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THIRD EDITION
National Meeting
on Hydrogeology

Conference Proceedings

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PREFACE

FLOWPATH 2017, the 3rd National Meeting on Hydrogeology, was held in Cagliari, from 14th to 16th June, 2017. According to the aim of the previous Editions of FLOWPATH (Bologna, 2012 and Viterbo, 2014), the conference has been an opportunity for Italian hydrogeologists to exchange ideas and knowledge on different groundwater issues.

This volume includes 77 peer-reviewed manuscripts submitted by scientists from more than 15 countries in Europe, USA and Africa. They are representatives of academic and professional word, in accordance whit the mission of the IAH Italian Chapter that is committed to ensuring the continuation of debate on different groundwater issues within the scientific and professional community, giving priority to proposals and ideas of young hydrogeologists.

Furthermore, 4 keynote lectures presented by invited international high ranking scientists are included in the conference proceedings.

The members of the Scientific Committees evaluated the abstracts.
The FLOWPATH 2017 was organized at the Department of Chemical and Geological Sciences; co-organizer was the IAH Italian Chapter, in particular Daniela Ducci, Sergio Rusi and Marco Petitta.

The conference focuses on four themes of great importance:

1. Groundwater quality protection
2. Hydrogeology of fractured rocks and karst aquifers
3. Groundwater flow and transport modelling
4. Groundwater management in arid and semi-arid region

The content of the Conference Proceedings is organized according to the four topics of the conference. The keynote lectures open the Sessions were they were presented, followed by the technical contributions in alphabetical order by first author's family name, at each session.
In order to facilitate the use of the volume, the Index of Authors is placed at the end of the volume.
The Conference has been supported by the University of Cagliari, by the Department of Chemical and Geological Science, Ferrarelle SpA, AQA srl, HCC group and MBT di Mario Armeni, FLOWERED (an EU H2020 Project coordinated by Giorgio Ghiglieri) and Engineering Service, Sardinia. Ferrarelle SpA provided the water during the Conference and Cantina Sociale di Santadi offered Sardinian products. We wish a special thanks to the Convitto Nazionale Vittorio Emanuele for hosting us during the coffee breaks and lunchtimes, and ITIS Baccaredda-Atzeni for the collaboration. The Comune di Portoscuso hosted the delegates for the lunchtime during the field trip and collaborated to its organization. The Comune di Iglesias allowed us a free visit in the wonderful site of Porto Flavia and provided brochures and tourist materials. Tourist materials were also provided by Comune di Cagliari.
This volume is published online at http://ojs.unica.it/index.php/flowpath2017/index, were DOI and ISBN codes are provided. We wish a special thanks to Sandra Astrella, Maria Franca Lorenzoni and Alessandra Moi for the implementation of the conference proceedings in the UniCA Open Jornals Platform and the UniCA Library System for addressing the challenges of Internet to distribute knowledge in accordance with the Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities.
A special thanks to Cristina Buttau for spending a great deal of time and weekends helping us in many issues, and also in creating the logo, which is now the symbol of the Conference held in Cagliari.

Thanks also to Sonia Aldana Martinez and Gabriela Afrasinei, Claudio Arras, Salvatore Vacca and Marco Pistis for their contribution.
Finally, we wish to say thanks to Antonio Funedda for walking us through the interesting geological peculiarity of the Sulcis-Iglesiente area during the field trip.

Editors:
Giorgio Ghiglieri
Stefania Da Pelo

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SESSION 1

Groundwater quality protection

Chairs: S. Da Pelo, D. Ducci, M. D. Fidelibus

Keynote lecture

GEOCHEMICAL BACKGROUND VALUES IN AQUATIC SYSTEMS

Rosa CIDU [1], Riccardo BIDDAU [1]

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European (Dir. 2000/60/CE, 2006/118/CE, 2014/80/EU) and Italian (Legislative Decrees 152/2006 and 30/2009) regulations require the chemical classification of water bodies, as compared to threshold values established at national level. In undisturbed environments, chemical compositions of waters depend on a series of processes involving the interaction of water with mineral and gas phases. Such processes result in the natural composition of water, i.e. the background condition. According to European rules, natural background values of dissolved substances are defined as concentrations corresponding to any or very minor anthropogenic alterations, with respect to undisturbed conditions. Threshold values are derived from background estimates and correspond to the upper limits of background variations.

Hydrogeochemical background values depend on different factors, such as climatic conditions (temperature, rainfall input and rate), chemical and biological processes, reactivity of minerals with which the water comes in contact from recharge to discharge areas, residence time and mixing processes (Appelo and Postma, 2005). Therefore, background values in natural waters are usually characterized by large spatial variations at a range of scales (Edmunds et al., 2003).

Human activities may alter background concentrations of constituents in the water. Inputs of pollutants to aquatic systems are often derived from inappropriate management of urban, agricultural, industrial and mining wastes. Specific pollutants, such as dissolved inorganic components, may derive from both natural and anthropogenic sources. Therefore, the knowledge of processes affecting water quality and the estimation of natural background ranges is crucial for distinguishing natural from anthropogenic sources of aqueous components.

From a regulatory point of view, the definition of threshold values is mandatory for the regional authorities that have to address a sustainable management of water resources. To this purpose, in order to properly classify the water bodies, it is imperative to have a comprehensive geochemical and hydrological understanding of aquifers, especially to avoid classification in bad status those water bodies that occur in natural hydrogeochemical facies.

Background ranges are generally estimated following statistical approaches. Calculations using the mean±2SD (SD = standard deviation) have been frequently used to assess the background ranges, implicitly assuming a normal distribution of values (Matschullat et al., 2000). However, geochemical data are usually heavily skewed and rarely follow a normal distribution, therefore, using the mean±2SD is considered inappropriate (Edmunds et al., 2003). The use of the median±2MAD (MAD = Median Absolute Deviation) has been suggested for skewed geochemical data (Reimann et al., 2005). Integrating different estimators provides more reliable background and threshold estimates (Matschullat et al. 2000).

Chloride, sulfate and fluoride are regulated components in water destined to human consumption. Background values of these components were estimated integrating geochemical, hierarchical cluster (Templ et al., 2008) and Geographical Information System (GIS) methods.

The water chemistry was investigated on the basis of dissolved components Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, SO_4^{2-} and F^{-}. Background concentrations of chloride, sulfate and fluoride were estimated for each group of waters identified by cluster analyses. The GIS method was used for mapping and spatial visualization. This research was carried out in Sardinia (Italy). Because industrial activities and intensive agriculture occupy only minor parts in Sardinia, and the population is mostly concentrated in few towns, large areas are potentially unaffected by anthropogenic impacts. Such characteristics allowed to consider Sardinia a good site for assessing near-pristine conditions of water quality. The geological heterogeneity of the study area, i.e. aquifer lithology made up of siliciclastic to carbonate predominant rocks, with ages spanning from Cambrian to Quaternary, and a comprehensive dataset acquired from regional and local surveys, provided an additional value in estimating the background concentrations (Cidu et al., 2017).

Hierarchical cluster analysis allowed to identify hydrogeochemical groups of waters statistically distinguished (dataset: 1553 groundwater samples). Each water group was associated with the predominant lithology constituting the water bodies. Values of total dissolved solids (TDS) were a major distinguishing factor in principal clusters, whereas relative proportions of major cations and anions, and median nitrate and fluoride, distinguished the sub-clusters. Chloride and sulfate threshold values above regulations were observed respectively in water from sediments and volcanic rocks, and water interacting either with sulfides or gypsum (Table1). These threshold values should be considered as upper limits in evaluating the good status of water bodies in Sardinia.

Table 1. Threshold values of chloride, sulfate and fluoride in principal clusters. Values in bold are above Italian limits of 250 mg/L (Legislative Decrees 152/2006)

		Threshold values		
Cluster	*Predominant lithology in water bodies*	*Chloride*	*Sulfate*	*Fluoride*
		mg/L	mg/L	mg/L
G1	Quaternary & Tertiary sediments	**422**	135	0.67
G2	Quaternary basalts & granitic rocks	155	59	0.45
G3	Quaternary & Tertiary sediments - volcanic rocks	**1280**	**446**	1.33
G4	Mesozoic & Paleozoic carbonatic rocks	180	103	0.64

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HYDROGEOLOGICAL AND HYDROGEOCHEMICAL MONITORING IN THE CUMAE ARCHAEOLOGICAL SITE (PHLEGRAEAN FIELDS, SOUTHERN ITALY)

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The Cumae archaeological site is extended over about 2.0 km2 along the Tyrrhenian coast of the Campania region (southern Italy), in the western sector of the Phlegraean Fields active volcanic field (Celico et al., 1991; Celico et al., 1992), about 10 km of the Naples city. It is the first Greek colony in mainland Italy, was founded in the 8th century B.C., and the site remained continuously occupied until the 12th century A.D.. Cumae site hosts an important archaeological park, among the most visited of southern Italy, located inside the Phlegraean Fields Regional Park and of the wetlands of the Mount of Cuma's Forest.

During the Holocene epoch, it has changed significantly, due to endogenous and exogenous phenomena, such as volcanic eruption and eustatic sea-level variations, associated to the creation of lake environments and palustrine wetlands. As a result of these natural processes, the coastal plain is characterized by a complex volcanic-sedimentary sequence formed by sands, silts, clays and volcanoclastic sediments, resting on a substrate of yellow tuffs and trachytic laves, outcropping in the surrounding reliefs.

A hydrogeological and hydrogeochemical monitoring from December 2013 to February 2015 on 13 wells (6 shallow wells and 7 deep wells), together with radon levels determination in groundwater have been carried out, with a monthly frequency. The study was motivated by the frequent flooding of archaeological excavations due to the rise of groundwater level, which threatens the integrity of ancient Roman ruins and the continuation of archaeological researches. Therefore the reconstruction of a comprehensive hydrogeological model of the archaeological site was considered an important goal to achieve for designing mitigation measures of hydrogeological risk.

The hydrostratigraphic and hydrogeological data allowed recognizing a multi-layered aquifer system, formed by shallow unconfined and deep semi-confined aquifers. The groundwater flow was assessed being strongly controlled by vertical and lateral lithological heterogeneities of volcanic-sedimentary deposits, as well as by groundwater pumping and drainage channel system. The dominant hydrochemical facies were Cl^--SO_4^{2-}-Na+-K+, HCO_3^--Ca^{2+}-Mg^{2+} and HCO_3^--Na^+-K^+ types. Variations in space and time of the hydrochemical facies were affected

by: i) dissolution and chemical weathering, ion exchange with volcanic-sedimentary deposits, ii) localised rise, along faults and fractured zones of the western edge of Campanian Ignimbrite caldera boundaries, of deep and highly mineralized fluids, indicated by outstanding levels in deep groundwater of F-, 6.4 mg L-1, and 222Rn, 31,500 Bq m-3, and in shallow groundwater, respectively with 3.3 mg L-1 and 5400 Bq m-3; iii) freshwater-saltwater interactions, induced by groundwater exploitation.

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URBAN GROUNDWATER WARMING IN TURIN AREA (NW ITALY)

Arianna BUCCI [1], Diego BARBERO [1], M. Gabriella FORNO [1], Manuela LASAGNA [1], Domenico Antonio DE LUCA [1]

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The large energy demand for heating and cooling of buildings has motivated a new interest for low enthalpy geothermal systems. For this reason shallow groundwater temperatures are nowadays regarded as highly important in Turin area (NW Italy). The area is located in a favourable geological context for geothermal applications: a thick alluvial body, forming the Po Plain, hosts a productive groundwater system. To assess the thermal features of the shallow, unconfined aquifer, thermal surveys in Turin city and in surrounding rural sectors have been carried out.

Multi-temporal downhole thermal logs have been performed by collecting temperature values along the entire water column (8-50 m depth) in various seasons, by means of an electronic water level meter equipped with thermometer.

Temperature profiles in Turin area highlighted a vertical variability up to 10-20 m below ground level: in spring logs the deep temperatures are higher than the shallow ones, while in autumn shallow temperatures are higher and they decrease with depth. Such depth and time variations are connected to the seasonal heating and cooling cycles of air temperatures. Furthermore, the seasonal temperature oscillations are smaller with greater water table depths, meaning that they are damped in the vadose zone. Underneath the seasonal oscillation zone, groundwater temperatures are spatially constant in most wells and residual small deviations are connected to hydrodynamic processes, such as upward or downward water movements of recharge and discharge areas.

Lateral variations of aquifer temperature have been also detected: there is an increase from high plain sectors close to the Alps towards the Po River, which is consistent with the regional groundwater flow direction. This means that colder temperatures of recharge areas -due to colder air temperatures- warm up during the pathway towards the discharge areas. Warmer temperatures are found below the city is likely linked to the large urbanized area: the urban warming intensity is +1.6°C in spring and +0.6°C in autumn. Sparse warm outliers (>17 °C) are connected to punctual heat sources and site-specific conditions, such as geothermal systems, industrial districts.

ENVIRONMENTAL CONCERNS OF BOREHOLE HEAT EXCHANGERS (BHE): THE ROLE OF HEAT-CARRIER FLUID AND GROUTING

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Borehole heat exchangers (BHE) are vertical loops placed into the subsurface to use the ground as a heat source/sink for domestic heating and/or cooling. The interest for environmental sustainability of such green renewable technology has been rising in recent years. The main concerns for groundwater quality regard the chemical riskiness of additives used in heat-carrier fluids circulating into the ground loops and inter-aquifer flow linked to defective borehole grouting.

In Italy the most common additive in BHE loops is the propylene glycol (PG), used for its anti-freeze properties. Introducing such organic compound into aquifers may enhance microbial activity and trigger alterations in redox conditions, with harmful consequences on groundwater, such as mobilization of heavy metals. The magnitude of metal release was investigated by means of microcosms, composed by a sandy sediment saturated with groundwater collected in two sites -one urban and one rural- in Turin Po Plain (NW Italy). In each microcosm an initial mass concentration of PG of 1% was set and the concentration of three Fe, Mn, Ni was monitored up to 60 days. Metals concentrations in water after 60 days reach nearly 104 µg/L for Mn, whereas Fe and Ni reach 400 and 1600 µg/L respectively. Such metal release is likely due to increase in microbial activity, stimulated by the PG, and the consequent change in redox conditions. In all cases the final concentrations are above the permissible quality thresholds for Italian standards: 200, 50 and 20 µg/L for Fe, Mn and Ni respectively. Triazoles (common corrosion protective agents in heat carrier fluids) were also detected in both fluids: concentrations (~0.05%) may be toxic for standard test organisms.

Concerning the second environmental concern, if the grout is uncomplete or damaged, there may be a hydraulic flow across the BHE and consequent groundwater quantity and quality degradation in multi-aquifer groundwater systems, such as the Piedmont Po Plain. To assess the grout integrity, a 7.5 m-long pilot BHE was installed in the SW Piedmont Po Plain. Many defects and void spaces were visually detected, likely due to the heterogeneity of the geologic medium (coarse gravels). Such observations were consistent with results from ultrasonic tests performed during and after grout maturation. A simplified analytical model was applied to detect the magnitude of the possible downward flux from shallow to deeper confined aquifers. The computed magnitude is up to 2.65 m^3/d in the worst scenarios with high head differences and thin separation layer. Such entity of inter-aquifer flow may lead to significant contaminants propagation from the shallow aquifer of Piedmont Po Plain, in which plumes are often found.

The two experiments indicate that carefulness is needed during BHE planning and installation phases. Additives for heat-carrier fluids of BHE loops should be avoided, if possible, and limitations should be proposed for new drillings in deep aquifers.

SPECIFIC VULNERABILITY OF THE CASERTA PLAIN (IT) TO NITROGEN LOSSES

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The use of nitrogen (N) fertilizers in agricultural fields and the increasing urbanization are among the most important non-point sources of pollutants. Efforts to identify and reduce N loads percolating towards shallow aquifers led scientists to develop various tools for groundwater vulnerability assessment. The aim of the study is to propose an integrated approach for vulnerability assessment combining indices of low data requirements to describe the vulnerability to nitrogen species for a) the topsoil using LOS (Aschonitis et al. 2013), b) the unsaturated zone using AVI (Van Stempvoort et al. 1992) and c) the aquifer system using SINTACS (Civita and De Maio 2004). This attempt aims to change the current perspective of the vulnerability maps from two-dimensional (latitude, longitude) to four-dimensional visualization by adding the dimensions of depth and time. The Caserta Plain (IT), was selected as case study due to its high population density and to the intensive agricultural activities. The application of the proposed approach to the study area, highlighted the strengths and weaknesses of each method and at the same time showed that their combination can provide an overall view of the threats posed to groundwater resources by the human activities affecting the territory. Considering both the benefits and the issues of the proposed approach, overall the combination of the aforementioned indices can be employed as a robust tool to assist water managers in establishing detailed monitoring programmes and measures to achieve the Water Framework Directive objectives of good groundwater status.

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WATER-BUDGET AS A TOOL TO EVALUATE THE SUSTAINABLE USE OF GROUNDWATER RESOURCES (ISONZO PLAIN, NE ITALY)

Chiara CALLIGARIS [1], Giacomo CASAGRANDE [2], Daniela IERVOLINO [3], Federica LIPPI [3], Paolo OLIVO [3], Massimo RAMANI [3], Francesco TREU [1], Luca Zini [1]

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Climate change and the necessity to preserve and provide good quality freshwater for human consumption has led researchers to study the aquifers of the Friuli Venezia Giulia Region (NE Italy) in more detail. Of particular interest is the Soča/Isonzo River basin, which contributed to the creation of a remarkable alluvial aquifer. The mountain basin of the Soča/Isonzo River extends into Slovenia and has an area of 1500 kmq. After about 100 km the river reaches the Isonzo plain. Before outflowing into Italian territory, the Salcano dam in Slovenia regulates its discharges. Once in the plain, the Isonzo leakages contribute to the recharge of an extensive alluvial unconfined aquifer, which evolve southward into a multi-layered confined aquifer before outflowing into the Adriatic Sea after 40 km. The aquifers greatly differ from a textural viewpoint: the northern part of the plain, the so-called High Plain, is more gravelly, while the Low Plain in the southern part, mainly consists of finer deposits that go from gravel to sand and silty sand.

Today more than 300.000 inhabitants are supplied by water withdrawals from AcegasApsAmga Hera Group and the IrisAcqua water companies, the water wells of which are located in the southern part of the High Plain. Taking into consideration the importance of this area for the inhabitants of the provinces of Gorizia and Trieste, in order to guarantee the sustainability of the actual use of the water resource, the necessity has arisen to compute a groundwater balance. The leakages of the Soča/Isonzo River and the effective infiltrations constitute the water balance input parameters. Outflow, evapotranspiration, spring discharges and groundwater withdrawals estimated for each type of use and for each aquifer system have been evaluated.

Withdrawal entity, resurgence belt discharge, phreatic levels and confined aquifer pressure are closely interdependent and in dynamic equilibrium. The sustainability of the actual use of the resource comes from the consistency and ratio between recharge and withdrawals. The more detailed and precise the input values in the water balance are, the more conscious is the management and safeguarding of this precious resource, avoiding pauperization in terms of quantity but especially quality.

Within the framework where trends in rising temperature are clear, (2014 and 2015 were the hottest years of the last century), trends in precipitation are not clearly indicated, groundwater balance can be understood as a starting point for any future planning.

ASSESSMENT OF BIOGEOCHEMICAL PROCESSES INVOLVED IN NH_4^+ AND NO_3^- ATTENUATION PROCESSES. EVIDENCES FROM DIFFUSE AND POINT SOURCE CONTAMINATION SITES BY A MULTI-ISOTOPIC APPROACH

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Increasing anthropogenic loading of reactive nitrogen (N) along the N cascade in the environment raises many concerns for drinking water quality, human health, freshwater ecosystems and coastal water degradation.
High-resolution vertical isotope data ($\delta^{15}N_{NO3}$, $\delta^{15}N_{NH4}$, $\delta^{18}O_{NO3}$, $\delta^{34}S_{SO4}$, $\delta^{18}O_{SO4}$ and $\delta^{13}C_{DIC}$) have been adopted to gaining insights into N species origins, fate and related attenuation processes in groundwater. Evidences from an anthropogenic impacted alluvial coastal aquifer (ACA) and a septic system plume (SSP) are presented as indicative of diffuse and point source contamination, respectively. Common stand-points for both sites relies on groundwater reducing conditions and elevated ammonium concentrations (up to 68.25 $mgNL^{-1}$ for the ACA and 40.61 $mgNL^{-1}$for the SSP).
Groundwater in the ACA is characterized by high DOC, DIC and sulphate concentrations but low to moderate methane content. $\delta^{15}N$ results suggested a geogenic source for the elevated ammonium in the ACA, originating by the mineralization of N-organic rich fine sediments (1÷3‰) while nitrate derives by septic effluent leaching (12÷15‰). Attenuation processes of ammonium are ruled by dilution and by nitrification, witnessed by the $\delta^{15}N_{NH4}$ enrichment (~7‰). The positive correlation between $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ agreed with the occurrence of heterotrophic denitrification. In the shallow part of the aquifer, $\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$ data highlight that oxidation of pyrite occurs but is not necessarily linked to nitrate removal. At the bottom of the aquifer, sulphate depletion together with sulphur and oxygen isotopes enrichment, testifies that sulphate reduction occurs via anaerobic methanotrophy (-40.4‰) coupled with sulphate reduction.
A well-characterized cross section in the SSP showed chloride remarkably uniform across the plume, suggesting that it is composed of straight sewage and excluding dilution effects. The total N in the septic tank is present as ammonium (40.54 $mgNL^{-1}$) which is abruptly attenuated at the bottom of the plume and at distal monitoring locations. Conversely, nitrate, here a by-product, significantly increases downgradient the source zone revealing peak values in the upper fringe of the plume (58.01 $mgNL^{-1}$). N and oxygen isotope signals ($^{15}N_{NH4}$, $^{15}N_{NO3}$,

$^{18}O_{NO3}$) suggest that multiple attenuation processes take place in the SSP: (i) nitrification in the unsaturated zone and shallow part of the plume, where high nitrate concentration is accompanied by depleted $\delta^{15}N_{NO3}$ (57.50 $mgNL^{-1}$ and -3.2‰, respectively), (ii) denitrification where nitrate concentration decreases (<1 $mgNL^{-1}$) with an enrichment trend for $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ (up to 44.8‰ and 26.8‰, respectively). Moreover, isotopes signals demonstrate that anammox activity is associated with N natural attenuation for which a concurrent enrichment of ^{15}N in both nitrate and ammonium is observed (up to 40‰).
From a comparison of the two investigated sites is apparent the variety of biogeochemical processes that can occur in the subsurface, which can be untangled only by using a complete suite of hydrogeochemical analyses (major and minor water species and stable water isotopes) coupled with high resolution multi-level sampling techniques. This study remarks the advantage of stable isotopes as a tool for tracing origin and attenuation processes in N cycle, especially in complex hydrogeological setting where steep geochemical reactions overlap.

THE HYDROGEOLOGICAL MONITORING OF AN EXPERIMENTAL SITE IN CAMPANIA FOCUSED AT THE EVALUATION OF THE CONTAMINANTS TRANSFER FROM THE SOIL

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In the framework of the Life_Ecoremed Project, aimed at the remediation of contaminated soils, some experimental sites, including one in the town of Teverola (Campania) covering about 1900 m^2, have been identified and studied.
The stratigraphic succession of the site has been defined by drilling 8 boreholes, 5 of them with continuous core recovery. Groundwater has been characterized and monitored by means of periodic piezometric measures, sampling and chemical analyses, and by means of a multi-parametric probe measurements: piezometric level, temperature, electrical conductivity and TDS. These activities were especially aimed at assessing the transfer of specific pollutants (Be and Sn) from the soil toward the groundwater table.
The subsoil consists of some meters of loose pyroclastic rocks, with levels of peat, above a clayey paleosoil (from 2 to 5 meters); these sediments overlay a tuff (Campanian Ignimbrite), locally unwelded. The paleosoil, almost impervious, determines the presence of two aquifers; one in the pyroclastic rocks above the paleosoil and the other one in the tuff. This last aquifer is confined and the groundwater level is higher (about one meter) than the level in the shallow aquifer. The groundwater flow direction in the two aquifers is quite different. The water table of the shallow aquifer is 2-3 meters below the ground level and his closeness to the ground level makes it more susceptible to contaminants transfer. The average hydraulic conductivity of this aquifer, evaluated by slug tests and pumping tests, is 5.4 x 10^{-4} m/s and the thickness of the saturated zone is about 7 m.
The groundwater chemical analyses have been screened, almost monthly for major ions and the contaminants present in the soil (Be and Sn). A strong nitrate contamination was identified and also a sector affected by a reducing environment was individuated. The contaminants present in soil have been found in groundwater only in low concentrations (< 1.0 µg/L), steady during the yearly monitoring, despite the low depth of the water table. The data of the multi-parametric probe were analyzed and modeled with different aims: a) groundwater levels vs rainfall for the recharge time and b) change in the chemical composition (TDS, electrical conductivity) over time to outline a hydrochemical model of the system.

MULTIDISCIPLINARY APPROACH TO ASSESS THE SEASONAL EFFECT ON REDOX PROCESSES OCCURRING IN A TROPICAL ALLUVIAL AQUIFER

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The detection of high concentrations on Mn and Fe in groundwater are usually related with the occurrence of redox processes, which are clearly due to organic matter oxidation (Palmucci et al., 2016). In hydrogeological contexts, where multilayer alluvial aquifers are in direct connection with surface-water heavily impacted by eutrophication (Lewandowski et al., 2015), the organic matter load in groundwater could change seasonally, due to the dilution effect related both to the river discharge variations and to the piezometric level fluctuation (i.e. wet season recharge), especially in tropical areas.
To assess this phenomenon, the San Pedro Sula alluvial aquifer, located in the north-west Honduras, was selected as study area. This is a tectonic basin filled by continental deposits whose thickness ranges from a few meters up to 250 m. For this multilayer alluvial aquifer, well known surface-water/groundwater interactions were identified (Di Curzio et al., 2016).
The datasets used for this research refer to two monitoring rounds performed in 2002, both in the wet (February) and in the dry season (May), each one consisting of 94 groundwater samplings, 32 surface-water samplings, 56 hydraulic head measurements and 9 river discharge measurements. For the assessment of the seasonal variation of redox processes extent, a multidisciplinary approach was chosen, integrating a Principal Component Analysis (Palmucci et al., 2016) on several chemico-physical parameters and a Mn and Fe speciation, using the modeling tool Phreeqc (Appelo & Postma, 2005), both for the wet and the dry season.
The first statistical, chemical and numerical results highlight a strong correlation of Mn concentration with redox processes, both in the wet and in the dry season. This is likely related to the organic matter transfer from heavy polluted surface-water to the aquifer and to the trigger of redox processes that solubilize Mn. For Fe, the correlation with redox processes has also been detected, enhancing the solubility of Fe in groundwater. In some cases, when the samples present high turbidity, the high concentration of Fe can be related to a fine colloidal phase that is formed when different groundwaters mix up in the wells, which are screened in different aquifers. As unusually expected, the colloidal phase formation increases during the dry season, when discharge of main streams and the precipitation are more abundant. In this condition, surface-water transfers more organic matter to the aquifer and the redox processes play the foremost role on Fe mobilization.

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MONITORING OF COMPOSITION OF LNAPL: ESSENTIAL TOOL FOR THE ESTIMATION OF FREE LNAPL SPECIFIC VOLUMES

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In an aquifer contaminated by LNAPL, it is possible to find different mixtures of LNAPL, characterized by different composition. Indeed, in function of percentage of C_6-C_9 and of C_{10}-C_{30}, it is possible subdivide the type of LNAPL in gasoline (more of 70% of C_6-C_9), diesel (more of 70% of C_{10}-C_{30}) and mixture of gasoline and diesel. Each mixture of LNAPL is, obviously, characterized by different properties such as density, viscosity, interfacial tension that influence the fate and transport of contaminant in groundwater and so the estimation of its volume. Over time, two different models are been developed for the volume estimation of the free phase: Pancake Model and Vertical Equilibrium Model. According to the first one, the migration of LNAPL to the water table and its lateral spreading through the capillary fringe creates a buoyant pool with uniform and constant saturation and so the thickness, measured in the monitoring well, is an apparent thickness (Baldi and Pacciani, 1997; CL:AIRE, 2014; Dippenear et al., 2005). Therefore, it is necessary correct the thickness measured in the well, through factors derived by field test, such as baildown test. This test provides an exaggeration factor, function of the LNAPL characteristics, through which it is possible, known the measured thickness, calculate the real thickness of free LNAPL in the aquifer and then the specific volume. Instead, the Vertical Equilibrium Model assumes that there is not a discrete layer of LNAPL floating on the water table, but that LNAPL can penetrate below the water table and the LNAPL saturation varies with the depth creating a saturation profile (ITRC, 2009; Lundegard and Mudford, 1998). A tool to obtain the LNAPL saturation profile is the LDRM (LNAPL Distribution and Recovery Model) application, distributed by the American Petroleum Institute (API, 2007). This application requires a lot of information about the LNAPL thickness in the well, groundwater elevation, soil properties and LNAPL characteristics as density, viscosity and interfacial tensions in order to display the saturation profile and calculate the specific volume. In order to evaluate the influence of LNAPL composition on this calculation, specific volumes have been estimated using both Pancake Model and Vertical Equilibrium Model. This estimation has been carried out applying in every examined monitoring point characteristics of three different LNAPL composition: gasoline, diesel and mixture of gasoline and diesel. The results showed that a variation of LNAPL composition and consequently of its characteristics, conduct to a sensible variation of estimated specific volume. Therefore, as it can been deduced, knowledge of type of free LNAPL and its characteristics are fundamental both for Pancake Model and Vertical Equilibrium Model. In addition, it has been observed in field, that often the LNAPL supernatant can change over the time, due to dissolution and degradation processes that can occur, with the resulting variation of LNAPL characteristics and

its fate. Hence, when a contaminated site is monitored for the evaluation of LNAPL volumes, it is fundamental observe with time, not only the supernatant thickness in the well, but also the compounds constituting the LNAPL, through the sampling of supernatant and its analysis.

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A PROPOSAL FOR GROUNDWATER SAMPLING GUIDELINES: APPLICATION TO A CASE STUDY IN SOUTHERN LATIUM

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Chemical monitoring of groundwater is required, in order to protect the environment, by legislation, in different sectors and at variable spatial scales, from groundwater body status assessment, to the control of the impact of anthropic activities at the site scale. Whatever the aim of the monitoring activity, sampling procedures as well as the laboratory activities, must strictly follow standardized and common procedures. Well-defined and common sampling procedures can reduce the error linked to wrong methods and, most important, the differences between the analytical results for samples collected by different operators.
These aspects are particularly relevant in the anoxic environments, where wrong sampling procedures may modify redox conditions and eventually the analytical results.
The current lack, in Italy, of a national guideline for groundwater sampling, has led in the past to significant differences in the analytical results derived by samples collected by different operators in several sites including the presented case study, raising uncertainties on the qualitative status of the groundwater body and the effective impact of the anthropic activities therein.
In order to fill this gap, the Water Research Institute was asked to produce a "best practice" document for groundwater sampling, based on international literature, and suitable in the Italian legislative framework. The proposed procedure include aspects such as:

- 1) the implementation of the conceptual model;
- 2) best sampling techniques;
- 3) appropriate treatment and preservation of samples and quality control (e.g. field and transportation blanks, blind samples, etc).

In this communication, we describe the application of the proposed procedure to a case study in southern Latium, where a phreatic aquifer of local interest is threatened by an industrial area including a waste-to-energy plant. Thick quaternary alluvial and pyroclastic deposits, outcropping above the Meso-Cenozoic limestones dislocated by normal faults, host the phreatic aquifer, which was sampled in more than 30 private wells in the study area following the mentioned sampling procedures. The collected samples were analyzed for anions, major cations and trace elements determination through ionic chromatography, ICP-OES and ICP-MS.
Despite the specific results and the possible exceedances of normative thresholds, our aim was to obtain a snapshot which is deemed representative of the chemical status of the groundwater both within and outside the site, with particular attention to redox sensitive elements like As, Fe, Mn and Al. As a result, when the proposed guidelines apply most of the exceedances observed by previous monitoring activities do not occur, hence they were ascribed to incorrect extraction and unfiltered samples.

Finally, it is important that all the operators involved in the same site, including site managers, control agencies as well as researchers, share the same procedures in order to have comparable results. This would avoid legal disputes about the obtained results, and the subsequent decision linked to them could be implemented in a more participated manner.

THE SUSTAINABLE GROUNDWATER MANAGEMENT AND ITS CONTRIBUTION TO A MORE RESILIENT ROME

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The largely invisible world of groundwater is involved in many aspects of a city life: water supply systems, sewage, surface-water features, the health of plants and trees, flood potential, and drought events. Recently, groundwater has been recognized as a cornerstone in the resilience of the cities (Tanner et al. 2009). Under this perspective, mapping and monitoring groundwater and surface water resources represents a fundamental step for optimizing the urban water system and minimizing water consumption and deterioration. In the city of Rome, even if at the beginning of its lifetime the local historical springs provided the water supply, nowadays most of drinking water supply derives from springs located far from the city, and is delivered to population through the aqueduct network. Even if, currently, there are not specific issues related to water quantity, however, the Rome municipality is dealing with many groundwater related problems. Some examples are: pollution (Ellis 1999), relationships between poor quality streams and aquifers, natural background levels of dissolved elements and compounds, differential settlements in streams valleys, subsidence and salinization (Manca et al. 2014) as well as groundwater flooding in the coastal aquifer. Consequently, the sustainable groundwater management in towns poses, not only scientific challenges, but also technical, socio-economic, cultural and ethical.

The knowledge base today is stronger in Rome, thanks to the new hydrogeological map (La Vigna and Mazza, 2015) and the new monitoring network implementation, and there are many advanced technologies not only for resources protection, but also for a correct management in a greater urban resilience perspective. This is particularly true when technologies like Managed Aquifer Recharge and Storage are considered to solve specific urban floods issues.

The impacts of groundwater within a specific urban area depend both on its geographical location and the economic status of the city or even the country. While for cities of developing countries the main interests are therefore water quantity and quality, in developed countries, urban groundwater is posed in economic and environmental terms. Use and managed recharge of groundwater may reduce pressure upon conventional freshwater supply sources. On the other hand, not using this groundwater may lead to flooding and structural damage to underground structures (underground railway systems, basements, underground parking areas, etc.).

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RELATION BETWEEN CLIMATIC CONDITION, TEMPERATURE AND MOISTURE IN THE SUBSOIL OF TURIN PLAIN

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The temperature distribution in shallow subsoil (<20 m below ground surface) is influenced by seasonal variations in air temperature and soil thermal conductivity. In addition, the advective heat transport, due to the presence of water flow in an aquifer, and variations of temperature related to rainfall and soil permeability, are expected to play a role. To evaluate the influence of these phenomena, an experimental site in the alluvial plain of Po River, about 10 km from Turin, was realized. Land use is mainly agricultural and density of buildings and paved surfaces do not have any important impact on the local thermal regime. From a hydrogeological point of view, an unconfined aquifer (to at least 10 meters thick) is hosted in the late Pleistocene and Holocene fluvial deposits. Below pre-Pliocene marine units of the Turin Hill constitute an impermeable substrate. The water table depth ranges between 4.5 and 5.5 m below ground surface.

The monitoring considered the following parameters: air, unsaturated zone (UZ) and saturated zone (SZ) temperature, moisture in the UZ, precipitation. Moreover, 3 piezometers (PZ1, PZ2 and PZ3) were installed for the measurement of the piezometric level oscillations and the realization of piezometric maps. All these parameters were correlated, in order to highlight similar trends.

The unconfined aquifer has a fairly constant flow direction at site scale, WSW-ENE directed, confirming the draining role of the Po River.

The results, consisting of two-year monitoring, show that while the air temperature fluctuated between -3° C and +30° C, in the subsoil at -0.60 m the oscillations are reduced to 30%, with respect to air temperature, to 70% at -1.80 m and to 88% at -3.80 m. In the SZ the temperature varies between 13°C and 15° C at 9.5 meters deep, with a damping of temperature fluctuations equal to 94%. Furthermore, a time shift of air peak temperatures in the subsurface was recorded. This result highlights a delay in the response of the soil, that is gradually higher at greater depths. The slowest response is in the aquifer, where the delay is about 3 months.

Soil moisture increases with depth, from about 15% to -0.60 m up to values greater than 35% to -3.80 m (capillary fringe). An increased moisture in response to rainfall was recorded up to -1.50 m; at -3.60 m below ground surface the moisture remains nearly constant throughout the year and is affected only by the oscillation of the water table.

Piezometric level and rainfall do not show a correlation. Furthermore, the analysis of groundwater temperature shows no significant correlation with rainfall. This outcome is conceivably connected to a rapid thermal equilibration of the infiltrating water in the UZ.

In conclusion, the groundwater in the investigated site scarcely records the seasonal temperature fluctuations: these, indeed, are largely dissipated in the above UZ. It can also be excluded that the groundwater temperature is significantly influenced by local rainfall input.

QUALITY OF WATER IN TWO AREAS AFFECTED BY PAST MINING ACTIVITIES IN ALPINE CONTEXT

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Abandoned mines can pose serious pressure on local water sources. Analyses of the possible water-related environmental problems connected to past mining activities was performed in two mining areas, Campello Monti and Gorno, NW Italy.

Campello Monti (Valstrona municipality, Piedmont region) is located in the basement of Southern Italian Alps in the Ivrea Verbano Zone. The area is characterized by mafic rocks (gabbros and pyroxenites) intruded by mantle periodite. Mines were used for nickel exploitation from 9th Century to 1940s. The groundwater circulation takes place in fractured rocks, waste dumps and tunnels used for mining exploitation. Strona stream and other minor creeks are located in the area.

Second site is in Gorno area (Lombardy region) where mines were used for zinc and lead exploitation. Zn-Pb mineralization is confined in a well known horizon, few ten meters thick and with an extension of about 80 km, called "Calcare Metalliferro Bergamasco". This horizon, stratigraphically confined between a thick sequence of carbonatic platform limestones at the footwall and a siliciclastic lagoon sequence at the hanging wall, hosts several Zn-Pb-F-Ba ore bodies, extensively mined during the last millennium. Gorno is one of them: hereabout 10 Mt raw sphalerite, galena and calamine ores were extracted. In the area of Gorno passes the Riso Creek that empties into river Serio (Val Seriana). In the area dolomites and limestones outcrop and groundwater flow in the area takes place in fractured karst media with high permeability. Numerous springs and aqueducts are used for civil purposes.

In both areas there are lots of extractive waste facilities, represented by rock waste dumps, operating residues and tailings ponds.

To study the impacts on local water sources, water sampling campaigns and analyses were performed. At Campello Monti, 11 groundwater samples (1 tap water, 4 from tunnels and 6 from springs) and 6 surface water samples were collected. At Gorno, 17 groundwater samples (2 from tunnels, 1 tap water, 14 from spring) and 4 surface water samples were collected. The samples were analyzed to measure alkalinity, electrolytic conductivity, pH, temperature, metals (Hg, Tl, Cd, Cr (total), Cr (VI), Ag, As, Pb, Se, Ni, Co, Mn, Al, Fe, Cu, Zn, B) and other analytes (CN^-, Fl^-, Mg^{2+}, Na^+, SO_4^{2-}, NO_3-,Cl^-).

The water samples collected from mining tunnels of Campello Monti showed nickel concentration ranging from 31.9 µg/l to 304 µg/l (limit values of groundwater quality, Concentrazione Soglia di Contaminazione in Italy for Ni according to D.Lgs 152/06 is 20 µg/l). Sample from one of the springs was found to have Ni concentration of 57.8 µg/ l and another one up to 266 µg/l and another secondary stream had Ni concentration of 512 µg/l. These all systems act as source to Strona creek.

The water samples collected at Gorno showed no contamination in both groundwater and surface water.
Both Gorno and Campello Monti are two areas that were affected by intense mining activity in past. The absence of contamination in water (groundwater and rivers) in Gorno compared to Campello Monti may be due to several concomitant factors apart from the different geological context: the higher pH of groundwater in Gorno, which facilitates the precipitation of heavy metals and the increased flow velocity in the karst limestone rocks in Gorno.

SQUARING THE CYCLE: THE INTEGRATION OF GROUNDWATER PROCESSES IN NUTRIENT BUDGETS FOR A BASIN-ORIENTED REMEDIATION STRATEGY

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Diffuse contamination of surface and ground waters resulting from the green revolution since 1950's represents a major threat to the long-term sustainability of water resources worldwide. Nutrients budgets, calculated in a wide array of river basins, have shown that a high amount of nutrients can be retained or lost within the watershed, where site-specific characteristics contribute to define their fate. In the Lombardy plain (North Italy) the uneven distribution of nitrates in groundwater, not fully matched to any of the civil, industrial and agricultural sources, suggests that local features and processes (e.g. depth of water table, land use, denitrification etc.) play a key role in preserving or removing nutrients.

In this framework, the INTEGRON project, funded by the CARIPLO Foundation (Grant number: 2015-0263), aims at evaluating the role of groundwater as a temporary or permanent sink or as a source in nutrient mass balances at the catchment scale in two key sub-basins of Po River, the Adda and the Ticino.

An innovative and integrated approach is proposed, considering both surface and groundwater, combining hydrogeology and biogeochemistry and targeting both N and P species. This includes: (i) the calculation of the nutrient surplus and the load exported by rivers at the closing section to quantify the amount retained within the basin; (ii) the groundwater dating to infer the residence time of nutrients; (iii) the estimate of the amount of nutrients exchanged between surface and ground waters and the identification of processes occurring at the interface; (iv) the investigation of the factors promoting the retention or removal of nutrients (e.g. denitrification, P adsorption); (v) a socio- hydrogeological analysis to identify key-actors in the implementation of new management practices.

Preliminary outcomes, referred to the previously described topics, show that:

(i) the Adda basin has higher percentage of agricultural surfaces, livestock density and fertilizer application than the Ticino basin, resulting in higher N and P surplus;

(ii) both increasing and decreasing NO_3^- concentration trends in groundwater with time are present in the higher plain;

(iii) NO_3^- in both rivers increases in correspondence of the transition between the higher and lower plain, in particular during the irrigation period. Groundwater feds springs located in the Adda basin and shows higher NO_3^- concentrations compared to Ticino basin;
(iv) elevated P contents may be found in shallow groundwater below rice paddies;
(v) a complex network of stakeholders, with conflicting interests and goals, is present.

In conclusion, groundwater has a complex role in nutrient mass balances, acting both as sink and source in each basin. Considering the temporal scale is essential to properly relate the nutrient surplus with the amount upwelling through the springs. The integration of hydrogeochemical and social results is a crucial step to understand the poor efficacy of mitigation actions and to propose new management practices where limitations imposed by EC Directives do not seem to be effective.

MULTIPLE ISOTOPE AND HYDRO-CHEMICAL TECHNIQUES INVESTIGATING DYNAMICS AND SOURCES OF DIC WITHIN A MULTIPLE AQUIFER SYSTEM OF A GROUNDWATER FED LAKE CATCHMENT (LOUGH GUR, IRELAND)

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Traditionally, Lake groundwater discharge (LGD) has been disregarded in many lake nutrient and eutrophication studies (Lewandowski et al. 2015). Hence, there is an urgent need for detailed research to quantify different groundwater nutrient sources and the likelihood of transport, transformation and storage along subterranean flow path conduits to and from lake systems. Understanding the temporal and spatial distribution of dissolved inorganic carbon (DIC) species is an important step in understanding the geochemistry of groundwater systems (Han et al., 2010). Isotope techniques including $\delta^{18}O_{H2O}$ and $\delta^{2}H_{H2O}$, in conjunction with hydro-chemical species were used to constrain sources of water to the lake and along a flowpath line which emerges as a spring outflow from the lake. In addition, other isotope tracers such as $\delta^{13}C$ in DIC and $\delta^{15}N$ and $\delta^{18}O$ in dissolved nitrate along with catchment well-lake gradients, vertical lake-aquifer hydraulic gradients and geophysical surveys were used to trace groundwater seepage and biogeochemical processes impacting lake hydrochemistry and transformation of nutrient to the lake and along the conduit flow path outflow. Hydrographs of wells and lake level from the north-east of Lough Gur along with precipitation data show rapid GW-SW connectivity. Groundwater flux data from the piezometer nest at the amenity centre to the north-east indicate nearshore groundwater seepage rates (~0.035 $m^3/m^2/day$) from the upper piezometer (1.07m). Falling head tests show the existence of a layer of lower hydraulic conductivity in the sediments in the upper piezometer depth, with higher values at the deeper depths. Rn survey on the lake identified three areas with strong anomalies and discharge. Negative correlation between $\delta^{13}C_{DIC}$ (‰) and DOC (mgl^{-1}) indicate dissolution of carbonates by carbonic acid in groundwaters. In contrast, positive correlation between $\delta^{13}C_{DIC}$ (‰) and DOC (mgl^{-1}) implies that oxidation of organic matter was a major source of DIC in surface waters and piezometers. ERT survey results show lateral and vertical variations in electrical and help constrain the orientation and extent of the subsurface conduit system at Lough Gur.

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HYDROCOMPLEXITY, AND SPATIAL AND TIME SCALES AS DRIVERS OF MONITORING AND MANAGEMENT APPROACHES FOR A KARST COASTAL AQUIFER (SALENTO, SOUTHERN ITALY)

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The study aims at representing the complexity of the hydrogeological scenario (as to the physical features and the system response) of a karst coastal aquifer (Salento aquifer - Apulia region, Southern Italy). Furthermore, the study intends to point out the issues related to groundwater monitoring and coastal aquifer management, which are consequent to the hydro-complexity, in order to define a suitable approach for the control of groundwater qualitative and qualitative status.

The karst coastal aquifer of Salento is, indeed, a complex aquifer. This complexity, enhanced by the coastal condition, is due to lithology, morpho-tectonic configuration and paleo-geographical history. Both the structural-tectonic characteristics, and the superficial and underground morphological features, defined by karst processes from place to place in a different way, guide the groundwater flow within the Mesozoic mass. As to the system response, groundwater reacts with a certain lag to stressing factors, such as climatic variations and groundwater exploitation. Therefore, if compared to input time, negative effects on groundwater qualitative and quantitative status are appreciable with time delays, which depend essentially on the scale of the flow system.

As matter of fact, the monitoring wells (which belong to the Regional Monitoring Net) intercept groundwater according to the hydraulic conductivity anisotropy, where preferential levels are vertically distributed, even over short distances, because of tectonic dislocations. This spatial condition poses objective limitations to a classical interpretation of groundwater quality status. Monitoring wells, even if specifically designed to saltwater intrusion control (long-screened monitoring wells, which intercept all the groundwater thickness up to salt water), have some limitations in providing a "general" summary about salinization status, inasmuch they identify the response (which varies according to permeability, distance from the sea, impact on groundwater resource) referred only to the areas surrounding the monitoring wells. Moreover, ordinary measures of hydraulic head are also affected by the presence of preferential flow levels (originating vertical flow in the wells) and they are density-dependent.

The study discusses monitoring methods implemented in the Salento area during the last decades and their efficiency in relation to the scenario of hydro-complexity and on the light of the action of the different drivers, which take place over spatial and time scales different from those of monitoring. These drivers cause “concealed” effects of “groundwater drought” and

salinization with time lags compared to the visible stress events.
The study aims at outlining a monitoring and management approach valid for complex coastal aquifers of large dimension.

PROPOSAL FOR AN INTEGRATED METHOD OF NATURAL BACKGROUND LEVELS ASSESSMENT IN GROUNDWATER

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Inorganic potentially toxic elements in groundwater may derive from both natural processes and anthropogenic activities. Natural background levels (NBL) are often defined to distinguish any anthropic contribution and eventually assess the environmental status of groundwater bodies, as requested by the Water Framework Directive. The geochemical approach for the NBL assessment requires the identification of groundwaters free from the human impact, using markers such as nitrates/ammonia in oxidising/reducing environments, organic compounds, isotopes, etc. The statistical approach involves the separation of uninfluenced and influenced populations by means of statistical procedures. In this study, we compare different study cases in the Plio-Pleistocene volcanic province of Latium (central Italy) with the aim of integrating the two approaches for the definition of the NBL.

After the validation of the total dataset, redox facies were distinguished on the grounds of Eh (> 100 mV) and O_2 (> 3 mg/L). In the geochemical approach, the influenced samples were discarded using NO_3/NH_4 (oxidising/reducing facies) to obtain the "pre-selected dataset". Instead of a fixed threshold for nitrates (e.g. 10 mg/L or 50 mg/L), we used a local threshold identified with the statistical techniques, representing the upper limit of the ambient (i.e. no longer pristine) nitrate background, provided it does not exceed 50 mg/L. For reducing facies, NH_4 (up to 0.5 mg/L) should be used.

Then, the natural background levels of As, F, Mn and SO_4 were estimated as follows. When data approximate one normal population, we assume that they all refer to the background population and the maximum value is proposed as NBL. When one or more outliers exist, we assume they represent different populations and processes. Regardless their anthropic or natural origin, the outliers usually represent localised phenomena, which differentiate from the background, and should be treated as such. Hence, the NBL was set at the boundary between the basal population and the outliers, identified with statistical techniques such as "box & whisker", probability plots, and others. However, when the outliers are certainly to be ascribed to natural processes, they should be considered when assessing the local NBL for monitoring purposes.

The geochemical approach and the diverse statistical methods applied, have provided often very variable results, with differences even of one order of magnitude in the defined NBLs, in particular for manganese. Hypothesis on normal distribution of data has been the main criterion for the final choice of NBLs. The values obtained for As and F are broadly comparable among the study cases and are always above the EU Drinking Water standards, while Mn and SO_4 show rather different NBLs, largely below the limits of the Italian legislation for the groundwater body chemical status definition.

The integration between multiple methods allows for a reasonable assessment of the natural

background levels in the study cases. The proposed procedure maintains the advantages of the pre-selection method (simplicity and reproducibility), minimising the main critical points, such as the choice of the nitrate threshold for the pre-selection of samples and the choice of the percentile to be adopted as NBL.

ISOTOPIC CHARACTERIZATION OF GROUNDWATER FOR DRINKING USE IN MULTILAYER AQUIFERS OF THE MILANO AND MONZA PROVINCES

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Management of groundwater resources for drinking purposes requires not only a classical chemical characterization for safety plans, but it implies the best possible knowledge of aquifer characteristics, recharge area extension and amount, seasonal and yearly changes in water table and discharge. A valid conceptual model of groundwater flow is a basic element for optimizing the groundwater withdrawals, both in terms of resource amount and of vulnerability to pollution.

In this framework, the use of isotope tools is based on several solid experiences in hydrogeology, but at the same time it is not frequently adopted by regional drinking water authorities. Besides of classical water stable isotope studies, analyses of nitrogen, carbon and sulphate isotopes are recently testified to be a fundamental tool for a dynamic management of water resources in areas affected by human activities.

Interaction between surface water and groundwater, origin and fate of contaminants, groundwater age evaluation, are some of significant improvements in groundwater conceptual model allowed by isotope field investigations.

For these reasons, the CAP Holding Company promoted in 2015-16 an extensive isotope characterization of groundwater used for drinking purposes in Milano and Monza Provinces (northern Italy). Three surveys have been conducted in November 2015, April 2016 and October 2016 by isotope analyses on more than 100 wells, tapping groundwater from different depths and related aquifer in the multilayer hydrogeological system of Padana Plain, between Ticino and Adda Rivers.

In addition to about 250 water stable isotopes ($\delta^{18}O$ and $\delta^{2}H$), more than 120 tritium analyses have been performed during the three surveys. Isotopes of nitrates ($\delta^{15}N$ and $\delta^{18}O$) and of sulphates ($\delta^{34}S$ and $\delta^{18}O$) are additionally investigated on more than 60 samples, as for $\delta^{13}C$ of DIC. An additional survey on $\delta^{14}C$ of DIC for 26 samples has been realized to compare groundwater age with tritium results. Finally, about 20 analyses have been conducted on chlorinated solvents for $\delta^{13}C$ and $\delta^{37}Cl$.

This study represents probably the largest isotope investigation on drinking groundwater in Italy and it is based on a conceptual model of groundwater flow developed by CAP Holding in the previous years. The available GIS with related database containing aquifer and aquitard limits, wells stratigraphy and filter location, and a large number of chemical analyses is

constituting a solid background for refining and confirming by this isotope study the abovementioned conceptual model.
Obtained results are useful to verify and implement the knowledge of the groundwater flow and resource regimen, indicating a significant stability of isotope values with time. Additional information have been acquired on nitrogen and chlorinated pollution origin and fate, and on local surface waters recharge, possibly due to irrigation channels and/or sewage systems. Relative groundwater age estimation is obtained and possible vertical exchanges in the multilayer aquifer system have been evaluated. Conclusions of the study will represent not only a valuable contribution for groundwater management, but they offer additional clues for further detailed characterization both at regional and local scale (up to single well management).

MAKING GROUNDWATER VISIBLE: A CONTRIBUTION FOR CLASSIFYING HYDROGEOLOGICAL RESEARCH AND KNOWLEDGE BY KINDRA H2020 PROJECT

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The H2020 KINDRA project (Knowledge Inventory for hydrogeology research, Grant Agreement 642047, www.kindraproject.eu), funded by the HORIZON2020 Framework Programme, is dealing at European level with research and knowledge in groundwater, the hidden component of the water cycle, fundamental for the environment and for human uses. The project intends to contribute for improvement of the Water Framework Directive (WFD) and the Groundwater Framework Directive (GWD), by an accurate assessment of the state of the art in hydrogeology research and knowledge.

Hydrogeology-related research activities cover a wide spectrum of research areas at EU and national levels, but they are widespread into several projects, plans, actions, fragmented into wider programs generally related to water, environment or ecology. At the same time, the management of groundwater brings additional challenges to the implementation of WFD, GWD and of the Circular Economy approach.

In the first year, a terminology and classification methodology on groundwater research and knowledge based on a keyword list has been realized. The Hydrogeological Research Classification System (HRC-SYS) has been developed categorizing groundwater research in three main categories: 1) Societal Challenges, 2) Operational Actions and 3) Research Topics. Each of these main categories includes 5 overarching sub-categories for an easy overview of the main research areas. The complete merged list of keywords, about 240, selected from WFD, GWD and from high impact scientific journals, has been organized in a tree hierarchy.

The classification system maps the relation between the three main categories through a 3D approach, where along each axis the 5 overarching groups are plotted. To facilitate analysis and report show the relationships, this approach also allows for a 2D representation for each of the 125 intersections among the three main categories in a 5x5 matrix.

The European Inventory of Groundwater Research (EIGR) is a tool which allows the application of the proposed classification. The EIGR is intended to be used in three different ways: i) for insertion of information pertaining to groundwater research and other available knowledge by the National Experts of the European Federation of Geologists (EFG); ii) for consultation during and after the project by people and organizations dealing with

groundwater research, but also possibly by non-experts; iii) for analyzing collected and stored information to identify trends, challenges and gaps in groundwater research by KINDRA partners. The EIGR contains metadata, referring and providing links to research that has been performed in Europe since 2000. The uploaded metadata, about 2000 records at the end of 2016, distinguish between 'research' and 'knowledge' according to four different classes identified by the level of the performed quality assurance.
The proposed classification system allows the immediate comparison of the two categories Operational Actions and Research Topics with the Societal Challenges identified by the European Commission in Horizon2020. The adopted set of performance indicators (classes of research/knowledge, technology readiness level, grants, etc.) are used for a trend&gap analysis on-going at the last stage of the project during 2017. The identification of research gaps will give useful suggestions for the actualization and continuous development of research and innovation agendas in line with WFD.

STOCHASTIC APPROACH TO HYDRAULIC BARRIER DESIGN: AN EXAMPLE IN NORTHEASTERN ITALY

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Starting from 2004, a progressively increase of volatile organic compounds (VOCs) in the public water supply wells located in a pre-alpine valley at northeast of Verona (Italy), reveals an extensive groundwater contamination by tetrachloroethylene (PCE) and trichloroethylene (TCE). The contamination involves a multi-layered aquifer system consisting of three main gravel aquifers intercalated by discontinuous clay layers and hydraulically connected by multiscreened wells. The first aquifer is between 48 and 60 m below ground level (m b.g.l.), the second ranges from 75 to 105 m b.g.l. and the third from 118 to 130 m b.g.l. The results of a preliminary characterization indicate that the source of the groundwater pollution is located in the middle part of the valley and it is related to the activity of a graphic industry. At the end of 2013, a plume of PCE/TCE was identified at the center of the valley between the source area and the northern outskirts of Verona, about 4000 m downstream. The plume is about 500 m wide and its concentrations in PCE and TCE respectively range from 731 to 0.07 µg/l and from 0.6 to 0.06 µg/l.

Currently, a new phase of investigation and monitoring has started. The aims of this phase are: (i) the upgrade of the conceptual hydrogeological model of the area, (ii) the realization of pumping tests for hydraulic conductivity estimation, (iii) the evaluation of the spatial and temporal evolution of the contaminant plume and (iv) the design of a hydraulic barrier involving all contaminated aquifers.

In particular, a three-dimensional numerical model of groundwater flow and advective transport is developed to design a hydraulic barrier. Steady-state saturated flow is simulated with MODFLOW-NWT (Niswonger et al., 2011), while MODPATH (Pollock, 1994) is used for particle tracking analysis. The approach used for dealing with uncertainty associated to the model implementation is stochastic simulation based on multiple equally plausible candidates of the site heterogeneity. Random Sampling (RS) and Latin Hypercube Sampling (LHS) are the two methods tested to generate different realizations of the hydraulic conductivity (K) zonation. Preliminary results of numerical simulation show that discharge rates ranging from 1.0 to 3.0 L/s are required to prevent further migration of contaminant downstream.

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HYDROCHEMICAL CHARACTERIZATION OF GROUNDWATER AND SURFACE WATER SUPPORTED BY MULTIVARIATE STATISTICAL ANALYSIS: A CASE STUDY IN THE PO PLAIN (N ITALY)

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Multivariate statistical analysis is a useful method for supporting the interpretation of experimental data, particularly in the case of large datasets. In the present study, cluster analysis (CA) and factor analysis (FA) are used to support the hydrochemical characterization of groundwater and surface water in an area located in the Po Plain (N Italy), highly impacted by human activities related to agriculture.
The study area is located in the Oglio River basin, between the outflow from Lake Iseo and the confluence into Mella River, and covers ~1900 km^2. The northern part of the study area (higher plain) hosts a mono-layer aquifer mainly composed of sands and gravels, whereas the southern part of the area (lower plain) hosts a multi-layer aquifer constituted by a vertical alternation of sands with silty clays; the transition between higher and lower plain is marked by the so called "spring belt".
During a field survey performed in fall 2015, 58 groundwater, 20 river (Oglio River and its main tributaries), 1 Lake Iseo and 7 spring samples were collected for chemical analysis. Physico-chemical parameters, major ions, trace elements and water isotope were measured. The CA was performed on total 86 samples and 18 variables; data were autoscaled. The Ward hierarchical method, based on squared euclidean distance, was used. The FA was done using 82 samples (4 outliers were excluded) using the Kaiser criterion to select significant factors. Results of multivariate statistical analysis were combined with the geomorphological and hydrogeological knowledge of the study area in order to give a hydrogeological explanation of each data cluster.
Results led to the identification of 5 main clusters: (1) higher plain groundwater and springs, characterized by an oxidized *hydrofacies* with higher NO_3, (2) lower plain groundwater, characterized by a reduced *hydrofacies* with higher As, Fe and Mn, (3) Oglio River, (4) Oglio River tributaries and (5) outliers. Within the cluster of higher plain groundwater, three subgroups can be identified: (a) samples with the highest NO_3 and a more enriched isotopic signature attributable to recharge by local precipitation, (b) samples located around the spring belt and characterized by intermediate NO_3 concentrations (average ~50 mg/L) and (c) samples located around the Oglio River and characterized by lower NO_3. Also within the cluster of lower plain groundwater, three subgroups can be identified: (a) samples with more reduced

states, (b) samples with earlier reduced states, likely due to some interactions with surface waters and (c) samples with the highest As concentrations.
The Oglio River cluster can be subdivided into 3 subgroups: (a) the river stretch with losing behavior, (b) the river stretch with draining behavior and (c) groundwater and spring directly fed by Oglio River water.
In conclusion, this work confirms how multivariate statistical analysis can sustain the interpretation of large hydrological datasets in order to support a hydrochemical characterization. The latter will bear the development of the hydrogeological conceptual model of the area, also oriented to groundwater/surface water interactions, that, in turn, will support the numerical flow modeling of the system.

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TEMPERATURE LOGS APPLICATION TO EVALUATE GROUNDWATER – SURFACE WATER INTERACTION IN AN AREA OF SABATO BASIN, IN SOUTHERN ITALY

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In recent years, temperature is being more and more used as natural tracer in hydrogeological field investigations in order to characterize groundwater flow systems and interaction between surface water bodies and groundwater (Anderson, 2005; Vandenbohede & Lebbe, 2010).
Down-hole temperature measurements are useful tools for groundwater investigations to provide information about groundwater flowpaths and residence times in small sites with complex hydrogeological settings. In deeper wells, the temperature anomalies resulting from groundwater circulation in surrounding formation or within the well itself can be significant (Michalski, 1989).
The overall objective of this study is to investigate and characterize groundwater and surface water mixing using temperature-depth (T-z) profiles in Campania region, Southern Italy.
The study area is located in Pianodardine (AV), on the left side of the Sabato River and is characterized by the presence of local groundwater mixing with stream water.
This area is mostly made of alluvial and pyroclastic deposits while the base of the stratigraphic series is made of clays and loose pyroclastic rocks of the Altavilla Unit (Di Nocera & Matano, 2011).
Down-hole temperature logging in 9 monitoring wells, referred to two monitoring campaigns in April and October 2016, have been compared to evaluate seasonal effects on water mixing processes.
Groundwater and surface water temperatures were recorded in the study area by means of a SEBA KLL-Q multi-parameter probe (Seba Hydrometrie). The temperature sensor has a measurement rage of –5° to 50°C with a 0.01 °C resolution and a ± 0.1°C accuracy.
Down-hole temperature measurements were made at 1 m step of increment from the ground surface. The results from these surveys have been coupled with the lithological and geological descriptions obtained from reports coming from drill holes within the study area.
The results of the comparison of the down-hole temperature logging obtained in April and October 2016 suggest that stream water interacts with the groundwater local flow in some parts of the area under study, due to the specific geological structure and is responsible of temperature anomalies. As a matter of fact the analysis of temperature logs let us distinguish where the mixing processes between stream water and groundwater are sensitive, and stream water feeds the shallow aquifer from where these processes are not present.
The temperature logging offers a non-expensive tool, able to acquire, rapidly, reliable data and to support hydrogeological studies in small sites or in high heterogeneity conditions.

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USING THE HYDROCHEMICAL DATABASE TANGCHIM TO MANAGE GROUNDWATER QUALITY DATA: THE CASE STUDY OF A LEACHATE PLUME FROM A DUMPING AREA

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This work deals with a preliminary characterization of a groundwater pollution from a dumping area using the new online hydrochemical database TANGCHIM as supporting tool.
The study area is located in an Alpine fluvial valley (NW Italy) where glacial excavation was followed by glacial, lacustrine, alluvial and fan deposition in the Pleistocene and Holocene forming a gravelly mono-layer unconfined aquifer with local subdivision into an unconfined upper aquifer and a semiconfined deeper aquifer which occurs in the dumping area due to a discontinuous silty layer. Groundwater mainly flows from West to East with some local perturbations due to wells pumping and surface water drainage. Closely to the dumping area, groundwater deth range from 1.5 to 9.5 m with seasonal fluctuations up to 2 m. The dumping area is monitored by more than 30 piezometers, all tapped in the upper shallow aquifer. The dumping area is composed of two main landfills: a legal landfill (more recent and currently used) and an old illegal landfill (currently closed) plus other smallest waste deposits of which the locations are unknown. The legal landfill is used as point of collection of municipal solid waste and sludge of wastewater treatment plants, whereas both the illegal landfill and the other smallest deposits were filled with inert, plastic and urban wastes of different and unknown composition. Only the legal landfill has an impermeable surface (a clay layer) 1 m thick. An important aspect to consider is that the old landfill is located close and upstream to the legal landfill, preventing a proper groundwater monitoring downstream the used landfill.
The chemical data from the groundwater monitoring network have been managed by the TANGCHIM database (DB). This DB is able to store, display, and process the hydrochemical data related to water wells. TANGCHIM can store more than 430 chemical compounds which can be modified or added by the user. It also manages synonyms of chemical compounds to avoid data duplication by providing well-structured data. Data export can be performed through queries based on: (1) temporal period, (2) location, (3) chemical compounds and (4) well name. TANGCHIM is linked to the hydrogeological well database TANGRAM that is able to manage all the data related to water wells. The coupled use of these DBs allows a better understanding of the results of groundwater monitoring.
Results of the groundwater quality monitoring in the study area showed reducing conditions with low dissolved O_2 and high COD, NH_4, Fe, Mn and As that are typically found in leachate plume. The analysis of both hydrochemical and hydrodynamic data suggested that the plume is mainly from the old landfill and, likely, from other unknown waste deposits located into the dumping area.
This work highlighted the importance of constructing a structured and robust hydrochemical database in hydrogeological studies related to groundwater pollution

HOW MUCH DOES AIR POLLUTION AFFECT GROUNDWATER QUALITY?

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It is renowned that rainfalls reduce air pollution in the troposphere, since contaminants are captured and dissolved by rain drops or involved in the formation of particulate matter. Consequently, a fraction of rainfalls, enriched in dissolved ions derived from air pollutants, infiltrates through ground surface and migrates through the vadose zone, contributing to groundwater contamination. This means that pollution moves away from air to surface water and, lastly, to groundwater. However, the quantification of the impact of atmospheric pollution on groundwater quality is still uncertain.

The path air–rainfall–infiltration water–groundwater is observed and analyzed in Milan and its surroundings, covering an area of 3000 km², where both urban areas and agricultural activities are extensively present. The reconstruction of the path is carried out following the procedure:

1) Collection of rainfall samples related to the same rainfall event at 12 monitoring points covering the entire study area. Rainfall collection is repeated several times during the year, covering at least the two main rainfall periods in spring and autumn.
2) Chemical analyses of rainfall samples to determine major anion concentrations through ion chromatography (e.g., NO^{3-}, SO_4^{2-}, Cl^-).
3) Comparison of rainfall chemistry and air pollution, to evaluate the influence of air pollution on rainfall quality.
4) Implementation of a numerical model to evaluate the amount of contaminant infiltrating through the vadose zone. The numerical model considers different hydrogeological and environmental contexts (i.e., urban and agricultural environments), according to the specific land use and land cover of the various sectors of the study area.

Preliminary results of the first rainfall collections have shown a direct relationship between high levels of air pollutants (NO_2 and SO_2) in the atmosphere and relatively high contaminant concentrations (NO^{3-} and SO_4^{2-}) in rainfall samples. Rainfalls sampled at the beginning of the precipitation, especially after a long dry period, show higher contaminant concentrations respect to those sampled at the end of the precipitation window. Further investigations are necessary to understand the spatial distribution of contaminant concentrations in the study area: a) urban against rural areas; b) proximity to emission sources (e.g., traffic roads, airports); c) evolution of the rainfall event during the sampling period (intensity and wind direction).

The numerical model uses contaminant concentrations obtained through the chemical analyses of rainfall samples to estimate the contaminant concentrations not related to direct sources of contamination (e.g., industrial wastes, leakages from the sewage systems and fertilizers). This allows identifying anthropogenic background values of pollutants in groundwater.

"LA MADDALENA" EXPLORATORY ADIT - BASE TUNNEL OF THE TURIN-LYON HIGH SPEED RAIL PROJECT: HYDROGEOLOGICAL MONITORING DATA ANALYSIS

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"La Maddalena" exploratory tunnel, located in the Italy Western Alps (Susa Valley), is one of the four exploratory adits, three in France, completed in 2010, and one in Italy, whose realization is related to Turin-Lyon high-speed rail project.
Concerning tectonical setting ''Pennidic Domain''is involved in the excavation, and more in details the contact between Piemontese Zone (mainly Calceshits and green stones Unit) and Brianzonese Zone (Ambin Massif Unit and related coverage). However from pk 0+200 m the exploratory adit crosses the Ambin Massif represented by gneiss and micascists. Several monitoring data have been recorded during the excavation, in order to asses geological parameters important for the future Base Tunnel realization. This exploratory adit is now still under completion.

The main aim of this work is to compare the experimental hydrogeological monitoring data with the project hypothesises (Italferr Spa, 2009) in order to check the correctness of inflow forecast in term of discharge, temperature and chemical facies of groundwater. The analysed monitoring data cover the period since the beginning of the excavation of "La Maddalena" exploratory adit to the pk 5+548 m (July 2016). During the excavation phase, the hydrogeological monitoring has then concerned:

- daily measure of the total inflow rate;
- bimonthly measure of conductivity, temperature and pH of each punctual water inflow;
- sampling and chemical analysis of some of the main inflows.

The comparison between expected and measured hydrogeological elements have given important information: water inflow began only after the Ambin Massif Unit was reached by excavation and therefore intercepted water flows were less than expected in design. At ch. 5+548 (27-07-2016) a total inflow of 55.4 l/s is reported. This value is below the minimum stable expected inflow rate. The temperature of inflows varies between 13.7 °C at ch. 0+246 and 39.5 °C at ch. 5+289 (20-22-07-2016). The trend of the total inflow rate analysed considering rainfall patterns registered in four rainfall stations, seems to show a generalised lack of direct correlation with precipitation.
Temperature and chemical composition of punctual water inflow have also given the possibility to find out some characteristics concerning the hydrogeological water supply circuits: i.e. the values of temperature registered along the excavation and the temperature water trend increasing with the excavation, indicate a quite slow hydrogeological circuit interesting the excavation area, even if the water temperature is generally lower than the temperature of the

rock measured over time along the excavation.
La Maddalena exploratory adit experience confirms the importance to realize exploratory tunnels previously the excavation of a main tunnel. Having regard to the rate and temperature of water inflows registered during the excavation, a possible geothermal use of this intercepted water resource could be evaluated more in details.

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POLLUTANTS TRANSFER FROM SOIL TO WATER: GEOCHEMICAL INVESTIGATION IN DIFFERENT WATERSHEDS

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Despite policies for sustainable management of watersheds and groundwater quality, a general decline of water quality is being observed, especially due to the human impact on the environment. In Italy over 130000 tons of phytosanitary products are used every year in the agriculture, thus increasing the pollution risk both in soils and in the waters.
In this study, a comparison between two areas in the Marche region, very different from a geological, pedological and hydrological points of view, has been performed with the objective to identify and study the transfer mechanism of pollutants from the pollution source, through the soil matrix to the surface and ground waters (Tazioli et al., 2015; De Bernardi, 2017).
The first area is characterized by a high human impact, in terms of agriculture activities, industries and urban settlements; the geology of the area is given by alluvial plains, sands and clays of the Plio-Pleistocene and sandstone of the Pliocene. The second area is more natural, but small crops (as alfalfa and cilantro) are cultivated in certain zones of the watershed. The geology is quite different, with the outcrops of the Umbria-Marche limestone ridge at the center of the basin (Scaglia rossa, Scaglia cinerea Fms.) and a less extended alluvial plain.
Periodic sampling of soils, surface water and groundwater were performed in the investigated period (March-July 2016), and chemical (F^-,Cl^-, Br^-, NO_3^-, HPO_4^{2-}, SO_4^{2-}, Ca^{2+}, Na^+, pesticide, organic and biomass carbon, FDA, Ni) and isotopic (^2H and ^{18}O in water samples) contents were determined in each sample. Soil sampling were performed by means of a hand auger, the samples put into a sealed bag and stored at 4 °C until the analyses. Water sampling were performed by means of manual sampler and glass bottles.
All the samples were collected in the spring/summer period, when the crops were in active form.
The chemistry of water soil was compared to that of surface and groundwater in the areas, allowing for the identification of the pollutants transfer mechanism; these results indicated also some differences in the two study sites, related to the difference in land use, geology and hydrological behavior. Chemical contents of Nichel were high in both the investigated sites (up to 31 mg/l), also in the more natural one, depending on the mineralization of water by rocks and soils. The isotopes, compared to the isotopic content in precipitation, confirmed the supposed mechanism of pollutants transfer and helped in the aquifers and rivers recharge identification. In particular, a mean value of about -6.8‰ VSMOW in the first area and -7.7‰ VSMOW in the second area was determined for the oxygen-18.

Further investigations are in progress in the areas to better detect and validate the proposed mechanism.

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BIOREMEDIATION OF LARGE CONCENTRATION OF ORGANIC COMPOUNDS IN LAGOON GROUNDWATER

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An old landfill close to the Venice lagoon was filled with industrial wastes and it produced a groundwater contamination plume with hydrocarbons and chlorinated compounds. Emergency P&T system was realised in the sandy aquifer (hydraulic conductivity about 10-5 m/s). Nevertheless, the low efficiency, the high costs and the long time needed for the cleanup with the P&T system suggested to consider a bioremediation system to improve the in situ remediation. More complications arise because the area is set below the sea level and land reclamation drainage pumps let the saltwater intrude.
Microbiological and chemical laboratory tests confirmed the feasibility of the bioremediation system. A field test with two different barriers was designed and realized: an anaerobic barrier close to the landfill to start the reductive dehalogenation of the chlorinated compounds and an aerobic one to treat their by-product and hydrocarbons.
In some anaerobic barrier's wells an organic substance able to increase the reductive dehalogenation of chlorinated compounds was injected. In the aerobic barrier an air sparging system was activated and nutrients were injected to treat hydrocarbons and to promote co-metabolism reactions for chlorinated compounds. In both the barriers the mixing of the re-circulated water with the dissolved substances was planned.
In situ chemical-physical parameters and laboratory chemical analyses upgradient and downgradient of each barrier have been executed to check the efficiency of each barrier for a test period of 16 months.
Pumping test and field test data were used to calibrate the withdrawal rate of the wells of the entire barriers and to realise a groundwater flow model in order to evaluate the effects of the enlargement of the field tests barriers.
The efficiency of each barrier was evaluated to be over 90% (concentration reduction) in the monitored period and the model did not show any problem to the enlargement of the barriers up to 400 m length. The positive results of the field tests and of the numerical model lead to enlarge the barriers to the entire side of the landfill.

SESSION 2

Hydrogeology of fractured rocks and karst aquifers

Chairs: M. Petitta, M. Pola, B. Vigna

Keynote lecture

ORIGIN OF FRACTURING IN HARD-ROCK AQUIFERS: WHAT ARE THE FACTORS CONTROLLING THE PROPERTIES OF THE FRACTURED LAYER?

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The discovery, during the last 1990s, of a thick fractured layer below the saprolite in lateritic profiles developed on crystalline rocks has resulted in a redefinition of hardrock aquifers. During the first 2000s, numerous researches were conducted in different continents in order to validate this new concept of stratiform hardrock aquifer linked to weathering processes. Commonly, the term of "lateritic profile" is used for subtractive weathering profiles developed on metamorphic, plutonic or volcanic rocks. They are the only rocks that are able to develop a fractured layer at depth.

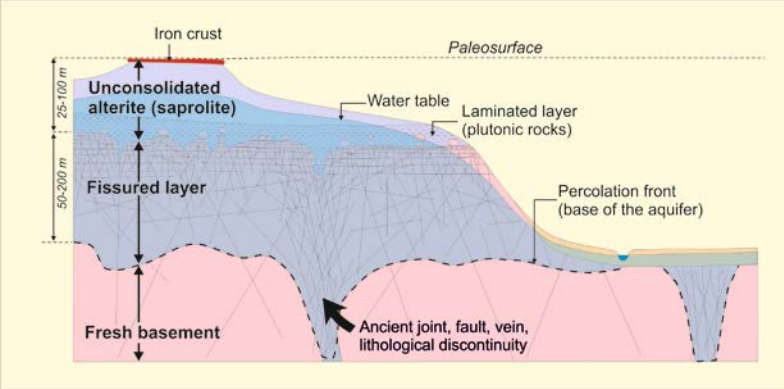


Figure 1 – Structure of a lateritic profile partially eroded by the present topography

A lateritic profile usually shows, from top to bottom (*Figure 1*):

- A ferralitic *duricrust*, 1 to 10 m thick, resulting from recrystallization of goethite (iron hydroxide) to hematite (iron oxide) due to seasonal desiccation of the top of the profile. Where preserved from later erosion and recharged by heavy rainfall this duricrust can give rise to seasonal perched aquifers, particularly in tropical humid areas.
- Loose alterites (*saprolite*), made up of a mixing of clays, hydroxides, oxides and residual minerals (quartz). At the top of saprolite, *mottled clay* (meter-thick) is a transition horizon to iron crust. In granular rocks (granitoids, gabbros), the lower part of the saprolite shows a characteristic laminated texture (*"laminated layer"*), due to high density of tension microcracks (millimetric spacing). The saprolite is of rather low hydraulic conductivity, about 10^{-6} m/s in granites, lower in their laminated layer and at the top (more clayey) of the

saprolite (10^{-7} - 10^{-8} m/s). This plays the capacitive role of the hard rock aquifer.

- A *fractured layer*, characterized by a high density of cracks in the hard rock that plays the permeable role of the hard rock aquifer. The density and connectivity of cracks are maximal at the top and decrease downwards. The primary rock stay hard and little weathered, except along fractures and capillaries. In isotropic granular rocks, fractures take the form of open, planar joints. The hydraulic conductivity of this layer can reach up to 10^{-4} m/s.
- The *fresh rock* is of very low hydraulic conductivity. Pre-existing heterogeneities such as veins, dykes, ancient faults or joints, contacts between different geological units may locally favor the weathering process and can create local hydraulic conductivity.

The thickness of the saprolite reaches commonly several tens of m, and can exceed 100 m. The fractured layer is generally twice as thick as the saprolite.

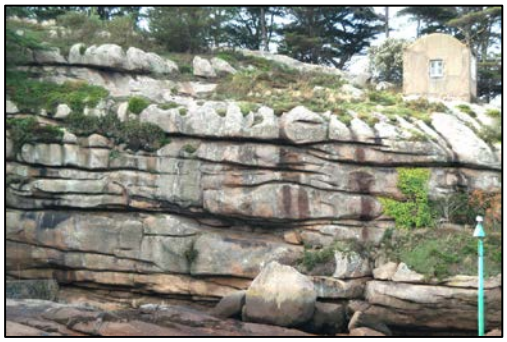
a  b 

Figure 2 - a: planar jointing in Ploumanach granite (Brittany, France); b: the fractured layer in gritty, folded schists (North of Massif Central, France)

The mechanism of fracturing has been understood by field observations and petrographic study on two core drills in granites. The weathering of biotite is clearly an early process, occurring when the rock is still indurated. The potential increase in volume of biotite crystals during the weathering process is 40%, due to inflating of interleaves from 10 Å to 14 Å. As they cannot inflate 'freely' due to rigidity of the rock, a stress tensor is created. In granular rocks like granites with a quasi-random orientation of swelling minerals, the potential expansion tensor is isotropic. At the beginning, the stress increase is also isotropic. Consequently, the horizontal stress component accumulates during the weathering. In the vertical axis however, the stress increases until the lithostatic component is offset, then lets place to vertical expansion, while horizontal stress continues to increase. Consequently, the resulting stress tensor is characterized by a minor vertical component (σ_3), and two major ones (σ_1 and σ_2) that are horizontal. When the stress deviator reaches the elastic limit of the rock, tension cracks appear. For granitic rocks, in accordance with rocks mechanics, the resulting fractures are perpendicular to the minor stress (subvertical) and consequently are subhorizontal, parallel to the gentle topography contemporaneous with the weathering, and leads to the formation of the subhorizontal jointing of granites (Figure 2a). In foliated and folded rocks, the variability of the orientation of the minerals able to swell as well as the ones of the weaker surfaces of the rock (foliation, schistosity) induce an anarchic fracturing, without any preferential orientation (Figure 2b).
Only three minerals are known for inflating during early stages of weathering: biotite, olivine and pyroxenes.
Weathering of plagioclase does not give way to inflating, nor amphiboles. Weathering of K-feldspar and white micas occurs at a later stage of weathering, when the rock is transformed into loose saprolite. Potentially, all rocks containing one of these three minerals can develop a

significant permeable fractured layer, if they have been emerged during a long time (ten millions years or more).

HYDROGEOLOGY OF OGLIASTRA AND BARBAGIA DI SEULO "TACCHI" (CENTRAL AND EASTERN SARDINIA)

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Field data surveyed in the "Tacchi", the carbonatic plateau mainly characterized by dolostones located in a wide region of the central and eastern Sardinia, has been used to develop a conceptual reference model and to test the applicability of Mangin's method (Mangin, 1970a) as well as his karst system classification (1975) to the mesozoic carbonate sardinian aquifers, in order to achieve a better understanding of their behaviour.
In this work, geologic, structural and hydrogeological data of the selected Tacchi has been used to describe their lithostratigraphy, hydrostructures, fracture permeability and karstic features of hydrogeologic relevance. All these data collected in a database has been used to implement a GIS project in order to analyze them.
The geological and structural features allowed to define the geometry of each aquifer, in order to elaborate a conceptual reference model to assess its permeability (Louis, 1974) based upon layering style of carbonate rocks and related fracturation patterns, according Vialon et al. (1976). A confrontation of these parameters and those deriving by the processing of hydrogeological data according Mangin (Mangin 1970a), lead to test the applicability of Mangin's classification of karstic systems (Mangin 1975) for mesozoic karstic systems of central and western Sardinia, to obtain informations about their behaviour.
This study led to recognize in each Tacco considered the upper high permeable unsaturated karst, mainly composed by up to metric layers of dolostones, and the lower saturated karst composed by up to decimetric limestones and dolomitic limestones. In the Tacchi there are some more or less weakly depressed morphostructures (poljie) in which the rainfall and streamflows are gathered and where infiltration occurs. The springs location is clearly imposed by dip direction of carbonate layers, by the orientation and conductivity of joints, and by "undefined permeability limits" (sensu Civita, 1973). Can be also recognized a correlation between Mangin's parameters (Mangin, 1970a), geologic, tectonics and hydrogeological features of all the systems related to each spring that allow to consider Mangin's method and his karstic systems classification (1975) useful mean to study and characterize mesozoic carbonatic aquifers of central and eastern Sardinia.

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PUMPING RESPONSE AND SUSTAINABLE WELL YIELD OF SOME HARD-ROCK AQUIFERS OF THE MEDITERRANEAN REGION

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The issue of sustainable yield of some wells drilled in hard rocks of the Mediterranean Region was examined. The objective of the study was to verify which information may be obtained from the results of pumping tests in order to define the long-term well functioning. Data on the behavior of these aquifers under pumping are scarcely available in the literature; on the other hand, these aquifers might play a strategic role in drinking and irrigation water supplies for the Mediterranean Region in a near future.

Data analyzed concern results of pumping tests performed in three areas with similar climate conditions, which differ in hard-rock type. The tests have interested Paleozoic granodioritic rocks, Paleozoic metasandstones and Eocenic granodioritic and andesitic rocks. In all these sites, the hard rocks are intensely fractured. The pumping data were interpreted with analytical techniques and commercial software. This allowed to recognize three main drawdown trends, coherent with three hydrogeological settings:

i) delayed response coherent with the presence of double porosity;
ii) rapid increase of drawdown coherent with the presence of a barrier boundary,
iii) stabilization of the water level over time coherent with the presence of a recharge boundary.

On the basis of the identified trends and hydraulic parameters, different pumping scenarios were simulated through available analytical solutions, MLU software and finite difference flow model (MODFLOW).

The transmissivity values derived from the pumping tests cover two orders of magnitude and permit to categorize the hard rocks in the classes III and IV according to Krásný's classification, corresponding to rocks from low to intermediate transmissivity magnitude. The storativity is included in a wider range of values. The previous hydraulic properties, together with the simultaneous response to pumping of the drawdown for the piezometer (or piezometers) and the pumped well, may permit to treat the aquifer as a porous equivalent medium at the volume scale of the pumping test. All these properties, associated with an appreciable aquifer recharge, make these aquifers of interest for the local water supply. In this regard, some suggestions to define the sustainable yield of a single well may be derived from the comparison of results of pumping tests with the performed simulations. The results show that the long-term trend in the drawdown and the initial thickness of the aquifer constrain the sustainable yield of a well. In the worst cases examined, namely those related to an aquifer with a barrier boundary and a delayed response of the aquifer, the sustainable well yield is from 1 to 2 L/s. These well discharge values are significant if compared with those found in other regions of the world, and may be related to the dense network of the discontinuities which characterizes the sites.

GROUNDWATER CHANGES IN THE NERA RIVER VALLEY DUE TO THE AUGUST-OCTOBER 2016 SEISMIC SEQUENCE IN CENTRAL ITALY

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The earthquake sequence occurred in central Italy in 2016 was the strongest in Italy since 1980, with 5 major shocks of Mw>5.4 and over 9000 shocks with magnitude Mw>2.0. The area interested by a ground deformation up to -70 cm, stretches for about 40 km in length and 15 km in width. However, the effects of seismic sequence affected a wide sector in central Apennines, involving the inner portions of Lazio, Marche, Umbria and Abruzzo regions.
As already observed for previous earthquakes (i.e. Adinolfi Falcone et alii, 2012), changes of the hydrologic regime have been recorded in regional carbonate aquifers. Particularly, this study describes the changes in groundwater discharge and in groundwater levels induced by the earthquakes in the upper Nera river. The study area, belonging to Umbria-Marche geological domain, is located in the epicentral zone of the earthquake sequence, with particular reference to the 26-30 October 2016 events.
The upper Nera River, located in the western area of Sibillini Mts., represents the main discharge of the basal aquifer at regional scale. The San Chiodo spring tapped for drinking purposes by the S.A.N. company, is interested by monitoring of seasonal and annual changes in piezometric levels and in discharge of the regional aquifer since 2011. Correlating hydrometric level and discharge at the gauging station along the Nera river, it has been possible to evaluate short- and mid-term changes in groundwater discharge, as additionally fed from basal aquifer, induced by the earthquakes. In fact, considering a base flow in the depletion phase of about 1.5 m^3/s, after the earthquakes of 30 October the discharge of the upper Nera river was more than doubled, trespassing 4 m^3/s. Furthermore, in the San Chiodo spring area a progressive increase of the water table elevation (from +2 m to +12 m) has been recorded. After August events, the response was limited to an average increase of about 1 m of the water table; the October events, which struck directly the spring area, caused a steep rise of both discharge and water table. This quick increase reached a steady state in December 2016. Taking into account the conceptual model previously suggested for the L'Aquila 2009 earthquake, a possible explanation could be related to an increase of hydraulic conductivity due to fracture cleaning in the recharge areas; conversely, a different conceptual model is based on a decrease of hydraulic conductivity due to geodetic elevation decrease, estimated in 25 cm in average in the study area. Additional monitoring, including hydrochemical and isotopic data, is useful to test the different conceptual models and mainly for estimating the future behavior of the basal aquifer interested by the above cited changes in hydrogeology. To ensure a correct management of groundwater resources and of the post-earthquake emergency, representative conceptual model of groundwater flow, previewing future evolution of the water table and spring and river

discharge, have been finally considered.

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3D HYDROGEOLOGICAL MODELLING SUPPORTING STUDIES ON THE SOURCES OF MANGANESE, SULPHATE AND TRICHLOROMETHANE IN GROUNDWATER AT PORTOSCUSO (SARDINIA, ITALY)

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The municipal area of Portoscuso (South-Western Sardinia, Italy) has been affected by considerable negative environmental impact, such that the whole territory was declared as a contaminated site of national interest by the Italian Government (D.M. March 12, 2003). Groundwater pollution is a crucial environmental issue in this area, where a volcanic ignimbrite succession up to 500 m thick outcrops, locally covered by sand deposits of variable thickness. Groundwater upgradient to the industrial district showed concentration exceeding threshold levels only for Mn, SO_4 and trichloromethane (Vecchio et al., 2010). In order to verify the origin of such elements, a multidisciplinary approach has been applied. A 3D hydrogeological model has been built, and studies on the geochemical features and stable isotope ratios ($\delta^{34}S$; $\delta^{18}O_{SO4}$; $\delta^{2}H$ and $\delta^{18}O_{H2O}$) in groundwater, together with further insights on mineralogy of Mn mineralizations and the sources of trichloromethane, are now ongoing.

The interpretation of geochemical data required the reconstruction of the geometry of the aquifers and the determination of their hydrodynamic parameters. Therefore, this work presents the methodology employed in the hydrogeological investigation and characterization of the volcanic and sandy aquifers.

The preliminary hydrogeological conceptual model derived from the analysis of geognostic boreholes and monitoring piezometers from previous studies (Vecchio et al., 2010).

Given the considerable extension of the study area, a multiscale approach was used to refine the 3D hydrogeological conceptual model and to understand the relationships between the hydrogeological parameters and the properties of discontinuities in the fissured volcanic aquifer. The fracture network was characterized using both digital photogrammetry and field measurements. Fracture network data was employed for the generation of an intersection fracture density map that was further interpreted through overlapping the piezometric maps. Furthermore, fracture frequency and their aperture were used to determine the hydraulic conductivity of fissured aquifer. Obtained data were compared with hydraulic conductivity data derived from the Lugeon test.

The 3D hydrogeological model allows the reconstruction of the geometry of aquifers. The volcanic aquifer showed variable permeability from low to medium (10^{-4} to 10^{-6} m/s), depending on vertical and lateral extension of the deposits and the structural framework.

The permeability decreases with depth. The sandy aquifer showed a thickness of less than 15 m and a medium permeability (10^{-6} m/s). The relationship between the groundwater flow directions and the fracture network could not be clearly inferred from the piezometric contour line from the fracture density map. However, in this 2D preliminary elaboration, sub horizontal fracture family that may be condition the groundwater flow has not been represented. Further investigations are ongoing aimed to consider all the families fractures in 3D environment.

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ELECTRICAL CONDUCTIVITY AS A TOOL TO EVALUATE THE VARIOUS RECHARGES OF A KARST AQUIFER

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One of the challenges in karst hydrogeology has always been the necessity to identify the various contributions to groundwater recharge in order to evaluate and protect water resources. Over the centuries, several different techniques have been used such as the chemical analysis of major ions, isotope analyses, dye-tracing and trace element analyses.
Electrical Conductivity, which is easy to collect and inexpensive to carry out, can also be used to discriminate between the different contributions of recharge, if the only meaningful differences in the ion composition are due to the concentration of calcium bicarbonate. In the Classical Karst Region (NE Italy-SW Slovenia), researchers focussed on this parameter in order to distinguish between the allogenic and autogenic contributions in the chosen sampling points under various hydrogeological conditions. Electrical Conductivity measurements were periodically supported by chemical analyses defining anions, cations and organic concentration.
The Classical Karst Region is a carbonate plateau approximately 750 km^2 wide and about 2000 m thick, made of limestone, dolomitic limestone and dolostone, aged between the Cretaceous and Paleogene. It is a mature karst where conduits allow a fast infiltration and drainage to the springs. The aquifer is replenished by the leakages of two rivers present in the area (Reka/Timavo and Soča/Isonzo) and by the effective infiltration.
At the extreme South-East of the karst plateau, the Reka River flows for approximately 50 km over a Flysch basin. Once it has reached the carbonates, it is completely swallowed, disappearing into the Vreme and Škocjan swallow holes with an average discharge of 8.6 m^3/s.
On the western side of the study area, the Soča/Isonzo River (with its source in the Slovenian Julian Alps), has an influent character and an estimated recharge of the Karst hydrostructure of about 10 m^3/s of water. The third contribution is due to the effective infiltration calculated at 21 m^3/s.
The three inputs outflow into a wide spring area which extends for about 9 km, from Monfalcone (to the W) to Aurisina (to the East), consisting of more than 50 spring points having a total discharge of 35 m^3/s.
Thanks to the experience gained over the last decade and thanks to the help received by the speleological groups (G.S. Amici del Fante and G.S. Talpe del Carso), a monitoring campaign regarding caves, piezometers and springs has taken place over the last three years.
The results on the western side of the hydrostructure, during low flow conditions, show a prevailing contribution due to the Soča/Isonzo River with EC values in the range 240 µS/cm.

Moving eastward, the role of the effective infiltration is more and more significant. The EC values measured in the caves and deep wells are usually higher reaching values of 470 µS/cm East of the Timavo Spring, still in low flow conditions, the input of the effective infiltration prevails and the Reka involvement is non-influential. In contrast, during floods on the western side, the effective infiltration prevails on the Soča/Isonzo. Moving eastward, the Reka/Timavo represents the major contribution into the spring discharge.

GEOCHEMICAL TRACERS IN COMPLEX HYDROGEOLOGICAL SETTINGS: THE ROCCAMONFINA VOLCANIC VS. MT. MASSICO SEDIMENTARY AQUIFERS (SOUTHERN ITALY)

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The Peri-Thyrrenian margin of central-southern Apennine chain hosts complex geologic structures. The Quaternary explosive volcanism covered several sedimentary basins. This complex geologic setting drives groundwater circulation between sedimentary vs. volcanic aquifers, which host important water resources for human supply. Geochemical composition together with traditional hydrogeological investigation methods provide useful information in the exploration of productive aquifers, allowing a correct management of water resources. Geochemical traces, elemental Sr and its isotopic composition are an useful tool to trace groundwater evolution along its flow-path. In the present investigation we report the results of a study conducted to determine the hydrogeochemical and ($^{87}Sr/^{86}Sr$) isotopic compositions of the Roccamonfina volcano and Mt. Massico groundwater. Fifteen water samples were collected from wells (18-168 m a.s.l) spread over a wide area on the northeastern flank of Mt. Massico (Casanova di Carinola area) and on the southern slope of Roccamonfina volcano (Cascano area). This area acts as "natural laboratory" where the relationship among Sr isotopic signature, chemical composition of groundwater and hydrogeological dynamics can be investigated in order to correctly define the hydraulic relationship between the Roccamonfina volcano and the Mt. Massico hydrogeological basins. Furthermore, Sr isotope ratio together with the results obtained from traditional methods, allow us to discriminate a) the influence of different lithologies during water-rock interaction processes, b) the recharge areas and c) the maturity of the aquifer. Two endmember water compositions were recognized characterized by distinguished Na^+/K^+ and $^{87}Sr/^{86}Sr$ isotope ratios. Groundwater samples collected on the southern slope of Mt. Roccamonfina (Cascano area) are alkali type and characterized by $^{87}Sr/^{86}Sr$ isotope ratios ranging from ca. 0.7087 to ca. 0.7096, in agreement with the chemical and isotopic composition of host rocks. Groundwater from the northeastern slope of Mt. Massico (Casanova di Carinola area) are alkali earth type and have $^{87}Sr/^{86}Sr$ ranging from 0.7084 to ca. 0.7090. Intermediate compositions have been detected in groundwater sampled in wells located along the boundary between Roccamonfina volcanic units and Mt. Massico limestones and dolostones in the Cascano area. In conclusion, chemical and isotopic data on ground water sampled from the Mt. Roccamonfina - Mt. Massico hydrogeological basins allow to clearly detect different mineralization processes related to the specific hydrodynamics produced by interaction with volcanic or carbonate host rocks.

GEODATABASE AND KNOWLEDGE OF COASTAL CARBONATE AQUIFERS OF THE ADRIATIC AND IONIAN SEAS

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The progressive population growth in coastal areas and the increasing groundwater discharge, together with peculiarities of carbonate coastal aquifers constitute a huge worldwide problem, particularly relevant for coastal aquifers of the Mediterranean basin.
Carbonate aquifers in coastal regions are well known to be highly vulnerable, especially if hit by karstic phenomena, to the quality and quantity degradation of groundwater resources, not only for the increasing water demand and the decreasing recharge due to climate changes. The coastal carbonate aquifers of the Mediterranean Sea, in particular the Adriatic and Ionian coast that extend between western Greece and Italy up to the eastern coast of Sicily, not only ensure the socio-economic development of the populations but feeds with spring waters valuable wetland environments with negative effects on ecosystems.
The aim of this study is to offer systematic and synoptic knowledge, useful to management and forecast tools, to assure enduring availability of high quality groundwater, conciliating water demand satisfaction with the ecological needs of coastal environment also in the case of transnational situations. A geodatabase, collecting information for all carbonate aquifers present along the Adriatic and Ionian coast, have been created. At the core, there is a Geographic Information System, in which are placed the spatial information regarding the geology of aquifers, hydrogeological and geochemical features, together with climatic data and specific information concerning past, present and future groundwater use.
The availability of tools that allow the integrated analysis of local hydrogeological situations, in reference to the wider areas where they are located, allows numerous applications. The system, in fact, is not only aimed to archiving, querying and mapping, but also to operate spatial analysis and the implementation of calculation systems, to return the hydrogeological conceptual models, supporting both the management of groundwater resources and the knowledge for the protection of coastal environments, and groundwater in general.

CO-SEISMIC AND POST-SEISMIC CHANGES IN GROUNDWATER DISCHARGE: FIRST RESULTS FROM THE EPICENTRAL REGION OF THE CENTRAL ITALY 2016 EARTHQUAKE

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Short and mid-term effects of earthquakes on groundwater flow were documented in several studies. Water level fluctuations in wells (Manga et al., 2012), temperature changes, increases in stream flow (Muir-Wood and King, 1993) and changes in groundwater flow (Amoruso et al., 2011; Carro et al., 2005) were observed in response to seismic events. The hydrogeological response of groundwater flow systems to earthquakes is very complex and due to significant changes in permeability. Such hydrologic changes may occur even at great distances from the epicenter (Amoruso et al., 2011; Carro et al., 2005) and their magnitude may be related to the proximity to the earthquake focus (Muir Wood and King, 1993; Hartmann and Levy, 2005). Central Italy has been hit by several large earthquakes since August 2016. On August 24th 2016 a Mw=6.0 earthquake struck a large area located among the Lazio, Marche, Abruzzi and Umbria regions. In the following six months, more than 1000 shocks were recorded (the main, Mw=6.5 on October 30th 2016). With reference to the carbonate aquifers located in the epicentral region, the following short term effects were observed: a significant increase of the spring discharges; several perched springs dried up and a number of comparable springs flowed again; a great increase in the Nera river flow. The deep-seated fault movements and fluid redistribution may cause water-level fluctuations as well as changes in groundwater discharge and composition. This study debates a preliminary characterization of such processes.

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DIFFERENTIATED KARST SPRING BEHAVIOR UNDER CHANGING HYDROLOGICAL CONDITIONS IN THE CANSIGLIO-CAVALLO AREA (ITALIAN ALPS)

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The Cansiglio-Cavallo plateau is a limestone massif shared between the Italian regions of Veneto and Friuli-Venezia Giulia (northeastern Italy). A high density of dolines characterizes the area and groundwater circulation is known to occur through very deep karst conduits. Three main springs (Molinetto, Santissima and Gorgazzo) located along a 4 km front on the southeastern margin of the massif are the main outlets of this karst aquifer, discharging a global mean annual flow rate higher than 10 m^3/s and giving origin to the Livenza river. Despite several previous studies and tracing experiments (e.g. Cucchi et al., 1999; Grillo et al. 2011; Vincenzi et al., 2011), the hydrogeology of this karst aquifer is still poorly known.
Geological, hydrodynamic and hydrochemical investigations were carried out in the area since spring 2015, in order to enhance our knowledge on this important aquifer. These included: 1) a lineament analysis to infer the most likely groundwater flow directions inside the massif, 2) groundwater sampling in caves and springs for the analysis of major ions, rare earth elements and stable isotopic signature of water ($\delta^{18}O$, $\delta^{2}H$), 3) continuous monitoring of water levels, EC, T at the three main springs, 4) discrete monitoring of flow rates at the three main springs for the construction of h/Q rating curves, 5) a cave-to-spring multitracer test using three different fluorescent tracers.
The hydrogeological study allowed to: 1) gather new detailed information on the geological and tectonic structure of the plateau; 2) calculate a water budget for the entire karst area based on all available hydrological data; 4) highlight the discharging behavior of the system with respect to different recharge conditions; 5) better define the recharge areas of the three springs and the effective groundwater flow velocities in different sectors of the massif.
The three springs, that apparently drain the same karst aquifer, show different patterns of behavior with respect to changing discharge conditions. In particular, the aquifer behaves as a

partially independent drainage system during low flow conditions, when the chemistry of the three main springs is clearly differentiated. The behavior becomes the one typical of interconnected systems during floods, when the groundwater discharging at the three springs shows very similar characteristics. These results suggest the occurrence of different recharge areas for the three main springs that are mostly independent during low flow conditions and drain the same reservoir during floods.

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ANALYSIS OF RECHARGE PROCESSES IN KARST SYSTEMS

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The recharge processes have been evaluated for several main karst massifs of southern Italy, Mt. Terminio, Mt. Cervialto and Matese massifs, characterized by wide endorheic areas. This paper highlights the contribute to springs discharge of open areas, closed areas and total catchment area of these massifs.
In order to estimate the recharge of these massifs, the model proposed by Fiorillo et al. (2015) has been used.
The annual means recharge has been estimated by GIS tools, from regression of annual mean values of different ground-elevated rain gauges and thermometers.
The recharge has been distinguished for endorheic areas and the other areas of springs catchment, and the ratio between the output spring and input rainfall has been also estimated (recharge coefficient).
The annual recharge has been used to calibrate a daily scale model, which allows to estimate the amount of effective rainfall, which is retained as soil moisture; the amount reaching the water table (recharge s.s.) and the amount of rainfall which develops the runoff and leaves the catchment.
All these amount vary through the hydrological year, in function of soil moisture deficit and daily rainfall intensity.
When soil moisture reaches the field capacity, daily rainfall exceeding a specific threshold values (for Cervialto, Termnio, and Matese Massifs), develops runoff; the runoff amount increases during wet year and reduces during dry years, highlighting the important role of the endorheic areas mainly during wet years.
Cervialto massif can be considered as a pure climate controlled aquifer, Terminio massif is moderately conditioned by groundwater abstraction and Matese massif is strongly conditioned by hydroelectrical exploitation.
The model provided in this paper allows to define the recharge conditions through the hydrological year representing then a useful tool for water management.

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MULTI-SCALE HYDRAULIC CHARACTERIZATION OF STIMULATED FRACTURED CRYSTALLINE ROCK AT GRIMSEL TEST SITE

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Natural and induced fractures make flow in oil and gas reservoirs, nuclear waste repositories and enhanced geothermal systems strongly heterogeneous and anisotropic. In such environments, characterization of the fractured medium through a combined multi-scale and multi-component approach could result into an improved understanding of the physical setting and behavior of the medium of interest.

As part of the In-situ Stimulation and Circulation (ISC) experiment at the Grimsel Test Site (GTS), which is located in the central Swiss Alps, a comprehensive hydraulic characterization campaign has been conducted in order to evaluate the efficiency of hydraulic fracturing and hydraulic shearing on the permeability enhancement and heat exchange capacity of the granitic host rock. The hydraulic characterization consists of tests of varying scale, ranging from single-hole (e.g. pulse injection and oscillatory injection tests) to cross-hole (e.g. constant rate injection and oscillatory interference tests) and reservoir scale (e.g. ling-term constant rate injection test). Moreover, various components in addition to hydraulic tests have been added to these measurements such as thermal and conservative tracer tests, single-hole and cross-hole geophysical measurements and strain/deformation measurements.

The results obtained indicate enhancement of permeability as well as non-integer flow dimension, and thereby natural heat exchange efficiency of the fractured zones. In addition to that, the characteristic of the thermo-hydro-mechanical (THM) behavior on the influenced fractures during the hydraulic/thermal characterization tests has been affected as more flow paths now contribute to the hydraulic system after the hydraulic stimulation. Finally, combinations of all above mentioned methods provide new insights on the heat exchange efficiency of the stimulated rock mass.

GROUNDWATER RECHARGE ESTIMATION IN KARST AQUIFERS OF SOUTHERN APENNINES (ITALY) BY INTEGRATION OF REMOTELY SENSED DATA

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In many Italian regions, the karst aquifers are main source of drinking water and play a crucial role for socio-economic development and hydro-bio-geomorphological conservation of groundwater-dependent ecosystems (Allocca et al., 2015). The reliable estimation of groundwater recharge of these aquifers is a fundamental tool for the management of water resources, also considering the effects of climate changes.

In karst areas of southern Apennines the high-altitude rain and air temperature gauges stations are absent and the conditions of land use are quite variable (Allocca et al., 2014) therefore the assessment of hydrological parameters, needed for the estimation of groundwater recharge, is a challenging issue to be faced. In such a framework an integration of terrestrial and remotely sensed data is a promising approach to limit uncertainties.

In this research, we report results of a study aimed to estimate actual evapotranspiration (ETa) and groundwater recharge in karst aquifers of southern Apennines, by using remotely sensed data derived by the MODIS satellite. In a GIS environment, hydrogeological, geomorphological and land use data (Allocca et al., 2014), were implemented, along with the time series of annual ETa, as estimated by the MODIS Global Evapotranspiration Project (MOD16) for the period 2000-2014. To assess uncertainties in the estimation of ETa, values estimated by the MODIS ETa dataset were compared with those calculated by Turc, annual rainfall and 150 time series of mean annual air temperature recorded by regional meteorological networks in period 2000-2014 were implemented in the GIS environment, in order to reconstruct distributed models of ETa and of groundwater recharge.

Results show a strong spatial variability of mean annual ETa and a significant relationship with air temperature, rainfall, land use and vegetation coverage. At regional scale, the mean annual ETa is about 670 mm for estimations derived by the MODIS data, and about 599, 539 and 695 mm, for estimation by Turc, Coutagne and Thornthwaite formulas; the mean annual groundwater recharge is about 448 mm considering MODIS Eta, and 494, 533 and 437 mm for estimations derived by the application of the Turc, Coutagne and Thornthwaite methods.

The obtained results reveal a new perspective in the assessment of actual evapotranspiration

and of groundwater recharge of karst aquifer at the regional scale given by the application of MODIS data, which allow to overcome the absence of meteorological gauge stations in high mountainous areas.

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INFERRING THRESHOLD BEHAVIOR OF THE SUPRAMONTE KARST AQUIFER FROM TRACER TEST AND ITS IMPLICATION FOR GROUNDWATER PROTECTION (SARDINIA, ITALY)

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Karst aquifer are very susceptible to contamination and the release of pollutant might be quickly transport over large distances in high water conditions or could reach springs with long delay during dry periods. For an efficient protection of karst water against contamination it is essential to understand the characteristics of the solute transport within the aquifer in different hydrological conditions. This can be investigated performing an artificial tracer test as simulation of a contamination event.

This approach was applied to the Supramonte massif, a karst aquifer hosted in a remote area of Sardinia (Italy), unfavourable for dense human settlement. For this reason, the quality of its groundwater is still relatively high. Nevertheless, due to its rapid recharge from allogenic and autogenic water, this aquifer is especially vulnerable to an eventual toxic substance infiltrated in its underground network.

At the end of July 2014, the fluorescein was diluted in the sinking stream just below the waterfall within the Dorgheddie Cave in the fluviokarstic canyon of Gorropu at the eastern side of the Supramonte aquifer, while 3-bags of charcoal were placed into the water of Gorrupu and Su Gologone springs, the main outflows of the karst aquifer,. The charcoal captor analysis were carried out after alcoholic potash extraction using a Turner Designs Digital fluorimeter equipped with a UV photomultiplier detector tube armed with fluorescein filters (E_{ex}=520 nm and E_{em}= 550 nm) with a detection limit 0.01 ppb. The water physical parameters were determined with a portable Hanna HI991301 sensor measuring pH, temperature and electrical conductivity. The alkalinity was determined in situ as bicarbonate ion concentration by titration.

In autumn and winter 2014-15 an extraordinary dry period lasted a few months. In the four months after the injection only one efficacious rain event occurred that was not sufficient for the mobilization of the tracer toward the spring. At the beginning of February 2015, six months later from dye injection and after few days of intense rainstorms, the fluorescein was detected at the Su Gologone spring with maximal concentration of 0.3 ppb. Even after several weeks of sampling no fluorescent tracer was detected in Gorropu spring.

The tracer test results proved the underground connection between the central-east area of Supramonte and the Su Gologone spring, in the northern sector of the aquifer. It also showed that at low water discharge there is a geological threshold that avoids water from the eastern drainage network to reach the main outlet in the northern side.

This study has contributed to the hydrogeological knowledge of the of Supramonte karst area

determining a new underground water flow connection. It has also delineated the catchment area of the Su Gologone spring at the eastern margin of the aquifer and the hydrodynamic behaviour for the water movement in the saturated zone towards spring in low flow conditions. It was also highlighted the groundwater vulnerability of this karst system to a hypothetic contaminant transport and the impact of drastic temporal variation on particular hydrological conditions.

GROUNDWATER TEMPERATURE AS NATURAL TRACERS TO CHARACTERIZE HYDRAULIC BEHAVIOUR AND GEOMETRICAL PROPERTIES IN CARBONATE AQUIFERS: M. NERONE KARST AQUIFER, CENTRAL ITALY

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Groundwater temperature is a physical parameter which is widely used in hydrogeological investigation. Analysis of natural responses of karst springs were used as additional information to characterize the different flow types and the structural organization of drainage patterns in karst aquifers (Roy and Benderitter 1986; Birk et al. 2004). A deterministic approach was adopted to model the spatial variability of discharge (Q) and water temperature (T) at main karst outlets, in order to observe the different responses to rainfall events, as suggested by Martin and Dean (1999) and Birk et al. (2004).

The Giordano karst system is located at SW limb of the Monte Nerone anticline in northern Apennines (central Italy), with a recharge area of about 3.8 km2 (Tamburini 2016). The karst system discharge about 32.2 l/s on average during over the hydrological year and it's characterized by two outlets: a basal-continuous spring (BCS) with a mean discharge of 8.9 l/s and an upper-intermittent spring (UIS) with a mean discharge of 23.3 l/s, located about 60 m above the previous one.

In the present study, flow patterns and geometrical properties (conduits and fractures) have been distinguished by combining discharge and groundwater temperature data, monitored continuously for six months from January to July 2016.

Results show significant difference in the two spring outlets between the time lags as well as non-simultaneous and not analogue responses of temperature (T) to the same recharge events: temperature of UIS range from 9.5 to 10.1°C whereas temperature of BCS remain rather stable, ranging from 9.8 to 9.9°C. This data suggests a stratification of the water along the aquifer probably associated by different residence times and linked to the structural organisation of karst aquifer (conduit and fracture networks): deeper and oldest water in the basal-continuous springs and youngest water in the upper-intermittent spring.

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DISCHARGE VARIATIONS OF SPRINGS INDUCED BY STRONG EARTHQUAKES: THE CASE OF THE MW 6.5 NORCIA EVENT (ITALY, OCTOBER 30TH 2016)

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Earthquakes are known to be responsible for modifications of different kind in hydrological systems, such as variations of water wells levels, transient and permanent changes of springs and streams discharge and alteration of water chemistry. Transient or instantaneous increases of spring discharge have been documented in several cases. These are frequently related to co-seismic temporary increase of water pressure and/or to dynamic strain modifications which induce temporary changes in permeability. This kind of variations generally dominate in the far and in the intermediate field. Permanent or long lasting changes of spring discharge are more frequent in the near field, where modifications of the stress state induced by fault movement can cause permeability variations and changes in groundwater circulation. In particular, long lasting spring excess flow is known to accompany major normal faults earthquakes.

On October 30th 2016 a M_W 6.5 earthquake occurred in Central Italy, about 5 km NNE of Norcia, at a depth of about 10 km. This has been the strongest earthquake of a long sequence, starting on August 24th, near Amatrice (M_W=6.0), and continuing for several months with earthquakes of M_W up to 5.9. All the mainshocks of the sequence show a normal fault mechanism, NNW-SSE trending, coherent with the well-known regional extensional field.

The sequence significantly affected the groundwater circulation of the area, particularly after the October 30th event. Right after the main shock, in the Norcia plane the Torbidone spring, which was dry since the 1979 Norcia earthquake (M_W= 5.9), was suddenly re-activated and its discharge continued to rise during the following weeks, reaching a value of about 1500 l/s in January 2017. The Torbidone spring is part of the Nera basin, and feeds the Sordo River, where an additional discharge increase was also observed.

In this study, using a multidisciplinary approach (hydrogeologic, structural, geochemical and isotopic), we analyse the Torbidone spring and its geological framework, with the aim of identifying the possible causes of the observed perturbation and forecasting the possible mid-term / long-term evolution, both in terms of flow regime and groundwater quality.

The main factor, which are thought to be responsible for the observed hydrological perturbation are:

- variations of structural permeability, both localized along the major fault zones and distributed in the hangingwall rock volume;
- variations of hydraulic gradients to be related with differential subsidence of aquifer hosting structures.

In fact, InSAR measurements of ground deformation outlined the presence of a large (about 30 km × 10 km) NNW-SSE elongated, subsiding area, located at the hangingwall of the major causative fault, producing up to 80 cm of subsidence with deformation gradients up to 30 cm/km. A large number of surface fractures were also mapped over a large area, suggesting a general, significant increase of structural permeability.

KINDS OF AQUIFER RECHARGES IN CARBONATE ROCKS

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What are the kinds of aquifer supplies in carbonate rocks?
Why is it important to know the supply factors of an aquifer in carbonate rocks?
The aquifers in carbonate rocks are mainly fed by contribution connected to primary recharge (autogenic) and/or from contribution linked to the secondary recharge (allogenic) (White 1969; Dreybrodt 1988; Bakalowicz 2005; Ford & Williams in 2007; Palmer 2007; Vigna 2016).
The contributions from the autogenic recharge are related to the direct recharge (rainfall or water of snow melting) which affects over time, only the carbonate massifs. The contributions from the secondary recharge, consist of water runoffs amount from low permeability rocks bordering the carbonate aquifer or of water circulating in secondary aquifers. These aquifers, usually detrital or fractured rocks, cover the carbonate ones and transfer their water to the karst aquifers. In order to examine the different recharge contributions of an aquifer in carbonate rocks, a series of karst systems located in the Southern Piedmont area, characterized by different hydrological situations, are examined. The springs of such systems have been equipped for several years with multiparameter loggers, in order to detect flow rate, electrical conductivity and groundwater temperature. Where surface water infiltrates in the ground, tests with artificial dyes and chemical analysis have also been carried out. In the same way in the spring areas, chemical analyses of groundwater have also been performed.
The hydrodynamics and the main chemical-physical parameters of the spring waters are in part influenced by different recharge contributions to the karst aquifers. In various studied karst systems, the contributions provide by runoff waters and/or overlying or adjacent aquifers, are proved particularly important. The monitoring data and the breakthrough curve of the tracer tests have allowed to reconstruct the kind of circulation of infiltration water into the karst aquifers and to calculate the velocity of groundwater flow. The chemical analysis of the water provided additional information to understand the correlation between runoff and spring waters. The study highlighted the importance of allogenic recharge coming from portions of insoluble rocks bordering the karst aquifers. In relation to these study cases, it is possible to define three different situations: aquifer with predominant primary supply, aquifer with primary and secondary supply, aquifer with predominant secondary supply.

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LINEAR TIME SERIES MODELLING FOR GROUNDWATER LEVEL FORECASTING: THE CASE STUDY OF THE FRACTURED AQUIFER SYSTEM OF MONSUMMANO TERME (CENTRAL ITALY)

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Accurate forecasting of groundwater level is a useful tool to support sustainable water management. This study addresses the problem of forecasting groundwater hydraulic heads using linear models. The studied system is the carbonate aquifer located at Monsummano Terme in Tuscany Region, central Italy. It has been identified as an independent thermal groundwater system, with a fractured structure, physically separated from the nearby aquifers; no interactions with the neighboring Lima river have been found. The average altitude of the recharge area has been identified in previous studies between approximately 150 and 300 m a.s.l., coinciding with local carbonate outcrops. The system's conceptual model and preliminary analysis of groundwater level and meteorological data suggest the presence of a linear relationship between precipitation (considered as the system input) and hydraulic heads in response to them (system output). This relationship has been investigated by implementing linear models such as Auto Regressive models (AR) and Auto Regressive models with exogenous inputs (ARx) on the following data series, available for the 2005-2015 period: (1) daily values of cumulative precipitation registered in a nearby meteorological station and (2) groundwater hydraulic heads measured in a pilot well. These models consist in linear combination of groundwater heads and precipitation at previous time-steps whose output is the predicted groundwater heads at the successive time-steps; like other data-driven techniques, their implementation requires a complete series of historical meteorological and hydrogeological data, but no other hydrogeological features are directly involved in the models implementation. This study was developed in three phases: (1) exploratory analysis of the available data and identification of the conceptual model of the system, leading to the choice of linear models as the most appropriate solution; (2) implementation of the models on the training set and determination of their order by comparing the effectiveness of several models with different orders on both training and test sets; and (3) results and error analysis aimed at determining the worthiness of these kind of solutions. An in-depth examination of the errors has been carried out aiming at both quantifying the errors (determining accuracy of the models) and understanding whether they contain residual information. The latter could indicate the occurrence of phenomena in the system that are not represented by the model. The predictive power of the models has been tested on one day and three days ahead predictions. The ARx model outperformed the AR model, reaching a fitting of 95.22% in terms of Normalized Root Mean Square Error (NRMSE) on the training set and 94.4% on a test set on the one day ahead prediction. On the three days ahead prediction the fitting was 87.14% on the training set and 85.35% on a test set. Results showed that linear models are appropriate techniques for

forecasting groundwater hydraulic heads in systems characterized by a linear and time-invariant input-output relationship such as small systems, with no snow accumulation and a relatively reduced effect of evapotranspiration. The accuracy of the forecasting models obtained in this study allows for further investigations of the system: they can be useful and accessible tools to explore future rainfall scenarios and to examine the effects of new groundwater abstractions on existing wells.

SESSION 3

Groundwater flow and transport modelling

Chairs: F. Lotti, M. Mastrocicco, G. Uras

Keynote lecture

NITROGEN AND OXYGEN ISOTOPES OF DISSOLVED NITRATE TO EVALUATE THE EFFICIENCY OF INDUCED GROUNDWATER DENITRIFICATION AT FIELD-SCALE

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Nitrate (NO_3^-), one of the most common groundwater pollutants, can cause health problems in humans and contributes to the eutrophication of surface water bodies. Frequent sources of NO_3^- pollution are linked to extensive application of synthetic and organic fertilizers, inappropriate placement of animal waste and spills from septic system effluents. Throughout the last three decades anthropogenic nitrate inputs into our environment have significantly increased, giving rise to important loads of nitrate in surface water and groundwater in many parts of the world. Nitrate pollution has become a major threat to groundwater quality as the maximum nitrate concentration allowed by the European Directive 98/83/CE in waters for human consumption (50 mg/L) is reached in most of the regional aquifers in Europe.

Denitrification reaction is one of the most effective processes to remove NO_3^- pollution from groundwater. However electron donor availability (organic C or reduced S compounds) is usually a limiting factor in natural environments to achieve relevant natural NO_3^- attenuation (Knowles et al., 1982). To overcome this restriction, biostimulation of heterotrophic denitrifying bacteria by means of adding an external organic electron donor has been commonly used. Frequently tested electron donors include pure compounds such as alcohols (ethanol, methanol) or sugars (glucose, sucrose) or alternative sources of organic carbon such as compost or sawdust (Akunna et al., 1993; Trois et al., 2010; Grau-Martinez et al., 2017). Strategies aiming to fill the lack of electron donors have gained attention. Laboratory (Carrey et al., 2014; Torrentó et al., 2011) and small scale pilot sites (Vidal-Gavilán et al., 2013) have already demonstrated that adding an electron donor is adequate to induce nitrate attenuation in groundwater.

Nitrogen and oxygen isotopes of dissolved nitrate have been used to evaluate nitrate sources and natural attenuation processes (denitrification) in groundwater in several nitrate vulnerable zones (Otero et al., 2009, Torrentó et al., 2011, Puig et al., 2016). The isotopic fractionation of ^{15}N and ^{18}O that is produced during denitrification provides a tool to also estimate the efficacy of induced attenuation. The present study aims to evaluate the usefulness of stable isotopes of ^{15}N and ^{18}O of dissolved NO_3^- to trace denitrification efficiency in the course of a large-scale induced groundwater bioremediation project.

This study presents a denitrification pilot plant consisting of 2 injection, 3 monitoring and 1 extraction wells. Acetic acid was selected to stimulate and sustain intrinsic heterotrophic

denitrifying bacterial activity. A total of 42 samples were collected in 10 field campaigns from June 2015 to October 2016, and analysed for chemical and isotopic parameters. In addition, batch microcosm experiments using acetic acid as electron donor were performed. The batch experiments simulated aquifer conditions, using sediment and groundwater from the pilot plant test site. The aim of the batch experiments was to determine the isotopic fractionation of ^{15}N and ^{18}O.

The ε values determined in the batch experiments were -12.6‰ for N and -13.3‰ for O. The obtained isotopic fractionation values were applied to evaluate NO_3^- attenuation capacity of the pilot plant at field scale. The isotopic results of the pilot-plant showed that induced denitrification was produced, reaching a nitrate removal percentage of up to 50%. The highest attenuation was measured in the monitoring wells closer to the injection wells. In addition, the isotopic composition of ^{15}N and ^{18}O of nitrate suggested the occurrence of nitrite reoxidation. Nitrite is an intermediate compound of denitrification considered more toxic than nitrate. Hence, the observed reoxidation is a favorable process to avoid nitrite accumulation during induced attenuation treatment.

Acknowledgements

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A COMPARISON BETWEEN TWO STOCHASTIC APPROACHES TO ASSESS GROUNDWATER PCE DIFFUSE POLLUTION IN MILANO FUNCTIONAL URBAN AREA

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Contamination of groundwater resources in highly urbanized areas has become, over the last two decades, one of the most important environmental issues at both European and National level. In Italy, the Po plain, and in particular the Lombardy Region, is one of the most populated European areas where human activities have caused a high impact on groundwater quality. Recently, the new National and Regional regulations consider the necessity to develop plans for the remediation and management of the most industrialized urban areas, affected by groundwater contamination due to both point sources (PS, associated with medium-large sources dimensions, i.e. hot-spots) and multiple point sources (MPS, constituted by a series of unidentifiable small sources clustered in a large area, that cause a diffuse contamination). Due to the European relevance of the topic, the EU project AMIIGA (Interreg. Central 2016-19) has recently started with the aim to set up a common methodology to assess MPS diffuse groundwater contamination in European Functional Urban Areas (FUA).

Because of the uncertainty related to the exact position and strength of MPS, it is complex to implement a numerical model able to simulate the fate and transport of a diffused contamination. Nevertheless, such kind of models are requested by Public Authorities as a tool to manage the groundwater resource and plan the necessary actions to improve water quality. To overtake this problem, a numerical stochastic model (code MODFLOW/MT3DMS) was implemented in a pilot area north-east of the Milano FUA. The proposed methodology allows to consider the uncertainties linked to diffuse contamination sources (MPS) using a Monte Carlo (MC) procedure. Several calibrated models were generated considering the effect of some parameters governing groundwater flow and transport (namely hydraulic conductivity, heterogeneity, and mass released by unknown sources).

Two different stochastic approaches were developed and compared:

- Particle backtracking (BT) through 400 MC realizations varying the distribution of hydraulic conductivity. Using MODPATH, placing particle starting points where a PCE was measured in low concentrations linked to diffuse contamination, it was possible to highlight the cells most frequently crossed by particles, interpreting them as the cells most probably hosting a MPS.
- Clustered MPS through 100 MC realizations considering the variability of contaminant mass released into the shallow aquifer. Using MT3D, for each domain sector it was possible to assess, in a probabilistic way, the distribution of MPS contaminant and the frequencies of mass inflow occurrence into the model domain.

The results of the two approaches were compared in order to collect information about those

areas that most likely host sources of the observed diffuse contamination. In most of the cases, the identified areas match. Some improvements are necessary though, mostly in areas near the boundary conditions of the models.
Regarding the computational aspects, it is possible to affirm that particle BT is faster than the clustered MPS approach. Moreover, the latter requires several information to implement the inverse problem.
Concluding, the study shows that mathematical models within a probabilistic framework have a high potentiality and can represent a powerful tool for groundwater management planning in FUAs susceptible to diffuse contamination.

HYDROGEOLOGICAL STUDY AND NUMERICAL MODEL OF GROUNDWATER RISE MITIGATION ACTIONS EFFECTS IN THE GLACIAL - FLUVIOGLACIAL TERRITORY OF GRANDATE (COMO, NORTH ITALY)

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The development of industry in Europe caused groundwater levels to fall up to tens of metres below ground level. As the water tables were so deep it was often assumed they could be safely ignored. Over the last 10-20 years a reduction in groundwater abstraction has led to a rise in water levels almost everywhere (Wilkinson, 1985).
On November 2014, the Municipality of Grandate, located 10 km southward the Como lake, had to deal with a great emergency caused by the flooding of several underground facilities of buildings and factories located in its territory. Grandate municipality entrusted Politecnico di Milano with the hydrogeological study of its territory in order to understand the causes of the groundwater flooding and prepare a pre-feasibility study concerning possible actions to be taken for groundwater control in order to avoid future occurrences. The study demonstrated the reason of the floods was the concurrence of two causes: the groundwater rising -which is happening in this zone and generally in Lombardy Region (Alberti et. al, 2001; Colombo et al. 2017)- and the abnormal quantity of rainfall that occurred in 2014. The territory setting makes the area of Grandate like a big bucket, surrounded by morenic hills, where water flows from the zones at higher elevations, infiltrates in the plain and hardly discharges southward. In fact, for the uplift of the bedrock, the outflow section shrinks in the southern zone of the plain. The hydrogeological conceptual site model was then the base for a transient numerical model developed to analyse the system behaviour under different scenarios. The flow model was applied to evaluate the effectiveness of some alternative actions for groundwater drawdown and seasonal control. The pre-feasibility study has been developed with reference to 2 kinds of possible mitigation actions: 1) public/private wells relocation and pumping rate increase and 2) low enthalpy geothermal open loop systems implementation. For the first case the wells don't need to extract continuously because the model suggests that it's possible to avoid further occurrences of floods by controlling the groundwater level when it rises up a threshold value. This level of alarm has been set 5 m below the ground. When groundwater exceeds the threshold, it's suggested to extract water from 8 pumping wells. This action creates in the area subjected to the flooding a groundwater drawdown of about 6 m in three months. In case of heavy rainfall period (typically autumn), this is sufficient to avoid flooding of underground structures.

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PERMANENT SAFETY MEASURES (MISP): EFFICACY ASSESSMENT THROUGH PUMPING TEST ANALYSIS, GROUNDWATER FLOW MODELING AND ENVIRONMENTAL ISOTOPE INVESTIGATION

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Managing heavy contaminated areas usually require, by the Italian national rules, the emplacement of safety actions in order to avoid the spreading of contaminant plumes and the deterioration of nearby receptors such for examples water bodies (Majone et alii, 2015). Dlgs 152/2006 force to take Permanent Safety Measures, MISP (Messa In Sicurezza Permanente actions) in situations where the level of contamination do not allow feasible and/or economical remediation of polluted groundwater and soils. MISP actions usually make use of physical barrier for contaminants retention, through slurry walls and impermeable barriers reaching down an impermeable natural horizontal barrier, such as a clay zone. This system should effectively impede the groundwater flow. Moreover, MISP are frequently used in combination with surface caps to produce a complete containment structure to prevent inside local recharge and water table (WT) levels rising. Still, most of MISP systems present unwanted behaviors, primarily WT levels inside rising.

A groundwater flow model was setup and calibrated over an extended area by using dataset from 1999 to 2016, the latter including several new piezometer installed in the vicinity of the MISP' slurry walls. A series of pumping test including long duration tests were performed in order to estimate aquifer parameters, and to investigate the potential for water flow through the slurry walls. Five locations along the wall were tested by using internal and external monitoring wells. A transient groundwater flow was developed to simulate the observed WT rise over the last years. Environmental isotopes including δ^2H and $\delta^{18}O$ of H_2O were measured on a monthly basis for a total of six campaigns.

Groundwater flow modeling and pumping test results demonstrated a very good hydraulic seal for the slurry walls. Permeability resulted to be lower than 10^{-9} m/s at all the investigated locations, confirming the parameters required by the MISP project proposal. The rising of the levels inside the MISP were in agreement with an entrance of groundwater from the underlying clay zone and a good agreement was find between the simulations and the measured values over the last years. A reasonable value for the specific yield was obtained. With regards to δ^2H and $\delta^{18}O$, internal and external monitoring wells showed different signals. Moreover, for the external monitoring wells on the west portion of the study site, δ^2H and $\delta^{18}O$ were helpful to demonstrate surface water-groundwater interactions.

The long duration pumping tests and modeling efforts were effective in describing the water dynamic between the underlying clay zone system, the alluvial side aquifer and the run-off

rainwater infiltrations through the capping system. Environmental isotopes confirmed the proposed conceptual model.

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GROUNDWATER NUMERICAL MODEL OF THE BISKRA INFÉRO-FLUX AQUIFER (NE ALGERIA)

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The Inféro-Flux phreatic aquifer is hosted by the Quaternary alluvium of the Oued el Hai-Biskra, in Northeastern Algeria. The most productive zone, near the city of Biskra, extends over a three km^2 surface. The aquifer overlies low-permeability Neogene deposits. Average annual precipitation of 150 mm/year, high evapotranspiration rates, and increasing water demand have led to the overexploitation of this groundwater resource. Indeed, extraction for drinking water occurring at twelve wells, for a total withdrawal of seven Mm^3/year, has led to more than ten metres drawdowns of the water table in the last forty years. The aim of the work was to develop and calibrate a 3D groundwater flow numerical model for estimating the spatial distribution of the hydraulic conductivity parameter and improve the knowledge on the aquifer dynamics, based on the definition of the aquifer boundaries through a 3D geological model.
Borehole reports and cartography derived from the literature and piezometric data, collected during various field surveys, were organised within a geodatabase. All the data, together with eighteen geological sections and following the geomorphological interpretation of the stream system, were implemented in the 3D MOVE software to reconstruct the geometry of the Inféro-Flux aquifer. The conceptual hydrogeological model was developed by integrating the 3D geological model, the SRTMGL1 DEM and the hydrogeological data acquired in May 1966 (SCET-COOP, 1967). They include piezometric heads, pumping rates and hydrological water budget. The MODFLOW-2005 code (Visual MODFLOW Flex Interface) was used in the design and calibration of a 3D steady-state groundwater flow numerical model. PEST was applied for automated calibration and estimation of hydraulic conductivities (k_x). Then, heads observations and pumping yields coming from a second dataset (WADIS-MAR, 2016), were used to validate the k_x obtained by the PEST code.
The 3D geological model provides the geometry of the Inféro-Flux aquifer. It showed a maximum thickness of 50 m, a steep slope on the left bank and a gentle slope rising towards the ground surface on the right bank. Results of the model calibration via PEST application show that 1) estimated hydraulic conductivities range from $2*10^{-4}$ to $8*10^{-3}$m/s, 2) residuals have a 0.05 m RMS (root mean square) error, and 3) the simulated inflow corresponds to 33500 m3/d. Results of the model validation show a RMS residual error of 1.5 m and a simulated inflow of 23500 m^3/d.
The 3D geological model allowed constraining the geometrical boundaries of the model domain. The numerical model well agrees with the conceptualisation of the system as

demonstrated by low residual values. The simulated inflow volumes allow the groundwater budget closure in both calibration and validation runs. However, potential recharge from direct rainwater infiltration is not enough to justify the simulated volumes and further lateral groundwater recharge should be considered. They can be related to the alimentation from deep groundwater systems rising to the surface.
The modelling will provide a valuable tool for the sustainable and integrated management of the groundwater resource and to evaluate the effectiveness of a Managed Aquifer Recharge (MAR) system designed in the frame of the WADIS-MAR Project (www.wadis-mar.eu) aiming to restore the water level (Ghiglieri et al., 2014).

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A CENTRAL APENNINE TEST SITE FOR LONG-TERM MONITORING: RELATIONSHIP BETWEEN SEISMICITY AND GROUNDWATER DURING 2016-17 EARTHQUAKES

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Since historic times, the response of aquifer systems to earthquakes has caught the attention of people. Macroscopic effects like increase of spring discharge, changes in river flow rate, and the sudden disappearance of springs or the generation of new ones have been recognized without the need for sophisticated equipment. By contrast, because most measurements of groundwater composition require discrete sampling of water and expensive and time-consuming laboratory analysis, observational data for earthquake-induced changes in water composition are limited. The aim of this study was to identify potential patterns of level changes in response to several earthquakes, and possible variations of ion concentrations, gas compositions and isotopic ratios in groundwater. Doglioni et al. (2014) propose that in the tensional tectonic environment, the triangle of crust above the brittle ductile transition remains "suspended" while a dilated area forms during the interseismic period. Fluids may enter the fractured volume and water level decreases, when the triangle of crust above the brittle ductile transition starts to drop, the fracture confines and water level hence rises. This increase of water level culminates in the coseismic period. The Bussi sul Tirino monitoring area in Central Italy, located in a region with abundant groundwater resources has been selected. It is located near the active normal faults of the Sulmona basin, along the southeast-ward prolongation of the faults that nucleated the L'Aquila 2009 Mw 6.3 event. This area is characterized by low strain rate, an indicator of potential future larger earthquake. In the site, seismic and GPS stations are acquiring data. Since July 2014, an experimental monitoring station is collecting data of piezometric level, electrical conductivity and temperature on a groundwater well 100 m deep, coupled with a time discrete sampling of the main springs for chemical and isotopic analyses. The recorded data have been subsequently filtered and correlated with the seismic events recorded by the National Seismic Network in a distance range of about 40 km from the monitoring well. The preliminary comparison shows statistically supported correlation between groundwater level changes and seismic activity. In detail, in several considered time slots, seismic events are preceded by a slight, but significant decrease of the water table and followed or accompanied by a strong increase of the water table itself in the monitoring well. The seismic sequence of 2016-17 in Central Italy affect the monitoring site showing a reversal trend respect with the depletion phase. In fact, as a result of earthquakes, piezometric levels raised approximately of 30 cm in August, 20 cm in October and 80 cm in January, testifying the

regional influence on groundwater flow caused by the seismic sequence .The results of chemical and isotopic analysis, repeated over time, highlight very steady characteristics due to the regional groundwater flowpaths, while trace metals content shows a different trend before and during the recent seismic sequences. Taking into account that the epicenters are located tens kilometers away from the study area, both water table and hydrochemical minor changes are in agreement with the theoretical previsions of seismic response for areas characterized by extensional tectonics.

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MODELLING GROUNDWATER FLOW IN CARBONATE RIDGES: THE CASE OF M. PAGANUCCIO AND CESANE (ITALY)

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In carbonate aquifers, the complex geological structures is reflected in the heterogeneous nature of groundwater fluxes, which is mainly driven by the fractures and conduits orientation and aperture. Here, the elevated cost of drilling wells in mountain areas suggests that geological and geomechanical surveys are cost effective tools to qualitatively solve groundwater directions in upland catchments. In addition, numerical modelling can help to quantitatively constrain the hydrogeological conceptual models of these aquifers. The aim of the study is to propose an integrated approach that combines the classical hydrogeological characterization by means of recharge estimates, spring and streams base flow discharge, hydraulic conductivity estimates from geomechanical surveys in well defined hydrogeological basins, with a three dimensional steady state flow model using MODFLOW-2005 in a MODEL MUSE environment (Winton 2009). This methodology aims to highlight the limitations of various modelling approaches, like the vertical/horizontal anisotropy in an equivalent porous medium or the conduit flow process (Hill et al. 2010) in fractured aquifers characterized by groundwater data paucity. The M. Paganuccio and Cesane (IT) carbonate ridges were selected as representative case studies due to their well-bounded hydrogeological basins. The results show that the application of the proposed approach to the study areas was able to highlight the weaknesses of each numerical approach. At the same time, this study shows that the comparison between different modelling approaches can provide constraints to the uncertainties related to highly sensitive parameters like hydraulic conductivity and recharge rate. This was established by comparing the long-term hydrogeological budget of each basin with the model output using the Zone Budget package and stream discharge measurement along the model domain.

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SUBSOIL GEOSTATISTICAL MODELING AS TOOL FOR HYDROGEOLOGICAL MODELING: TRANSITIONAL PROBABILITY APPROACH APPLIED UPON A HETEROGENEOUS SITE

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Nowadays, a detailed hydrogeological characterization is the base of an effective hydrogeological modeling aimed to plan and manage both the groundwater and the environment systems. Every single groundwater numerical simulation needs a hydrogeological conceptual model of the subsoil in order to define parameters and boundary conditions as well. The better the subsoil is reconstructed, the more accurate the results of the modelling will be. Several methods are available to perform a 3D simulation of the subsoil; however, their application depends on the heterogeneity of the investigated area. This study aims to perform a 3D model of a heterogeneous site covering an area of 3.8 km^2 close to the Venice lagoon (northeastern Italy). This area is relevant from the environmental perspective because the shallower aquifer (about -4 meters above sea level) is affected by arsenic contamination (Dalla Libera et al., 2016; Trevisani & Fabbri, 2010). Approximately 119 stratigraphic logs are available in this site, confirming the presence of alluvial deposits (clay, silt, sand and peat) with high heterogeneity. Considering that, we decided to use a transitional probability geostatistics approach to perform the 3D subsoil model (Carle, 1996). Firstly, we analyzed borehole data to calculate material proportions, mean lens lengths and transitional probabilities. Secondly, the transition probabilities were used to generate multiple realizations of the subsoil heterogeneity. Every realization was conditioned by borehole data, preserving the geologic tendencies. The results produced a detailed 3D structure of lithological architecture that is fundamental to perform a further reactive transport numerical model of groundwater (in our case for arsenic contamination). Therefore, the considered approach enhances the geological/stratigraphic knowledge of the hydrogeological system for a further discussion on the regional environmental management.

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WATER PLANNING AND MANAGEMENT IN THE CORNIA RIVER PLAIN BY MEANS OF THE GIS-INTEGRATED FREEWAT PLATFORM

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In several Mediterranean areas, coastal aquifer development is often intensive and subject to salinity problems, as result of overexploitation and seawater intrusion.
In the lower Cornia valley (Tuscany, central Italy), groundwater represents the main source of water (providing also part of the water supply to the Elba Island) and it is hosted in a multi-layered aquifer. The water balance has been characterized for years by quantitative imbalance, caused by an intensive exploitation of groundwater for civil, industrial and agriculture supply. In the area, the Cornia river is recharging the aquifer providing about 1/3 of the whole estimated recharge. Since the 1950, groundwater withdrawals largely impacted the hydrologic system, resulting in consistent head lowering (up to 12 m inland), water balance deficit (about 8 Mm3 from the 70s to 2001), subsidence, reduction of groundwater dependent terrestrial ecosystems, and salinization of the coastal side of the aquifer.
Rebalancing the water budget of the hydrologic system of the lower Cornia valley is one of the main aim of the LIFE REWAT project (sustainable WATer management in the lower Cornia valley through demand REduction, aquifer REcharge and river REstoration). Within this project, five demonstration measures are foreseen. They consist in: (1) setting up a Managed Aquifer Recharge facility; (2) river restoration of a Cornia river reach; (3) water saving in the civil water supply sector; (4) water saving in agriculture; (5) reuse of treated wastewater for irrigation purposes.
These demonstration interventions are supported by a Geographic Information System and a hydrologic model based on advanced modeling tools integrated in the FREEWAT platform (developed within the H2020 FREEWAT project - FREE and open source software tools for WATer resource management; Rossetto et al., 2015). FREEWAT is a free and open source, GIS-integrated modelling environment which provides spatially distributed and physically based codes (e.g., MODFLOW and related USGS-family codes) for the simulation of the

hydrologic cycle. The model developed allows: (i) simulating groundwater availability over the last decades; (ii) assessing issues related to salinization and water quality, (iii) evaluating water consumption for agriculture purposes, and (iv) managing the demonstration pilot design and operation.
The model is built on a spatial domain 17.0 km x 18.6 km large, using a dynamic process by which, starting from an initial grid based on 200 m x 200 m large cells, the investigated domain is further refined and new elements are added as soon as new data are gathered. Data implemented are related to surface water and groundwater hydraulic head, detailed riverbed bottom profiles, hydrodynamic parameters, depth of aquifer bottom assessed by both existing boreholes and passive seismic measurements, water quality data. By this means, the final model is achieved with cells 20 m x 20 m large and detailed information on surface water bodies/aquifer interactions are input. Analysis of conjunctive use of ground- and surface-water is then accomplished through the Farm Process module embedded in MODFLOW-OWHM (Hanson et al., 2014), and SEAWAT(Langevin et al., 2007) is used to treat density-dependent flow for the simulation of saltwater intrusion.
The model developed also allows designing scenarios to support project activities (i.e., the demonstration pilot design and operation) and analyzing relevant processes impacting the hydrologic cycle. Finally, this allows building a reliable and robust data-based tool for water planning and management of the Cornia plain.

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THE EFFECTS OF LOW ENTHALPY GEOTHERMAL SYSTEM ON GROUNDWATER OF THE CESINE WETLAND

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The Cesine Wetland represents one of the most valuable wetlands of Apulia. It is located in Salento, along the Adriatic coast, not far from Lecce. It was recognized as "wetland of international interest"; it became "state natural reserve" and since 1980 it is managed by the "World Wide Fund for nature" (WWF).
The protected area, 620 hectares wide, is shaped as a narrow and elongated strip that follows the coastline. It is crossed by numerous artificial channels, some of which represents the inland boundary. The core of the reserve, the eastern sector, includes the brackish water marshes, wooded areas and those of the Mediterranean marquis that give hospitality to the major habitats of community interest. The environmental peculiarities of the Cesine Wetland are due to a complex hydrogeological pattern, the high contribution of groundwater outflow, and to a peculiar dynamic equilibrium with sea, also due to the role of the wide coastal aquifer of Salento. The western part hosts the reclaim activities, where the ancient rural building "Masseria Cesine", used as the wetland visit center.
This visit center site was selected for the construction of a low-enthalpy geothermal power plant as part of a pilot project funded by the EU IPA Legend 2007-2013 Adriatic. The pilot plant is a case perhaps unique in a protected wetland, made to check the replicability of geothermal air conditioning systems in environmentally valuable contexts. It was designed and realized for the monitoring of the environmental effects of heat exchange.
The geothermal heat pump system consists of two double U-shaped geothermal probes, 200 meters deep, intercepting three aquifers separated by aquiclude levels with different hydraulic and hydrogeochemical characteristics. Piezometric boreholes were realized at different depths and different distances from the system, allowing the estimation of several parameters or measurements of physical variables, including temperature. Hydrogeological conceptualization and periodic measurements support the implementation of a numerical model, designed for future assessment of environmental effects.
The heat transport numerical model was developed in FEFLOW, in order to estimate the extension of the thermal plume generated within the aquifers after a long period of heat exchange.
The numerical model was developed assigning different values of hydraulic, thermal and geochemical properties to each layer, considering in particular saline concentration of groundwater. The model parameters definition was based on thermal properties of ground

samples, Ground Response Test (GRT), groundwater level measurements, temperature logs and groundwater surveys.
Initial simulation results contributed to the evaluation of geothermal plant influence on groundwater, a fundamental resource ensuring the existence of wetlands and autochthonous plant and animal species, and confirmed the sustainability characteristics of the heat pump system.

1-D REACTIVE TRANSPORT MODELING TO EVALUATE THE INTERACTION AMONG DIFFERENT COMPOUNDS IN A COMPLEX CONTAMINATED SITE DRIVEN BY REDOX PROCESSES

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The redox processes are the main drivers that condition the behaviour of different compounds within a plume in a contaminated site. The fuel-derived organic compounds (BTEX and MTBE), that can be released in the aquifer through an oil spill, trigger in groundwater heavy redox condition. This is due to the direct mineralization of organic matter (Palmucci et al., 2016) or to the mineralization of fermentation by-product (e.g. H_2, Acetate, Phenol, etc.), that represent the substrate for microbial growth (Watson et al., 2003; Chambon et al., 2013). When a contamination by chlorinated ethenes (i.e. PCE, TCE, DCEs, VC) also occur, the reductive dechlorination process, which leads to their degradation, can be inhibited by others redox-sensitive compounds (i.e. NO_3^-, Mn(III,IV) hydr-oxides, Fe(III) hydr-oxides, SO_4^{2-}, etc.) naturally and/or anthropically present in the aquifer, because of the competition among the corresponding microbial species (McCarty, 1997; Chambon et al., 2013). The modeling of reactive transport, considering and comparing different kinetic degradation equations (e.g. first-order equation, Monod equation, etc.), can be considered an up-to-date method to understand in detail the processes occurring within the plume, in order to evaluate the best remediation technique.

As study area, a coastal aquifer has been selected, where 10-15 meters thick sandy and silty sandy deposits aquifer overlays an clayey aquiclude (Desiderio & Rusi, 2003; Di Curzio & Rusi, 2016). Here, several foundry wastes burials, an oil spill from a fuel station tanks and a residual chlorinated solvents residual phase were detected.

The reactive transport has been simulated along the main flowpath (1-D model) using Phreeqc (Appelo & Postma, 2005) and the dataset used for the model validation consists of chemical analyses made on groundwater samples collected in a 43 wells monitoring network.

The first results show a persistence of reductive dechlorination by-products (i.e. DCEs and VC) in groundwater near one of the largest discovered foundry wastes burial containing Mn and As-rich Fe hydr-oxides. Thus, the higher is the metals' content in the solid matrix, the slower is the progress of reductive dechlorination, suggesting a strong competition for the substrate among the different microbial species.

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RESULTS OF A RESEARCH REGARDING THE VARIABILITY OF SPRING DEPLETION CURVES

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In most cases, the discharge process of springs during no recharge periods - or depletion curve (DC) - is described by three well-known functions (or by a combination of them): a) Maillet or Exponential (EF); b) Tison or Hyperbolic (HF); c) Linear (LF). Each of the three functions can be obtained as a solution of a differential equation, assuming some simplifying assumptions. Each of the three equations, according to theoretical considerations, should correspond to a different hydrogeological setup, so that, for the same spring, the type of function and its depletion coefficient should remain constant from one year to the other. However, in many cases, this does not occur: often for the same spring, the depletion coefficient can change notably from one year to the other. Furthermore, even the type of DC can change. To understand the possible reasons for such discrepancies, we carried out an investigation on both theoretical and actual data sets. In this work, we present the results regarding the influence of measurement errors on the DC.

The first part of the research was carried out on a set of theoretical DCs. The theoretical data have been corrupted adding three sets of random errors (5%, 2%, and 1%), generated by a Monte Carlo procedure. In a non-negligible number of cases, the statistical analyses of results have shown that not only the depletion constant changed notably, but even the type of function was different from the original. These results were confirmed by the analyses of actual spring data.

The findings confirm the need for high-quality data. Furthermore, as there is no measurement without error, the research stresses the importance of taking into consideration the uncertainty coming from measurement errors and the need to interpretate the theoretical results in the light of the known hydrogeological setup of the spring.

TESTING INDIRECT METHODS TO INFER HYDRAULIC CONDUCTIVITY IN STREAMBED SEDIMENTS: PRELIMINARY RESULTS

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The saturated hydraulic conductivity (K) is an essential parameter in physically-based models for simulating water flow and chemical transport in soils.
Streambed K can be derived from empirical relationship between K and various statistical grain-size parameters such as the geometric mean, median, and effective diameter (Vukovic & Soro, 1992).
Although many direct and indirect methods can be selected to determine hydraulic conductivity of unconsolidated sediments, each method has faults that limit its application. Compared to other methods, grain-size methods are less expensive and less dependent on the geometry and hydraulic boundaries of the streambed (Song et al., 2009).
The aim of this study is to test about fourteen methods to determine the permeability by indirect measurement estimating the value of the hydraulic conductivity (K) from the particle size distribution curves. Reliability of the methods were evaluated comparing the calculated parameters with those obtained through in situ infiltration tests with the double ring infiltrometer and with constant head permeability test in the laboratory carried out on the same samples used for grain size characterization.
To test the methodologies, seventeen samples ranging between poorly sorted gravelly sand with fines and poorly sorted sandy gravelly silt with fines were used. The uniformity coefficient (Cu) varied in the range of 40-7000.
Different empirical methods have been used based on the equation presented in Vukovic & Soro (1992), as a function of certain coefficient and effective grain size, usually corresponding to d10. Because of the high value of the coefficient of uniformity of samples, according to Urumovic & Urumovic (2014) the Kozeny-Carman model was applied using the value of the geometric mean of the grain size in place of the effective diameter d10. Indeed, for alluvial samples showing a wide range of diameters, the geometric scale is much more suitable than the arithmetic scale. Conversely, when d10 is used, the Kozeny-Carman model returns correct values of permeability only for uniform deposits (Urumovic & Urumovic, 2014). The K values obtained from distribution curves have been compared with the results of infiltration tests. These values were generally lower of an order of magnitude, compared to the calculated dataset. This may be due to the different depth of sediments sampling for laboratory analysis compared to the infiltration test in situ. In fact the infiltration double ring tests were carried out on the surface in places subject to grazing cattle, were compaction of soil occurs. Instead, the preliminary permeability tests provided results more consistent with those obtained from the application of the Kozeny-Carman model.

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CONTINUOUSLY OPTIMIZING A GROUNDWATER REMEDIATION SYSTEM IN COMPLEX FRACTURED MEDIA

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To contain environmental impacts of a former chemical plant of 150 ha located in Manfredonia (FG), a complex groundwater remediation system with 61 extraction wells and 68 infiltration/injection wells has been installed. Groundwater flow at the site primarly occurs within a complex karstic and fractured media.
A continuous groundwater monitoring has been performed since years, including monitoring of groundwater and seawater levels, daily measurements of pumping rates, groundwater sampling as well as periodically runs of a 3D finite elements numerical model.
Due to the Public Authorities' request to better detail the aquifer anisotropy a continuous analysis and evaluation of the previous data have been carried out. Thus, after several years of performance and monitoring, the complexity of the site has been investigated through an integrated analysis of new hydrogeological surveys, including numerical modelling and photo-geological mapping through the study of aerial photographs.
The site-scale conceptual model has been optimized conducting and evaluating 11 long term pumping tests and a detailed photo-geological study to better define the fracture pattern and aquifer anisotropy. In addition, the influences of tidal effects and of the Pump&Treat&Injection system have been taken into account.
The new outcomes allowed to update and recalibrate the existing groundwater flow numerical model. The numerical code used is FEFLOW, based on the Finite-Element technique. The flexibility of triangular finite elements gives the model the capacity to simulate the complex groundwater features of the aquifer media.
Due to additional hydrogeological investigations, a general confirmation of the known range of hydraulic conductivity values of the aquifer has been achieved and most of the data gaps were filled. The updated model was calibrated and then validated in a transient regime. In addition, using the numerical model, the remediation system has been evaluated with the aim of an extraction/injection wells system forthcoming optimization.

INFLUENCE OF GROUNDWATER TEMPERATURE VARIATION ON THERMAL PLUME MODELLING IN GEOTHERMAL OPEN LOOP SYSTEMS

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The Groundwater Heat Pump system is a technology that withdraws water from a well or surface water, passes it through a heat exchanger and discharges the water into an injection well or nearby river, developing a thermal plume of colder/warmer re-injected water, known as the Thermal Affected Zone (TAZ). Plumes are considered a potential anthropogenic geothermal resource or pollution, in fact they might pose a risk to groundwater use downgradient. It is then important to know early in the project whether the aquifer is suitable for the system to be implemented and whether the TAZ will interfere with existing wells, subsurface infrastructure or land use.

Physical processes affecting heat transport within an aquifer include advection (or convection), mechanical dispersion and diffusion (Diao et al., 2004). Plume propagation occurs primarily through advection (Lo Russo and Taddia, 2010), and tends to "degrade" following conductive heat transport, and convection within moving water (Hecht-Mendez et al., 2010). The results of a sensitive analysis realized by Lo Russo et al. (2012) indicates that the main hydrodynamic parameters that influence the heat transport are hydraulic conductivity and gradient.

As the hydraulic conductivity varies according to the temperature due to the variation of the water dynamic viscosity, in the present study we evaluate the influence on heat transport of the groundwater temperature variation induced by an open-loop system reinjection system. To investigate this topic a sensitive analysis has been realized using FEFLOW® 6.2 package developed by Diersch (2010).

FEFLOW gives the possibility to include or disregard the dynamic viscosity variation related to the groundwater temperature and therefore we simulated these two scenarios. For each of them nine different cases have been considered using the combination between three different conductivity classes and three different injection temperatures values. For each case (K-T_{reinj}) the isotherms obtained in both scenarios have been compared geometrically.

The two scenarios analysed highlighted that the variation of the dynamic viscosity with the groundwater temperature affects the extension of the TAZ in the cases of higher values of aquifer hydraulic conductivity and/or in the situations of warmer injected water and therefore in these modelling contexts it should be taken into account to correctly assess the subsurface thermal perturbation.

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ASSESSMENT OF SEAWATER INTRUSION AND GROUNDWATER QUALITY IN THE ANTHROPIZED RECLAMATION AREA OF ARBOREA (W SARDINIA)

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Groundwater represents an important very sensitive natural resource exploited for human consumption, agricultural and industrial activities. In Mediterranean area, one of the common environmental hazard for groundwater, that may affect coastal aquifers, especially in agricultural areas, is represented by the phenomenon of seawater intrusion. The intensive use of groundwater resources for the agricultural practices and for irrigation may generate the deterioration of groundwater quality, in the areas particularly vulnerable to seawater intrusion. Such phenomenon is one of the major problems in Sardinian coastal aquifers (Italy). In particular, it has been detected in the reclamation area of Arborea plain (west Sardinia) where intensive agriculture and dairy farming are the mainstays of the local economy.
In this research SINTACS and GALDIT vulnerability indexes and the numerical model for simulating groundwater flow have been applied for evaluating respectively the intrinsic vulnerability to pollution, seawater intrusion and groundwater flow for a typical Mediterranean phreatic alluvial aquifer such as Arborea plain aquifer. All these three methods have been applied under variable hydrogeological conditions in different research periods (2007 and 2015). All parameters used for this vulnerability assessment were prepared, classified, weighted and integrated in a GIS environment.
Results show that the vulnerability to contamination of groundwater obtained by solving the SINTACS equation has a range from very high vulnerability to low. The vulnerability map indicates that the zones which are most vulnerable to groundwater pollution are located in the coast North-West of the plain (where on the sandy land there is very low protection for the groundwater). In these areas the geology is formed by alternating layers of clay and limestone. The area with the lowest value of vulnerability is located in the South West coastal shores and small claimed areas where the clay matrix forms a protection against the groundwater pollution. The other part of the area, where the soil is characterized by alternating layers of gravel and sand is highly vulnerable to pollution. As concerns the application of GALDIT vulnerability index the results obtained show that in the studied area the range of the vulnerability to seawater intrusion is from very high to moderate, there are no areas that are not affected by this phenomenon. The numerical simulation results shows that the trend of the flow lines have direction East-West and especially in the coastal area confirm the results obtained with the two parametric methods. In fact, the piezometric head in this area results zero or above the sea level even if the aquifer depth is remarkable. In conclusion the application of SINTACS and GALDIT vulnerability indexes and flux numerical models may offer a valuable contribution to the team of existing tools in the field of seawater intrusion and groundwater quality modelling by allowing to punctually monitor the progressive degradation of groundwater resources in

coastal areas and then to identify action plans aimed at informing and training farmers end users of the groundwater resources in much better management.

UNRAVELLING THE IMPORTANCE OF FRACTURED ZONE IN REGIONAL FLUID FLOW: INSIGHTS FROM THE HYDROTHERMAL MODELLING OF THE EUGANEAN GEOTHERMAL SYSTEM (NE ITALY)

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The Euganean Geothermal System (EGS; Veneto region) is one of the largest and most extensive utilized geothermal system in northern Italy. The naturally emerging thermal water is exploited by approximately 200 wells from a 300-1,000 m deep thermal aquifer. The water has a temperature from 65°C to 86°C, and it is used for balneotherapy forming the famous Euganean spa district. The Euganean Geothermal Field (EGF) and thermal fluid have been subject of multidisciplinary studies over the last 50 years, and their results were used to propose a structural controlled conceptual model of the system (Pola et al., 2015). The thermal water is of meteoric origin and infiltrates to the north of the EGF in the Veneto Prealps. The water flows for approximately 100 km in the subsurface of central Veneto and emerges to the southwest in the EGF. The regional flow and the local rising are controlled by the regional Schio-Vicenza fault system (SVFS) that is a system of NW-SE trending, NE dipping faults buried beneath the Quaternary cover of the Veneto alluvial plain. The former is enhanced by the damage zone of the Schio-Vicenza fault. The latter takes advantages of a local network of fractures associated with an interaction zone between the faults of SVFS. In the present study, the conceptual model is implemented in 3D coupled flow and heat transport numerical model to quantify the role of these highly permeable structures on the flow. The geological setting is reproduced by 5 units with different hydrodynamic and thermal properties using an Equivalent Porous Medium approach (EPM). The fractured zones are simulated increasing the hydrodynamic properties of the EPM. In addition, discrete elements are superimposed to reproduce the local network of fractures. The simulations are carried out for 2.5 Ma to obtain quasi-stationary solutions. The results show temperatures in the EGF reservoir higher than in the surrounding areas, despite a uniform basal regional crustal heat flow. In particular, the modelled temperature in the thermal aquifer of the EGF varies from 44°C at the top (depth of 0.4 km) to 118°C at the bottom (depth of 1.6 km). In addition, the discrete elements drive a local outflow of $0.72*10^6$ m^3/y in the interaction zone. These results are consistent with temperature logs into the wells, the reservoir equilibrium temperature inferred with geothermometers and historical data on the natural outflow of the Euganean thermal springs. The performed numerical model corroborates the proposed conceptual model, and it suggests that the outflow is strictly related to the local

structural setting. In particular, the regional, deep-seated, fluid flow is preferentially conducted to the surface by the high-connected fractures beneath the EGF, warming up on its way.

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THE FREEWAT PLATFORM FOR PLANNING AND MANAGEMENT OF CONJUNCTIVE USE OF GROUND- AND SURFACE-WATER

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Integrating advanced simulation techniques and data analysis tools can represent a valuable contribution for sustainable management of conjunctive use of ground- and surface-water. As such, developing innovative software tools to address water management issues is of paramount importance, especially for the application of EU and other water-related Directives (Rossetto et al., 2015).

Within the EU HORIZON 2020 FREEWAT (FREE and open source software tools for WATer resource management – www.freewat.eu) a free and open source platform, QGIS-integrated, for planning and management of ground- and surface-water resources was developed. The FREEWAT platform, a large QGIS plugin, allows simulating the hydrologic cycle, coupling the power of GIS geo-processing and post-processing tools in spatial data analysis with that of process-based simulation models. This results in a modeling environment where large spatial datasets can be stored, managed and visualized and where several simulation codes (mainly belonging to the USGS MODFLOW family) are integrated to simulate multiple hydrological, hydrochemical or economic-social processes.

The FREEWAT platform includes so far six modules:

- AkvaGIS allows to produce plots and thematic maps for the analysis of hydrochemical and hydrogeological data;
- Observation Analysis Tool facilitates the import, analysis and visualization of time-series data to support model construction and calibration;
- groundwater flow dynamics in the saturated and unsaturated zones may be simulated using MODFLOW-2005 (Harbaugh, 2005);
- solute transport in the saturated zone can be simulated using MT3DMS (Zheng & Wang, 1999);
- simulation of viscosity- and density-dependent flows is accomplished through SEAWAT (Langevin et al., 2007);
- management of conjunctive use of ground- and surface-water in rural environments is accomplished by the Farm Process module embedded in MODFLOW-OWHM (Hanson et al., 2014);

• UCODE_2014 (Poeter et al., 2014) is implemented to perform sensitivity analysis and parameter estimation to improve the model fit.

The FREEWAT platform is now applied to 14 selected case studies aiming at addressing specific water management issues. Such case studies may be divided in two clusters: i) 9 case studies (8 in EU Countries and one in Switzerland) are specifically referred to meet the requirements of the Water Framework Directive, Ground Water Directive and other water-related Directives for water resource management; ii) 5 case studies (2 in EU Countries, one in Ukraine, one in Turkey and one in Africa) are devoted to address water management issues mostly related to the rural environments.

In the framework of these case studies, relevant stakeholders are involved in the technical activities in order to enlarge and present to a wider audience the benefits of ICT tools in water planning and management.

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THE IMPACT OF THE LAST GLACIATION ON GROUNDWATER FLOW IN THE NORTHERN BALTIC ARTESIAN BASIN (BAB): A NUMERICAL STUDY

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Several evidences of subglacial recharge of meltwater are found in groundwater flow systems that were overridden by ice-sheets during past glaciations, in North America and in northern Europe. Numerical models confirmed that subglacial recharge can disturb the regional flow of groundwater to a very large extent and over several thousands of years after the final retreat of ice-sheets. Such mechanism is of particular relevance to freshwater resources and to the safety of deep nuclear waste repositories. However, calibration of subglacial recharge models is challenging, because field data are missing to simulate this process and other glacial processes under past environmental conditions.

In Estonia, the northern Baltic Artesian Basin offers a good case-study for developing better grounded models of subglacial recharge, because many field data have been collected during the last decades. Evidences of subglacial recharge include the most negative values of $\delta^{18}O$ ever measured in groundwater in Europe (c. -22‰), as well as low salinity, high excess air and cold recharge temperatures inferred from noble gases. ^{14}C dating indicates ages ranging from 30 to 19 ky BP. Those geochemical and isotopic evidences suggest that subglacial recharge took place during the Last Glacial Maximum (LGM), during which the entire region was recovered beneath the Fennoscandian ice-sheet.

To test this hypothesis of recharge, two 2D cross-sectional models were built which cross the northern BAB along a NW-SE direction. Groundwater flow and $\delta^{18}O$ transport were simulated from the beginning of the LGM until present-day. $\delta^{18}O$ was used as a tracer for distinguishing initial pre-LGM groundwater, glacial meltwater, and modern recharge. To account for the uncertainty related to the hydraulic properties and to the numerical representation of subglacial recharge, several sets of hydraulic properties and several scenarios of subglacial recharge were tested in a few thousands simulations. The numerical code FEFLOW was used.

Many simulations provide a satisfying fit between the observed and the computed values of $\delta^{18}O$, which means that subglacial recharge is a likely mechanism to explain the present-day distribution of $\delta^{18}O$ in groundwater in the northern BAB. Simulations show that meltwater entirely recharged the shallow part of the basin. After the retreat of the Fennoscandian ice-sheet, meltwater was preserved in confined aquifers and flushed away elsewhere by modern recharge. Large volumes of meltwater were also probably preserved beneath the Baltic Sea. Beside these local findings, these simulations also show that simplifying the representation of subglacial recharge with respect to previous studies was a good strategy, as it succeeded to reproduce field data while providing results easier to interpret. The technique offers an interesting perspective for future hydrogeological models of subglacial recharge.

HYDROGEOLOGICAL CONCEPTUAL MODEL OF A HIGHLY IMPACTED WATERSHED: THE CASE STUDY OF OGLIO RIVER (N ITALY)

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Objective of this study, regarding the Oglio River watershed, is the reconstruction of the hydrogeological conceptual model. This is a primary step to reach a suitable construction of a numerical hydrogeological model.
The study area, 92 km long and 58 km large, includes the Oglio River watershed from Lake Iseo to the Mella River inflow. It is located in the northern part of Italy.
The study is part of a research project whose key aspect is to consider and analyze the different water bodies (i.e., Lake Iseo, the Oglio River, the spring belt, the irrigation canal network and groundwater) as a single compartment in order to quantify their mutual relations.
The Oglio River natural regime is strongly modified due to multiple water uses. A lake dam regulation supervises both the Lake Iseo stages and the Oglio River outflow, hydroelectric power plants temporarily subtract and release relevant water volumes, large artificial diversions feed an extensive network of irrigation canals. The agricultural demand determined an increase in the Lake Iseo outflow to the Oglio River in summer season (from July to August) up to 90-150 m^3/s against an average of 50 m^3/s all over the year.
In order to implement the conceptual model, the following analysis and elaborations were carried:
a) a reconstruction of distributed values of hydraulic conductivity. More than 4600 stratigraphic logs coded and stored in the well database TANGRAM were analysed and imported into a 3D grid in GOCAD®. Geostatistical technique was used to reconstruct the 3D spatial distribution of hydraulic conductivity;
b) a monitoring of hydrodynamic properties. Four field surveys (between November 2015 and September 2016) were carried out in order to measure groundwater heads (55 well monitored in each survey), river discharges along the Oglio River and its main tributaries (16 station monitored in each survey) and river stages (34 stations monitored in each survey);
c) a reconstruction of potentiometric maps. Four potentiometric maps were elaborated, related to the different seasons, in order to evaluate the variations in groundwater/surface water interrelations.
Results leads to implement the hydrogeological conceptual model that is characterized by:
a) a distribution of the hydraulic conductivity ranging between ~2.3*E-03 m/s in the higher plain and~ 8*E-08 m/s in the deeper part of the lower plain;
b) a main groundwater flow direction oriented from North to South; seasonal groundwater table fluctuations are mainly influenced by irrigation. In the higher plain, the highest groundwater heads are in the autumn at the end of the irrigation period, whereas in the lower plain

groundwater heads oscillation are reduced even if the higher values are in summer season;
c) the presence of significant groundwater/surface water interactions. The Oglio River is losing in its first stretch 20-30 km long, then it becomes gaining for the rest of its course. The groundwater discharge to the river in its gaining stretch reaches 0.3 m^3/s*km in summer season, and around 0.09 m^3/s*km in winter season. The transition point between losing and gaining behaviour moves according to the seasonal oscillation of groundwater table within a length of 5 km.
This work represents the first step for the development of a detailed 3D numerical flow model of the Lake Iseo-Oglio River system.

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PARAMETERS OF FLOW IN POROUS ALLUVIAL AQUIFERS EVALUATED BY TRACERS

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Dye tracer tests are a good technique useful to determine the hydrogeological parameters of aquifers, especially in alluvial plains, where the heterogeneity of the lithology is a key factor leading the groundwater circulation. In the last decade, new tracers have been developed and introduced in the hydrological and geological context, one of them is the DNA biotracer, a synthetized molecule composed by 72 nucleotides used in the same way as the traditional tracers (Tazioli et al., 2016).
In this study, some experiments in piezometers and wells (draining an alluvial plain in the Marche Region, Italy) were performed with the aim of comparing the behavior of different tracers (Uranine, NaCl) in the evaluation of an alluvial aquifer's parameters, and to test the suitability of the DNA-tracer in a geological context different respect to the one studied by Aquilanti et al. (2016).
Single well and multiwell tests have been performed during the winter and spring seasons of the present year, involving one piezometer (30 m depth) and 4 wells (tapped by the aqueduct, with depth varying between 12 to 20 m). The tracer test results highlight faster zones of flow in the alluvial plain, being located at different depths, which levels are characterised by gravel and sand layers. Average flow velocity of about 3 cm/day have been obtained by the single well tests, executed both in the piezometer and in the wells; the main direction of flow is along the watercourse axis, as resulted by the multi well tracer test (tracer injection in the piezometer and tracer recovery in the wells).
The obtained results confirm that the fluorescent tracers are a reliable tool very valuable in the determination of groundwater velocity, groundwater flow direction and dispersion parameters, even in cases of multi-layer aquifers. DNA tracer is very helpful in the determination of faster circuits and vertical flow even in multi-layered aquifers.

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THERMAL IMPACT EVALUATION OF AN OPEN LOOP HEAT PUMP SYSTEM: INTEGRATED APPROACH WITH PROJECT DATA, NUMERICAL MODELING AND GROUNDWATER MONITORING

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One of the crucial aspects about open loop low enthalpy geothermal applications is thermal impact estimation, already required from the first step of the hydrogeological study. But, without any monitoring dataset available, ante operam numerical model can't be calibrated with a consistent series of field observations and so it won't be initially able to reach an adequate reliability level. Therefore, the following groundwater monitoring period, maintained during the experimental operation of the geothermal system, is fundamental to relevantly improve the numerical model efficiency, adding new experimental information to the existing database.
The heat transport simulation is always more often requested from public authorities to authorize an initial experimental testing period of the pilot geothermal plant. At the same time, the model is used to support plant design and engineering, defining optimized values of pumping and reinjection rates and finding the best placement of the wells. Moreover, the case study experience confirmed the importance of following model calibration, used with a bilateral approach in order to enhance forecast performance and to test initial assumptions validity.
Case study heat pump system consists of a single couple of pumping and injection wells, together with a monitoring network of 4 piezometers drilled to a depth of about 40 m from ground level, at different distances from the reinjection point. Well screens intercept a 25-30 m thick confined aquifer, composed by highly permeable sandy gravel with hydraulic conductivity values in the range of 1E-03 m/s. After initial investigations, including several pumping tests to estimate aquifer hydraulic properties, experimental monitoring of thermal impact started in March 2013; so actually about 4 years of groundwater level and temperature data series have been collected.
During the first period of heat pump system activity, the numerical simulation realized with FEFLOW-DHI responded correctly to temperature trends measured in monitoring wells, confirming the accuracy of model setup and allowing an effective thermal parameters calibration. After a model update with more recent temperature observations, a comparison between calculated and observed values suggested the necessity of further investigations to confirm the offsite hydrogeological properties, specially relating to larger scale groundwater flow direction. Then a new monitoring well was drilled near the calculated heat plume centerline, to verify the revised simulation scenario; after a short monitoring period, the new measured temperature trend confirmed model hypothesis and a better representation of real thermal impact has been obtained.

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TWO-DIMENSIONAL NUMERICAL MODELLING OF THE ROCCAMONFINA VOLCANIC AQUIFER TO CONSTRAIN THE RECHARGE FROM DEEP RESERVOIR

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Two-dimensional numerical models can represent a valid support to regional 3D modelling. Numerical investigations can be performed isolating a few salient hydrogeological properties, to clarify dynamics, which cannot be understood with a high number of unknowns. A local preliminary 2D model was built on a 1 km section with a high concentration of observed data. The finite element code was FeFlow 6.2 and calibration of data was performed via inverse modelling through FePest (PEST code). The study area corresponds to the eastern slope of the Roccamonfina Volcano and the Riardo Plain. The geological setting was elaborated using borehole stratigraphic data. The carbonate basement is covered by 20 meters of clay deposits and by 240 meters of volcanic deposits. A volcanic and a carbonate aquifer can be distinguished at regional scale. The multilayered volcanic aquifer presents a radial flow towards gaining streams and it is recharged by direct infiltration. Regional information about the carbonate aquifer are not available, since the monitoring points are mainly placed in the Ferrarelle bottling plant. The basement upraise and the fault systems allow the local mixing between the carbonate and volcanic aquifers. As a result, the potentiometric levels nearby the mixing area are very similar in absolute values and trends. The recharge of the volcanic aquifer was calculated elaborating thermo-pluviometric data of 2000/14 period and calculating the potential evapotranspiration using Thornthwaite's method. Recharge of the carbonate aquifer is likely to upflow from the deep reservoir, but no direct information are available about rates and spatial distribution. Aim of the 2D numerical model was to test different hypothesis of possible bottom recharge ranges. Transient calibration of the model was performed trying to fit the static levels recorded in 2000/04 period into two wells, one tapping the volcanic and the other the carbonate aquifer. Groundwater levels during the monitoring period show an annual cyclic trend related to the rainfall recharge and to the agricultural withdrawals. A longer superimposed trend seems to be present in the analyzed time interval. In the 2D simplified system, rainfall recharge was applied daily as calculated from the budget and the vertical discretization of the aquifers was set according to the stratigraphic information. A constant bottom recharge was fixed, splitting the time series on a yearly basis. The calibration, performed over conductivity and specific storage, gave good results of the yearly level oscillations but seems not able to reproduce the long time trend, which therefore, requires further evaluations. The obtained results show the higher amount of the rainfall recharge (around 60%) over the carbonate recharge (around 40%). This fundamental information will be extended to the complete time series, and included in a

complex highly-parametrized regional 3D model in order to constraint the ranges of the applicable carbonate recharge.

SESSION 4

Groundwater management in arid and semi-arid region

(dedicated to Prof. G.M. Zuppi)

Chairs: G. Ghiglieri, M. Polemio

Keynote lecture

GROUNDWATER MANAGEMENT IN ARID AND SEMI-ARID REGIONS: CHALLENGES AND OPPORTUNITIES

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Groundwater often represents the main source of fresh water supply for domestic and agricultural needs in areas characterized by limited surface water resources and low precipitation rates, like coastal zones in Southern Europe and in the Middle East and North Africa (MENA) Region.

These areas are being increasingly characterized by rapid population growth, also due to internal migration towards the most productive coastal regions, and tourism activities, thus resulting in a severe rise of water needs and consumption. Indeed, physical water scarcity is becoming a major concern in both urban and rural zones along the Mediterranean basin, where there is often not enough water to meet all demands, including environmental flows. In these situations, groundwater is intensively used for irrigation, industrial and domestic consumption, and consequently, due to the lack of adequate control, intensive abstraction can lead to aquifer overexploitation, and subsequent water table lowering.

In addition, in these regions (like in many aquifers worldwide), groundwater quality degradation is also threatening the natural aquifer characteristics, and the associated wellbeing of local populations and dependent natural ecosystems. In this regard, aquifer salinization (mainly associated –but not exclusively due– to sea water intrusion) and pollution (caused by intensive anthropogenic activities and by the lack of adequate control of sewage and waste disposal) are generally identified as the main issues to be addressed.

Indeed, unregulated abstraction and uncontrolled contaminant loads (e.g. unconfined septic tanks, lack of adequate sanitation facilities, excessive use of fertilizers and pesticides) are severely endangering already scarce groundwater resources, while the combined impact of all these processes acts synergically towards an increase in groundwater mineralization, hence affecting aquifers' quality and their potential suitability for current and future uses.

Understanding the main causes of groundwater contamination and salinization, together with a more effective control on groundwater abstraction, is of paramount importance in order to ensure adequate water quality protection measures, and to avoid potential health and food security issues. The unequivocal identification of contamination sources is therefore a fundamental step for the correct long-term aquifer protection, especially in arid and semiarid regions, where the sustainable management of water resources is a permanent challenge, due to the increasing demand combined to the negative impacts of climate changes. Nevertheless, the crucial role of science in supporting effective management practices must also be considered in this process, while also assessing the real needs of the populations relying on groundwater resources. For this reason, it is of paramount importance to identify the best approaches to foster the connections among scientists (and more generally water professionals) and all the relevant stakeholders (including water end-users and marginal groups), and to reach new –shared and

science-based– groundwater management strategies.
This presentation will discuss the main issues relative to groundwater resources management in arid and semi arid regions, with a particular focus on developing countries and examples form Morocco, Tunisia and Senegal. In addition, the role of hydrogeologists as advocates for public engagement in water governance, and the potentialities of the socio-hydrogeological approach to contribute bridging the gap between science and society will be presented.

AN INTERDISCIPLINARY METHODOLOGY TO DESIGN INTEGRATED AND INNOVATIVE MAR SYSTEMS IN ARID AND SEMI-ARID REGIONS. TWO CASE STUDIES IN ALGERIA AND IN TUNISIA

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In order to combat drought and desertification, it is essential a holistic approach such that represented by the paradigm of the Integrated Water Resources Management (IWRM). Within the IWRM framework, an effective solution consists, in particular in arid and semi-arid regions, in sustainable water management practices which in many cases provide for a combination of both water harvesting and Managed Aquifer Recharge (MAR) techniques.
This research was developed within WADIS-MAR demonstration Project (2011-2016) (www.wadismar.eu), funded by the EC under the SWIM Programme (www.swim-sm.eu). An interdisciplinary methodology was developed to define guidelines for the design and implementation of integrated and innovative MAR systems that can be applied in arid and semi-arid environments. This approach was tested in two watersheds in Maghreb Region: Wadi Biskra in Algeria and Oum Zessar in Tunisia. Both areas are characterized by water scarcity and overexploitation of groundwater resources. As required by the application of this methodology, the different components of the Water Resources System (WRS) were defined: the water budget, the 3D hydrogeological model and the hydrogeochemical and isotopic characterization. A physiography-based indirect method for determining the runoff coefficient (Ghiglieri et al., 2014) was applied at sub-basin scale for three watersheds in the Tunisian study area. The water budget was estimated on a daily time scale basis, over a 10-year period (2003-2012) through a simplified water balance model, modifying the model proposed by Allen et al. (2006), that considers effective infiltration as part of the surplus from water storage in the soil. An average Available Water Content (AWC) of soils and an average runoff coefficient were considered for each sub-basin. 3D hydrogeological models were implemented for both study areas through the realization of several balanced geological cross-sections and data processing in a 3D environment by 3D MOVE software. A detailed hydrogeochemical characterization was carried out, including bulk chemistry and multi-isotopic analyses of water and solid samples. The estimated average annual groundwater recharge of the aquifers is consistent with the reference values found in literature. 3D hydrogeological model reconstruction showed that groundwater circulation and aquifers geometry are strongly influenced by several tectonic

structures. This is confirmed by hydrogeochemical and isotopic data. All these results allowed to design innovative MAR systems including some technical innovations to improve the efficiency of MAR schemes: the recharge chambers and the Passive Treatment System. Finally, the estimated potential recharge rate (m^3 $year^{-1}$) for the target aquifers related to the designed MAR systems are about 1.7 hm^3 $year^{-1}$ and 1.2 hm^3 $year^{-1}$ in Algerian and Tunisian study area, respectively.

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WATER BALANCE ESTIMATES FOR DETERMINING NATURAL AQUIFER RECHARGE IN THE ARID CONTEXT OF THE OUM ZESSAR AREA (SE TUNISIA)

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This research was developed within WADIS-MAR demonstration Project (2011-2016) (www.wadismar.eu), funded by the EC under the SWIM Programme (www.swim-sm.eu). An interdisciplinary methodology was developed to define guidelines for designing and implementing integrated and innovative MAR systems in the Oum Zessar study area (SE Tunisia). A relevant component of its application was the water budget calculation for three watersheds (Koutine, Megarine-Arniane and Hajar) within the study area, in order to estimate the natural groundwater recharge. Due to the lack of an appropriate data set for hydrological modeling, a physiography-based indirect method for determining the runoff coefficient (Ghiglieri et al., 2014) was applied at sub-basin scale for the three watersheds. The coefficient was calculated using specific physiographic characteristics (slope, vegetation land cover and outcrop permeability) and the aridity index that defines climatic conditions. In order to calculate the annual average aridity index over a 30-year period (1981-2010), spatial interpolations of average monthly precipitation and temperature data were performed through single and multiple regressions, considering elevation and sea distance, obtained from the SRTMGL1 DEM, as independent geographic variables (Canu et al., 2014). Considering that in such arid environments, only after short but intense events, rainfall can greatly exceed evapotranspiration, leading to runoff and recharging the aquifers, the water budget components were estimated on a daily basis, over a 10-year period (2003-2012). For this purpose, a simplified water balance model was applied modifying the model proposed by Allen et al. (2006) that considers effective infiltration as part of the surplus from water storage in the soil. An average Available Water Content (AWC) of soils and an average runoff coefficient were considered for each sub-basin. Results show that sub-basins covered mainly by the “artificial” soils of tabias and jessour, the traditional Tunisian water harvesting structures, with average AWC values greater than 150 mm, didn’t contribute to groundwater recharge during the period considered. Indeed, only very intense rainfall events can saturate these soils and generate a water surplus, especially after dry periods. A necessary trade-off between the spread of the traditional water harvesting systems for agricultural purposes and the need in ensuring an adequate natural recharge for aquifers must be considered. In these studies, a more refined approach combining hydrological and agronomic models that require wide and complete datasets in input is therefore essential.

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USING ICT TOOLS TO PROMOTE THE GOVERNANCE OF GROUNDWATER RESOURCES IN SEMI-ARID AREAS OF SOUTHERN AFRICA: THE STAMPRIET TRANSBOUNDARY AQUIFER SYSTEM

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The Stampriet Transboundary Aquifer System (STAS) area extends over about 87000 km^2 from Central Namibia into Western Botswana and South Africa's Northern Cape Province. The STAS is a low-transmissivity system in which the yield is dominated by withdrawal from storage, and thus the propagation of drawdown to larger distance is slow.

Due to the lack of permanent surface water in such arid area, human activities (mostly related to agriculture) only rely on groundwater and the STAS is particularly vulnerable to overexploitation and pollution. Further to these factors, the lack of a proper monitoring network seriously hampers a systematic analysis of the stresses identified. Within this framework, activities were carried out by UNESCO International Hydrological Programme (UNESCO-IHP) in cooperation with the Governments of Botswana, Namibia and South Africa, within the GGRETA (Governance of Groundwater Resources in Transboundary Aquifers) project, funded by the Swiss Agency for Development and Cooperation (SDC; UNESCO-IHP, 2016).

The major purposes of the GGRETA project is to enhance cooperation on water security, prevent water-use conflicts and improve environmental sustainability. During the first phase of the project, an in-depth assessment about the importance and vulnerability of the STAS was undertaken. This was done by collecting, compiling and analyzing relevant data from different regional and national sources which were then structured into tables, thematic maps and databases. This information has been harmonized to provide a regional outlook on the status of the STAS and to support the establishment of a Multi-Country Cooperation Mechanism (MCCM) for its management and governance. The establishment of the STAS MCCM would be the first example in Southern Africa.

The joint development of a numerical model is crucial to foster such cooperation as it provides a baseline for the formulation of sound policies for the governance of the STAS. The model is being developed through the application of the FREEWAT platform, developed within the H2020 FREEWAT project (FREE and open source software tools for WATer resource management, www.freewat.eu; Rossetto et al., 2015). FREEWAT is a free and open source,

GIS-integrated modelling environment which integrates spatially distributed and physically based codes for the simulation of the hydrologic cycle aiming at facilitating water planning and management. FREEWAT applicability is demonstrated by running 14 case studies, including the STAS, and enhancing participatory approach and evidence-based decision making in water resource management.
Thanks to the involvement of UNESCO-IHP within the FREEWAT Consortium, the model implementation is fully supported through the coordination and integration of research outcomes from the GGRETA project and from previous modeling applications. The STAS model, indeed, was developed adapting an existing model of the Namibian part of the aquifer, where the STAS was discretized using rectangular cells about 40 km^2 wide and a stack of three aquifers and three aquitards with variable thicknesses and heterogeneous hydraulic properties. The model was then extended to Botswana and South Africa and boundary conditions and hydrologic stresses (i.e., rainfall infiltration and abstraction for irrigation purposes) were re-defined.
The STAS model construction will help achieving a state-of-the art representation of the STAS based on available data, forecast dynamics and possibly highlighting any existing knowledge gaps. This will strengthen capacity on groundwater governance at the national and transboundary levels through supporting the process of establishment of the MCCM, thus harmonizing cooperation among the three counties for development of joint strategies for the protection of current and future status of the STAS.

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USING NUMERICAL MODELING TOOLS FOR MANAGED AQUIFER RECHARGE AT INDUCED RIVERBANK FILTRATION SCHEMES

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Among Managed Aquifer Recharge (MAR) techniques, Induced RiverBank Filtration (IRBF) is widely used when aquifers are hydraulically connected with surface water bodies. It consists in enhancing the filtration process through the riverbed sediments, with proven positive effects on quality and quantity of groundwater.
At the Sant'Alessio IRBF plant (Lucca, Italy), aquifer storage is increased by means of a weir (raising groundwater head) and 12 vertical wells along the Serchio river embankment. The Sant'Alessio IRBF allows withdrawal of about 0.5 m3/s by enhancing river bank infiltration into a high yield (10-2 m2/s transmissivity) sandy-gravelly aquifer, thus providing drinking water for 300000 people of the coastal Tuscany (mainly to the towns of Lucca, Pisa and Livorno). The Sant'Alessio IRBF scheme is one of the FP7 MARSOL project demo sites (demonstrating Managed Aquifer Recharge as a SOLution to water scarcity and drought; http://www.marsol.eu/).
A Decision Support System, consisting in connected measurements from an advanced monitoring network and modelling tools was set up to demonstrate the benefits of switching from un-managed artificial recharge to MAR. The modelling system is based on advanced modeling tools integrated in the FREEWAT platform (developed within the H2020 FREEWAT project - FREE and open source software tools for WATer resource management; Rossetto et al., 2015). FREEWAT is a free and open source, GIS-integrated modelling environment which incorporates spatially distributed and physically based codes for the simulation of the hydrologic cycle.
As one of the main concern is about exchanges between ground- and surface-water, especially in case of pollution events in the river water, the impact of such events on recharged groundwater and the time available to set in place remedial actions were estimated. This was done through building a hydrological and mass transport model using FREEWAT (which integrates MODFLOW-2005 and MT3DMS). Simulations were performed over an area of about 5.2 km2, with a focus in the vicinity of the river embankment and the Sant'Alessio well field. The model allowed demonstrating the importance of the weir in enhancing aquifer recharge in the Sant'Alessio plain and the efficiency of the IRBF scheme. Further modeling efforts allowed: (i) defining the well-head protection areas for the Sant'Alessio well field, by outlining isolines at selected times (10, 20, 30, 45, 60, 90, 180, and 365 days, as required by the Italian legislation); (ii) inferring expected concentration in the Serchio river for a particular

pesticide, in relation to duration of surface water pollution events, likely to cause pollution at the IRBF well field; (iii) simulating the impact of contamination events of agricultural origins on the areas adjoining the drinking wells.
Results show that the Sant'Alessio IRBF scheme is a reliable and robust one in term of security of supply and quality of the groundwater abstracted. However, the availability of a reliable operational monitoring protocol is necessary to foresee potential pollution events on time and to set in place remedial actions.

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THE ROLE OF THE HYDROGEOLOGICAL AND ANTHROPOGENIC FACTORS ON THE ENVIRONMENTAL EQUILIBRIUM OF THE UGENTO WETLAND (SOUTHERN ITALY)

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The Ugento Wetland, recognized as a Site of Community Importance (SCI, European Directive 92/43/CEE) from 2005, is a "Regional natural littoral Park" from 2007, located along the Ionian coast, in south-eastern part of Salento (Apulia region). The environmental peculiarities of the Ugento Wetland are due to a complex hydrogeological pattern, the high contribution of groundwater outflow, and to a peculiar dynamic equilibrium with sea, also due to the role of the wide coastal aquifer of Salento.

The main objectives of the present research are the definition of the hydrogeological conceptualisation to create a basic knowledge of the physical environment, to be used as a basis for the design of effective management policies of water resources to safeguard the ecological and environmental equilibria, considering the relevant impact of anthropogenic activities.

In this area, the human pressure on water resources was detected in terms of surface water pollution, probably due to illegal dumps and the use of fertilizers and nitrogen compound for agricultural purposes, which is the origin of an exponential growth of the floating macro-algae mass in basins. As a consequence, some event of eutrophication triggers the algal growth, the effect of which is the sharp reduction, almost to zero, of the surface water velocity, up to, in some cases, to a widespread fish mortality. Apart from water pollution effects, during the dry season, due to the increase of groundwater discharge, the sharp piezometric decline improves the effects of seawater intrusion on groundwater.

A geological and hydrogeological survey and study were realised and merged with the characterisation of the land use modifications back to the fifties.

The attention was focused on the analysis of the complex hydrogeological characteristics, which is due to the overlapped effects of shallow and deep aquifers and of their outflow along the coastal area. The focal role of the shallow aquifer, which is predominant and extremely importance for the hydrological balance and so for the ecological equilibria, a specific monitoring groundwater network of quantitative and qualitative parameters was implemented.

The merging of hydrogeological factors and anthropogenic modifications was discussed using indicators.

Two main macro-indicators, water and soil, were selected. The critical issues related to the management of human activities potentially dangerous for the wetland environment, was considered with the definition of guidelines for their mitigation, based on the discussion of the indicators.

THE MANAGEMENT OF WATER RESOURCES BETWEEN TRADITIONS AND SUSTAINABILITY: THE QANATS OF SHAHROOD PROVINCE (NORTH-EASTERN IRAN)

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Many towns and villages in Iran are nowadays supplied by qanats, a hydraulic and mining technology dating back thousands of years, probably native of Middle East area and widespread in Asia and North Africa. As part of a scientific cooperation agreement between the University of L'Aquila, the Institute of Chemical Methodologies of the Italian Research Council (IMC-CNR) and the Shahrood University of Technology, some qanats of the Province of Shahrood were selected and studied according to the intended use of their waters.

This multidisciplinary study involved: the qanat of the town of Shahrood (150,000 inhabitants), whose water resources cover about a third of the water demand; the qanat of Beyarjomand, used to meet the agricultural water needs of the area; the qanat of Torud, which is the traditional water resource for agricultural and sanitary purposes of this village (1000 inhabitants) located within the Kavir Desert.

Surveys of qanat branches were carried out, identifying the areas and points (mother wells) of recharge. Discharge flow measurements were performed at hydraulic work outlets to evaluate water availability. Physical-chemical parameters data of the collected waters (e.g. temperature, electrical conductivity and pH) have been acquired. In order to complete, as far as possible, the information framework of the three studied areas, three weather stations were installed (recording temperature, relative humidity and rainfall data). Moreover, the presence of radon in qanat waters and inside the maintenance wells has been evaluated. Interviews with technical and maintenance personnel of the qanats were conducted to better understand management processes and their issues. Contextually, investigations were conducted on the historical artifacts related to the studied hydraulic works (such as mills and checkpoints located along the track of the qanats).

The acquired information was georeferenced to implement the 3D reconstructions of the water systems in GIS environments and to facilitate the definition of preliminary hydrogeological conceptual models. Measured water availability of the studied qanats ranges between several tens and hundreds of liters per second. The collected interviews indicate a gradual decrease of such flow rates over time due to climatic and anthropic causes. Water

temperatures of qanats are quite variable, but can reach 20-25 °C. Water electrical conductivity varies between 450 and 5800 uS/cm. The assessed values can be related to the locations of the sites ranging from the southern foothills of the Alborz Range (Shahrood) and the northern part of the desert (Torud). Radon concentrations in water are very low.
Despite the increasingly widespread recourse to drilled wells to tap groundwater, qanats are still important and valuable resources for water supply in areas located near deserts. Wells withdrawals are depressing groundwater level, decreasing (or, at worst, preventing) the sub-horizontal gravity drainage of these traditional water works. The observed water availabilities of the qanats and their temperatures suggest the implementation of low enthalpy projects (heating and/or greenhouses). This would allow a more rational use of qanat water and a better exploitation, especially in winter, when water demand is lower and traditional agricultural activities stop.

GEOLOGICAL AND HYDROGEOLOGICAL FEATURES CONTROLLING MECHANISMS OF FLUORIDE ENRICHMENT IN GROUNDWATER IN THE EAST AFRICAN RIFT SYSTEM

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The H2020 FLOWERED project (de-FLuoridation technologies for imprOving quality of WatEr and agRo-animal products along the East African Rift Valley in the context of aDaptation to climate change) aims to address environmental and health (human/animal) issues associated with fluoride contamination within the East African Rift System (EARS), in three case study areas in Ethiopia, Tanzania and Kenya.

A regional review of geology and structural geology was performed to define the hydrogeological features along the EARS and the geological/geochemical conditions associated with the presence of fluoride in groundwater. The results of this research will address future investigations for the assessment of the processes controlling the natural enrichment of fluoride in groundwater in the three target areas.

The EARS, being an active continental rift, is characterized by widespread volcanism and tectonic extension. The rift architecture controls the regional fault pattern, and it can be subdivided into orthogonal rifting (which produces long, extension-orthogonal boundary faults) and oblique rifting (yielding general en-echelon arrangement of faults, relay zones and basins with less subsidence).

The regional fault pattern and the volcanism are strongly associated also to rifting maturity stages. Early stages of rifting infer widely-spaced faults, volcanism and hydrothermal fluids ascent localised on the rift border, while mature stages express closely-spaced fault pattern, diffuse volcanism and hydrothermal fluids ascent in the rift floor. An intermediate stage between these two end-members implies an incipient internal faulting.

The orientation of faults strongly influences the recharge area, the geometry and relationship between aquifers and groundwater flow direction.

The hydrogeochemical evidence indicated that fluoride concentration in EARS aquifers reaches up to 70 mg/L and is related to different factors. These include temperature, pH, solubility of fluorine-bearing minerals, anion exchange between hydroxyl and fluoride ions, and water residence time. Water - rocks interaction, exacerbated by heat anomaly generated along regional faults or from recent hot eruption centres, favor high fluoride incorporation into groundwater. Safe fluoride groundwater also occurs, mainly related to basaltic or phonolitic unaltered lava-flow fractured or autobrecciated.

The results of this review showed that fluoride circulation in groundwater of the EARS is strongly conditioned by the volcano-tectonic processes, in terms of the interplay between characteristics of faults and lithology, degree of tectonic segmentation and displacement, and volcanism. The aforementioned features are governed by the rift architecture and stage of maturity. In central Ethiopia (oblique rifting in an intermediate stage of maturity) and in central Kenya (orthogonal rifting in a mature stage), fluoride concentration mainly increases from border towards the centre of the rift, and its concentration in groundwater is strongly controlled by the diffuse volcanism in the rift axis and the high degree of fracturing, and tectonic segmentation. In the rift centres of this areas, axial and/or transverse groundwater circulation can be strongly influenced by the arrangement of fault pattern. Conversely, in northern Tanzania (early stage of maturity), fluoride occurrence in groundwater, even though of volcano-tectonic origin, may be controlled by lithological and mineralogical features and hydrothermal deep circulation to a greater extent than the degree of tectonic segmentation.

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FLOW PATTERNS AND RECHARGE PROCESS IN ALLUVIAL FANS: A CASE STUDY OF THE SEMI-ARID PUNATA FAN IN BOLIVIA

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Alluvial fans are generally located in arid and semi-arid zones, and they have the nature of having permeable layers where water can be stored, thus, they can be important sources of water supply. For sustainable management of groundwater, however, knowledge of origin, recharge process, flow direction and mineralization is needed. The overall aim of this study is to show the efficiency of using three different hydrochemical methods for providing information and propose a hydrogeological model of the groundwater recharge, flow patterns and chemical evolution in alluvial fans. The Punata alluvial fan is used as a case study.

There are available many methods for studying hydrogeological processes in groundwater, however the use of one single method sometimes is not enough for having a complete hydrogeological characterization. This study used the integration of three different methods: 1) major ion chemistry and chemical weathering process, 2) Stable isotopes (deuterium and oxygem-18), and 3) statistical analysis (Hierarchical Cluster Analysis and Principal Component Analysis). This study included a total of 45 samples. The samples come from two different sources: groundwater and surface water. The samples from groundwater are located within the Punata alluvial fan, while the latter are distributed along water bodies in the neighboring basins. The samples were spatially distributed in order to take into consideration all the possible recharge sources.

The analysis of the $\delta^{18}O$ and $\delta^{2}H$ concentration in water samples assisted in identifying that groundwater in the Punata alluvial fan is mainly recharged by heavy flash floods, rather than precipitation or rivers base flow. The multivariate statistical and hydrochemical analysis indicated that weathering of carbonated rocks contributed to the increase of Ca^{2+} concentration, and that there is an increase of Cl^{-} and TDS concentration in the middle and distal part of the fan. these changes in the ion concentrations leads to established that groundwater flow is from the East to the West and Northwest of the fan.

The results from this study has implications for the knowledge of hydrogeological processes in alluvial fans in general in that it shows that the integration of hydrochemistry, stable isotopes and multivariate statistical can be useful tools for characterizing such processes. The integration of the results might contribute in the making of policies for sustainable groundwater management in alluvial fans.

A HYDROGEOLOGICAL STUDY TO SUPPORT THE OPTIMIZED MANAGEMENT OF THE MAIN SEA LEVEL AQUIFER OF THE ISLAND OF MALTA

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The Maltese Islands are located in the central Mediterranean area, on the Malta-Sicily Platform. The archipelago consists of three main islands, Malta, Gozo and Comino, and several small uninhabited islets. Malta, the largest of the three islands, has an extent of 246 km^2.
The islands present a typical central Mediterranean semi-arid climate with hot dry summers and mild wet winters. The mean-annual rainfall stands at around 550 mm but with high inter- and intra-annual variability. The size of the islands precludes the formation of significant bodies of surface water and therefore the main natural water resources of the islands are the groundwater aquifer systems, in particular the sea-level aquifer systems present in the two larger islands. These aquifer systems are sustained in a carbonate formation (the Lower Coralline Limestone) and take the typical shape of a Ghyben-Herzberg freshwater lens.
The high population density of the islands is also reflected in a high level of urban development, where around 25% of the total land area of the islands has been built up. This has altered the physical characteristics of the landscape by significantly increasing the quantity of impermeable surfaces, thereby reducing infiltration processes to groundwater, and increasing the generation of rainwater runoff following rain events.
The islands thus present a mixed land-use scenario where domestic, agricultural and commercial activities are operating side by side and depending on the same type of water resources. Of particular reference is the islands' highly developed tourism and recreational sector which places added strain on the water supplies during the dry summer months. Groundwater use for municipal supply is supplemented by the use of sea-water desalination by reverse osmosis. The agricultural sector is mainly dependent on groundwater resources, although water re-use is currently being introduced on a wide scale to supplement (and replace) groundwater use. The use of alternative water resources has thus, in recent years, reduced the pressures on groundwater resources.
The aim of this paper is to describe the collaboration between CNR and EWA aimed at the undertaking of a hydrogeological study to support the eventual development of management tools for optimizing the use of Malta's groundwater resources, with specific focus on the main sea-level aquifer system in the island of Malta. As part of this collaboration a review of the hydrogeological environment of the aquifer systems has been undertaken and important data gaps have been identified and are being addressed. The eventual groundwater body

management tool to be developed under this collaborative initiative will enable the formulation and testing of updated groundwater exploitation strategies which ensure the protection of the groundwater bodies from regional and localized sea-water intrusion, whilst taking full consideration of the potential effects of climate change, including the variability of recharge, sea level and seawater salinity.

EXPLORING THE USE OF MODELLING TOOLS WITHIN THE PARTICIPATORY APPROACH TO PROTECT THE WATER RESOURCE

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Information and Communication Technology may provide relevant tools for water planning and management issues, as detailed, i.e. by the ICT4WATER initiative (www.ict4water.eu). In this regard, numerical modelling is a valuable and robust method to represent hydrological systems and relevant human stresses and to provide simulated answers to relevant water problems, such as protection of groundwater resources.

Because these tools require a high level of knowledge and skills pertaining to various disciplines (i.e., hydrology, physics, statistics, computer science, environmental sciences, etc.), they are often disregarded as too complex to be used or as "tricky games" whose results cannot be fully understood. This is of course a barrier to the uptake of existing and state-of-the-art technologies for water management.

Within the framework of the H2020 FREEWAT project (FREE and open source software tools for WATer resource management, www.freewat.eu; Rossetto et al., 2015), the use of modelling tools is combined to the participatory approach in order to follow a path where modelling activities are run together with the stakeholders involved or with interest in the water cycle (the so-called FREEWAT approach). FREEWAT is a free and open source, GIS-integrated modelling environment which incorporates spatially distributed and physically based codes (e.g., MODFLOW) for water planning and management.

The FREEWAT approach is tested in 14 case studies throughout Europe and beyond. In this communication, we will present what done for the Massaciuccoli lake case study. The Massaciuccoli lake is a coastal lagoon of fresh to brackish water located north of Pisa (Tuscany, central Italy), at the foot of the Apuan Alps. During the last decades, this area has been heavily affected by large land reclamation works for agriculture purposes. This caused severe subsidence (2 to 4 m during the past 70 years), which left the lake perched, having the land surface around the lake at -4 m with respect to the mean sea level. Water resources are further affected by salinization and poor water exchange, as result of water balance deficit during the summer period.

Because of this, the Massaciuccoli area has been the object of several activities aiming at protecting the equilibrium of the ecosystem and overcoming the issues presented above. Among these activities, the FREEWAT approach is tested to devise shared solutions in order to protect

the water resource. The focus of the FREEWAT experimental application is to revise the potential application of the measures foreseen in the Serchio River Basin Plan, according to the requirements of the Water Framework Directive.
A Focus Group (FG) was formed and it is composed of all the relevant (technical and non-technical) stakeholders for the area (river basin authority, municipalities, farmer's associations, research institutions, environmental protection agency, environmental associations, etc.). FG meetings are run about once a month. During such meetings, data used to build the model and model activities are discussed and shared. Model construction is performed through the application of the Farm Process embedded in MODFLOW-OWHM (Hanson et al., 2014), which allows to dynamically integrate crop water demand and supply from ground- and surface-water.
FG meetings aim at creating a common space for discussion and for sharing ideas and perceptions on the work done. Some of the issues brought to the discussion are: (i) estimate water volumes raised to the lake by the land reclamation areas; (ii) evaluate the water balance in the study area during the summer period; (iii) evaluate the consistency of water supply with respect to the actual water need of relevant crops.
FG also takes decisions on the scenarios to be simulated for planning and management of the water resource and discusses the final results, with the final scope of enhancing participatory approach and evidence-based decision making in water resource management.

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DEVELOPMENT OF A SUSTAINABLE WATER MANAGEMENT FOR THE SU GOLOGONE KARST SPRING (SARDINIA, ITALY)

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During recent decades the Mediterranean region has been facing with an increased drought frequency among land areas across the globe. In the last IPCC report, this region is projected to experience the greatest droughts in the last decades of the twenty-first century and has been incorporated in the list of major "climate change hot spots" concerning the threats posed to the good-quality water security.
Also Sardinia (Italy) is included as one of the zones with the highest sensitivity to water deficiency. In this island, the karst water supply is of strategic importance especially during dry periods and considering the growing demand of good-quality water, it is of primary importance to ensure the long-term adequate quantity of potable water.
One of the main karst aquifers in Sardinia is the Supramonte massif in the catchment area of Su Gologone (Central-East Sardinia), an important source of drinking water to the local population. This spring drains a well-developed karst system through two outlets with discharges of about 120 L/s during low flow conditions and up to 5,000 L/s during ordinary floods. However, its recharge is closely related to the unpredictable seasonal climate regime typical of the Mediterranean areas.
Since temporal hydrological variations are of great significance and have a major impact on the groundwater availability, the main objective of this research is to understand how the karst system would react in possible different meteorological conditions and to develop a flexible and appropriate approach for its karst water exploitation both taking into account the special features of the Supramonte karst landscape and without affecting the quality and quantity of the resource.
For this purpose, Su Gologone spring has been equipped with a multi-parametric probe for continuous monitoring of water level, electrical conductivity and temperature. During the monitoring period flow rates were performed monthly at the spring. The recharge was calculated from the meteorological data supplied by the Department of Meteorology and Climatology of the Environmental Protection Agency of Sardinia (ARPAS).
The analysis of historical and present-day discharge rates yielded a rating curve based on the range between the minimum values of the main spring and 3,000 L/s. Based on this scale, the discharge duration curve (which reports the number of days of the year for which the flow rate is greater than a certain threshold value) has been traced. Thanks to the high permeability of

this aquifer, this value allows the calculation of the amount of water resources directly exploitable from a sampling point placed at a sufficient distance from the spring without perceptibly altering its hydrodynamic regime and following its natural recession curve. This means the water withdrawal has to guarantee that the maximum width of its zone of influence has a piezometric level approximately equal to the static level of the spring.
This flexible management of water pumping makes possible to vary the quantity of exploited groundwater from year to year in relation to the actual weather conditions. This means more water can be extracted during the wettest years and vice-versa. This approach requires the continuous monitoring of spring discharges associated with the detection of the main groundwater physical-chemical characteristics and it is able to use alternative water sources in dry periods thanks to the existing artificial reservoirs of Preda Othoni and Olai dams.

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