitation in complex well field schemes and performing simulations on pollution events for deriving time estimates and effectiveness of remedial actions to be set in place. All these simulations will be used to draft an operational and contingency plan for the Serchio IRF well field in accordance with the government authorities and the company manager.

Since the successful implementation of a DSS is to be measured not only in terms of traditional marketing metrics, a systemic market assessment will be performed. In particular, after an exhaustive identification of stakeholders, related competences and evolutionary trajectories, economic and strategic performances will be analysed from a systemic respective, thus introducing life cycle thinking principles. Both a comprehensive literature review and in field investigations will inform the analysis. Dissemination activities will include: setting up an Italian network on MAR; focus group for policy makers and group of citizens (associations for the protection of the environment, etc.); training for private professionals (chartered engineers, geologists, agronomists, chemists, etc.) and technicians of public authorities.

Acknowledgements

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[80] APPLICATION OF NUMERICAL MODELING FOR GROUNDWATER-LAKE INTERACTION ANALYSIS, BRACCIANO LAKE (CENTRAL ITALY)

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Keywords: Numerical groundwater model, groundwater-lake interaction, Lake Bracciano

Introduction

Modelling tools are necessary for quantitative assessment of groundwater dependent systems, such as interacting groundwater aquifers and lakes. An analysis of groundwater/lake interactions is presented, focused on the Bracciano volcanic caldera-lake (north of Rome, Italy). Around Bracciano Lake, the human pressure on the water resources has grown in the last 30 years. The effects of global warming are also increasingly evident (IPCC 2007), and are expected to lead to an increase in the use of water. A numerical groundwater flow model was constructed using the finite-difference code MODFLOW2000 and implemented for both steady state and transient (monthly time steps over six years) conditions. There are few available quantitative studies of volcanic lakes in the literature that are capable of incorporating the time dependent effects of development and climate change. The Bracciano model was applied to simulate possible climatic and water-use scenarios to better understand the behavior of an example volcanic lake under multiple stresses.

Main Body

The Sabatini Hydrogeological Unit (SHU) hosts the Bracciano volcanic caldera lake (Mazza et al. in press and reference therein).- Studies indicate that it is in direct contact with the main aquifer (Fig. 1). The area is exposed to continuous stresses from several public and private pumping wells tapping the groundwater aquifer. Over the last thirty years the withdrawals from the aquifer have increased. A second stress on the system is climate change leading to changes in precipitation and temperature conditions, which in turn affect aquifer recharge and the lake water budget.

A numerical groundwater flow model was constructed using the finite-difference code MODFLOW2000 in Groundwater Vistas 6.1 (Rumbaugh and Rumbaugh 2004). A two layer model was built to represent the aquifer. Hydraulic conductivity was assigned to the model based on the results of several well pumping tests made in the Latium volcanic region. Water balance factors such as recharge, evapotranspiration and runoff were calculated on the basis of distributed hydrogeological budget method (Taviani 2011 and literature therein). A spatial interpolation of weather station information including rain and temperature (data over last 40 years), were considered as input values for the model lake simulation. On the order of 2000 pumping wells have been inserted in the model to take account of different uses. Water supplied for potable uses has been estimated from regional water management plan data. Water needed to satisfy agriculture and industry activities was calculated from data taken from Italian statistics institution. A steady-state version of the model was calibrated using PEST (Doherty 2008) to calibrate observed and simulated water level and flux conditions. The lake and tributary streams have been simulated with dedicated MODFLOW packages (Feinstein 2012). The steady-state results provided initial conditions for a six-year transient simulation that extended from 2000 to 2005. Conditions of increased temperature and evaporation were simulated leading to a shift in the importance of the three drivers that control lake level (Net precipitation, groundwater, and surface water inflow).

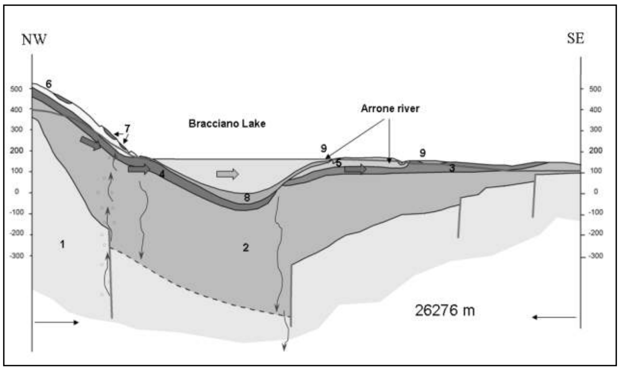

Fig. 1 – NE-SW oriented hydrogeological cross section – 1 undefined pre-volcanic deposits, very low permeability (P) 2. undefined volcanic units, low-intermediate P; 3. tuff deposits, intermediate-high P; 4. tuff deposits, intermediate-high P 5. highly porous tuff deposits, very high P; 6. Pyroclastic fall deposits, very high P; 7. lavas and scoria cones, intermediate-low P; 8. lakebed deposits, low P; 9. Alluvium sediments, P very variable.

The steady state calibrated model yields performing results consistent with the estimated water balance for the lake. Outflows from the model, such as flow to tributaries upstream of the lake, and the surface outflow from the lake draining from the system toward the southern Latium coastal area, also correspond closely to measured values. More than 100 head targets (year 2008) were considered over the model domain. The calibrated steady-state model produced an Absolute Mean Error of 10.2 m for head targets, a reasonable discrepancy for a basin scale model. The use of the model in transient mode furnishes insight into the controls on lake level and flows for example the analysis of the 73 monthly stress periods from the transient simulations shows that changes in lake level are dominated by trends of net precipitation (precipitation minus evaporation), rather than groundwater or surface water inflow (Fig. 2). The model was used to simulate various scenarios, including a drought (reduced recharge by a 0.9 factor and increased lake evaporation by a 1.1 facto), which led to a gradual decline of the lake level equal to 0.3 m after six years compared to the calibrated base case. The model shows that an increased groundwater contribution (due to stronger aquifer gradients toward the lake) partially compensates for decreased precipitation.

The Bracciano model can be considered as a case study for volcanic lakes that are well connected with groundwater. The on-going objective is to test the vulnerability of such systems to anthropogenic and climatic stresses by using sophisticated modeling techniques and stress representations that account for the time-varying mechanisms which jointly control the aquifer and lake water budgets.

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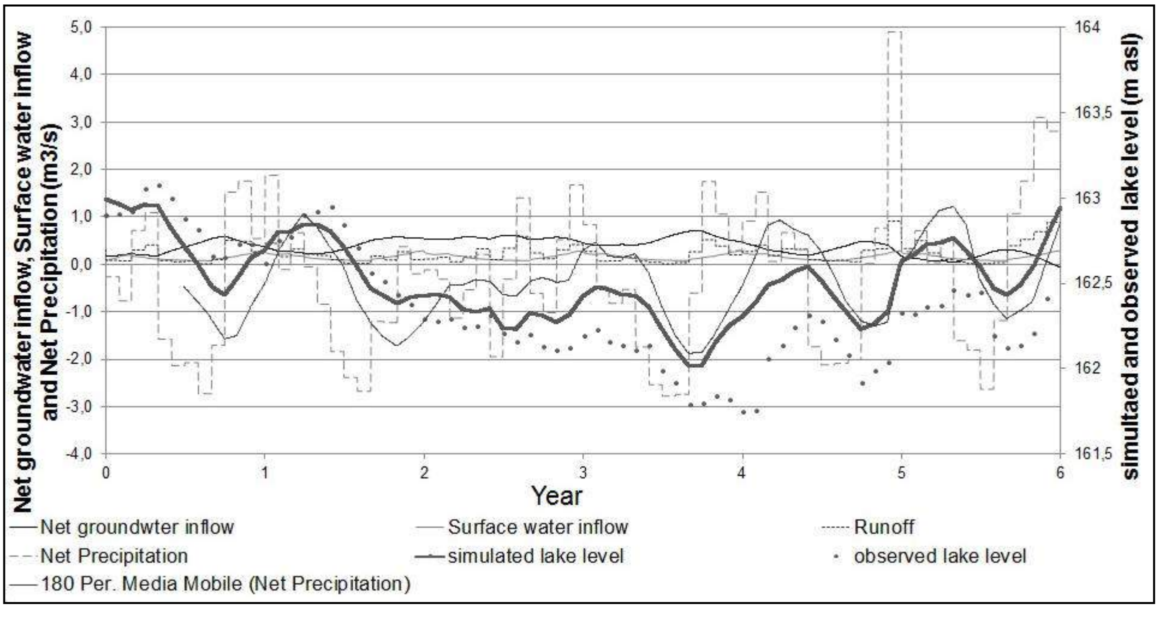

Fig. 2 - Observed and simulated lake level from transient simulation. Component of lake hydrologic water balance: Net groundwater and Surface water inflow; Runoff; Net precipitation (NP) and 6 months moving average NP.

[81] RELATIONS BETWEEN SNOWFALLS AND FLOODS OF SOME SPRINGS FED BY AQUIFER HOSTED IN CARBONATE ROCKS (SOUTHERN PIEDMONT - ITALY)

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Keywords: snow, monitoring, snow melting flood

Work performed within the Project Alirhys – ALCOTRA

Introduction

The increase of the globally air temperatures, with a variation of the amount of snowfall, can significantly affect the aquifers recharge. In this work we want to emphasize, that for dry winter seasons, the spring discharges is very low and the spring flood is very short. In contrast, during the snowy years, the spring hydrographs show high flow rate (from March to summer), especially in cases of low-permeability aquifers (De Walle 2009; Vigna and Suozzi 2009).

In Piedmont, the most important spring water resources are located at the base of important carbonate massifs. The recharge areas of these springs are located at high altitude, whereby the main annual precipitation are snowy.

From November to March, in general, the spring discharge are rather low. The infiltration, in fact, is quite limited because the snowpack, that accumulates progressively during the winter, does not melt due to low air temperatures. From early spring, the spring hydrographs show increases of flow rate, linked to the beginning of snow melting in the areas located at a lower altitude of the recharge areas. With the increase of air temperature and the occurrence of rainfall on the snowpack, the infiltration rises, causing a significant grow of the discharge values.

The spring flood can last until summer months and in the systems with delayed response (fractured aquifers) until early autumn.

The contribution of snow is extremely important for aquifer recharge, because melting is extend over time and melting water occurs in small daily volumes: these factors favor the infiltrative events. On the other hand, such a result of heavy rainfall, particularly in low permeability aquifers, the rate of infiltration is reduced due to the high runoff.

To better explain these situations, it was examined data of spring discharge (since 2006) of four springs monitored by Politecnico di Torino (Italy). These springs, located in the south of Piedmont (Italy), are fed by aquifers set in carbonate rocks. The aquifers are characterized by different types of circulation (springs: Fuse, Borello superiore, Dragonera, Tenda).

Description

Follows, a brief hydrogeological description of the four monitored springs and the aquifers that feed them. The elevations of the four spring catchment areas are comprised between 1000 m a.s.l. and 2500 m a.s.l.

Fuse spring is fed by a highly karst aquifer that mostly receives water from rainfall (primary recharge; Vigna 2013). Borello superiore spring, caught for drinking water, is partly fed by a karst aquifer and in part by water runoff on the metamorphic basement rocks (secondary contributions). Part of this water infiltrates in glacial deposits located over limestone. Dragonera spring, caught for drinking water, is fed by an aquifer host in highly fractured carbonate rocks. Close to the discharge area, the aquifer is characterized by the presence of phreatic karst conduits. Tenda spring, caught for drinking water, is fed by an aquifer host in highly fractured and poorly karst limestone.

The effects of the snow melting floods are recognizable for a series of daily oscillations in highly permeable aquifers. These daily variations (Fig. 1) are strictly connected with daily trend of air temperature and can last until the summer.

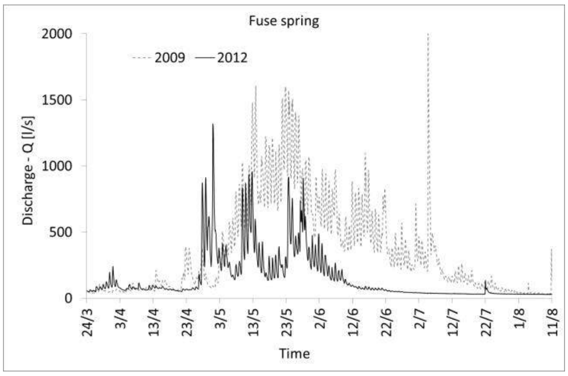

Fig. 1 – Spring flood of Fuse in 2009 and 2012.

Generally, the volume of the spring flood is significantly higher than the sum of the volume of flood of the other periods of the year. In the less permeability aquifers, it is observed only a great flood that can last until the autumn season. This trend is clearly visible in Tenda spring hydrograph (Fig. 2), where the contribution of the snow melting process conditions the flow rate until autumn.

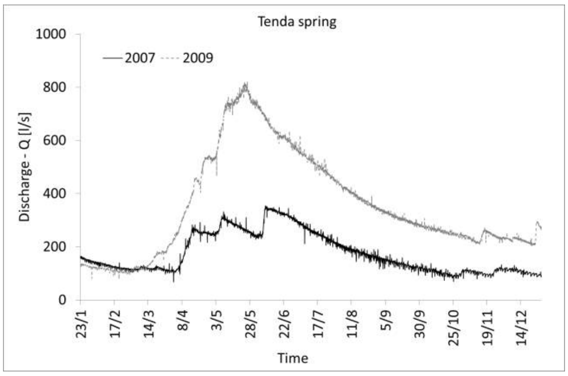

Fig. 2 – Spring flood of Tenda in 2007 and 2009.

In this study we was examined height of snow trends in several years. Data are measured and recorded at two meteorological stations of ARPA Piemonte (a local environment office). The stations are located in proximity of the spring catchment areas. These meteorological data were compared with the trend of the flow rate of the four examined springs. It is possible to put in evidence the connections between the height of the snow and the total volume discharged during these spring seasons (Figs. 3 and 4).

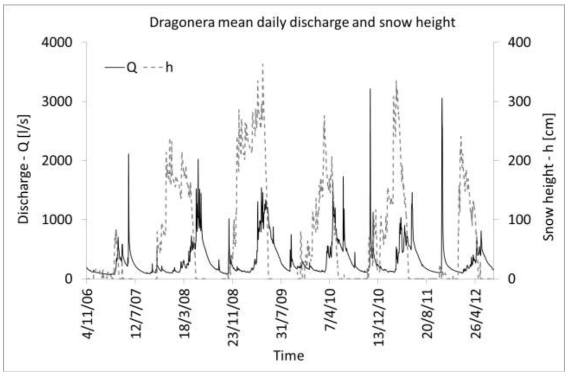

Fig. 3 – Pluri-annual trend of Dragonera data.

In particular, the data of spring discharge linked to a dry winter are compared (season 2006-2007 - Figs. 2, 5 and 6), with those connected to a very snowy winter (2008-2009). For Fuse spring, it was considered the 2011-2012 period, such as dry winter, because in 2006-2007 water levels data logger was broken (Fig. 1). Each system is characterized by different floods related to the type of aquifer.

Conclusion

With the gradual increase in winter temperatures, in the future, snowfall may be reduced, affecting the spring hydrodynamic. This paper highlights the close relationship between snow height and trends of the main annual floods related to snow melting in different kind of aquifers in dry and wet winter seasons.

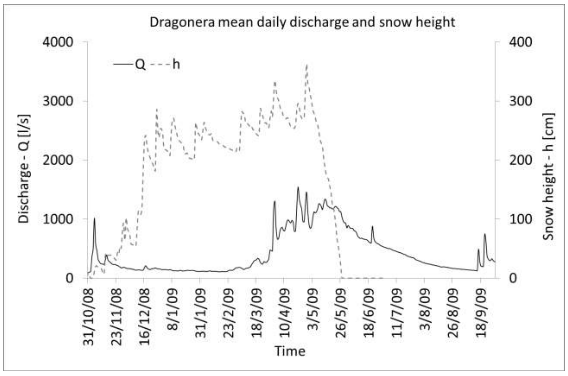

Fig. 4 – Annual trend of Dragonera data.

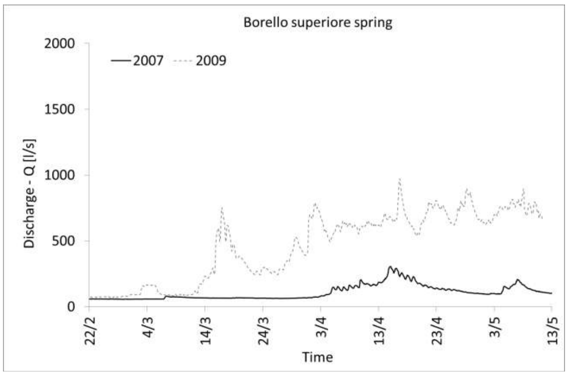

Fig. 5 – Part of spring flood of Borello superiore in 2007 and 2009.

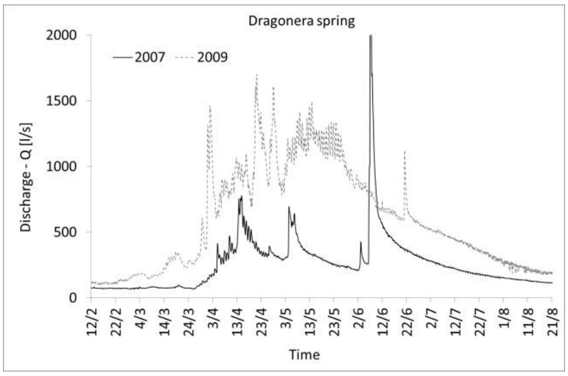

Fig. 6 – Spring flood of Dragonera in 2007 and 2009.

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