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Editors
Luca Alberti
Tullia Bonomi
Marco Masetti

Technical Editing
Tullia Bonomi
Marco Faggioli
Stefania Stevenazzi

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info@ledizioni.it

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Preface

FLOWPATH 2019, the 4th National Meeting on Hydrogeology, was held in Milan from 12th to 14th June 2019. According to the aim of the previous Editions of FLOWPATH, held in Bologna (2012), Viterbo (2014) and Cagliari (2017), the conference is an opportunity for Italian hydrogeologists to exchange ideas and knowledge on different groundwater issues.

The objectives of the conference are:

- To promote dialogue and exchange of scientific knowledge among young hydrogeologists;
- To deepen the theoretical and practical aspects of our understanding on groundwater;
- To update all the stakeholders, researchers and professionals on recent challenges in the hydrogeological sciences;
- To encourage researchers, professionals and administrators to contribute to the improvement of water resources management.

This Volume of Conference Proceedings contains the abstracts of oral and poster contributions accepted to FLOWPATH 2019. The abstract were evaluated by the Scientific and Organizing Committees. This volume contains 99 abstracts, submitted by Authors coming from Universities, Public Authorities and Private Companies of Italy and many other countries, such as Australia, Belgium, Croatia, Czech Republic, Greece, Hungary, Israel, Malta, Morocco, Nigeria, Spain, Switzerland, The Netherlands, U.K., and U.S.A.

The conference focuses on four themes of great importance:

1. Groundwater Resource Management
2. Fractured Rocks and Karst Aquifers
3. Contaminated Sites
4. Urban Hydrogeology

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 scientific contributions in alphabetical order by first author's family name.

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Marco Masetti

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Groundwater Resource Management

Conveners:

Prof. Giovanni Pietro Beretta (Università degli Studi di Milano)

Ing. Giovanni Formentin (Tethys S.r.l.)

Dr. Marco Rotiroti (Università degli Studi di Milano-Bicocca)

The management of groundwater resources in the Maltese Islands

Manuel Sapiano

Energy and Water Agency, Malta

KEYNOTE LECTURE

The semi-arid climate and small aerial extent of the Maltese islands precludes the formation of economically exploitable surface water resources, and hence groundwater is the main naturally renewable source of freshwater in the islands. Groundwater occurs as two main aquifer typologies:

- the mean sea-level aquifer systems, essentially freshwater lenses floating on the denser sea-water and sustained in the lower coralline limestone formation, and
- the perched aquifer systems, high-lying small groundwater bodies sustained in the upper coralline limestone formation by an underlying layer of blue clay.

The mean sea-level aquifer systems are by-far the most important groundwater resources of the islands, representing around 80% of the sustainable groundwater yield. These aquifer systems were first exploited in the late 1800's when the advancement of drilling technology permitted the exploitation of deep groundwater resources. Due to their importance the mean sea-level aquifers are extensively monitored with regular qualitative results dating back to the 1940's. These results highlight the vulnerability of these aquifer systems to sea-water intrusion and anthropogenic contamination by nitrates.

Due to an ever-increasing national water demand, these aquifer systems are under increasing quantitative stress, and hence Malta's water management strategy focuses on the development of water demand management and supply augmentation measures to enable an efficient water demand to be met, whilst ensuring the sustainable use of groundwater resources. In this respect, various initiatives are currently being implemented to ensure the effective protection and sustainable use of groundwater. These include:

- the development of new numerical models of the groundwater bodies, which enable different future water management scenarios to be assessed;
- the development and application of Managed Aquifer Recharge techniques;
- the distribution of groundwater abstraction and the development of predictive water quality functions for abstraction stations;
- the optimisation of groundwater monitoring infrastructure, enabling the monitoring of salinity distribution in the freshwater lens; and
- the development of monitoring tools to enable the effective regulation of private groundwater abstraction.

These initiatives form part of Malta's 2nd River Basin Management Plan, which has as its primary objective the achievement of sustainable groundwater use levels by 2021.

Estimating the effect of the Desert-Adapt measures on porewater availability for ten agricultural sites in Europe

Luigi Alessandrino[1], Eleonora Grilli[1], Simona Castaldi[1], Micòl Mastrocicco[1]*

[1] Università degli Studi della Campania, Luigi Vanvitelli, DiSTABiF, Caserta, Italy.
**Corresponding email: micol.mastrocicco@unicampania.it*

ABSTRACT

IPCC identified Mediterranean ecosystems as the most likely to be affected by climate change, with a clear tendency towards drier and hotter conditions. This will probably lead to a depletion of surface and ground waters, salinization in coastal areas and desertification. Shortage of water is expected to threat key ecosystem services and decrease crop productivity. The LIFE project DESERT ADAPT (http://www.desert-adapt.it/index.php/en/the-project) aims at demonstrating the positive effect of an integrated ecosystems approach, through climate-resilient land use, soil conservation and plant support, in areas subjected to land degradation and desertification in Italy, Spain and Portugal. To parametrize the 10 project field sites and to quantitatively assess the improvements derived from the application of the Desert Adapt measures, several indicators concerning soils, water, biodiversity, and agricultural properties were considered.

Keywords: climate change, water availability, infiltration capacity, land use, soil organic matter

METHODS

The Desert Adapt measures are carried out in 10 demonstration sites, covering over 1000 hectares, located in Portugal (Beja district), Spain (Extremadura) and Italy (Sicily, provinces of Enna, Caltanissetta, Caltagirone and Lampedusa), which are among the European areas with the highest levels of vulnerability to desertification. The field activities at the 10 sites included: water infiltration capacity (WIC) tests using a double ring infiltrometer, according to the procedure suggested by Bagarello et al. (2012); soil composite samples collection in uniform areas in terms of macro descriptors, like land use, geomorphology and vegetation cover, for a minimum set of 5 to 10 replicates, generally down to 10 cm; soil cylinders collection according to the MiPAAF method (1997). Additionally, the laboratory activities allowed measuring: water retention capacity according to the European Method (https://www.agvise.com/educational-articles/water-holding-capacity/); soil bulk density according to the MiPAAF method (1997); soil texture according to the MiPAAF method (2000); TOC by sulfochromic oxidation (ISO 14235:1998) and SOM according to Van Bemmelen (1890); the available water content (AWC), the field capacity (FC) and the wilting point (WP) according to Rawls et al. (2003).

RESULTS

Bulk density values were strictly related to land use in all the field sites. Pinewood topsoil show the lowest bulk density values, while grassland for pasture had high values of bulk density. Jara shrubs plot and uncultivated plot have the highest water retention capacity values while the old pinewood and the olive grove plot have the lowest values of water retention capacity. The WIC is elevated in sandy soils, although the standard deviation is high, witnessing a high degree of heterogeneity. WIC resulted to be inversely proportional (with a linear relation; R^2 0.72) to the degree of compaction of the soils for all sites and directly proportional (with a linear relation; R^2 0.82) to the SOM content for all sites. Pinewood has the highest AWC even though the soil is sandy, due to the high content of organic matter. The prickly pear orchard has the lowest AWC, due to the high percentage of sand present in this field site. AWC resulted to be inversely proportional (with a linear relation; R^2 0.74) to the sand content for all sites and directly proportional (with an exponential relation; R^2 0.86) to the SOM content for all sites.

CONCLUSIONS

The DESERT ADAPT measures are specifically designed to counteract aridification and land desertification. To reach this goal, the project aims to identify those indicators (Karlen et al., 1997), whose change ensures the widest improvement of soil, water, biodiversity, and agricultural properties in the 10 field test sites. From a hydrological point of view it was evident that the SOM content is the most promising soil indicator to work on, since it is positively correlated both with the WIC and the AWC. Conversely the degree of soil compaction and the abundance of sand have detrimental effect on hydrological properties of soil intended for agricultural use in territories subjected to desertification.

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Hydrogeological characterisation of the Flumendosa plain

Claudio Arras[1], Roberto Balia[2], Paolo Botti[4], Cristina Buttau[1], Pierluigi Cau[3], Stefania Da Pelo[1], Antonio Funedda[1], Giorgio Ghiglieri[1], Alfredo Loi[1], Mario Lorrai[4], Maria Teresa Melis[1], Maurizio Testa[5]*

[1] *Università degli Studi di Cagliari, Dipartimento di Scienze Chimiche e Geologiche, Monserrato (CA), Italy.*
**Corresponding email: arrasclaudio@gmail.com*

[2] *Università degli Studi di Cagliari, Dipartimento di Ingegneria Civile, Ambientale e Architettura, Cagliari, Italy*

[3] *Centro di Ricerca, Sviluppo e Studi Superiori in Sardegna (CRS4), Pula (CA), Italy*

[4] *Regione Autonoma della Sardegna, Servizio tutela e gestione delle risorse idriche, vigilanza sui servizi idrici e gestione delle siccità, Cagliari, Italy*

[5] *Agenzia Regionale per la Protezione Ambientale della Sardegna (ARPA Sardegna), Cagliari, Italy*

ABSTRACT

The alluvial plain of the Flumendosa River, in south-eastern Sardinia (Italy), is filled by detritic and alluvial deposits of Upper Pleistocene and Holocene Epoch and hosts a shallow phreatic aquifer and a deeper confined one. The plain is surrounded by hill reliefs made up of metamorphic and plutonic rocks of Palaeozoic Era.

Progressive seawater intrusion and soil salinization have occurred over the last few decades probably due to decreasing surface water supply from the Flumendosa River caused by dam construction upstream the plain and groundwater overexploitation for irrigation and household purposes related to increasing touristic request during summer periods (INEA, 2011).

The EU Water Framework Directive (WFD; 2000/60/EC) and the Groundwater Directive (GWD; 2006/118/EC), implemented by the Italian national regulation in the D.Lgs. 30/09, establishes that all groundwater bodies of member countries must be monitored to assess their quali-quantitative status. The Flumendosa plain represents one of 114 groundwater bodies (GWB) of the Hydrographic District of Sardinia and it is monitored since 2011 by the Regional Environmental Protection Agency of Sardinia (ARPA Sardegna). Since it has been classified in a poor chemical and quantitative status there is the need to better understand the hydrodynamic context and to plan effective remediation actions that will be included in the next update of the River Basin Management Plan of Sardinia (RAS, 2016).

Keywords: Water Framework Directive, 3D geological model, piezometric data

METHODS

A systematic review of various geological, geophysical and hydrogeological data acquired in the last four decades has been performed. These data include 39 stratigraphic logs, 4 seismic reflection

profiles, a gravimetric survey, more than 50 electric geophysics points, piezometric data and hydrogeological parameters from several hydrogeological surveys.
According to the analyses of geological and geophysical data interpreted through the principles of sequence stratigraphy, a 3D geological model of the plain was realised by interpolating 52 geological sections using the software MOVE (Midland Valley).
Groundwater dynamics and response to intense rainfall events and surface water release from upstream dams were investigated by correlating daily piezometric levels measured at three piezometers with daily precipitation and hydrometric data for the period March 2016 – December 2017.

RESULTS

Interpretation of the stratigraphic logs has allowed the identification of seven hydrogeological formations characterised by the following geometrical relationships:
the Palaeozoic basement (basement LB-I) can be considered as an aquiclude even if, locally, groundwater circulation can occur within alteration zones or fracture networks; it occurs at depth ranging from few tens of metres, in the piedmont sector, to more than 400 metres along the coastline.
Upper Pleistocene alluvial fans (aquifer AB) are made of slightly consolidated coarse and fine sediments; in the western and piedmont sector of the plain they host a phreatic aquifer while in its central-eastern sector they deepen and the facies succession changes laterally into the aquiclude AB_{im}; probably, the aquifer AB extends below the AB_{im} but supporting data are missing so far.
Aquiclude AB_{im} is an almost 70 metres thick of argillaceous succession whose upper limit occurs at 50 meters depth below the ground surface in the central and eastern part of the plain.
Holocene alluvium (aquifer AA1 and AA2) is mainly made of coarse fluvial deposits with high hydraulic conductivity values; a shallow phreatic aquifer AA1 occurs along the whole plain while in its central part the occurrence of the aquiclude $AA2_{im}$ generates a locally confined aquifer AA2.
Aquicludes $AA2_{im}$ and $AA1_{im}$ are mainly composed of argillaceous facies with silty and sandy intercalation of lagoon environment; the first one occurs at a depth of 10-15 metres below the ground surface while the second one outcrops in the backshore locally confining the AA1 aquifer.
Daily precipitation and hydrometric measurements were compared to piezometric data from three piezometers intercepting either the aquifer AA1 or AA2. Results have shown that during the wet season significant groundwater level rise occurs for more than 20 mm/day precipitation rates in both the aquifers. During the dry season, when no precipitation occurs, little groundwater level rise could be related to surface water release from dams. Groundwater level rise occurs after a delay time of few days for both precipitation events and dam releases.

CONCLUSIONS

The hydrogeological framework of the Flumendosa Plain is characterised by the occurrence of different aquifer systems locally confined by aquiclude formations. Piezometric data from both the aquifer AA1 and AA2 indicates a generally good response to direct precipitation recharge and river-aquifer exchange. Those results will represent the input data of a groundwater flow numerical model

that will be used for simulating different management scenarios of the groundwater resources capable to restore the good status of the GWB as requested by the WFD.

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Geological criteria to the 3D delimitation of groundwater bodies (GWB) in the hydrographic district of Sardinia

Claudio Arras[1], Roberto Balia[2], Paolo Botti[4], Cristina Buttau[1], Pierluigi Cau[3], Stefania Da Pelo[1], Antonio Funedda[1], Giorgio Ghiglieri[1], Alfredo Loi[1], Mario Lorrai[4], Maria Teresa Melis[1], Maurizio Testa[5]*

[1] Università degli Studi di Cagliari, Dipartimento di Scienze Chimiche e Geologiche, Monserrato (CA), Italy.
**Corresponding email: cbuttau@gmail.com*

[2] Università degli Studi di Cagliari, Dipartimento di Ingegneria Civile, Ambientale e Architettura, Cagliari, Italy

[3] Centro di Ricerca, Sviluppo e Studi Superiori in Sardegna (CRS4), Pula (CA), Italy

[4] Regione Autonoma della Sardegna, Servizio tutela e gestione delle risorse idriche, vigilanza sui servizi idrici e gestione delle siccità, Cagliari, Italy

[5] Agenzia Regionale per la Protezione Ambientale della Sardegna (ARPA Sardegna), Cagliari, Italy

ABSTRACT

The Water Framework Directive 2000/60/EC (WFD), establishing a framework for Community action in the field of water, has introduced for all Member States the obligations relating to the identification of surface and groundwater bodies and their monitoring, classification and definition of programs of measures to achieve a good status of all water bodies. In compliance with this statement, the River Basin Management Plan of Sardinia (Regione Sardegna, 2015) has identified and delimited 114 groundwater bodies (GWB). Main criteria were the identification of geological boundaries at the scale of 1:200,000, hydrogeological divides, analysis of pressures, and chemical status of groundwater.

In order to have a better knowledge of groundwater bodies boundaries, a more detailed delineation and characterization is in progress. As a first step of delineation the geological map of Sardinia at the 1:25,000 scale was used. Considering that the aim of this map was not for hydrogeological purpose, its reinterpretation was mandatory.

Every geological context needs in-depth knowledges to describe and model it properly. A further hydrogeological analysis can allow new interpretation of existing model according to the most recent methodologies developed. Each GWB required a different investigation specific approach. For example, incoherent recent deposits (gravels, sands, silts, clays, etc.) hosting groundwater bodies are characterized by porous aquifers types. Thus, necessary to consider the geometric relationships between stratigraphic units and the depositional environment provides important information on the lateral variation of hydrogeological features. Otherwise, the groundwater bodies hosted in crystalline rocks show continuous lithological characteristics for wide zone, but the primary relationships with neighboring units are often modified by tectonics (Feroni Cerrina et al., 2008).

The geological, hydrogeological and hydrogeochemical knowledge of GWBs becomes necessary to understand the quantitative state (extension and thickness of the area, yield, specific storage) and qualitative state (chemical state) for the correct delimitation of the GWB.

Keywords: geology, CIS, groundwater, Sardinia

METHODS

The methodology for the definition of GWBs, based on the criteria of the WFD guidelines and by the Italian Legislative Decree 30/09, consists in the identification of aquifers on geological and hydrogeological basis and then the identification of groundwater bodies taking into account main changes in anthropogenic pressures and changes in quantitative/chemical status. This process has been divided into three main phases:

1. Input, for data collection;
2. Processing, for expert data control and interpretation;
3. Output, for the delimitation of the GWBs and the extraction of their geographical and geometrical attributes.

The basis for the aquifers/GWBs re-measurement operation has provided for an initial phase, during which the limits were extracted from the official geological map of Sardinia in scale 1:25,000 (http://www.sardegnageoportale.it/). Then the limits between aquifers/GWBs have been updated on the base of geological criteria identified at the new scale of representation. In this phase, especially where overlapping aquifers are present, the limits were defined and validated basing on the geological information of the terrain and the stratigraphic data, obtained from the recent and historical cartography, and the control of the available stratigraphic logs.
The study has been done in ESRI ArcGIS environment.

RESULTS

The methodological approach provided a 3D reconstruction of the groundwater bodies (GWB), considering all the geological features (sedimentological, stratigraphic, tectonic, etc.) that shaped them and that can separate one from each other. In particular, to define a 3D model of the Plio-Quaternary GWBs in coastal plains the main effort was made in relating each sedimentary body with the proper depositional environment. In this way, the lithological sequence detected in well logs or geophysical logs can be extended laterally considering them as depositional sequences. This allowed to reconstruct the geometries of the GWB in a reliable way in space and time. Further, one of the main challenges in studying coastal plains is to estimate the stratigraphic thickness. In this case, when well logs were not available, the GWB thickness of recent deposits along the river branches has been inferred taking into account the slope geometry. Some lithostratigraphic units of reduced thickness were excluded after a case-by-case analysis. They, while exercising a hydrogeological function, do not constitute a significant permanent resource, since are saturated for short periods of the year. Moreover, the occurrence of the water intakes allowed to identify buried GWB. Less important than for other kind of GWB are the occurrence of tectonic structures, considering the recent geological evolution of Sardinia. Finally, construction of detailed geological sections was useful for the 3D reconstruction of GWB and to validate the final model.

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The role of the Norcia Plain aquifer in the groundwater flow of the Sibillini Mts. hydrostructure: a preliminary numerical model based on the effects of 2016 seismic sequence

Francesca Banzato[1], Alessandro Lacchini[1], Lucia Mastrorillo[2], Stefania Passaretti[1], Chiara Sbarbati[1], Daniela Valigi[3], Sara Veroli[1], Marco Petitta[1]*

[1] Università degli Studi di Roma La Sapienza, Dipartimento di Scienze della Terra, Roma, Italy.
**Corresponding email: francesca.banzato@uniroma1.it*

[2] Università degli Studi Roma Tre, Dipartimento di Scienze, Roma, Italy

[3] Università degli Studi di Perugia, Dipartimento di Fisica e Geologia, Perugia, Italy

ABSTRACT

The 2016 seismic sequence strongly affected the groundwater flow in the Sibillini Mts. ridge area, mainly after the Norcia main shock of 30th October 2016. Water-table and discharge changes of fractured carbonate aquifers have been already highlighted (Petitta et al., 2018) and one of the most influenced zone is the intramontane basin of the Norcia plain.

Nowadays, long-term effects are still observable in the Norcia plain aquifer: groundwater table levels remain several meters above the pre-seismic conditions and a surplus discharge in the Sordo river has been monitored. However, a seasonal recharge signal is affecting the water table since March 2018.

This study focalized on the hydrogeological changes (short- and middle-terms) due to the seismic sequence and on the implementation of a preliminary numerical model used to test the validity of the conceptual model based on the pre-seismic hydrogeological condition of the Norcia aquifer. Further monitoring will allow a refinement of the proposed preliminary model, necessary to understand the role of the Norcia aquifer in the regional groundwater flow of Sibillini Mts. hydrostructure, before and after the 2016 seismic sequence.

Keywords: earthquake hydrology, Norcia aquifer, numerical model.

METHODS

Pre-mainshock hydrogeological data refer to three hydrogeological surveys performed in the 2010-2011 period. The collected information, related to piezometric levels in 28 wells of the Norcia plain and discharge measurements in the Sordo river basin (Petitta, 2011), are considered representative of the background hydrogeological setting of the aquifer. After the main shock of 30th October 2016 new hydrogeological surveys have been carried out in order to quantify water-table and discharge changes in the study area.

A preliminary numerical model of the Norcia aquifer has been implemented related to pre-and post-seismic (February 2017) hydrogeological conditions. Specifically, the northern portion of the aquifer has been simplified into a single homogeneous layer with a thickness of 150 meters. The model has been implemented by the finite difference code MODFLOW using FREEWAT as graphical user

interface (Rossetto et al., 2018). It represents an area of about 17 km^2 with an extension of approximately 5.8 x 4.5 km.

RESULTS

Before the 30th October 2016 earthquake the Sordo River emerged from the Marcite spring area, near Norcia village and its discharge downstream of the Plain has been evaluated in 0.7 m^3/s (Petitta, 2011). This discharge cannot be referred only to the net recharge in the alluvial deposits, computed in 200 mm/year, but a contribution from the adjacent carbonate aquifers has to be considered. The analysis of piezometric levels evidenced a seasonal steady regime of water table of the Norcia aquifer between 550 and 585 meters a.s.l. in the northern sector. Instead, in the eastern and south-western sectors the water table ranges more than one meter reaching up to 610-615 meters a.s.l.

Subsequently the Norcia mainshock, the water-table of the aquifer has shown a sudden hydraulic head increase, which contributes to the re-activation of the Torbidone spring (Valigi et al., 2018). Indeed, until May 2017 a progressive increase of the water table elevation has been recorded from +1 m (in the north-western sector) to + 8/15 m (respectively in the south-western and eastern sectors). As a consequence, the discharge of the Sordo River also reacted with a gradual increase estimated over 2.0 m^3/s, receiving also the Torbidone spring discharge.

In the following months, the earthquake effects gradually reduced, with consequent lowering of the water-table and a progressive decrease of Torbidone spring discharge. Since March 2018, changes in groundwater levels show a seasonal recharge signal; however, groundwater table levels remain several meters above the pre-seismic conditions and a surplus discharge of +1.1 m^3/s in the Sordo River is yet highlighted (Fig. 1).

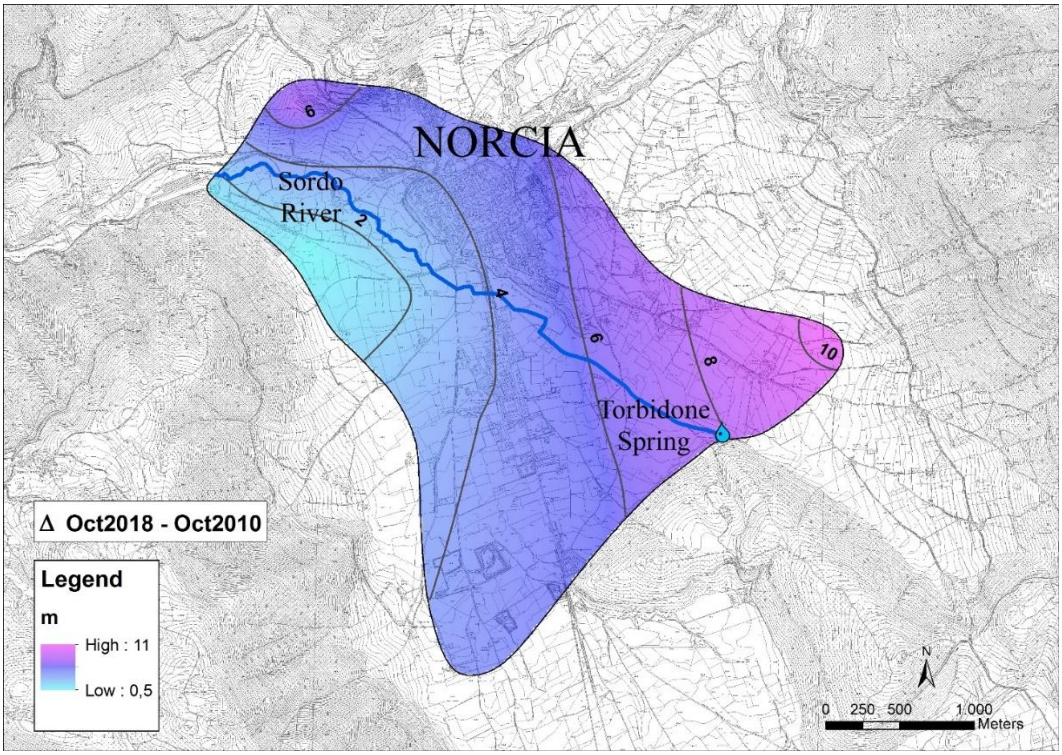

Fig. 1 - Variation of groundwater levels in Norcia plain due to the seismic sequence

The results of the preliminary numerical model also allowed to confirm that the Norcia aquifer is fed mainly by adjacent carbonate hydrostructures and that the drainage occurs from East and from South towards the north-western sector of the plain, where the springs of the Sordo river are located. This is supported also by the calculated hydrogeological budget: the groundwater surplus of the Norcia Plain, due to the 2016 seismic sequence, is also shown by the simulated water-table levels.

CONCLUSIONS

After the 2016 seismic sequence a surplus of groundwater flowed in the Norcia plain from the adjacent carbonate hydrostuctures. This fact is highlighted by the rise of water-table, by the increase of Sordo discharge and by the reactivation of the Torbidone spring.

Further monitoring, that includes geological, hydrogeochemical and isotopic data, will allow a refinement of the proposed preliminary numerical model, necessary to evaluate the role of the Norcia aquifer in the regional groundwater flow of Sibillini Mts. hydrostructure, before and after the 2016 seismic sequence.

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Inferring different hydrogeochemical processes in a coastal aquifer via factor analysis

Gianluigi Busico[1], Nerantzis Kazakis[2], Emilio Cuoco[1], Nicolò Colombani[3], Dario Tedesco[1], Micòl Mastrocicco[1]*

[1] Università degli Studi della Campania, Luigi Vanvitelli, DiSTABiF, Caserta, Italy.
**Corresponding email: gianluigi.busico@unicampania.it*

[2] Aristotle University of Thessaloniki, Dept. of Geology, Thessaloniki, Greece

[3] Università Politecnica delle Marche, Dipartimento di Scienze e Ingegneria della Materia, dell'Ambiente ed Urbanistica (SIMAU), Ancona, Italy

ABSTRACT

Groundwater mineralization is due by several processes such as, water-rock interactions, mixing with different waters and intense human activities. Usually the alluvial plains represent the hardest situation for a hydrogeochemical characterization, because all those processes act at the same time frame. Multivariate statistical analysis has been successfully applied to discriminate between different processes occurring in aquifers (Busico et al., 2018; Kim et al., 2009). Factor analysis identifies four different factors and seven hydrogeochemical processes in the study area. Six were related to the natural geological background of the area and one to the anthropogenic pressure. Overall, the conceptual model derived from the factor analysis was coherent with the regional hydrogeological pattern and land use features, underlying the effectiveness of this statistical technique to discriminate different overlapping processes.

Keywords: Multivariate statistical analysis, alluvial aquifer, groundwater mineralization.

METHODS

Forty-three groundwater samples were collected mainly from agricultural wells in the alluvial plain of Garigliano River. The determination of the chemical parameters has been performed in the geochemical laboratory of University of Campania "Luigi Vanvitelli" via ion chromatography via a Dionex DX-120 for major ions Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, NO_3^{-} and using an Agilent 7500 CE ICP-MS for trace elements Fe, Mn, Zn, B, V, Li, U, Cr, Ba, Sr, As and Ni. Factor analysis (FA) was used on the entire database to identify all the hydrogeological processes acting in the Garigliano River plain and to discriminate between geogenic and anthropogenic processes

RESULTS

Four factors emerged from the FA application (Table 1): Factor 1, composed of Cl^{-}, SO_4^{2-}, Na^{+}, Mg^{2+}, Ca^{2+} and Ba, represents the main salinization factor for the studied aquifer. Inside this factor is possible to identify more processes: i) the lateral inflow from carbonate massive of Massico Mountain, with a Ca-Mg-HCO_3 groundwater composition, ii) the seawater intrusion near the coastline and more evidently at the Garigliano River mouth which represents a preferential path for seawater

intrusions (Kazakis et al., 2019) and finally iii) the interaction with marine sediments in the central part of the study area. The Factor 2 shows a correlation between F^-, As and V, elements commonly found in groundwaters hosted in volcanic rocks. The Factor 3 consists of three species, NO_3^-, U and Sr. The spatial distribution of this factor suggests an anthropogenic origin of these elements like agricultural activities, and sub-urban activities (Busico et al., 2017). The last factor, with the 11% of the total variance explained, has only B that was probably released by reworked silica sediments.

	Factor 1	Factor 2	Factor 3	Factor 4
HCO_3^-	0.59	-0.02	0.23	0.33
F^-	-0.20	0.83	-0.12	0.18
Cl^-	0.97	-0.01	-0.06	0.13
NO_3^-	-0.03	0.02	0.82	-0.10
SO_4^{2-}	0.93	-0.11	0.17	0.12
Na^+	0.97	0.01	-0.07	0.14
K^+	0.59	0.49	-0.28	0.30
Mg^{2+}	0.97	-0.01	0.11	0.13
Ca^{2+}	0.84	-0.15	0.32	0.24
Li	0.38	0.68	-0.28	0.28
B	0.30	0.19	0.16	0.75
V	-0.08	0.63	0.24	-0.49
Mn	0.27	-0.07	-0.13	0.65
Ni	0.41	-0.40	-0.07	-0.15
As	-0.07	0.72	0.01	-0.21
Sr	0.08	0.02	0.78	0.32
Ba	0.93	-0.07	-0.12	0.24

Table 1 - Factor score for applied FA

CONCLUSIONS

The application of the FA describes the main hydrogeochemical processes acting in the study area. Results of this study can be widely used in coastal aquifers to distinguish between different hydrogeochemical processes, and to recognize pollution sources

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The ENeRAG project: towards a dynamic system approach for geofluids

Corrado Camera[1], Daniele Pedretti[1], Ferenc Mòlnar[2], Teppo Arola[2], Timea Havril[3], Anita Erõss[3], Marco Masetti[1], Juha Kaija[2], Judit Mádl-Szőnyi[3]*

[1] *Università degli Studi di Milano, Dipartimento di Scienze della Terra "A. Desio", Milano, Italy.*
**Corresponding email: corrado.camera@unimi.it*

[2] *Geological Survey of Finland (GTK), Espoo, Finland*

[3] *Eötvös Loránd University, Department of Physical and Applied Geology, Budapest, Hungary*

ABSTRACT

Historically, physical and biochemical similarities among geofluids (e.g. shallow groundwater, geothermal fluids, hydrothermal mineral-rich fluids) have not been treated under a common research sphere. Also, little knowledge is available regarding geofluid interactions and a common legislative framework for their management and use does not exist in the EU. The main objective of the ENeRAG project is to develop a sustainable and cost-effective dynamic system approach (Tóth, 1999; Deming, 2002; Ingebritsen et al., 2006) to deal with geological resources, relying on a scientific understanding of the connections and interrelationship among geofluids.

The ENeRAG – Excellency Network Building for Comprehensive Research and Assessment of Geofluids project is a twinning project funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No 810980. This presentation covers the main development, actions and goals of the projects, highlighting key achievements and incoming milestones.

Keywords: geothermal fluids, groundwater, hydrothermal fluids, interaction, resource assessment, resource management

METHODS

The project tackles three main topics linked to geofluids:

1. Hydrogeology
2. Low enthalpy energy and reutilization of shallow subsurface heat
3. Hydrothermal formation of mineralogical resources

The core of the project consists of capacity enhancement activities (e.g. training workshops, winter and summer schools, expert visits, laboratory and field trainings) and networking programs (e.g. staff and junior researcher exchanges, co-organization of conference sessions and seminars), whose outcomes should impact both science and society through specific dissemination actions (participation in scientific conferences, scientific publications, stakeholder workshops, policy round-tables, and participation in events open to the general public). In detail, during the three years of the project, 4 training workshops mixing field, laboratory and traditional class activities; 2 summer

(winter) schools; 5 conference session, 4 staff and research exchange actions for a total of 12 project participants being hosted at partners facilities; and 1 field symposium will be organized.

Detailed directions of development of the project include: i) improvement of knowledge on geofluid systems, tracing of fluids in the underground, and transport modelling; ii) development of sustainable solutions for geofluid management and utilisation; iii) transfer of knowledge to business services and outreach to society. All research and innovation activities are implemented with a focus on knowledge-transfer among partners, since it is the pillar of twinning projects.

RESULTS

The ENeRAG project will form scientists able to follow the latest scientific developments in the field of geofluids, with the necessary skills to face related environmental issues with an integrated approach. Also, their knowledge will ideally foster and pave the way to a first concept of policies and regulations dealing with the connections between geofluids and formation, preservation and harvesting of various geological resources linked to them. A number of 10 papers will be published at the end of the course, while the exchange of 12 researchers supports the development of new skills to be adopted directly on the Hungarian territory (Hungary is the main target of the Twinning action) as well as exported within the EU and beyond.

CONCLUSIONS

Strategic and wise management of geological resources is intrinsically needed for a sustainable future development of our environments, societies and economies. Considering that fluids play a role in nearly all geologic processes and are ubiquitous in the continental crust to depths of at least 10 to 15 km (Deming 2002, Ingebritsen et al. 2006), the integrated study of geofluids, as proposed by the ENeRAG dynamic system approach, is a key element to reach these objectives.

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Depth profiles of H_2O, C, N and S stable isotopes in a shallow aquifer-aquitard below agricultural fields reveal large hydrochemical heterogeneities in contrasting soils

Nicolò Colombani[1], Ramon Aravena[2], Giuseppe Castaldelli[3], Micòl Mastrocicco[4]*

[1] *Università Politecnica delle Marche, Dipartimento di Scienze e Ingegneria della Materia, dell'Ambiente ed Urbanistica (SIMAU), Ancona, Italy. *Corresponding email: n.colombani@univpm.it*

[2] *University of Waterloo, Earth and Environmental Department, Waterloo, Ontario, Canada*

[3] *Università degli Studi di Ferrara, Dipartimento di Scienze della Vita e Biotecnologie (SVeB), Ferrara, Italy*

[4] *Università degli Studi della Campania, Luigi Vanvitelli, DiSTABiF, Caserta, Italy*

ABSTRACT

Lowland agricultural landscapes as the Po delta (Italy), are intensively cultivated, and often affected by large nitrogen (N) and carbon imbalances due to fertilizers leaching to groundwater and export via run-off. Agricultural-derived N imbalance usually leads to nitrate accumulation in groundwater (Paradis et al. 2018), which triggers other biogeochemical reactions linked to the carbon and sulphur cycling (Zhang et al. 2013). Moreover, since groundwater flow rates can be extremely slow in lowland environments (Colombani et al., 2016), to infer which are the most impacting land uses in term of aquifer diffuse pollution, the definition of the temporal scale of recharge and residence times is of utmost importance (Meals et al. 2010). Besides, recharge rates at field scale can be heterogeneous, affecting residence time in the vadose zone which in turn affect lag time in groundwater quality response due to agricultural practices. To verify if recharge rates are heterogeneous and determine the main biogeochemical reactions, multi-level sampler (MLS) monitoring wells were installed at two sites (GUA and BAN) characterized by contrasting depositional environments and groundwater samples were analysed for major ions and H_2O, C, N and S stable isotopes. Results show high heterogeneities in recharge due to local variation of hydraulic conductivity (k). Stable isotopes provided a clear distinction between different sources of N present in both sites, from synthetic fertilizers to sedimentary N pool and atmospheric input. Nitrification was the main N transformation in the vadose zone while denitrification was restricted to a narrow transition zone between oxic and reduced zones. Pyrite oxidation was the main source of sulphate in both sites and sulphate reduction and methanogenesis were found to be active processes in the deeper part of the BAN site.

Keywords: recharge, denitrification, shallow aquifer, pyrite oxidation, redox zones

METHODS

Two contrasting soils were selected and equipped with MLSs to monitor the main biogeochemical reactions. The first site (GUA) pertains to a freshwater paleo-river environment poor in sedimentary organic matter (SOM); the second site (BAN) pertains to a coastal brackish swamp environment, characterized by SOM abundance and peat lenses. MLSs were sampled in March 2018 and slug tests

were done to characterize the k variations. Major ions, DOC, DIC, H_2S, CH_4 and stable isotopes composition ($\delta^{15}N_{NO3}$, $\delta^{18}O_{NO3}$, $\delta^{15}N_{NH4}$, $\delta^{34}S_{SO4}$, $\delta^{18}O_{SO4}$, $\delta^{13}C_{DIC}$ and $\delta^{13}C_{DOC}$) were analysed in groundwater samples.

RESULTS

The hydrogeological characterization highlighted the presence of long residence times despite the presence of shallow water tables, between 1 and 2 m below ground level, at BAN and GUA, respectively. The long residence times were due to the low k values found and limited recharge rates (approximately 150 mm/y). The average k values were $7.1*10^{-6}$ and $4.2*10^{-7}$ m/s for GUA and BAN, respectively. The δ^2H-H_2O and $\delta^{18}O$-H_2O depth profiles showed the presence of large differences among the two MLSs located in BAN and GUA. In fact, despite the MLSs were in the same cultivated plot, differences of up to -3‰ for $\delta^{18}O$-H_2O and -22‰ δ^2H-H_2O were found for samples located at the same depth. Given that the rainfall and evapotranspiration rates could be considered homogeneous at the plot scale, the elevated spatial heterogeneities could be, beside local recharge by precipitation, related to the input of irrigation water from nearby channels which source of water is the Po river. This pattern was also reflected by the elevated differences in NO_3^- and NH_4^+ concentrations found in both GUA and BAN MLSs. In GUA only NO_3^- was present, while in BAN NO_3^- prevailed near the water table while NH_4^+ prevailed at deeper depths. This was due to the presence of peat rich in organic N and highly reducing conditions. Results from N isotopes showed a clear distinction between different sources of N in both sites: synthetic fertilizers were prevalent in GUA while sedimentary N pools, responsible for abnormal NH_4^+ concentrations, were prevalent in BAN. The atmospheric N input was well distinguishable especially in BAN because of the lower k values typical of this sedimentary environment and thus reflecting pre-industrial fertilizers N inputs. The ubiquitous presence of pyrite and its oxidation produced large amount of SO_4^{2-} in groundwater, this source was well identified by the multi-isotopes approach ($\delta^{18}O$-SO_4^{2-} and $\delta^{34}S$-SO_4^{2-}). Denitrification was restricted to a narrow transition zone between oxic and reduced zones and sulphate reduction and methanogenesis occurred in the deeper part at the BAN site.

CONCLUSIONS

This study highlights that large variations in stable isotopes can be found in the same agricultural plots. This is due to heterogeneities in k distribution that in turn drives the recharge rate at the plot scale and to the presence or absence of SOM that can further trigger biogeochemical reactions. Besides, the groundwater residence time can be relatively slow in these environments and MLSs devices resulted to be key monitoring tools to distinguish the different redox zones and water origins.

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Hydrogeochemistry and natural background levels for the groundwater body of Sele river plain (southern Italy)

Alfonso Corniello[1], Daniela Ducci[1], Mariangela Sellerino[1], Del Gaudio Elena[2]

[1] Università degli Studi di Napoli Federico II, Dipartimento di Ingegneria Civile, Edile e Ambientale, Napoli, Italy.
**Corresponding email: alfonso.corniello@unina.it*

[2] Outside expert, Italy

ABSTRACT

The coastal plain of Sele River (about 230 Km^2) is an area affected by natural land subsidence active during the Quaternary.

Deep drillings and geophysical investigations (AGIP, 1977; Santangelo et al., 2017) identified, in the central sector of the plain, a carbonate bedrock underlying flysch and conglomerate-clayey-sandy sediments. These deposits constitute the main aquifer of the plain; groundwater flows in the coarser grained levels, in confined or semi-confined conditions (Budetta et al., 1994).

Within the Campania Transparent Project (funded by Campania Region) 75 groundwater samples in the plain were analysed, also with the aim to define the Natural Background Levels (NBLs) of some ions. The peculiar hydro-chemical characteristics stressed the need to define in detail the hydrogeological setting for distinguishing in the plain different sectors: presence of reducing environment, Na-Cl mineral groundwater etc.

Keywords: Sele River plain, alluvial aquifers, hydrogeochemistry, NBL

METHODS

Between December 2016 and June 2017, in Sele River plain 75 groundwater samples were collected and subsequently analysed. During the sampling, measures in situ of groundwater level, conductivity, temperature, pH and redox potential were performed. Hydro-chemical analyses carried out by ARPACampania (https://www.arpacampania.it/web/guest/365) were also added to the dataset.

For the calculation of the NBLs for the chemical parameters exceeding the reference values (D. Lgs. 31/2001), the value to be adopted as NBL is given by the statistical distribution of the dataset, applying the guidelines proposed by ISPRA (Italian Institute for Environmental Protection and Research, 2017).

RESULTS

The Piper diagram of the collected groundwater (Fig. 1) highlights two hydrochemical types.

The first one, mainly represented, is calcium-bicarbonate type; in some areas, located on the left side of Sele River, peats deposits in the subsoil determine reducing conditions. The second groundwater type characterizes the springs located at the southern corner of the plain and the waters of the downstream wells; these waters have high levels of Na, Cl and SO_4 (Celico et al., 1982).

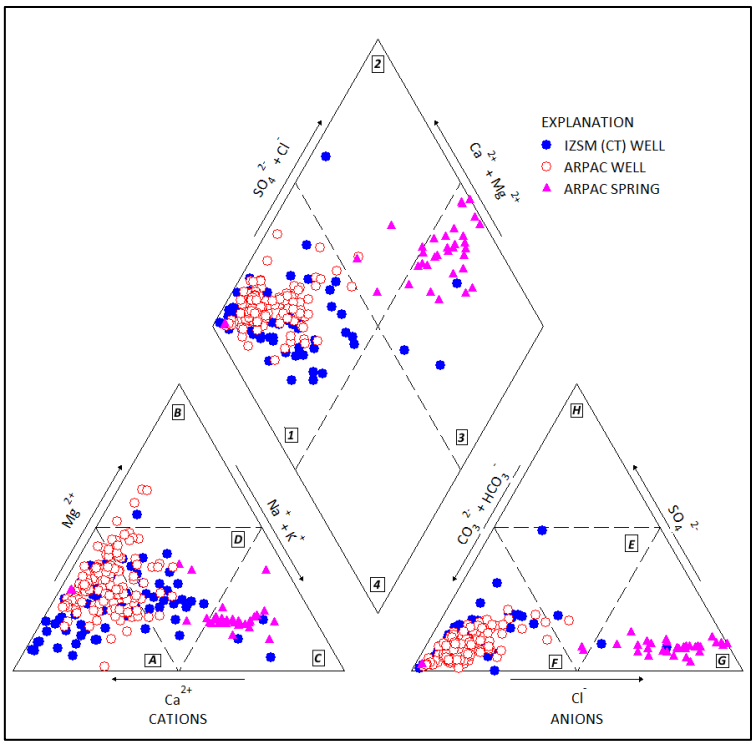

Fig. 1 - Piper diagram of the collected groundwater

CONCLUSIONS

The hydrostratigraphical data and the definition of the groundwater flow in Sele River plain allowed an accurate characterization of the local hydrogeological model.

This model, the analysis of the hydrochemical data and the NBL evaluation have led to confirm that the high values of Mn and Fe sometimes observed in groundwater of the plain are of natural origin.

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Evaluating conjunctive use of ground- and surface-water and crop yield in rural environments by means of simulation tools

Giovanna De Filippis[1], Federico Triana[1], Matteo Ghetta[1], Iacopo Borsi[2], Wolfgang Schmid[3], Rudy Rossetto[1]*

[1] Scuola Superiore S. Anna – Istituto di Scienze per la Vita, Pisa, Italy.
**Corresponding email: g.defilippis@santannapisa.it*

[2] TEA Sistemi S.p.A., Pisa, Italy

[3] Commonwealth Scientific and Industrial Research Organisation, Perth, Australia

ABSTRACT

During the last decades, attention is being payed to Water Resource Management (WRM), especially due to the growing pressure related to overexploitation and climate change. This holds especially true in rural areas, where the bulk of water consumption occurs. As such, conjunctive use of ground- and surface-water is being increasingly adopted worldwide to enhance crop production sustainability, while managing the use of water resources. In this framework, ICT (Information and Communication Technology) tools, such as modelling engines integrated in GIS environments, may allow water managers to estimate the effects of natural and anthropic impacts on groundwater resource and to properly manage water use for agricultural purposes.

Within the H2020 FREEWAT (FREE and open source software tool for WATer resource management) project, this topic has been taken into account, as rural WRM was considered a major priority by the involved stakeholders.

Keywords: conjunctive use, crop yield, FREEWAT, Farm Process, Crop Growth Module

METHODS

The FREEWAT project aimed at promoting and simplifying the application of EU water-related directives through the application of a free and open source, GIS-integrated platform for the simulation of several processes involved in the hydrologic cycle (i.e., groundwater dynamics, interaction with surface water bodies, solute transport processes, conjunctive use of ground- and surface-water, etc.).

Among the others, the FREEWAT platform integrates modelling tools to deal with conjunctive use of ground- and surface-water in rural areas. To this aim, the Farm Process (FMP), embedded in MODFLOW-OWHM (MODFLOW One-Water Hydrologic Flow Model; Hanson et al., 2014), was integrated within the FREEWAT platform. FMP calculates supply-and-demand components of the irrigated agriculture on a farm scale (including head-dependent inflows and outflows, such as canal losses and gains, surface runoff, surface-water return flows, evaporation, transpiration, and deep percolation of excess water), and integrates such components within the hydrological budget calculated by MODFLOW-2005 (Harbaugh, 2005).

Within the FREEWAT platform, FMP was also coupled to a module, the Crop Growth Module (CGM), for the simulation of the crop growth cycle. CGM is a radiation-based model belonging to the EPIC family models (Williams et al., 1989), which estimates crop yield at farm and basin scale, under different climatic and water supply constraints. Specifically, CGM exploits FMP results related to water availability in the unsaturated zone, and crop water demand and water uptake, by taking also into account how weather affects the crop growth cycle.

RESULTS

The FMP-CGM approach is demonstrated by a simple synthetic application, where the growth cycle of irrigated sunflower in a Mediterranean area was simulated between 1st April and 31st August 2017. Model results show that crop irrigation demand is satisfied by natural uptake and surface water resources up to the end of May, while a supplementary source of water (provided by groundwater wells) is needed during the summer season, due to poor surface water availability and increased evapotranspiration demand. The following supply-and-demand components were quantified: rainfall recharge, irrigation provided via ground- and surface-water resources, direct uptake from the capillary zone, runoff, water percolation to the aquifer, evaporation from irrigation and from groundwater, transpiration from irrigation, from groundwater, and from precipitation. Sunflower yield at harvest was thus inferred.

CONCLUSIONS

The approach presented in this contribution aims at providing water authorities and public/private companies with a dynamic tool for agricultural water management. In this framework, the proposed approach aims at supporting the design of efficient irrigation schemes able to manage conjunctive use of ground- and surface-water, thus reducing unplanned use of private irrigation wells. Also, the efforts spent to design this approach aims at boosting digitalization in the agricultural water sector for improving WRM.

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Promoting water resource management through the use of ICT tools and participatory approach

Giovanna De Filippis[1], Iacopo Borsi[2], Laura Foglia[3], Massimiliano Cannata[4], Rotman Criollo[5], Enric Vázquez-Suné[5], Irena Kopač[6], Björn Panteleit[7], Pio Positano[8], Marco Saulo Nannucci[8], Manuel Sapiano[9], Daria Svidzinska[10], Mykhailo Grodzynskyi[10], Rudy Rossetto[1]*

[1] *Scuola Superiore S. Anna – Istituto di Scienze per la Vita, Pisa, Italy.*
**Corresponding email: g.defilippis@santannapisa.it*

[2] *TEA Sistemi S.p.A., Pisa, Italy*

[3] *UC Davis, Davis, California*

[4] *Scuola Universitaria Professionale della Svizzera Italiana, Lugano, Switzerland*

[5] *Institute of Environmental Assessment and Water Research (IDAEA), CSIC, Barcelona, Spain*

[6] *Institute for Ecological Engineering, Maribor, Slovenia*

[7] *Universität Bremen, Bremen, Germany*

[8] *Regione Toscana, Firenze, Italy*

[9] *Energy and Water Agency, Valletta, Malta*

[10] *Taras Shevchenko National University of Kyiv, Kyiv, Ukraine*

ABSTRACT

Even if several efforts is being spent to address Water Resource Management (WRM) issues, this is still an underrated topic at decision-making level. This is also due to the poor capacity by researchers to properly communicate problems and results about WRM.

ICT (Information and Communication Technology) tools may help in dealing with WRM. Among these, integrating modelling tools in GIS (Geographic Information System) environments is a valuable methodology to represent the hydrologic systems and their response to anthropic and climate stresses.

Within the H2020 FREEWAT (FREE and open source software tools for WATer resource management; www.freewat.eu) project, the application of ICT tools was combined with an innovative participatory approach and capacity building activities to promote the use of ICT tools for WRM. This contribution aims at presenting the most relevant results of the FREEWAT project, showing some application examples to real-world case studies.

Keywords: participatory approach, FREEWAT, GIS, ICT, technological transfer

METHODS

The FREEWAT project aimed at simplifying the application of EU water-related directives through the application of a free and open source, GIS-integrated platform for the simulation of several

processes involved in the hydrologic cycle (i.e., groundwater dynamics, interaction with surface water bodies, solute transport processes, etc.). This was accomplished within the framework of an innovative participatory approach, aimed at combining the scientific approach and the decision-making process for WRM, thus creating a shared environment among stakeholders, providing results for supporting the application of management and planning policies.
The FREEWAT platform was applied to several case studies involving stakeholders during the whole phase of technical characterization and modelling of the investigated groundwater body. This participatory approach allowed to test the effectiveness of strategies and measures foreseen within the RBMP and designed by EU Member States for achieving the good quantitative and qualitative status of groundwater bodies. At each case study, a Focus Group made of local stakeholders and technicians from river basin authorities, municipalities, research institutes, environmental protection agencies, environmental associations, etc., was set. Periodic meetings were organized to involve the participants during the technical phase of data collection, conceptual model definition, numerical model implementation and scenarios design, in order to test the effectiveness of measures foreseen within the RBMP.

RESULTS

Some of these above-mentioned experiences will be presented.
At Vrbansky plato (Slovenia), FREEWAT was applied to manage a Managed Aquifer Recharge facility within an alluvial plain near Maribor. The local water authority is intended to use the model develped to monitor the effects of polluting activities occurring at Maribor.
A groundwater flow model was developed to test the effects of sea level rise and rainfall scarcity up to 2100 in the Bremerhaven district (Germany). This was aimed at setting a strategy for climate change adaptation involving the local water authority.
Regarding the case study of Scarlino-Follonica (Italy), the FREEWAT model will be used by the regional authority to test groundwater remediation strategies in a large contaminated industrial site.
The density-dependent flow model developed for the aquifer system of the Gozo island (Malta) will allow assessing the qualitative and quantitative status of groundwater, currently classified as "poor" within the Water Framework Directive.
Within the Bakumivka river basin (Ukraine), three groundwater management scenarios were simulated in a rural environment, to compare different spatial patterns of land use and use of water resources.

CONCLUSIONS

Within the H2020 FREEWAT project, the application of ICT tools was combined with an innovative participatory approach and capacity building activities. During the technical phase of FREEWAT application to real-world case studies in EU and non-EU Countries, local stakeholders were involved and their perspective about the importance of using ICT tools for WRM was discussed. As a result of this approach, public authorities have the chance to build a dynamic representation of the hydrological systems, and to share it with decision-makers involved in WRM.

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The VISTA Project: a test site to investigate the impact of traditional and precision irrigation on groundwater (San Gemini basin, Central Italy)

Lucio Di Matteo[1], Stefano Casadei[2], Francesco Peppoloni[2], Francesco De Giorgi[1]*

[1] Università di Perugia, Dipartimento di Fisica e Geologia, Perugia, Italia.
**Corresponding email: lucio.dimatteo@unipg.it*

[2] Università di Perugia, Dipartimento di Ingegneria Civile ed Ambientale, Perugia, Italia

ABSTRACT

The increase of anthropic pressure and the intensification of prolonged drought periods require the improvement of the effectiveness of agricultural systems by means of precision irrigation techniques. This study presents the VISTA project (PSR Umbria mis.16.2.1), aiming to evaluate water resource usage, comparing traditional with precision irrigation techniques. A test site located in the San Gemini hydrogeological basin has been selected: it is characterized by the outcropping of travertine rocks hosting an important multipurpose aquifer (mineral waters, drinking waters, and agricultural uses). The main aim of the work is to investigate – by using a soil–water budget model – the impact of water uses on two adjacent plots of land characterized by the same crop (tomato) and by different irrigation techniques.

Keywords: Groundwater, precision irrigation, soil-water budget model, VISTA project

METHODS

The VISTA Project (PSR Umbria mis.16.2.1) aims to communicate the agri-food transparency. Within the project, an important task is to make both producers and consumers aware of water use and efficiency of irrigation systems. The project is composed of about 15 farms located in the Umbrian territory and by some research partners. A local irrigation advisory service will be developed at farm to support precision irrigation scheduling and smart irrigation methods, taking into account about 2 years of tests level. In this framework, two adjacent plots of land characterized by the same crop (tomato) and by different irrigation systems (traditional and water-saving techniques) are selected in the San Gemini basin (Fig. 1): both are irrigated using water from a pumping well drilled in a multipurpose aquifer hosted in travertine rocks. The study involves the understanding of the climatic and hydrogeological conditions and the using of precision irrigation systems. Agro-meteorological data are taken from a new weather station installed on February 2019 close to the test site (42.661735 – 12.545272): data will be validated with those of two neighbouring weather stations of the Umbria Region weather network. In order to implement an integrated decision support system for irrigation a self-made daily water budget model will be used. The groundwater pumped will be monitored separately on the two plots of land by means of two volumetric water counters. The water consumptions on the two adjacent plots of land will be discussed taking into account the monthly

groundwater availability and evaluating drought and wet periods by applying some well-known climate indices such as SPI (McKee et al., 1993) and RDI (Tigkas et al., 2016).

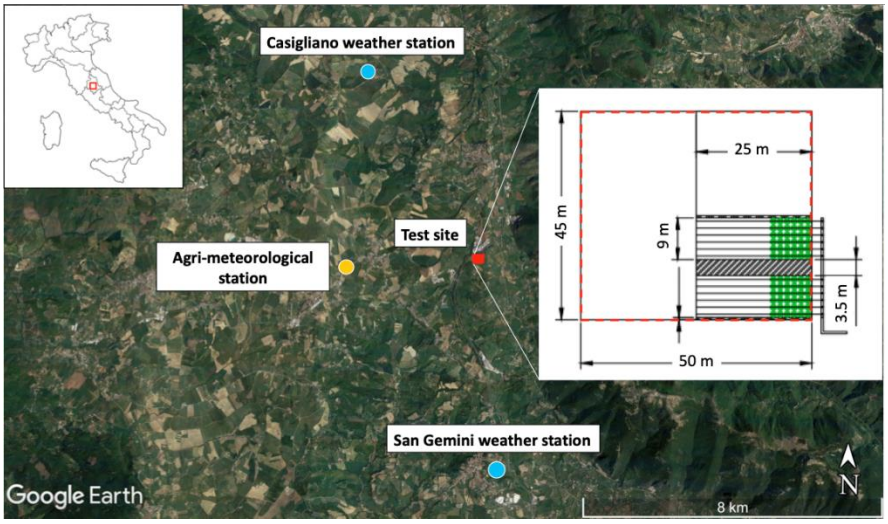

Fig. 1 - Location map of the test site.

RESULTS

The project part concerning the area of San Gemini has just started: therefore, in this phase results of previous investigations are reported, useful for the understanding of the hydrogeological system and the climatic characteristics of the study area. According to a pumping test carried out on a neighbouring well by Di Matteo (2003), the travertine aquifer is characterized by transmissivity values ranging between 0.02-0.03 m^2/min. The test was carried out at the end of a severe drought period. The San Gemini basin – as other important aquifer in Central Italy – experienced at least five severe droughts in the last two decades with an increase of frequency and magnitude of droughts. According to 12-months SPI index, the latest moderate-to-severe drought period occurred in 2016-2017 with a reduction of yearly water surplus – computed by Thornthwaite-Mather method – of about 15% (380 mm/year vs a mean value of 443 mm/year). The project is still on-going, thus the data that will be acquired in next few months on the test site will be useful to optimize the groundwater exploitation for agricultural purposes in an area affected by the intensification of prolonged drought periods.

CONCLUSIONS

Methods and approaches proposed by the VISTA project may contribute to optimize the agricultural water use, a very important issue in the context of the on-going climate change in Central Italy and considering requirements of both producers and consumers. The optimization of agricultural water use in the San Gemini basin contributes to the territorial connotation of farms, the activities of which are located on a key hydro-geological basin having a vocation for drinking and mineral water exploitation. The results of the case study may be useful in similar hydrogeological systems, where different uses of water coexist.

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Use of piezometric time series for the identification of groundwater hydrodynamic behaviours and controlling factors: the case study of the Piedmont plain (Italy)

Manuela Lasagna[1], Susanna Mancini[1], Domenico Antonio De Luca[1]*

[1] Università di Torino, Dipartimento di Scienze della Terra, Torino, Italy.
**Corresponding email: manuela.lasagna@unito.it*

ABSTRACT

The assessment of groundwater hydrodynamic behaviour is an essential starting point for highlighting the response of groundwater to natural factors (e.g. climate; Radfar et al., 2013; Trenberth et al., 2007) and anthropic ones. In this study, piezometric levels in 36 monitoring points, homogeneously distributed in Piedmont plain (NW Italy), were analysed. The aim is to classify and describe the groundwater table hydrodynamic behaviours, their spatial distribution and the controlling factors.

Keywords: piezometric level, hydrodynamic behaviour, rainfall, irrigation

METHODS

Analysed piezometric data are referred to monitoring points of the automatic monitoring network of shallow aquifer of Piedmont Region. Daily piezometric series recorded in 2002-2017 were collected and analyzed. An analysis of the distribution of average monthly piezometric level in the period 2002-2017 was performed, in order to understand the hydrodynamic behaviour of the water table. Daily pluviometric series were also studied, covering the same time period. Monthly aggregated data were then elaborated to highlight possible correlation with piezometric levels. Finally, the yearly fluctuations of piezometric levels were evaluated, considering their variation in time.

RESULTS

Timeplots of piezometric level permitted to describe different hydrodynamic behaviour of the groundwater table in the Piedmont Plain. Hydrodynamic behaviours were classified based on two main criteria: (1) presence of a main maximum in spring and a main minimum at the end of summer – start of autumn (Group A); (2) presence of a main maximum in summer and a main minimum at the end of winter - start of spring (Group B). Moreover, some subgroups (A1, A2, B1, B2) were identified, in which 1 or more than 1 maximum or minimum were observed (Fig 1a). For the sake of clarity, one piezometer is selected in each group to illustrate the general behaviour of the group (Fig. 1b-1c).

Analysing the distribution of the different hydrodynamic behaviours on a regional scale is possible to observed that most of piezometers belonging to Group B are located within agricultural areas with irrigation method for submersion (rice fields in Vercelli plain; Fig.1c). Monitoring wells of Group A are distributed in the rest of the Piedmont plain.

The rainfall pattern shows a main isolated maximum in November, a secondary maximum in spring, a main minimum in summer and a less pronounced minimum in December-January. Group A is generally connected to precipitation. However, the response of piezometric level to rainfall is delayed for 1- 2 months. Subordinately, piezometers near main rivers have a piezometric level strictly connected to river discharge.

The average yearly piezometric level fluctuation in the period 2002-2017 ranges between 0.37 m and 4.58 m. More specifically, 36% have an average yearly fluctuation less than 1 m, 44% is between 1 and 2 m, and the remaining 20% have values above than 2 m.

Finally, a comparison of groundwater hydrodynamic behaviour was conducted separately in two periods (2002-2008 and 2009-2017). This analysis shows that in some cases the seasonal behaviour seems to change over time, with variation both in the values of the piezometric level and in the positions of maximum and minimum.

CONCLUSIONS

The analysis of piezometric level fluctuation of superficial aquifer shows hydrodynamic behaviours in Piedmont depending on natural factors and anthropic causes. The main natural factor is precipitation and locally the presence of a near river. The main anthropic factor is represented by irrigation, especially connected to the rice-fields, that represent the main controlling factor of the yearly fluctuation.

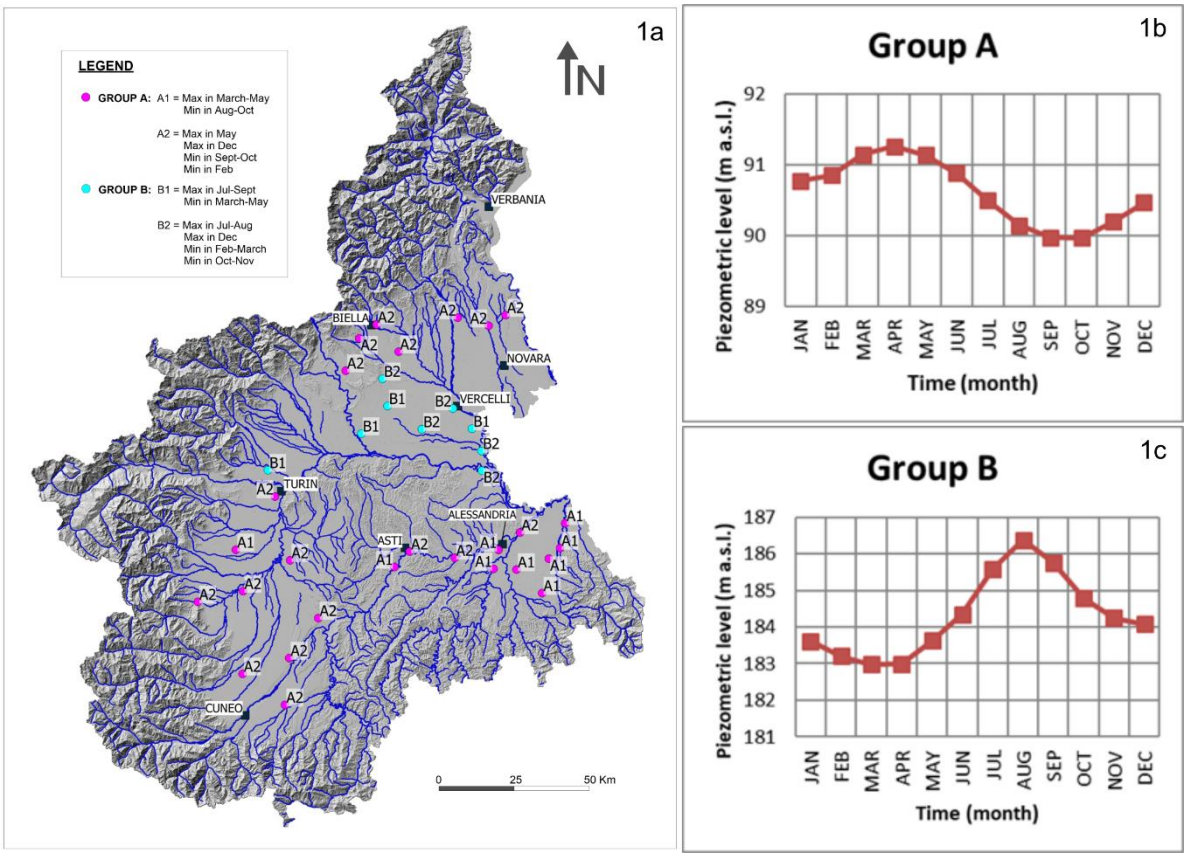

Fig.1 - Location of piezometers belonging to Group A and B (Fig. 1a). Hydrodynamic behaviour of Group A and B: an example of subgroup A1 (Fig. 1b) and B1 (Fig. 1c).

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Impact of environmental, hydraulic and construction parameters on nitrate removal rate and nitrous oxide release of denitrification walls in a subtropical climate

Fabio Manca[1], Daniele De Rosa[1], Lucy Reading[1], David Rowlings[1], Clemens Scheer[1], Peter Grace[1]*

[1] Queensland University of Technology, Institute for Future Environments, Brisbane, Australia.
**Corresponding email: f.manca@qut.edu.au*

ABSTRACT

In agricultural systems, nitrogen (N) in excess of plant and animal needs can leach to shallow groundwater (Schipper et al., 2010), generating environmental pollution. Excess N inputs can also be lost into the environment as gaseous emissions, contributing to anthropic climate change via nitrous oxide (N_2O) emissions (Rowlings et al., 2016). Emissions of N_2O hold a warming potential 298 times higher than carbon dioxide (Myhre et al., 2013), and are responsible for the depletion of stratospheric ozone.

The Great Barrier Reef (GBR) adjacent to the Queensland coast receives increasing harmful nutrient loads including nitrate (NO_3^-; Devlin and Brodie, 2005) which have been linked to the dramatic growth of corallivores. The GBR has also been subject to coral bleaching as a response to elevated sea surface temperatures (Baker et al., 2008) and is a direct consequence of greenhouse gas (GHG) emissions induced by global warming.

Bioreactors are a low-cost technology for NO_3^- remediation using heterotrophic denitrification to progressively reduce NO_3^- to dinitrogen (N_2) with N_2O as an intermediary. The process is performed by microbes that use organic carbon (OC) as an electron donor to perform their respiration under anaerobic or anoxic conditions.

Bioreactors include denitrification walls, which are carbon media-filled permeable trenches able to intercept NO_3^- polluted groundwater and catalyse denitrification. They can provide relatively complete NO_3^- removal and potentially act as N_2O sinks (Elgood et al., 2010).

This study addresses the scientific question: How effective is this low-cost technology in Australia's subtropical conditions in terms of reducing N loads to the GBR whilst reducing N_2O emissions?

The hypothesis is that in subtropical environments, bioreactors can be optimised to ensure complete denitrification occurs with minimal production of N_2O.

This study investigated the impact of construction materials (OC source), environmental (NO_3^- flux and temperature) and internal parameters (hydraulic residence time, saturation, and chemo-physical parameters) on NO_3^- removal in bioreactors in subtropical Australia, and to quantify N_2O released in the bioreactor using field trials.

Keywords: bioreactor, denitrification wall, groundwater mitigation, nitrate, nitrous oxide, Australia.

METHODS

Twin denitrification walls filled with different woodchips (softwood and hardwood, Fig. 1) were installed on a pineapple farm located 70 km North of Brisbane (Queensland, Australia). The area is characterized by a sandy soil underlaid by a shallow impeding clay layer, which forces the groundwater to flow through the denitrification walls. The water table height in the bioreactors was monitored using a dipmeter and using pressure transducers for hourly monitoring.

Water samples were collected using a pump, stored in PET bottles and analysed photometrically to evaluate NO_3^- concentrations and using a combustion catalytic oxidation to quantify dissolved OC. Chemo-physical parameters were collected in the field with portable instruments.

The quantification of the dissolved N_2O accumulated in water was performed collecting water samples with a syringe and storing them in pre-evacuated exetainers to determine the dissolved N_2O fraction, using gas chromatographic techniques. The hydraulic characteristics of the bioreactors were tested using natural gradient saline tracing tests.

The study was funded by the Queensland Government Office of the Great Barrier Reef in collaboration with the Queensland Department of Agriculture and Fisheries.

RESULTS

Significant NO_3^- removal rates were observed under subtropical conditions using different OC substrates. Both the woodchips supported full removal of NO_3^- from the denitrification walls and a reduction in N_2O emissions, with low or negligible concentrations detected in the groundwater flowing through the denitrification walls.

CONCLUSIONS

This is the first study on bioreactor performance in in humid subtropical conditions. The results of this study will provide the Queensland Government with a technical tool to improve a cost-limited technology able to maximize NO_3^- removal in groundwater whilst reducing N_2O emissions.

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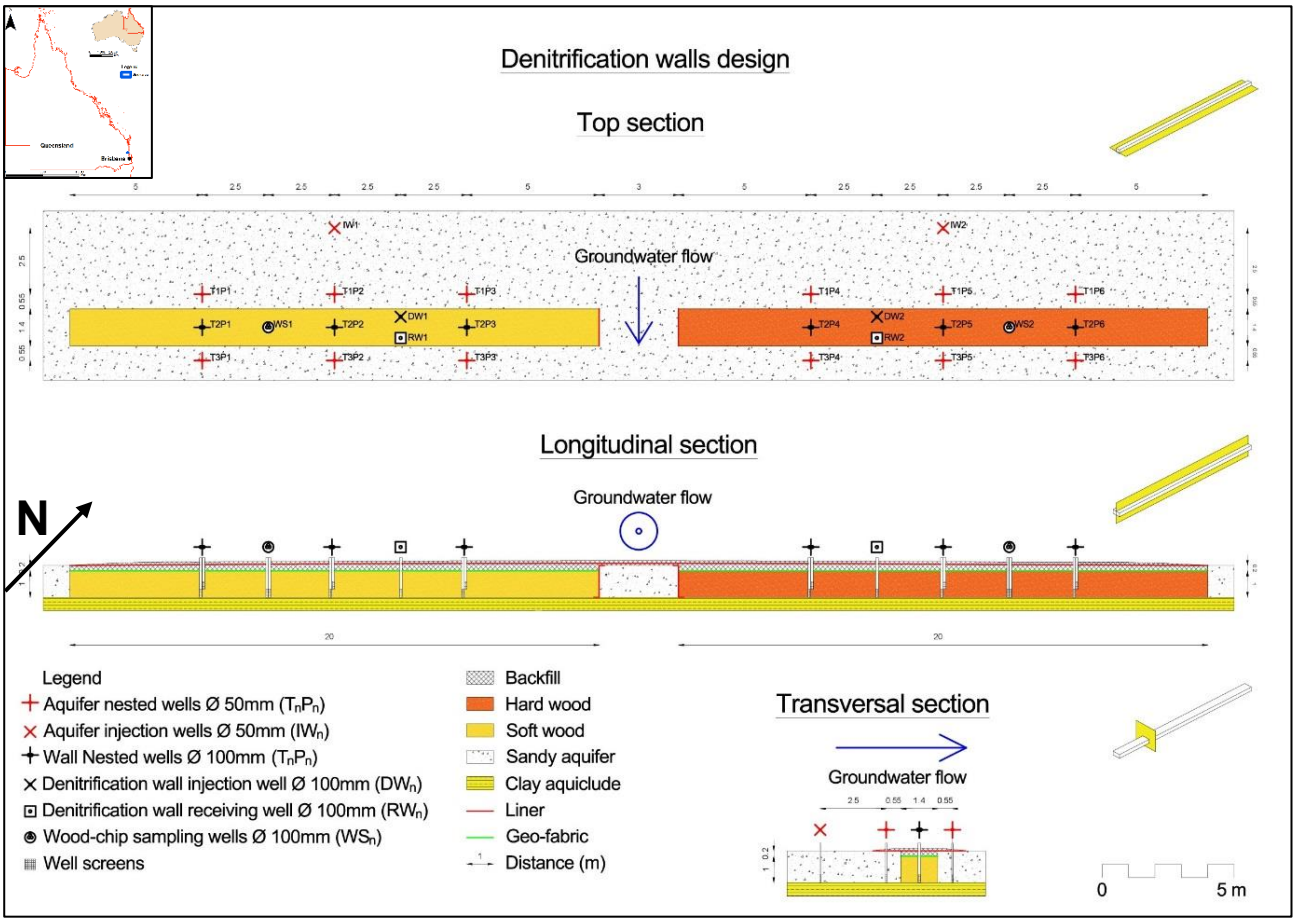

Fig. 1 - The two twin denitrification walls installed on the pineapple farm located 70 Km North of Brisbane.

Methods for the analysis of piezometric level evolution in time as response of climate change: current trends and resource status in Piedmont plain (NW Italy)

Susanna Mancini[1], Manuela Lasagna[1], Domenico Antonio De Luca[1]*

[1] Università di Torino, Dipartimento di Scienze della Terra, Torino, Italy.
**Corresponding email: manuela.lasagna@unito.it*

ABSTRACT

Monitoring and analysis of piezometric levels is one of the tools for identifying possible alterations in the quantitative status and highlighting the response of groundwater to climate change.
Different methods are available to analyse the piezometric level evolution in time. In this study four methods were considered and compared. The methods were applied to the shallow aquifer of Piedmont plain (western Po Plain, NW Italy).

Keywords: piezometric level, trend, change points, groundwater depletion

METHODS

Four methods were applied, and specifically: a) trend analysis, b) change point analysis, c) percentiles method and d) analysis of anomalies.
Trend analysis was performed applying the non-parametric Mann-Kendall test to piezometric series in the period 2002-2017. The change point analysis was conducted using the Pettitt test, to determine changes in groundwater level time series. The percentiles method considers 25th and 75th percentile of the mean monthly piezometric levels of the reference period 2002-2015 (defined as natural fluctuation). The monthly piezometric level of 2016 and 2017 were then compared to the natural fluctuation and a piezometric level decline over than 15-30% of the fluctuation was considered as a critical situation (ISPRA, 2013).
The analysis of anomalies evaluated the difference between the mean yearly piezometric levels and the value in the reference period 2002-2015.
Daily pluviometric series were also studied, covering the same time period, and monthly aggregated data were then elaborated with the same methods as for piezometric levels.
These methods were applied using 37 piezometric series recorded in 2002-2017 and referred to piezometers of the automatic monitoring network of shallow aquifer, homogeneously distributed in Piedmont plain.

RESULTS

Trend analysis highlighted the presence in the period 2002-2017 of an upward trend in 9 piezometers (variation between 1.5 cm/year to 14.6 cm/year) and a downward trend in 8 piezometers (0.4 cm/year to 11.0 cm/year). The others 20 showed no trend. Rainfall generally showed no trend.

The change point analysis permitted to observe a main change point in 2008 both in piezometric series and in pluviometric series. Moreover, piezometric level showed two minor change points in 2004-2005 and 2015. Generally, a decreasing trend in piezometric levels was detected between 2002 and 2008, a further decreasing trend (less negative) in the period 2008-2017.
The percentiles method highlighted that generally a situation of groundwater depletion in both 2016 and 2017 is present. The analysis of anomalies confirmed the results of percentiles. The maximum groundwater table lowering is above 4 m. An example of the results for a piezometer located in the southern Piedmont plain in reported in Fig. 1.

CONCLUSIONS

The analysis of groundwater resource status permitted to identify the advantages-disadvantages of the four different used methods.
The analysis of trends is highly dependent on the analysed periods. Thus, it is essential to evaluate the change points in the piezometric levels series, and to evaluate the trends in different time intervals. Method of percentiles shows intuitive diagrams but does not return the magnitude of groundwater depletion. The evaluation of anomalies, instead, makes more evident the extent of the lowering. Finally, the combined use of the four methods permits to reach a better understanding of the analysed phenomena.

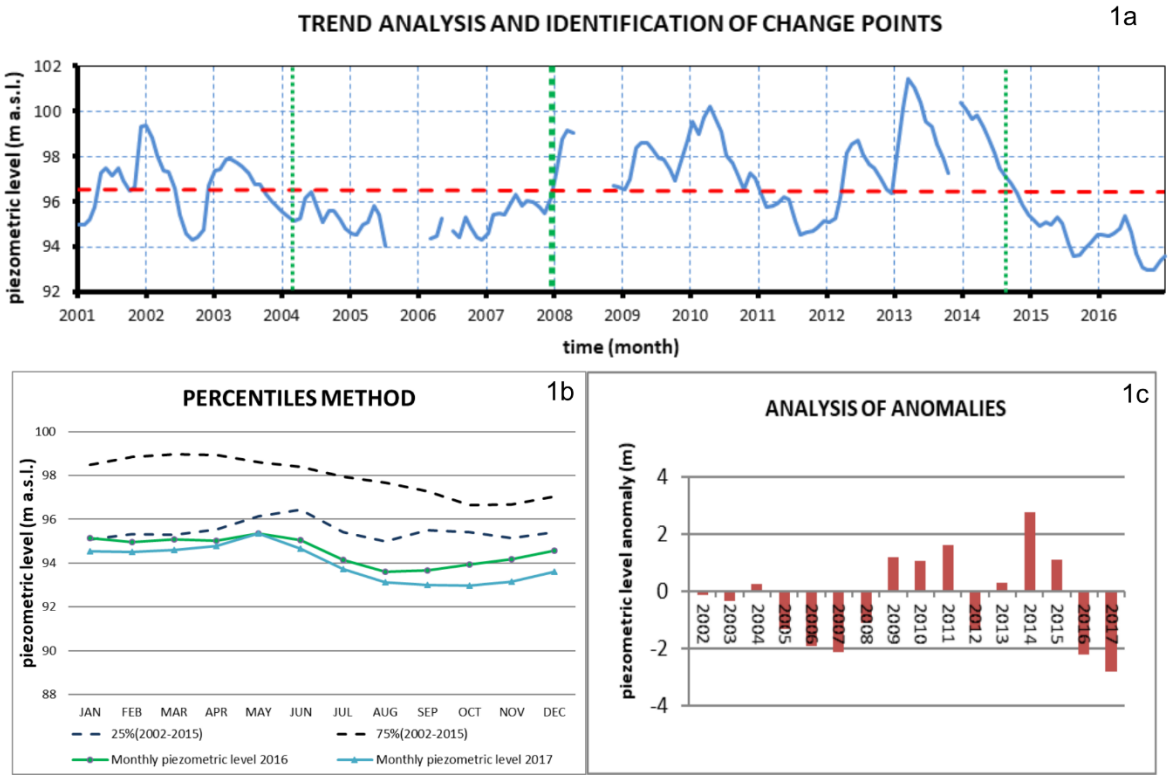

Fig. 1 - Example of the results in a piezometer of the southern Piedmont plain. Trend analysis and change points analyses (1a): the red line represents the trend line (in this situation there is no trend), green lines are located in correspondence of change points; percentiles methods with natural fluctuation range of piezometric level (delimited by the two dotted lines) and monthly piezometric level of 2016 and 2017 (1b); analysis of anomalies: the red histograms represent the difference between the mean yearly piezometric level and the reference period 2002-2015.

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Stochastic analysis of hydraulic head's series for optimizing monitoring networks: application to the Bacchiglione Basin

Mara Meggiorin[1,2], Giulia Passadore[1], Silvia Bertoldo[2], Andrea Sottani[2], Andrea Rinaldo[1,3]*

[1] *Università di Padova, Dipartimento di Ingegneria Civile, Edile e Ambientale, Padova, Italy.*
**Corresponding email: mara.meggiorin@dicea.unipd.it*

[2] *Sinergeo S.r.l., Vicenza, Italy*

[3] *École Polytechnique Fédérale de Lausanne, Laboratory of Echohydrology (ECHO/IIE/ENAC), Lausanne, Switzerland*

ABSTRACT

In the presence of a monitoring network of sensors aimed at measuring the hydraulic head in a given domain, the statistical analysis of time series not only provides insight into the general aquifer behaviour, but can also return parameters useful to optimize and enhance the efficiency of the measurement network. Specifically, these parameters are the correlation scales of relevant heterogenous properties; and the Pearson correlation coefficient. The analysis is carried out for the case study of acquired data within the alluvial basin of the Bacchiglione river (Veneto Region).

Keywords: monitoring network, hydraulic head, groundwater, Bacchiglione Basin

METHODS

Firstly, the study selects suitable series using two or more years of data, with few missing values, hence creating a plausible interpolation and checking their stationarity in variance. Then, it evaluates the microscale showing the time interval in which data are perfectly correlated. This parameter can be estimated in different ways; thus, a scale range is defined. Finally, the analysis carries out an evaluation of the correlation between detrended series. Specifically, it considers two sequences as correlated if their Pearson correlation coefficient (Isaaks and Srivastava, 1989) is higher than 0.95. Based on this threshold, areas of intercorrelated couples are defined. The Kolmogorov-Smirnov test enforces the similarity between correlated series looking at their probability distributions, identifying couples considered as samples of the same distribution (Young, 1977).

RESULTS

In the Bacchiglione Basin, the study analysed time series of 92 groundwater data-loggers, installed in wells screening the unconfined aquifer. After checking series length, interpolation of missing values and stationarity in variance, we evaluated the local mean microscale for 43 sensors. The parameter ranges between 7 and 78 days, depending on the location. A pattern seems to emerge in the scale: high values are frequent in deepest points near to a paleochannel and low values are instead more frequent in points near to a river. Due to a fast interconnection with surface waters, the river causes fast variations on the piezometric surface entailing a relatively short period in which groundwater level data are correlated.

To assess the correlation between sensors, 73 time series with minimum two years of data and with not-interpolated missing values are investigated. We found many intercorrelated couples, defining 8 areas in which time series are correlated. Next, the Kolmogorov-Smirnov tested these pairs and the test fails to reject the null hypothesis of equal distribution for 6 couples, with a confidence level of 99.999%.

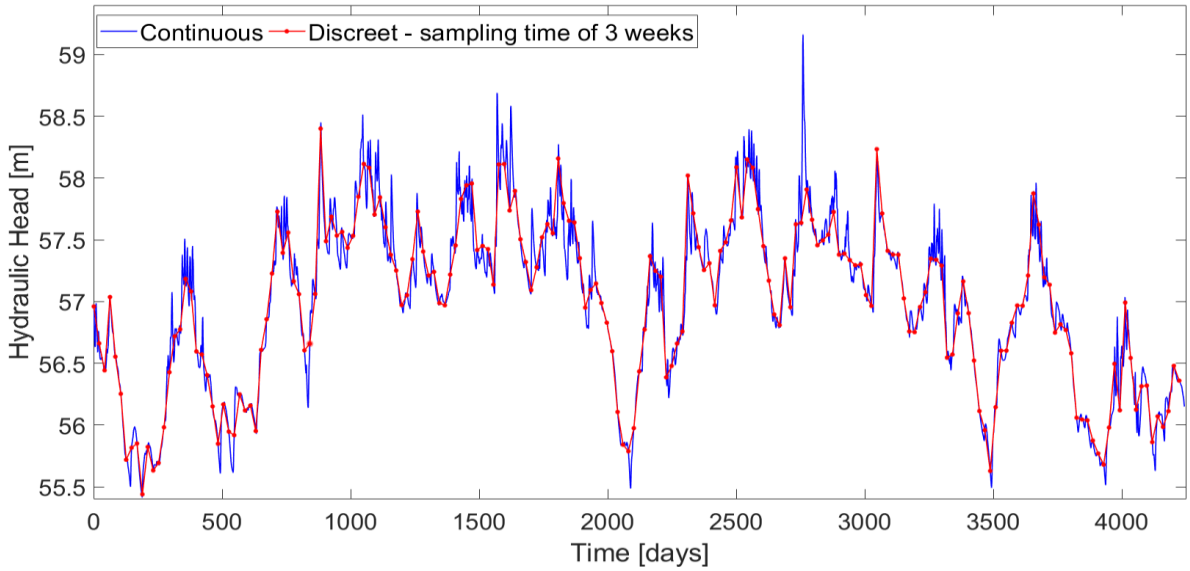

Fig. 1 - Comparison of the continuous monitoring versus the discreet series with a sampling time defined by the microscale parameter

CONCLUSIONS

This analytical procedure is particularly interesting in cases where a considerable number of sensors, continuously measuring the hydraulic head in several locations, are available. The oscillations correlation produces a map of correlated areas which are characterized by similar behaviour: the automatic monitoring is necessary only for one location in each area and other interesting correlated points can be measured manually with longer sampling time to correctly transpose series in the specific location. Therefore, extra sensors can be moved to uncovered areas, in order to improve the system knowledge. Hence, this analysis allows for the optimization of an existing network built following other purposes and not initially structured to serve as a large-scale monitoring system.

The microscale estimation is useful when it is necessary to interpret local piezometric trends, but observation points are without any sensor. Indeed, the parameter estimates the necessary sampling time for manual measures in order to see the water table trend, even if shorter oscillations are obviously missed and some peaks could remain unseen. Figure 1 shows an example of discreet series obtained by measuring the hydraulic head with a sampling time defined as the maximum evaluated microscale value. This parameter can be estimated in the specific location if a past time series is available, alternatively the parameter can be evaluated in an equipped observation point nearby in cases where there are not significant changes of hydrogeological setting.

The proposed statistical analysis of hydrogeological data provides integrative decision support to improve representativeness and effectiveness of monitoring networks used for the qualitative and quantitative groundwater control.

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Stochastic analysis of temperatures' time series for characterizing a fluvial work efficiency on a regional Managed Aquifer Recharge pilot site

Mara Meggiorin[1,2], Giulia Passadore[1], Silvia Bertoldo[2], Andrea Sottani[2], Andrea Rinaldo[1,3]*

[1] *Università di Padova, Dipartimento di Ingegneria Civile, Edile e Ambientale, Padova, Italy.*
**Corresponding email: mara.meggiorin@dicea.unipd.it*

[2] *Sinergeo S.r.l., Vicenza, Italy*

[3] *École Polytechnique Fédérale de Lausanne, Laboratory of Echohydrology (ECHO/IIE/ENAC), Lausanne, Switzerland*

ABSTRACT

In order to understand river-groundwater connections, this work applies a stochastic analysis to study water temperatures' time series. The aim is to compare their trends to verify how they influence each other in stream seepage pathways. Specifically, the goal is to assess whether a fluvial work built in the Brenta river to increase the aquifer recharge is working properly. The series available are obtained by a water gauge placed directly on the river (WGR), two piezometers on the banks (Pz1 and Pz2) and one piezometer relatively far away to portray the regional groundwater thermal trends (PzA).

Keywords: river-groundwater connection, temperature, stochastic analysis, Brenta river

METHODS

Temperature is used as natural tracer: it is easy to measure and therefore a continuous monitoring is possible (Stonestrom and Constantz, 2003).

A stochastic analysis of temperature series is carried out. Firstly, the Fourier analysis moves time series into the frequency-domain to have more insight into the phenomenon (Bras and Rodriguez-Iturbe, 1994). Indeed, power spectra point out local periodicities that depend on the main flow input. Secondly, the auto-correlation function, defined as the Pearson coefficient (Isaaks and Srivastava, 1989), gives insight on the persistence and periodicity of the signal. Lastly, the analysis evaluates the correlation between series. In particular, the coefficient is not defined for whole series but for a movable window of two years, this way the time-variant cross-correlation is observable.

RESULTS

A shorter time series for the WGR is available but, noticing that the available data is similar to one of Pz2 except for daily oscillations, its missing values prior to the gauge installation are assumed equal to ones of Pz2. The trend of PzA is more stable than the river's one. Looking at series of Pz1, three phases are identified: before, just after and five years after the work construction.

Power spectra show similar shape for WGR and Pz2 for all phases in both periodicities' identification and in energy magnitude, while PzA is always different. Pz1 shows different spectra depending on the phase: first, it has intermediate peaks and energy magnitude; then its spectrum resembles the one of WGR with lower energy; finally, observations are like ones of the first period.

Autocorrelation functions are defined for each series and in each phase. In the first period, functions do not significantly differ due to the short time interval. On the contrary, functions of the second period clearly show two different behaviours: WGR and piezometers nearby exhibit a periodic signal while PzA exhibits strong persistence but not periodicity. In the third phase, WGR and Pz2 still show similar periodic signal and PzA shows the persistent signal, while Pz1 has a function much closer to the regional aquifer behaviour but with a weak periodicity.
The final analysis is the cross-correlation of time series that identifies similar behaviours in order to understand if piezometers are influenced more by the river or by the groundwater flow. This result is reported in Figure 1. The correlation function Pz2-WGR is always high with a minimum of 0.8 in the final phase, while it is always low correlated with PzA. Looking at the correlation between Pz1 and WGR, it is high just after the construction (2nd phase), but in the first and third phase it is lower.

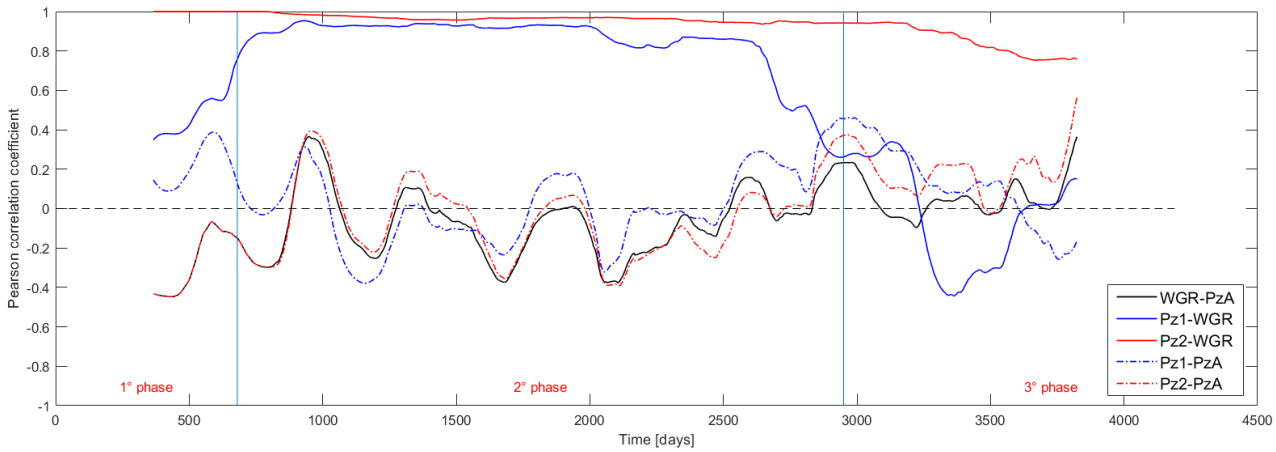

Fig. 1 - Functions of cross-correlation between series of water temperature

CONCLUSIONS

The stochastic analysis of temperature's time series returned uniform results that point to similar conclusions. Prior to the fluvial work's construction, Pz2 shows behaviours and thermal oscillations typical of superficial waters confirming the natural river recharge. On the contrary, Pz1 behaviour differs: its temperature barely oscillates due to its farthest position respect to the main river channel. After the construction, the wet area just before the MAR work increases and the recharge to the aquifer raises too; indeed, both piezometers reproduce the river trend. In the last phase, Pz1 is less influenced by the river. Two concurrent phenomena may explain these results: the river is slowly going back to a narrow main channel that is closer to Pz2 than Pz1; at the same time, there could be some clogging phenomena (Hutchinson et al., 2013). This clogging would cause a permeability reduction of the riverbed due to the porosity obstruction by fine material.

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Hydrogeological conceptual model of loess deposits: a case study from eastern Croatia

Marco Pola[1], Ivica Pavičić[2], Staša Borović[1], Teuta Vranješ[2], Lidija Galović[3], Lara Wacha[3], Vedran Rubinić[4], Kosta Urumović[1]*

[1] *Croatian Geological Survey, Department of Hydrogeology and Engineering Geology, Zagreb, Croatia.*
**Corresponding email: mpola@hgi-cgs.hr*

[2] *University of Zagreb, Faculty of Mining Geology and Oil Engineering, Zagreb, Croatia*

[3] *Croatian Geological Survey, Department of Geology, Zagreb, Croatia*

[4] *University of Zagreb, Faculty of Agriculture, Zagreb, Croatia*

ABSTRACT

Loess is a predominantly silt-sized continental aeolian sediment covering 10% of the Earth's land surface. Groundwater generally represents the most important source of potable water in loess areas, where loess is the aquitard overlying aquifers. Despite its importance in aquifer protection, its hydrogeological properties are partially investigated. This work reviews the well-established depositional and post-depositional processes affecting this deposit to elucidate its hydrogeological behaviour. The result is beneficial to propose a hydrogeological conceptual model of aquitard-aquifer systems in loess areas.

Keywords: loess, conceptual modelling, eastern Croatia

METHODS

Pleistocene loess deposits crop out in eastern Croatia where they represent the layer separating aquifers, exploited for water supply and agricultural purposes, from the surface. Tectonic uplifting and river erosion expose loess in several representative sections investigated using sedimentological, mineralogical, geochemical and geochronological approaches (e.g., Galović, 2016; Wacha et al., 2013). Conversely, the hydrogeological setting of these deposits is not established. Similarly, the underlying sandy aquifers were investigated by local studies, but their results have never been put in a regional context. First, available sedimentological data extended by new investigations and complemented by literature reviews (e.g., Barta, 2011; Smalley et al., 2016) were used to evaluate the impact of the depositional and post-depositional processes on the hydrogeological behaviour of loess. Afterwards, three regional scale areas in eastern Croatia were selected (Fig. 1a). The available geological and hydrogeological data were collected to reconstruct their hydrogeological settings.

RESULTS

Loess in the representative sections contains 80-90% silt-sized particles and small amounts of clay. The original sediments, which were formed by glacial grinding of bedrock in Alpine region, were transported by fluvial systems towards periglacial areas, deposited on alluvial plains and subsequently remobilized by wind. The windblown silts were redeposited either on land or in lakes and wetlands

forming loess or loess-like deposits (Fig. 1a), respectively. During interglacial periods, pedogenesis could occur. Several organisms lived in both the soil and the underlying original deposit producing different types of discontinuities. Vertical or subvertical root channels are common (Fig. 1b) and, if they are not filled by clayey material, they can represent a preferential path for the water flow even through well-developed palaeosoils. The deposition of secondary carbonates and iron minerals (Fig. 1c) at the border of these channels testifies to the occurrence of flowing water corroborating their impact. Loading by newly deposited sediments and concomitant wetting result in the compaction and contraction of the previously deposited loess. Polygonal cracks produced by the hydroconsolidation (Fig. 1d) or fissures related to neotectonic deformation are typical post-depositional features in loess constituing preferential flow paths as well. Furthermore, compaction produces a decrease of the void ratio affecting the porosity of the deposit. Studies about ideal packing suggest that the void ratio usually decreases from 1 to 0.6 in loess. The resulting theoretical total porosity is 37%, a value that approaches the lower limit of loess porosity range reported in literature (42-55%; Li and Quian, 2018). However, calculations based on a few grain size distributions of eastern Croatian loess deposits and their mean referential grain sizes point to a low effective porosity from 5 to 9%.

CONCLUSIONS

These are the first results of a recently started research investigating the hydrogeological characteristics of loess deposits in Croatia. The proposed hydrogeological conceptual model suggests that loess is a partial aquitard characterized by low effective porosity. This points to its generally low permeability. However, several depositional and post-depositional processes can produce mm to cm scale voids increasing its value at the macroscale. The reinterpretation of stratigraphic logs in the three study areas is still ongoing. The obtained results will allow to establish the horizontal and vertical contacts among recent alluvial sediments, loess and water-bearing sandy layers and to reconstruct their hydrogeological settings. The reconstructions will be populated with multi-scale porosity and permeability measurements of loess and sandy layers investigating the scale dependency of these properties to achieve a representative multiscale hydrogeological conceptual model of loess-sand aquitard-aquifer systems.

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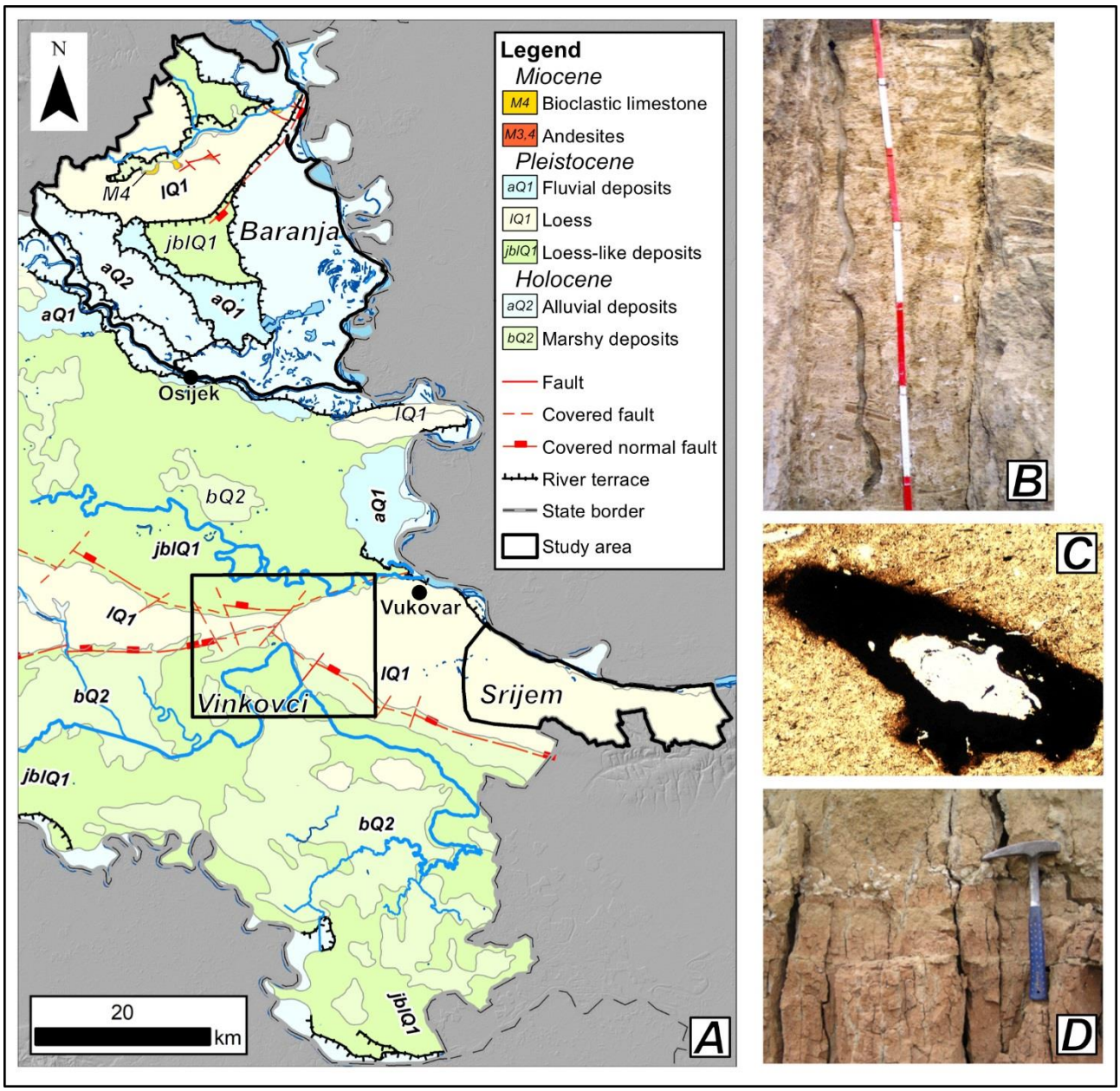

Fig. 1 - (A) Geological map of eastern Croatia. (B) Root channel in loess-paleosol sequence. (C) Hypocoating deposited in a root channel. (D) Vertical cracks due to hydroconsolidation of loess.

Multi-Technique groundwater flow system analysis and dating of a deep aquifer in Alessandria Basin (Piedmont)

Nicola Quaranta[1], Elena Cogo[1], Adriano Simoni[2], Elisa Sacchi[3], Mariachiara Caschetto[4], Massimo Marchesi[4]*

[1] *GEO engineering S.r.l., Torino, Italy. *Corresponding email: quaranta@geoengineering.torino.it*

[2] *EGATO6, Alessandria, Italy*

[3] *Università di Pavia, Italy*

[4] *Isotope Tracer Technologies Europe S.r.l., Milano, Italy*

ABSTRACT

The aim of the study was to set up a protection system from pollution of the deep aquifer of the Alessandria basin, by redefining the recharge areas, focused on this portion of Piedmont territory, and therefore by creating some reserve areas of deep groundwater, to be preserved for future human drinking purposes.

Keywords: groundwater system, groundwater model, stable and radioactive isotopes

METHODS

In addition to the classical hydrodynamic and geochemical monitoring techniques, the groundwaters were analyzed with reference to a monitoring network of 25 selected wells with deep screens (80-300 m below ground surface) combining radiochemical dating (^{14}C and $\delta^{13}C$ of dissolved inorganic carbon - DIC) with anthropogenic tracers (CFCs, SF_6) as indicators of recent recharge/mixing (IAEA, 2006; Busenberg and Plummer, 2000).

Stable isotope composition ($\delta^{2}H$ and $\delta^{18}O - H_2O$) was assessed during a 1-year sampling of snow-rain precipitations gauges distributed in altitude in order to define Local Meteoric Water Lines (Giustini et al., 2016); the isotopic composition was also seasonally measured for the main rivers and in selected deep-wells (adding in some of these $\delta^{37}Cl$ and $^{87}Sr/^{86}Sr$ determinations).

Areal distribution of stable isotopic composition in deep aquifer reflected alpine-type or appenninic basin recharge patterns (Marini et al., 2000). As a consequence, considering the seasonal fluctuations in stable isotopic composition, the degree of confinement and need for protection was defined.

The 3D numerical model was implemented in FEflow platform and calibrated on the basis of the available monitoring data; it was used as a support tool in the delimitation of the recharge areas, starting from the analysis of the distribution of flows (areas with descending flow component > 2 m/d); the "regional" mesh has been strongly refined nearby the "target zone", such as "reserve areas". This model was crucial for delimiting the "reserve areas", since it was able to simulate groundwater flows using both purely advective transport conditions (particle tracking technique), and more realistic conditions of advective and dispersive transport, by introducing dispersive parameters and using the Life Time Expectancy (LTE) reservoir distribution (Cornaton and Perrochet, 2011).

RESULTS

As a result, it was possible to assess the degree of confinement and the protection need of deep aquifers. Groundwater dating also permitted to differentiate the circuits in the investigated hydrogeological system, identifying waters of the Holocene-current age, near the recharge areas, and of the middle Pleistocene (Wurm) in the depocentral area of the basin.
The recharge areas (394 km^2) were outlined by stratigraphic and hydrodynamic evaluations (vertical hydraulic gradient), through the support of a mathematical flow model; the "reserve areas" (10.8 km^2) were referred to a zone surrounding the future pumping stations, with LTE until 25 years (designed for extraction-rate of 0.7 m^3/s, corresponding to 80% of water requirement in the ATO-6 Alessandria District).

CONCLUSIONS

The integrated use of "traditional" techniques of regional groundwater flow system monitoring (hydrochemistry, stable isotopic composition) and of dating techniques based on radioactive isotopes and anthropogenic tracers, provided a reliable support to the validation of flow and transport simulation model, oriented to identify recharge areas and "reserve areas" of future extraction of deep groundwater for drinking purpose.

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Hydrological behaviour of a complex landslide: a case study in the Northern Apennines (Italy)

Melinda Raimondo[1], Alessandro Chelli[1], Fulvio Celico[1], Emma Petrella[1]*

[1] Università di Parma, Dipartimento di Scienze Chimiche, della Vita e della Sostenibilità Ambientale, Parma, Italy.
**Corresponding email: melinda.raimondo@studenti.unipr.it*

ABSTRACT

The combination of the rainfall regime and the groundwater flow dynamics can play an important role in reactivating landslide movements. Therefore, the aim of this research is to define a specific monitoring system in order to investigate the hydrogeological behaviour of a low-permeability heterogeneous medium in a complex landslide, located in the northern Apennines. Case Pennetta active landslide, caused by roto-translational slides and complex active earth slides-earth flows, mainly involves sandstones and claystones (Scabiazza Sandstones, Ligurian Unit; Quagliarini et al., 2017). Two multilevel groundwater-monitoring systems (cluster type), the monitoring of different springs and artificial drains in landslide coupled with rainfall data, allowed to characterise groundwater flow dynamics in the landslide mass, defining the timing and the amplitude of response of the hydraulic heads to the rainfall events.

Keywords: landslide hydrology, multilevel groundwater-monitoring system, northern Apennines

METHODS

The monitoring plan was based on two multilevel groundwater-monitoring systems. The well cluster A is made of two piezometers, while the well cluster B is made of three piezometers. In each of the them, a pressure transducer with data-logger has been installed to monitor the hydraulic head on an hourly basis for almost two hydrogeological years. The variation of EC in groundwater has been measured in order to analyse possible haloclines, according to several Authors (e.g., Petrella et al., 2009). Temperature and EC logs were performed on a monthly basis with a downhole probe. Measurements were carried out at 1-m-depth intervals. Moreover, discharge and physico-chemical parameters were monitored in several springs and artificial drains.

RESULTS

Based on the data collected it was possible to define a groundwater flow scheme. The two series of well clusters allowed to identify the coexistence of two overlying saturated zones within the studied rock mass. In fact, the upper well cluster shows a different behaviour over time. The piezometer Pz1 recorded a groundwater regime that does not seem to follow the rainfall distribution. Instead, Pz2 recorded rapid changes in groundwater level in agreement with the rainfall, with a delay between the rain events and the rise of the piezometric level of the order of a few hours/days. Actually, the lower well cluster shows variations in groundwater levels congruent with those recorded in Pz2, confirming

the direct and rapid relationship between the shallow aquifer portion and the rainfall. EC logs show a very complex distribution of groundwater salinity over depth and time. A less conductive shallow circuit shows lower values in high flow (less than 1000 µS/cm) and higher ones during the depletion phase (up to 3700 µS/cm), in agreement with the infiltration processes dynamics. A more conductive deep circuit, recorded at the head of the landslide, shows EC values that gradually increase over time (from 2500 up to 4200 µS/cm) and seem to be not influenced by depletion/recharge phases. Springs and artificial drains show values variable from 526 up to 1000 µS/cm, in agreement with a very shallow flowpath.

CONCLUSIONS

This study allowed a better understanding of the hydrogeological behaviour of a low-permeability heterogeneous medium in a complex landslide area. In particular, overlying saturated zones, characterized by different time and amplitude of response to the rainfall regime, occur in this type of mass movements where a slope displacement locally influences the vertical distribution of the hydraulic head. Moreover, high lateral and vertical heterogeneity of the medium causes high variability of the salinity on groundwater. The EC values are in agreement with the results obtain in another landside not far from the case study (Ronchetti et al., 2009). Further interdisciplinary investigations, such as isotopic ($\delta^{18}O$, $\delta^{2}H$ and ^{3}H), chemical and microbiological analyses and soil parameterization, can further refine the groundwater flow and contribute to the knowledge of the hydrogeological roles played in a possible new phase of movement.

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Groundwater Modelling in Support of Water Resources Public Management within the Metropolitan area of Milan

Chiara Righetti[1], Desdemona Oliva[1], Maurizio Gorla[1], Luca Alberti[2], Agata Angela Cristaldi[1]*

[1] Gruppo CAP, Ufficio Progetto PIA e Bonifiche - Direzione Ricerca e Sviluppo, Milano, Italy.
**Corresponding email: chiara.righetti@gruppocap.it*

[2] Politecnico di Milano, Dipartimento di Ingegneria Civile e Ambientale (DICA), Milano, Italy

ABSTRACT

Groundwater resources will play an increasingly strategic role in supplying fresh drinking water in the future. Basin scale groundwater numerical models represent an important tool for an efficient and sustainable water management (Anderson and Woessner, 1992). In this framework, CAP Holding S.p.A. (Gruppo CAP) developed a project to implement this kind of aquifer resources evaluation.
Gruppo CAP is a public company owned by local authorities, managing the integrated water service in around 200 municipalities of Milan Metropolitan area (Northern Italy). Within the Research and Development Sector of CAP, the Geology Department has implemented a basin scale 3D groundwater numerical model to analyse regional flow systems, to simulate water budget components changes, and to optimize groundwater management scenarios.
The study was carried out following the technical-scientific consultancy agreement between CAP Holding S.p.A. and Politecnico of Milan to use a conceptual model of the Metropolitan area shared with Universities and Public Authorities (Lombardy Region).

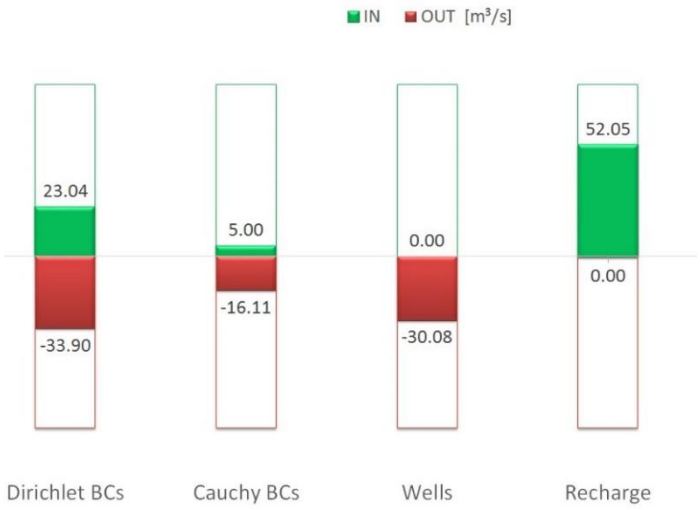
Keywords: groundwater model, drinking water, water management

METHODS

The study was carried out in the area (3000 km^2) between Adda -Ticino in the provinces of Milan and Monza-Brianza. This densely populated area is characterized by exploitation of groundwater resources for domestic, industrial and agricultural uses.
The hydrogeological conceptual model of the area, based on hydrogeological, hydrological, geochemical and isotopic characterization, was developed in GIS. The conceptual model of the area was carried out with the data provided by Politecnico of Milan and approved by Lombardy Region.
Hydrogeology in the area is characterized by the presence of three aquifers (Group Aquifer A, B and C; Regione Lombardia and ENI Divisione Agip, 2002).
The groundwater flow is oriented North-South and it is influenced by the main rivers; the area is characterized by a complex hydrographic network.
A 3D groundwater flow numerical model was implemented by using the finite element code FEFLOW (Diersch, 2014). The steady-state flow model was calibrated to achieve the water mass balance. The calibration includes 337 piezometric level in the three aquifers coming from the groundwater survey data realized by Lombardy Region in May 2014.

RESULTS

The results of the calibrated model pointed out the good accuracy of the model which allowed to simulate groundwater flow of the three main aquifer. The rate budget pointed out the following main results: high recharge contribution; small internal river contribution; wells exploitation is well balanced by recharge (precipitation, irrigation).



Basin scale flow model has been used to support the Aqueduct Sector for the implementation of the Water Safety Plan and to support the Technical Design Sector. The basin flow model has been applied to achieve the following results:

- evaluation of capture zones of public wells and interference between nearby wells considering the quantification of water exploitation within the three aquifers;
- calculation of the flow through the municipalities border within considered area to understand the different contributions coming from local inflow/outflow;
- the backward streamlines from wells was applied to have a preliminary assessment of the potential impact on drinking wells related to the groundwater contamination distribution and to support for water treatment costs/benefits evaluation.

CONCLUSIONS

The Research and Development Sector of Gruppo CAP has implemented a basin scale 3D groundwater numerical model to analyse regional flow systems, to simulate water budget components changes with the aim of optimizing public groundwater management scenarios, including climate change perspective. The study was carried out starting from the conceptual model of the Metropolitan area shared with Politecnico of Milan and Lombardy Region.

The basin scale groundwater model will be the starting point to develop local flow and contaminant transport models to investigate groundwater contamination problems and quantitative management of groundwater resources. Besides to compare different hypothesis of groundwater circulation and

allowing evaluation about groundwater age and origin, GRUPPO CAP promoted in the last four years an extensive isotope characterization of groundwater used for drinking purposes not only in the managed municipalities but has also realized investigations in the other Lombard provinces in collaboration with other Water Authorities. The study was carried out following the technical-scientific consultancy agreement between CAP Holding and Sapienza University (Rome) and Waterloo University (Canada).

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Managed Aquifer Recharge as a solution to cope with water scarcity: the LIFE REWAT Suvereto infiltration basin

Rudy Rossetto[1], Giovanna De Filippis[1], Simone Maria Piacentini[1], Marta Lazzaroni[1], Simone Neri[2], Davide Continanza[2], Mirko Brilli[3], Patrizio Lainà[3], Marco Masi[4], Alessandra Pei[4], Valentina Menonna[4], Federico Lazzaroni[4], Alessandro Fabbrizzi[5]*

[1] *Scuola Superiore S. Anna – Istituto di Scienze per la Vita, Pisa, Italy.*
**Corresponding email: r.rossetto@santannapisa.it*

[2] *West Systems S.r.l., Firenze, Italy*

[3] *ASA S.p.A., Livorno, Firenze*

[4] *Regione Toscana, Firenze, Italy*

[5] *Consorzio di Bonifica 5 Toscana Costa, Campiglia Marittima (LI), Italy*

ABSTRACT

The intentional recharge of aquifers, although being a widespread tool used at global scale for increasing water supply, is not always supported by adequate monitoring systems aiming at guaranteeing safety of recharging operations (Dillon et al. 2019). A pilot Managed Aquifer Recharge (MAR) two-stages infiltration basin for harvesting flood-water from the Cornia River started operations in December 2018 in Suvereto (Italy). The MAR scheme fulfils all of the requirements of the new-issued Italian regulation on artificial recharge of aquifers (DM 100/2016). A central element of the recharge scheme consists in the hi-tech automated and remotely controlled system for operating the plant and monitoring water quantity and quality. The presence of such monitoring infrastructure may improve MAR social perception as an opportunity, moving it from the common view of a threat to the safety of aquifers.

Keywords: managed aquifer recharge, water scarcity, groundwater monitoring

METHODS

The LIFE REWAT Suvereto MAR scheme diverts excess surface water from River Cornia by means of a pumping system first into a settling pond and then into a larger fine sands and gravel basin (less than 1 ha large; Fig. 1). The infiltration basin is located at a pre-existing topographical low near the Cornia River. The river, having intermittent flow, provides the recharge water during high flow periods, including floods, and when discharge is above the minimum ecological flow. The infiltration basin is set in a natural groundwater recharge area. A preliminary project and an executive one were designed and discussed with the relevant authorities, following one-year long monthly monitoring of surface- and ground-water. The project was supported by a groundwater flow modelling-based approach using the FREEWAT platform (www.freewat.eu).

The automated operating system allows diversion from the Cornia River using: i) the data acquired by a level sensor at a Cornia River hydrometer - this to avoid that diversion takes place at flow conditions lower than the minimum ecological flow; ii) the data acquired from a S::CAN Spectrolyser probe providing the spectral signature of the surface water and parameters of interest, such as turbidity, nitrates, TOC, DOC, UV254 and color, so to guarantee that good quality water (on legal basis) is used for recharge. A head sensor in the infiltration basin regulates the basin filling in order to avoid overflow.

The effectiveness and impact of the intentional recharge process on the aquifer is then monitored using: i) a multi-parameter probe placed in a piezometer downstream - whose role is to highlight any negative change in the aquifer system, and ii) a further series of six sensors gathering T, h and EC positioned in piezometers downstream the MAR scheme for recording the variations induced in the aquifer by the recharge process. Thresholds are set and alarm messages are sent to the managing technical staff in order to inform and to allow timely reaction to any inconveniences may be happening. The control unit hosting the database and recording the gathered data may be accessed from everywhere with basically any kind of device. The operational monitoring is complemented by a network of about 30 piezometers/wells where monthly measurements/sampling are performed.

Fig. 1 - View of the inlet point and detention basin, and discharge into the infiltration basin

RESULTS

Depending on the climatic conditions, it is estimated that the volume of diverted surface water may vary between 300000 m^3/year and 1.3 Mm^3/year. Minimal site development and modification was required, resulting in a no-impact water-work, while providing ecosystem benefits by reconnecting and inundating former abandoned riverbeds. The cost of construction of the plant is about 300000 €, well below the cost of a surface water reservoir for a similar storage.

CONCLUSIONS

The effectiveness of such pilot demonstrates the potential for Flood-MAR schemes to increase water availability in scarcity prone areas. The implemented MAR scheme is a classic example of Smart Infrastructure for the management of water resources.

Acknowledgements

This paper is presented within the framework of the LIFE REWAT project (sustainable WATer management in the lower Cornia valley through demand REduction, aquifer Recharge and river REstoration; http://www.liferewat.eu). The LIFE REWAT project received funding from the European Union's Life Programme LIFE 14 ENV/IT/001290.

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Water Management in Limpopo National Park Area

Giuseppe Sappa[1], Maurizio Barbieri[2], Stefania Vitale[2]*

*[1] Università degli Studi di Roma La Sapienza, Dipartimento di Ingegneria Civile, Edile e Ambientale (DICEA), Roma, Italy. *Corresponding email: giuseppe.sappa@uniroma1.it*

[2] Università degli Studi di Roma La Sapienza, Dipartimento di Scienze della Terra, Roma, Italy

ABSTRACT

Limpopo National Park, one of the jewels in the crown of Mozambique's protected areas is the site of interest in the present study carried on the framework of the SECOSUD Phase II, called "Conservation and equitable use of biological diversity in the SADC region (Southern African Development Community), a project supported by the Italian Ministry of Foreign Affairs in the SADC.

The ambitious target of this project profile is to consolidate and to harmonize the management of natural resources, promoting a coordinated use and management of surface and groundwater resources. The growing interest in groundwater use in the SADC region, of which Mozambique is part, is prompted by the fact that surface water resources have been unable to satisfy the water demand required for socio-economic development Furthermore, the increasing demand for water, population growth, and climate change are increasingly putting pressure on groundwater resources in the SADC, stressing the resilience of people living in these developing countries.

Current database management of groundwater data is poorly developed. The real lack of management of groundwater resources is also evident in community water supplies, where in some cases groundwater resources are developed in not sustainable way, generating contamination and overexploitation of aquifers in some areas, and additional water supply problems, such as land subsidence, and the deterioration of groundwater-dependent ecosystems.

The aim of this study is to provide not only an appropriate water and management techniques, but also to develop a better understanding of system aquifer in order to protect it and the ecosystems depending on groundwater quality and quantity.

The starting point of the ongoing study has been to know the current state of the water resources in Limpopo National park buffer zone and how the knowledge of hydrological and hydrogeological characterization can guide and support the conjunctive management of surface and groundwater systems throughout the area of concern in addressing water security and biodiversity conservation.

Keywords: Limpopo National Park, groundwater resources, hydrogeochemistry, water management challenges

METHODS

The Limpopo National Park spreads on a surface of about 11.433,156 km^2 in the Mozambican part of Limpopo River Basin, situated in the East of Southern Africa. where Limpopo Mobile Belt is one of the main geological features (Fig. 1).

The hydrogeology of the basin is dominated by the Limpopo Mobile Belt, a metamorphic zone of high grade, that lies in the collision zone between the KaapVaal craton and the Zimbabwe craton, two Archean continental shield areas.

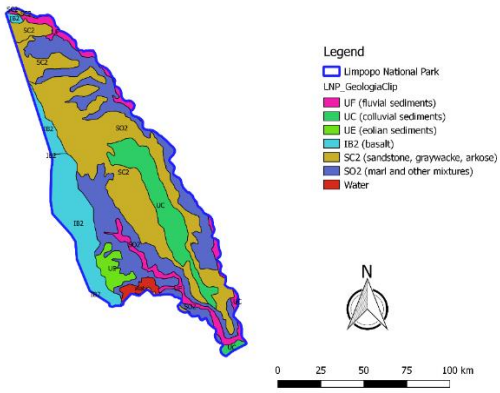

Fig.1 - Simplified geological map of Mozambique and Limpopo National Park

In the aim of better understanding the quantitative and qualitative picture of the water resources, the hydrogeological inverse budget was applied in order to estimate the groundwater recharge meteorological trends referred to Limpopo National Park. At the same time a geochemical characterization of groundwater, was carried on more than 10 points of groundwater exploitation and some riverbanks.

RESULTS

The geochemical assessment pointed out that groundwater presents very high salinity, due to their long staying in the rock masses. On the other hand, results coming from the hydrogeological budget highlighted that in the area under study, most part of precipitations doesn't infiltrate but, due to their hard intensity, runs on the surface and gives its large contribution to the seasonal flooding events, which affect, every year this area.

CONCLUSIONS

Standing on these results, it comes out that infiltration n in this area is very poor, due to high evapotranspiration coupled with the very low permeability of outcropping formations. As a matter of fact, the investigations carried on groundwater wells explored in the buffer zone around the Limpopo National Park looks like confirming this hypothesis.

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Groundwater and surface water quality characterization with positive matrix factorization

Chiara Zanotti[1], Tullia Bonomi[1], Letizia Fumagalli[1], Marco Rotiroti[1], Gennaro Alberto Stefania[1], Sara Taviani[1], Marco Faggioli[1], Valentina Soler[1], Martina Patelli[1], Veronica Nava[1], Davide Sartirana[1], Giulia Stefenelli[2], Francesco Canonaco[2], Andre S.H. Prévôt[2], Barbara Leoni[1]*

[1] *Università degli Studi di Milano-Bicocca, Dipartimento di Scienze dell'Ambiente e della Terra, Milano, Italy. *Corresponding email: c.zanotti@campus.unimib.it*

[2] *Paul Scherrer Institute, Laboratory of Atmospheric Chemistry, Villigen, Switzerland*

ABSTRACT

Groundwater and surface water quality characterization consists in identifying the main hydrochemical features of a system by analysing experimental datasets. This requires proper statistical techniques to be carried out. Multivariate statistical analysis, in particular Factor Analysis (FA), has been widely applied for investigating water quality data. FA presents some limitations: the uncertainty of the data is not considered, and it aims at gathering together positive and negative correlated variables.

In this study Positive Matrix Factorization (PMF) has been investigated as an alternative to FA (Paatero and Tapper, 1994). PMF is a multivariate analysis aimed at source identification and apportionment, specifically designed to cope with environmental data and to manage their uncertainty. PMF has been widely applied in studies concerning air pollution. A few studies demonstrated that PMF can be successfully applied to datasets concerning different environmental matrices (e.g. lake sediments and soil) to reach a more realistic representation of the sources affecting different systems. Here, the effectiveness of PMF as a tool to perform water characterization is investigated, by applying it to water quality data and comparing its results with those obtained with the more widely used FA. The study area is a part of the Oglio River basin after the outflow from Lake Iseo. It is a system characterized by strong relationships between groundwater and surface water bodies strongly impacted by agricultural landuse. This work is a result of the project "Lake, stream and groundwater modelling to manage water quantity and quality in the system of Lake Iseo – Oglio River" supported by Fondazione Cariplo (grant number 2014-1282) carried out between 2015 and 2018.

Keywords: Multivariate statistical analysis, water quality, Positive Matrix Factorization

METHODS

The considered dataset is the result of four field surveys conducted in the study area between 2016 and 2017. In each campaign samples from 68 monitoring points were collected, including 44 wells, 17 rivers (Oglio River and tributaries), 6 springs and the Lake Iseo, for a total of 270 samples. Each

sample was analysed for dissolved oxygen (DO), total phosphorous (P-tot), alkalinity, major ions and trace elements.

FA and PMF were applied to the resulting dataset, and the results were compared by analysing the resulting factor profiles and their spatial distributions.

The PMF algorithm was solved using the Source Finder toolkit (Canonaco et al., 2013) for Igor Pro software package (Wavematrics, Inc.). FA was applied on the same dataset by means of the software IBM SPSS®. Factor profiles resulting from PMF and FA were interpreted considering the conceptual model of the system developed in previous studies (Rotiroti et al., 2019) and the landuse, and the spatial distribution of the contribution of each factor to each sample was represented and interpreted in a GIS environment.

RESULTS

PMF results consist in 5 factors, representing different processes and sources affecting each water sample. Fig. 1 shows the relative contribution of each environmental parameters to each factor, allowing to characterize each factor as a combination of several compounds with certain proportions. The first factor represents highly oxygenated water, with SO_4 and a small content of major ions and it was associated to surface water bodies directly connected with Lake Iseo. Its spatial variability shows high values, other than in surface water samples, also in several wells in the higher plain, even if far from rivers. This could be related to the irrigation processes. The second factor, related to As, Fe, P-tot and NH_4, was associated to the advanced stages of reducing processes determined by the degradation of natural buried organic matter.

The third factor, characterized mainly by Mn and SO_4, was related to the early stages of the reducing process. The fourth factor, characterized by major ions, was linked to water – rock interactions, which lead to higher major ions concentrations especially over longer residence times. The fifth factor is characterized by NO_3, mostly associated with the use of fertilizers. Therefore, it was associated to anthropogenic impact due to agricultural landuse.

Factor analysis output consist in three factors representing each a combination of different PMF factors.

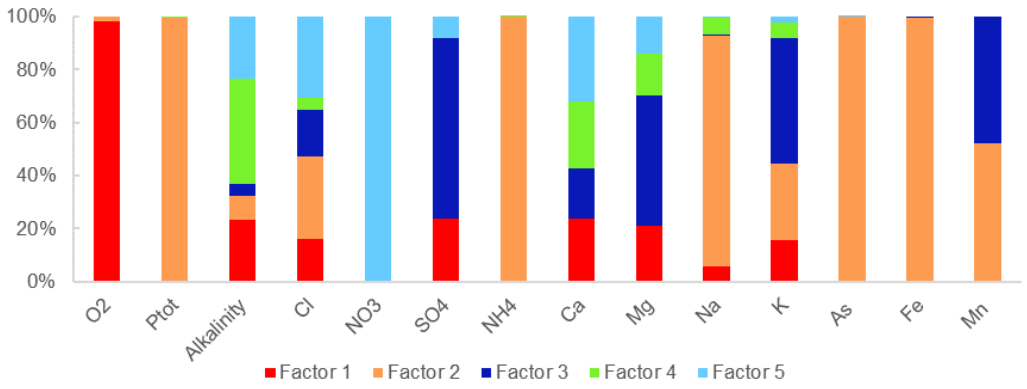

Fig. 1 - Bar chart of the factor profiles of the PMF solution

CONCLUSIONS

PMF allows for a more detailed description of the system, revealing and characterizing more features and processes compared to FA.

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Fractured Rocks and Karstic Systems

Conveners:

Prof. Francesco Fiorillo (Università degli Studi del Sannio)

Dr. Francesca Lotti (Kataclima S.r.l.)

Dr. Livia Emanuela Zuffianò (CNR-IRPI Bari)

Methodological approach for investigation in Karst Hydrogeology

Andreo-Navarro Bartolomè

University of Malaga, Spain

KEYNOTE LECTURE

It is established that karst aquifers constitutes around 12% of Earth surface and their resources are used for water supply 20-25% of world population, which justifies the global relevance of this type of aquifers. They are abundant in Mediterranean countries where their groundwater has been used along the history by all cultures and civilizations.

In spite of the importance and the long history of use by the humanity, the major advances on Karst Hydrogeology occurred after middle 20th century, on the basis of the predominantly geomorphological knowledge acquired in the previous century. The main reason for that was probably the complexity of karst system, its heterogeneity in the distribution of hydraulic properties (porosity and hydraulic conductivity), the different modalities of recharge (autogenic or allogenic; concentrated and diffuse) and the diversity of flow conditions from diffuse flow to conduit flow behavior. This diversity of conditions implies that methodologies of classical hydrogeology can be not directly applied to karst aquifers, and consequently techniques have been adapted or specially developed to investigate karst systems, starting from the always fundamental geological, geomorphological and hydrogeological background.

Hydrodynamic analysis (mainly spring hydrograph) inform about the changes in volume of water recharging and discharging the systems and how rapid these occur, but not about the transit or residence times and processes occurring. These aspects can be inferred from the hydrochemistry, considered as hydrodynamic interpretation of chemical composition of groundwater. Besides, natural hydrochemical tracers as total organic carbon and natural fluorescence of groundwater inform about the role of the epikarst-unsaturated-saturated zones in the functioning of the system. Isotopic data permit to contrast the chemical interpretations, both in terms of residence time (radioactive isotopes) or another concerns of the aquifer behavior (stable isotopes): mixing of waters, altitude of recharge, evaporation, etc.). Hydrothermal response is another useful complementary tool. However, the most effective methodology is dye tracers, which permit to probe the hydraulic connection between surface and groundwater, and to calculate flow velocity.

Each technique contributes to the knowledge of the karst aquifers but the most interesting approach is the integration of data from these different sources, avoiding the uncertainty of using only one. Thus, hydrogeological interpretation became more robust, which constitutes the basis of modeling, both conceptual and particularly mathematical procedures. There is an increasing number of numerical models (distributed, lumped and hybrid) in Karst Hydrogeology with diverse objectives from the integrated analysis of hydrogeological responses to the prediction and management of water resources under the impact of the global climate change. However, in many karst aquifers, the most interesting model is the conceptual one, which is basic for everything.

Hydrogeochemical monitoring of natural waters from Central Apennines, Italy: multiparametric acquisition and processing to identify possible seismic precursors

Marino Domenico Barberio[1], Francesca Banzato[1], Alessandro Lacchini[1], Valentina Marinelli[1], Marco Petitta[1], Chiara Sbarbati[1]*

[1] Università degli Studi di Roma La Sapienza, Dipartimento di Scienze della Terra, Roma, Italy.
**Corresponding email: marinodomenico.barberio@uniroma1.it*

ABSTRACT

Seismic precursors are an as yet unattained frontier in earthquake studies. This study aimed 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. A multiparametric observatory has been established in Central Italy, near the active normal faults of the Sulmona basin. The monitored area has been chosen considering: i) the geodynamic relevance; ii) the maximum release of energy related to normal faults; iii) the seismic hazard related to the Mt. Morrone faults system (Gori et al., 2014); iv) the logistic opportunity of monitoring groundwater related to regional groundwater flowpath affected by deep contribution; v) the existence of a cluster of superficial and deep monitoring wells; and vi) the existence of a robust conceptual model of groundwater flow in the study area. With the aim of making a step towards this frontier, it has presented a hydrogeological and hydrogeochemical dataset associated with the 2016 Amatrice- Norcia seismic sequence (central Apennines, Italy). The intensity of the induced groundwater level changes was correlated with seismic magnitude and distance to epicentres.

Moreover, monitoring a set of selected springs in the Sulmona area (central Apennines), a few hydrogeochemical anomalies were observed months before the onset of the seismic swarm, including a variation of pH values and an increase of As, V, and Fe concentrations. Cr concentrations increased immediately after the onset of the seismic sequence. On November 2016, these elements recovered to their usual low concentrations. Also, Rn concentrations in groundwater were continuously measured in the Giardino Spring, together with groundwater levels in a nearby well installed into a fractured regional aquifer. Data were processed and then analysed to produce the Fourier. These spectra were compared with the spectrum of tidal forces. Results showed that diurnal and semidiurnal cycles of Rn concentrations, and oscillations of groundwater levels with solar and lunisolar components of tidal forces.

Keywords: Groundwater monitoring, Isotope, Geochemistry, Earthquake;

METHODS

Hydrological and hydrogeological monitoring was carried out from July 2014 until the time of writing this work. During this period, the rainfall and temperature data of the Bussi Officine thermo-pluviometric station were collected. Two piezometers have been equipped, through the installation

of multiparameter probes for continuous monitoring of temperature, electrical conductivity and piezometric level.
From the hydrogeochemical point of view, eight spring water were identified and monitored in the area of the Sulmona plain and the Gole di Popoli. Samplings started in November 2014. For each spring the values of temperature, electrical conductivity and pH were measured, and samples were taken for the analysis of the major, minor elements and for the isotopic analysis of H_2O (∂^{18}O-D), SO_4 (∂^{34}S-∂^{18}O), B (∂^{11}B) and Sr (^{87}Sr / ^{86}Sr). Also, in the attempt to identify variations in the deep degassing, it was decided to consider for the monitoring also the Rn and CO_2 concentration, two of the gases that showed higher sensitivity to seismic activity.

RESULTS

In the first analysis, the hydrogeological monitoring allowed to identify the peculiar hydro-sensitive characteristics of the chosen site. The processing of the piezometric data also allowed to identify a strong relationship between the micro-seismicity recorded in the monitored area and the piezometric levels. Geochemical monitoring permitted to recognise characteristic trends in the time series of the various geochemical parameters. The imminent releasing of the seismic sequence of Amatrice-Norcia 2016-2017 has meant that some of these concentration trends diverged from the typical values identified (As, V, Cr, and Fe). Also, co-post-seismic effects, which include increases in piezometric levels, flow and spring discharge, activation of some intermittent spring and deactivation of others, have been identified. Gas monitoring has made it possible to achieve remarkable results concerning the interactions between solid tidal periodicity, gas concentrations and changes in piezometric levels.

CONCLUSIONS

- Hydrogeological and hydrogeochemical monitoring in the central Apennines carried out before and during the seismic sequence of Amatrice-Norcia 2016-2017 has allowed identifying as potential seismic precursors the concentration increases of As and V in the groundwater;
- The regional response of the carbonate aquifers to the significant events of the seismic sequence (Mw> 5.5) highlights for the umpteenth time the sensitivity of the fractured aquifers to the triggering of these events. However, further studies are necessary for a complete understanding of the phenomenon.
- Identify oscillations of the piezometric levels of the regional water table in the Gole di Popoli as a result of the propagation of surface seismic waves induced by strong events (Mw> 7.5) occurred thousands of kilometres away;
- Recognise the mainly diurnal and semi-solar components of the Earth's solid tide in the oscillations of the piezometric levels and the activity of the dissolved Radon in the Giardino spring.

Multidisciplinary geophysical surveys for 3D hydrogeological conceptual model reconstruction in areas contaminated by fluoride in Nakuru area, East African Rift System (Kenya)

Stefano Bernardinetti[1], Chiara Gargiulo[1], Alessio Barbagli[1], Andrea Zirulia[1,2,3], Tommaso Colonna[1,3,4], Enrico Guastaldi[1,3,4], Paolo Conti[1], Lisa Serri[1], Stefano Bonfigli[1], Claudio Zanghirati[1], Luigi Antolini[1], Elias K. Ucakuwun[5], Stefania Da Pelo[2], Roberto Balia[6], Marco Pistis[2], Giorgio Ghiglieri[2]*

[1] *CGT – Centro di GeoTecnologie, Università di Siena, San Giovanni Valdarno (AR), Italy.*
**Corresponding email: bernardinetti@cgt-spinoff.it*

[2] *Università degli Studi di Cagliari, Dipartimento di Scienze Chimiche e Geologiche, Monserrato (CA), Italy*

[3] *Geoexplorer Impresa Sociale S.r.l., Arezzo, Italy*

[4] *CGT SpinOff S.r.l., Arezzo, Italy*

[5] *University of Eldoret, Department of Environmental Earth Sciences, Eldoret, Kenya*

[6] *Università degli Studi di Cagliari, Dipartimento di Ingegneria Civile, Ambientale e Architettura, Cagliari, Italy*

ABSTRACT

An extensive geophysical fieldwork was performed in Nakuru county (Kenya), Autumn 2018, aiming to study the shallow structure of the rift valley, within the framework of FLOWERED activities, an H2020 European Commission project (www.floweredproject.org). The overall objective of the project is to contribute to the development of a sustainable water management system in East African Rift areas affected by natural fluoride contamination.

The investigated area is located in South-western Kenya near Nakuru, in the central part of the Kenya Rift. The area is characterized by a thick volcano-sedimentary succession of Pleistocene-Quaternary age, with volcanic rocks as lavas (phonolites, basalts, and trachytes) and pyroclastic flows and fall deposits (tephra, tuffs and fall deposits), intercalated with alluvial gravel and sands. The geophysical fieldwork was designed to implement a local detailed three-dimensional hydrogeological model of Nakuru area. We performed resistivity surveys at two different scales by using electrical resistivity tomography (ERT) and Hybrid-Source Audio Magnetotelluric (HSAMT), integrated by single station passive seismic measurements (HVSR). Overall, the performed surveys were helpful to delineate: a) depth and thickness of aquifers, b) aquitards or confining units and c) locating preferential fluid migration paths such as fractures and fault zones (Ghiglieri et al., 2017).

Keywords: geophysics, magnetotellurics, geoelectrics, passive seismics, hydrogeology, fluoride contamination

METHODS

To integrate the existing hydrogeological conceptual model, we perform 3 different geophysical methods: ERT and HSAMT for resistivity measurements, HVSR for passive seismic measurements. The surveys were planned taking into account main geological/hydrogeological targets (Ghiglieri et. al., 2017) and logistical constrains, i.e. the technical suitability of survey areas according to geophysical methods applied. Resistivity measurements (i.e. ERT and HSAMT) were located across the rift valley area along three different lines, two sub-orthogonal to the main geological features, oriented North-South, and one oriented North west – South east crossing the entire valley and reaching the reliefs to the eastern part of the rift. HVSR were wide spread across the study site in order to cover as much area as possible. Electrical and electromagnetic techniques are commonly applied in groundwater research due to the correlation between electrical properties, geological features and fluid contents. Electrical resistivity maps obtained using electrical or electromagnetic surveys, are used in hydrogeological studies in order to recognize different water sources based on their salinity differences (see for instance Bauer et al., 2006, or Befus et al., 2012). HVSRs, a method widely used for a quick survey of seismic-amplification effects, were also performed at dozens of locations across the whole study area to achieve information about the spatial variability of superficial deposits thickness.

RESULTS

Due to the geological/geophysical complexity of the site, the best state-of-the art rendering for the geophysical data was used as preliminary results. In such area, the presence of complex water circulation and alteration of minerals make hard the interpretation of resistivity variations. In fact, bulk resistivity is mainly related to ionic conduction and surface conduction in presence of clayey minerals. However, we distinguished few principal geophysical features consistent with geological outcroppings and literature works of the study area. Although the best colour scale of resistivity results differs slightly for each single technique (i.e. ERT and MT), we unified both ranges in order to identify a common colour scale, useful for the comparison and in the interpretation phase. By the integration of geophysical methods, it was possible to obtain valuable information about site-specific conditions within the thickness of the exploited contaminated aquifers. These data allow to refer the hydrogeophysical framework to the different situations affecting wells and the relative concentrations of fluoride.

CONCLUSIONS

The evidence obtained by the integration of the different geophysical approaches have determined some important results: a) the data obtained with the two geophysical techniques show important elements of convergence and allowed to realize models of resistivity with a common interpretation criterion; b) the results obtained with HVSR measurements allowed to spread shallow information provided by ERT and MT, even outside the survey lines; c) the hydrogeophysical reconstruction of the study area allowed to identify local causes of the presence of high fluoride concentrations in groundwater; d) the overall geophysical framework is the starting point for the future integration with geological and hydrogeological information and for the realization of a 3D geological model.

Acknowledgements

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Statistical analysis of the impact of snow melting and rainfall recharge on the discharge and physico-chemical characteristics of the Verde spring (Central Apennines)

Alessandro Chiaudani[1], Diego Di Curzio[1], Sergio Rusi[1]*

[1] Università degli Studi "G. d'Annunzio" di Chieti-Pescara, Dipartimento di Ingegneria e Geologia (InGeo), Chieti, Italy.
**Corresponding email: sergio.rusi@unich.it*

ABSTRACT

The relations between meteorological recharge and hydrodynamic and hydrochemical behavior of the Verde spring, the main discharge of the Majella Carbonate aquifer system (central Apennine), exploited for drinking and hydroelectric purposes, were analysed by statistical techniques.
The results allowed to identify several flow paths, characterized by different sizes, hydraulic conductivities, and distances from the spring, that get activated depending on the type (rain or snowmelt) and the amount of the inflow.

Keywords: groundwater, multiparameter time-series, carbonate aquifer, snow melt

METHODS

In order to get a deeper insight on the Majella system groundwater flow, multiparameter daily time-series were considered, all related to the same time period (1803 days; about 5 years between 1997 and 2002) and collected in different monitoring point all over the Majella aquifer. In detail, the snow cover thickness was measured by means of a graduated scale by the Meteomont State Forestry Authority Service. The rainfall data, collected by automated rain gauges and representative of the overall rain precipitation on the Majella massif, were provided by the Hydrographic Service of Abruzzo Region. The Verde spring discharge data is a sum of two different monitoring (i.e. SASI SpA and Hydrographic Service of Abruzzo Region), performed by automated water level stations with calibrated flow section. In addition, for the Verde spring also the water electrical conductivity and temperature were measured by a physico-chemical multiparameter probe connected with a data logger, located in the spring tapping.
The raw and residual multiparameter time-series were then analyzed by the Autocorrelation Function (ACF) and Cross-Correlation Function (CCF), to investigate how the spring parameters react to the different inflows.

RESULTS

The results obtained by the ACF and the raw and residual CCFs, together with the knowledge of the hydrogeological features of the Majella aquifer (Nanni and Rusi, 2003; Fiorillo et al., 2015), allowed to implement a refined conceptual model. The Autocorrelation analysis showed that the variability of the spring discharge and Electrical conductivity time-series can be accounted by the combined effect of both rainfall (i.e. random component) and snowmelt (i.e. systematic component) recharge.

At first sight, the CCF values between raw input and output datasets describe that the snow cover thickness vs spring parameters relationship are an order of magnitude higher than the ones related to the rainfall-spring parameters relationship. This noticeable gap is attributable to the difference in water volume infiltrating during and after snowmelt and after rainfall events. In fact, the Majella aquifer system recharge is mainly due to the snow cover that accumulates, during the fall-winter period, and then melts, during the spring period. Rainfall events, even intense and widespread, supply little water to the aquifer with respect to the water volumes accumulated in the form of snow, in the recharge areas.

The Raw Rainfall vs Residual Spring Discharge CCFs show clear peaks characterized by response times equal to 5, 13, 22, 35, and 45 days. The CCFs between raw rainfall and residual spring physico-chemical parameters exhibit a similar pattern of the significative negative peaks, but the response times so not always coincide.

The results obtained clearly demonstrated that the snowmelt contribution is predominant with respect to the rainfall one. The travel times in the unsaturated and saturated zones of the water moving toward the Verde spring and the aquifer recharge modes depend on the different inflows (i.e. snowmelt and rainfall), their distribution in the recharge areas, their intensity and distribution in time. In detail, the multiparameter time-series analyses allowed to identify several recharge modes related to different flow paths, that are characterized by different sizes, hydraulic conductivities and distances from the spring, in both the unsaturated and saturated zones.

The level of detail obtained by the multiparameter time-series analyses is high, although below the one provided by tracer tests. In fact, this methodological approach allowed to account for small changes in the spring parameters, such as the electrical conductivity (about ± 15 μS/cm) and temperature (about ± 0.1° C), that are considered meaningless.

CONCLUSIONS

This study demonstrated that the multiparameter hydrodynamic and hydrochemical time-series analyses, related to heterogenous fractured and/or partially karst aquifer systems, can provide more detailed information about the groundwater flow and the recharge modes, without using tracer tests. Although they are more precise and the used tracers non-toxic, their implementation is often difficult because of the logistic conditions and the environmental restrictions, especially when the aquifer systems are wide, and the related groundwater exploited for drinking purposes.

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Nossana Karst Spring behaviour under future Climate Change Scenarios

Andrea Citrini[1], Corrado Camera[1], Giovanni Pietro Beretta[1], Jacopo Terrenghi[2]*

[1] Università degli Studi di Milano, Dipartimento di Scienze della Terra "A. Desio", Milan, Italy.
**Corresponding email: andrea.citrini@unimi.it*

[2] Indipendent geologist, Italy

ABSTRACT

Nossana spring, located in the province of Bergamo, is one of the most important Northern Italy water resources for domestic supply. It sustains a large water distribution system managed by Uniacque S.p.a. The aim of this work is to forecast the behaviour of this spring, and its hydrogeological parameters, under future climate change scenarios (IPCC, 2014).

The study of the response of Nossana spring may give important guidelines to enforce managing tools in case of future severe climatic trends.

Keywords: Nossana spring (Italy), climate change, karst waters, water management, IPCC

METHODS

Nossana spring behaviour of discharge has been simulated using the lumped-parameter model RRAWFLOW (Long and Mahler, 2013; Long, 2015). RRAWFLOW uses daily rainfall and daily minimum and maximum temperature as input to calculate discharge.

Uniacque S.p.a. provided discharge and meteorological data for the period 1998-2018. Thirteen years (1998-2010) were taken as calibration period while the remaining eight years (2011-2018) were used to validate the model. The quality of calibration and validation was assessed through two indices, Nash-Sutcliffe Efficiency (NSE) and Root Mean Squared Error (RMSE), as suggested by Legates and McCabe (1999). For future projections of spring discharge, the meteorological variable timeseries needed as input were derived by statistical downscaling of climate models, performed using change factors and a rainfall-temperature generator (Burton et al., 2010; Richardson, 1981).

Change factors were calculated for five twenty-year intervals, from 2021 to 2100, for a total of 40 different regional climate model runs. These model runs refer to three different Representative Concentration Pathway (RCP) scenarios with increasing severity (2.6; 4.5; 8.5) according to IPCC (2014).

Future simulations of spring discharge are still in course. Eventually, they will allow the preparation of probabilistic scenarios of discharge amounts under each RCP condition. Statistical significance of discharge changes in comparison to observations will be evaluated, too.

RESULTS

RRAWFLOW simulation shows a NSE for calibration and validation of 0.46 and 0.44, respectively. Similarly, RMSE is equal to 2.17 and 2.21. These values indicate a satisfactory parameterization and a certain robustness of the model.

Results suggest that there is a strong correlation between recharge rate -both in cases of more frequent single precipitation event (summer – storm) and less frequent continuous event- and Nossana spring discharge rate. In fact, hydrograph indicates that discharge variation occurs mainly within 1-2 days from the beginning of a rainfall event. This is a typical behaviour of a karst spring in temperate regions .as in the case of Val Seriana.

Climate change projections are still being processed; once available they will be used to simulate projected discharge behaviour.

CONCLUSIONS

To meet public water needs, Nossana spring, which is characterized by a variable discharge from 0.4 to 18.0 m^3/s, must supply 0.5 m^3/s of water; below this warning threshold, the water distribution system needs to resort to other sources, which are usually more expensive and difficult to manage.

Simulations of extreme meteorological conditions are useful for waterworks managers to identify exceptional situations when it is necessary to integrate the water supply (i.e., activating supplementary water wells).

This study demonstrated that lumped – parameter models can lead to good discharge predictions in karst environment. For this reason, if a complete simulation of the processes is not needed, they can be a better option for discharge simulation in karst environments than 3D models, which usually need a large amount of data and longer computational times.

In addition, when completed, this work could be used as an implementing tool to support the policy of the public water company in future climatic change scenarios.

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New hydrological and isotopic surveys on the Poiano karst system

Vincenzo Critelli[1], Manuela Deiana[1], Vladislav Ivanov[2], Massimo Ercolani[3], Alessandra Curotti[4], Mario Mussi[5], Alessandro Corsini[1], Stefano Lugli[1], Monica Papini[2], Laura Longoni[2], Francesco Ronchetti[1]*

*[1] Università degli Studi di Modena e Reggio Emilia, Dipartimento di Scienze Chimiche e Geologiche, Modena, Italy. *Corresponding email: francesco.ronchetti@unimore.it*

[2] Politecnico di Milano, Dipartimento di Ingegneria Civile e Ambientale (DICA), Polo Territoriale di Lecco, Italy

[3] Federazione Speleologica Regionale dell'Emilia-Romagna, Italy

[4] Parco Nazionale Appennino Tosco-Emiliano, Italy

[5] Consiglio Nazionale delle Ricerche, Istituto di Geoscienze e Georisorse (CNR-IGG), Pisa, Italy

ABSTRACT

This paper aims to assess the hydrogeological model for the Poiano karst system by applying hydrologic water balance, in-field discharge measurements and water stable isotope methods. The results obtained downgrade the role of the Lucola River in feeding the Poiano Spring and show that the Secchia River is likely one of the main sources of the karst system.

Keywords: karst, Poiano, water isotope, evaporitic, spring

METHODS

This paper deals with the application of an empirical hydrologic water balance, in-field measurements of river/spring discharge and stable isotope analyses to evaluate the most recent Poiano karst spring hydrogeological model proposed by Chiesi et al. (2010). The Poiano karst system is made up of Triassic gypsum/anhydrite evaporites outcropping in Emilia Romagna (Italy), in the northern part of the Apennine chain, and is bounded by the Lucola, Secchia, Sologno and Ozola rivers. According to the current hydrogeological model, this aquifer is mainly fed by the Lucola River. The Sologno River and meteoric recharge are believed to be secondary sources. This study aims to evaluate the reliability of the model mentioned above. The estimation of the hydrologic budget is based upon the Thornthwaite and Mather (Thornthwaite and Mather, 1955) water balance method, through which the definition of surplus was obtained for each of the rain gauge stations, simulating two (minimum and maximum) soil moisture coefficient scenarios (u = 100 and 0 mm). The surplus term was then transformed into effective infiltration and runoff by multiplying each term by the infiltration coefficient related to each outcropping lithology. The average annual runoff volumes obtained for each watershed were then considered to be the average volume of water outpouring at the basin outlet, while the average annual infiltration rate was considered to be the effective recharge of the karst system. Field discharge measurements were made on the rivers and the Poiano Spring in different months using salt tracers and a propeller flowmeter. The initial results from 46 water stable isotope

analyses (δ ^{18}O, δ ^{2}H) sampled monthly between Aug-2017 and May-2018 from the Poiano Spring, 3 shallow springs (representative of local meteoric recharge, according to Cervi et al. (2016), and 15 river gauges were used as natural tracers to define the recharge shares for the Poiano karst system.

RESULTS

The estimation of runoff for the hydrological year 2017-2018 reveals the following average annual discharges corresponding to each depicted scenario: (2017-2018) Lucola = 359 ÷ 393 [L/s]; Sologno = 344 ÷ 368 [L/s]; Secchia = 6731 ÷ 7167 [L/s].

The same estimation for the effective recharge rates acting over the karst aquifer is as follows: (2017-2018) Surplus = 695 ÷ 798 [mm]; Recharge = 90 ÷ 103 [L/s].

Mean river/spring discharge measurements: (2017-2018) Lucola = 170 [L/s]; Sologno = 80 [L/s]; Poiano = 335 [L/s].

The water balance reported here does not support the current hydrogeological model, since Poiano Spring discharges are always much higher than the estimated discharge rates of the Lucola River, which is not subjected to heavy seepage into the groundwater system. The in-field measurements reported above also are not consistent with the current hydrogeological model, but they highlight that other inflow sources must be considered in order to better depict the karst spring discharge. The preliminary isotope results point out a new highlight with respect to the recognized hydrological model. The δ ^{18}O - δ D analysis reported in Figure 1 shows a scarce isotopic affinity of the Poiano Spring with the Lucola River, a strong isotopic affinity of the Poiano Spring with the Secchia River, and a moderate isotopic affinity among the Sologno River, Ozola River and shallow springs (effective recharge).

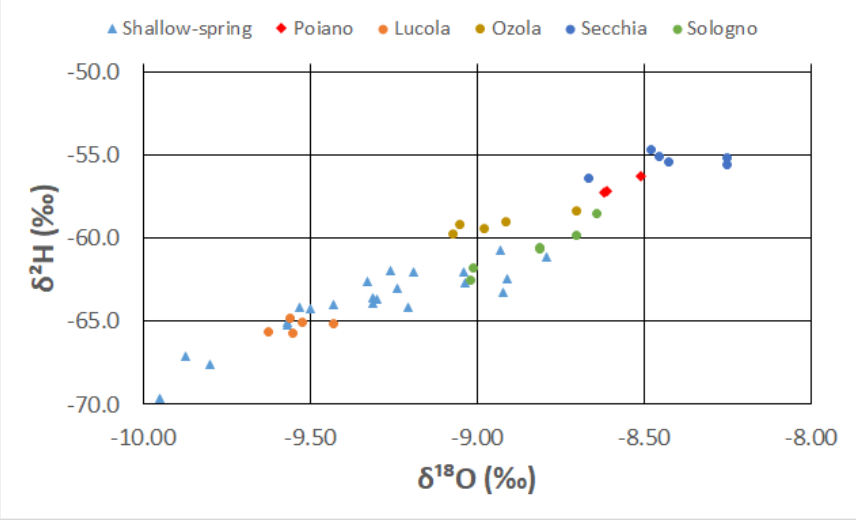

Fig. 1 - Plot δ ^{18}O and δ D analysis results separate by rivers, shallow springs and Poiano karst outlet.

CONCLUSIONS

The preliminary and new results of the empirical hydrological model, in-field spring and river discharge measurements and the water stable isotope analysis of the springs and rivers are not in line

with the most recent hydrogeological model of the Poiano karst spring presented by Chiesi et al. (2010). In particular, the empirical hydrological model and in-field discharge measures highlight that the Lucola and Sologno rivers and the effective recharge cannot justify the Poiano karst spring discharge. The results of the isotopic analysis indicate that the Secchia River must be considered one of the main sources that contributes to the total discharge of the Poiano Spring.

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A simple graphical method to visualize the end-member fractions in a three-component groundwater mixing: the example of Ferrarelle system (Riardo, southern Italy)

Emilio Cuoco[1], Stefano Viaroli[2], Vittorio Paolucci[3], Lucia Mastrorillo[2], Roberto Mazza[2], Dario Tedesco[1]*

[1] *Università degli Studi della Campania, Luigi Vanvitelli, DiSTABiF, Caserta, Italy.*
**Corresponding email: emilio.cuoco@unicampania.it*

[2] *Università degli Studi Roma Tre, Dipartimento di Scienze, Roma, Italy*

[3] *Ferrarelle SpA, Riardo (CE), Italy*

ABSTRACT

The Ferrarelle groundwater system is located in a highly fractured area in the Riardo Plain (southern Italy) at the base of the northern slope of Mt. Maggiore. It is the product of three endmembers mixing: deep mineralized, shallow volcanic and lateral carbonate groundwater. The three-component mixing has been calculated by using V and K which are reliable conservative elements. The mixing fractions calculated through mass balance for each sample are shown in the element-element triangle plot. This graphic method provides similar results obtained by numerical computation obtained by mass balance.

Keywords: three-component mixing, hydrogeochemistry, Ferrarelle Groundwater System

METHODS

The Ferrarelle groundwater system (FGS) is mainly governed by the mixing of waters from i) a deep CO_2 super-saturated and mineralized (CO_2 ~ 0.01 mol/kg; Electric Conductivity ~ 3500 µS/cm) fractured aquifer in the carbonate basement and ii) a low mineralized (CO_2 ~ 0.004 mol/kg; Electrical Conductivity ~ 400 µS/cm) aquifer hosted in a shallow volcanic succession (Cuoco et al. 2010). Relative fractions of each endmember in mixed groundwater can be calculated by mass balance through an element-element binary plot considering conservative elements in solution (Albarede, 1995). A lateral groundwater input from the Mt Maggiore carbonate aquifer (Mazza et al., 2013) introduces a third endmember in the FGS (Fig.1a). The final scenario shows a three-component mixing in a binary diagram where the endmember (components) are located in the three angles of a triangle (Carrera et al., 2004).

IC coupled with ICPMS analytical techniques provide a large number of variables in the dataset, both major (HCO_3, Cl, NO_3, SO_4, Na, K, Mg, Ca) and minor/trace elements (F, Li, B, V, Mn, Fe, As, Sr, Rb, Ba, Cs), useful to be used for a validation in the mass balance processes. Groundwater samples were monthly collected from eight wells tapping the FGS since October 2017 in order to test this methodology.

RESULTS

The schematic cross section (Fig. 1a) was realized using field piezometric measurements.

In the FGS the detected end-members are as follows: i) D corresponding to the deep and mineralized aquifer (V 0.2 ppb; K 87 ppm), ii) N being the shallow, volcanic and low mineralized aquifer (V 15 ppb; K 28 ppm), and finally iii) F being the lateral inflow from the Mt. Maggiore carbonate aquifer (V 2 ppb; K 3 ppm), see Fig.1a. The three numerical end-members define the triangle plot showed in Fig.1(b). We used three equation mixing (for the 3 end-members, F - N - D) represented by each side of the triangle, while "f" are the theoretical fractions for each end-member, calculated between the two components at the adjacent corner and fixed equal to 0 to the third one.

The final calculated fractions for each sample for the three different end-members, are easily visualized in Fig. 1 (b). The highest fractions of D are detected in the wells (e.g. W5, W6) located as in Fig.1 (a) close to a faults system allowing CO_2-rich groundwater upwelling (see Fig.1). Conversely, at shallower pumping depth (W4) the percentage of F increases due to the a lateral leak discharge from Mt. Maggiore.

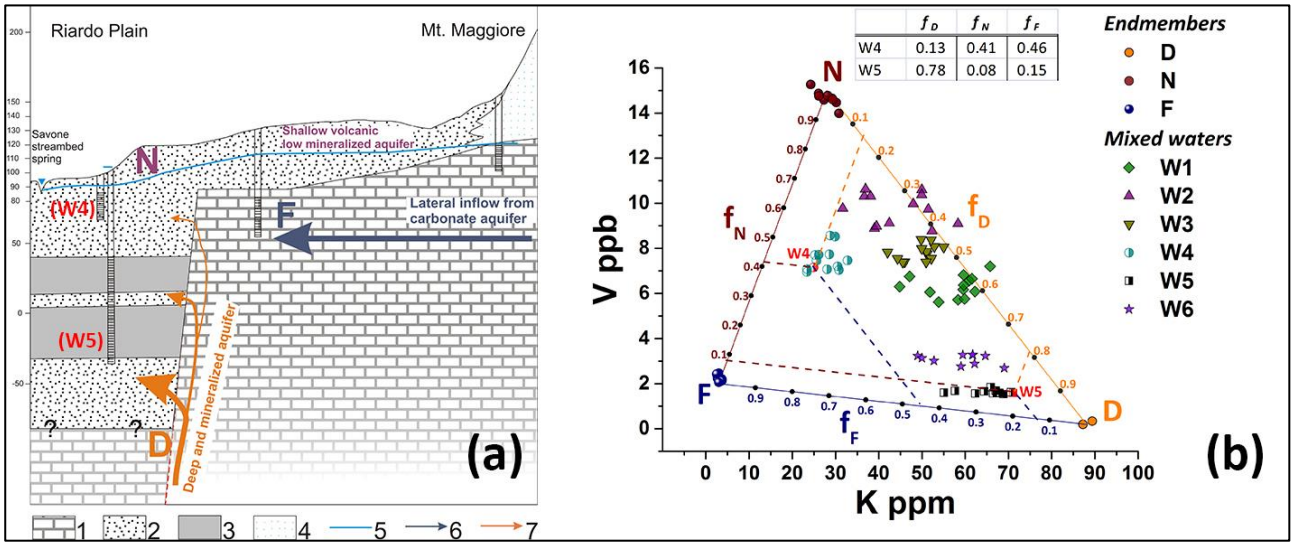

Fig.1(a) Schematic cross section of the FGS involved in the ternary mixing dynamics: 1) carbonate units; 2) pomiceous units; 3) massive volcanic units; 4) detrial deposits; 5) groundwater table elevation; 6) Lateral inflow from carbonate aquifer; 7) deep and mineralized aquifer; (b) graphical estimation of the fractions (f) of each endmember. The table with two examples (points in red) of the numerical results of mass balance is reported above.

CONCLUSIONS

V and K seem be the most functional variables to evaluate groundwater mixing in volcanic vs. carbonatic water reservoirs in the FGS. Triangulation of mixing functions in the element-element plot allows a fast visualization of fractions of the three components calculated by the numerical mass balances.

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Results of a research regarding springs which follow the hyperbolic recession function with n <1

Walter Dragoni[1], Simone Maria Piacentini[1], Vincenzo Piscopo[2]*

[1] Università degli Studi di Perugia, Dipartimento di Fisica e Geologia, Perugia, Italy.
**Corresponding email: walter.dragoni@unipg.it*

[2] Università degli Studi della Tuscia, Dipartimento di Scienze Ecologiche e Biologiche, Viterbo, Italy

ABSTRACT

Herewith we present the preliminary results of a research aimed at understanding in which cases a spring, during no-recharge periods, follows a hyperbolic function having the exponent n < 1.

It is well known that one of the most common functions describing the recession of springs is the so-called hyperbolic function (HF):

$$Q_t = Q_0/[1 + \alpha(t - t_0)]^n \qquad (1)$$

In Eq. (1) the symbols meaning is:
t_0 (d) = time chosen as the start of the recession;
Q_0 (m^3/d) = discharge at time t_0;
Q_t (m^3/d) = discharge at time t (d);
α (d^{-1}) = recession constant;
n = non dimensional coefficient.

Equation (1), with n = 2, was proposed by Boussinesq (1903). The theoretical scheme of Boussinesq corresponds to a linear spring, i.e., to an aquifer with parallel flow draining into a rectilinear watercourse. In the original Boussinesq scheme, the aquifer is homogeneous and isotropic, and it is characterized by an impermeable horizontal bed, located at the same elevation of the spring (i.e., the spring has no permanent water storage). More than one century of use of Eq. (1) indicate that, in many cases, this equation describes well the recession of point springs (i.e., with a convergent flow), even when the low-permeability boundary is not horizontal and is at a moderate depth below the elevation of the spring.

Various authors have worked on eq. (1), confirming the validity of it: e.g., Maillet (1905); Tison (1960), Dewandel et al. (2005). In this context, a work by Drogue (1972) is of particular interest. In that paper, by a statistical analysis of 100 cases of depletion curves of karstic springs, the author states that n frequently assumes values other than 2. Drogue (1972) reports that it is not uncommon to find cases where n = 0.5 and, in his data set, he found that a maximum value of n = 5. Referring to Drogue's seminal work, the case of n = 0.5 is some time mentioned in the literature (e.g., Kresic and Stevanovic, 2010; Kresic, 2013; Civita, 2005) but as far as we know, no author put forward any comment about the structure of the corresponding aquifer/spring or the characteristics of the dynamic storage. Anyway, according to our experience, the cases of springs with hyperbolic depletion curves with n < 1 are somewhat rare.

This research was conducted both on a theoretical basis and by simulating the dynamics of various hydrogeological structures by finite differences modeling.
Our preliminary results indicate that:

a) apart from the possible cases where the analysis is perturbed by poorly approximated data, a HF with $n \leq 1$ corresponds to non-homogeneous structures, with well-defined geometries, consisting of formations with different permeabilities;

b) in the case of $n \leq 1$, the estimation of the dynamic resources by integrating equation (1) between any time t and $t = \infty$ gives an indefinite result;

c) a HF curve with $n \leq 1$ sooner or later evolves towards a HF with $n > 1$ or an exponential Maillet function;

d) in principle, it appears that springs having $n \leq 1$ in the initial part of the recession, are suitable for exploitation by long horizontal or sub-horizontal drains.

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Long-term hydrogeological impacts of the "Firenzuola" high-speed railway tunnel (northern Apennines)

Maria Filippini[1], Piero Civollani[1], Giovanni Mazzei[1], Enrico Dinelli[1], Alessandro Gargini[1]*

*[1] Alma Mater Studiorum Università di Bologna, Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Bologna, Italy. *Corresponding email: maria.filippini3@unibo.it*

ABSTRACT

A high-speed railway line was realized between 1996 and 2005 connecting Bologna and Florence. The line crosses the northern Apennines through multiple tunnels. Significant hydrological and hydrogeological impacts due to tunnel drainage of surface and groundwater were monitored during the construction of the railway line (e.g. drying of springs and base-flow losses at mountain streams) (Vincenzi et al., 2014). Such large impacts were unexpected since the turbiditic formations crossed by the tunnels were thought to behave as aquitards before tunnel drilling. Instead, the formations turned out to be highly fractured and faulted behaving as "sedimentary hard rock aquifers" (Gargini et al., 2008).

The results of a new monitoring performed 13 years after the completion of the line are presented here to assess the long-term evolution of the impacts induced by the draining tunnels.

Keywords: draining tunnel, northern Apennine, monitoring, hydrogeological impact

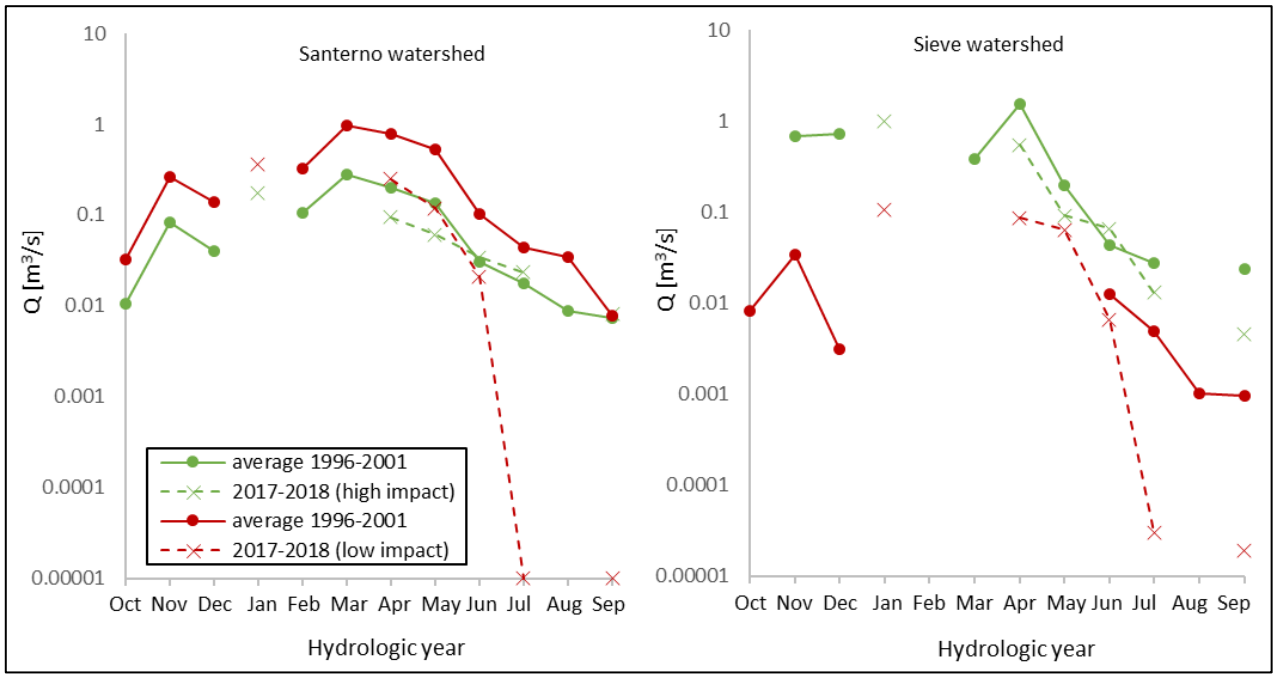
METHODS

The new monitoring focused on the most impacting among the nine tunnels of the railway line, known as "Firenzuola tunnel". The tunnel rides below the Santerno River watershed (north of the main Apennine divide) for about 7 km and for about 8 km south of divide, below the Sieve River watershed. The flowrates of mountain streams were monitored in six rounds between January and September 2018. 14 stream sections were selected among the 73 monitored during the railway line construction. An Acoustic Doppler Velocimeter (Flowtracker Handheld-ADV, SonTek ©) was used for flowrate measurements. Water samples for geochemical and water stable isotope analyses were collected in July 2018 at the 14 stream sections and in 7 inspection wells into the Firenzuola tunnel right below the Apennine divide. Tritium was also analyzed in the samples from the tunnel. The data collected in 2018 were compared with the monitoring preformed during tunnel construction to assess the evolution of impacts over time.

RESULTS

The flowrates at the monitoring stream sections are similar or lower than the ones monitored during tunnel construction. The main impacts in terms of flowrate losses are observed during the low flow season (summer). Examples of highly (red) or slightly (green) impacted sections from both watersheds are shown in the Figure. A particular case is the one of stream Ensa in the Sieve watershed

that flows parallel to the tunnel about 5 km to the east, outside of the area of impact as it was defined shortly after tunnel construction. The stream didn't show relevant evidences of impact during tunnel construction whereas now is clearly impacted. The connection between the stream and the tunnel is likely facilitated by high-angle faults of kilometric lateral extent in the WNW-ESE direction.
The geochemistry and the water isotopes allowed inferring an affinity between the surface water flowing north of the Apennine divide (Santerno watershed) and the groundwater drained by the tunnel immediately south of the divide.



CONCLUSIONS

The overall impacts on stream flowrates observed in 2018 are in line or slightly higher than those registered during tunnel construction. The particular case of stream Ensa located 5 km eastward from the tunnel suggests that the impact area is spreading radially over time in the Sieve watershed. A similar lateral spreading of impacts was not registered in the less faulted Santerno watershed. Geochemistry and water isotopes from streams and from the tunnel showed that the main hydrogeological divide is shifted to the south compared to the topographic divide, suggesting a southwestward "fault driven" rather than a northeastward "stratum driven" groundwater flow direction.

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The upwelling groundwater flow in the karst area of Grassano-Telese springs (southern Italy)

Francesco Fiorillo[1], Guido Leone[1], Mauro Pagnozzi[1], Vittorio Catani[1], Giovanni Testa[1], Libera Esposito[1]*

[1] Università degli Studi del Sannio di Benevento, Dipartimento di Scienze e Tecnologie (DST), Benevento, Italy.
**Corresponding email: pagnozzi.mauro@libero.it*

ABSTRACT

The hydraulic phenomenon of upwelling groundwater flow affecting karst area of Grassano-Telese springs (southern Italy) has been investigated through piezometer data, discharge and chemical-physical monitoring of springs. In the karst area of Grassano-Telese, the phenomenon of the upwelling flow is supported by different types of evidences such as: the presence of sinkholes connected to hypogenetic speleogenesis processes, constancy of temperature and hydraulic conductivity of spring water, hydraulic head increases with depth. In order to support the hypothesis on upwelling flow of discharge area, hydraulic model has been built up using different MODFLOW tools.

Keywords: karst springs; upwelling flux; artesian; sinkholes; groundwater modeling;

METHODS

Remotely sensed data and topographic maps have been used in order to map all the sinkholes in Grassano-Telese karst area, analyzing their distribution and morphometry.

To model the groundwater flow, numerical codes has been used in MODFLOW environment, to simulate the phenomenon of the upwelling flow. The simulation is calibrated by the hydraulic head measurements upstream spring outlet, and provides the path of the flow and equipotential lines under specific hydraulic boundary conditions (Chiang and Kinzelbach, 1998). The aim is to simulate the groundwater flow paths highlighting the upwelling phenomenon under the spring, rather than to estimate the discharge amount.

RESULTS

A huge number of small to medium-sized sinkholes affect Grassano-Telese karst area.

A very high concentration of sinkholes were observed for the carbonate relief of Montepugliano located in the northern sector of the study area. The Montepugliano relief are typically connected to collapse phenomena; they involve mainly carbonate rocks of Cretaceous and can be defined as collapse sinkhole (Ford and Williams, 2007). Besides, these sinkholes develop mainly in the unsaturated zone of the aquifer.

The sinkholes genesis and their exceptional concentration (the latter is not found in others sector of the considered karst system), seems to ascertain the hydraulic phenomenon of upwelling. The

groundwater artesian conditions detected in the Telese plain, located along the southern side of the Montepugliano relief, can be explained by the upwelling flow, which locally is confined by the aquitard role of the alluvial deposits of the plain. The groundwater converges towards discharge zone as modelled using MODFLOW tools. This convergence occurs in the vertical plane along the main direction of the groundwater flow, and highlights the upwelling phenomenon feeding springs (fig.1).

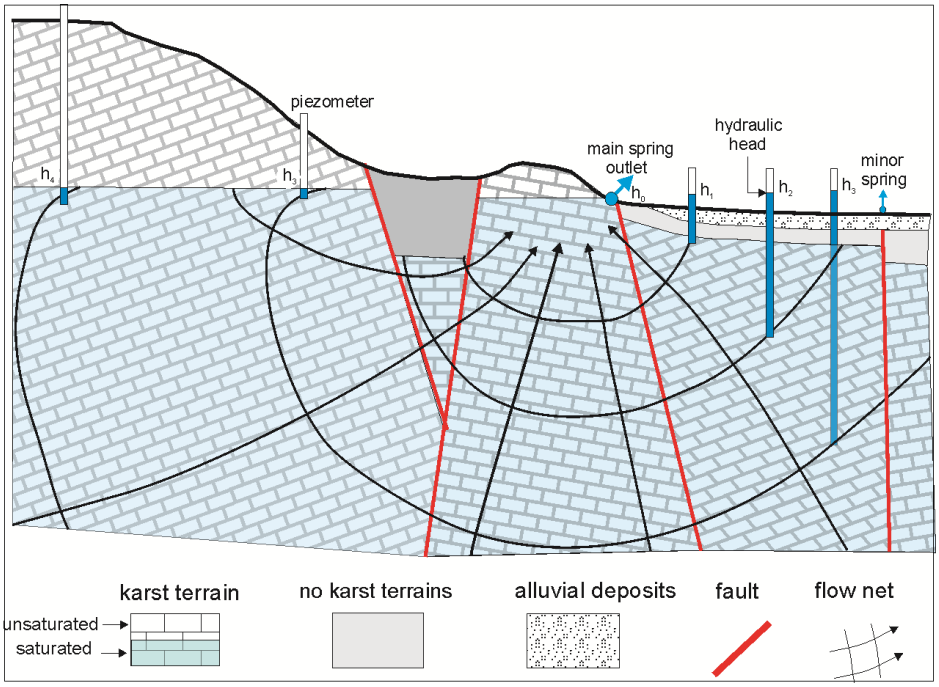

Fig. 1 - General sketch of the groundwater path with flow net deducted from hydraulic heads detected into piezometers located upstream and downstream main spring outlet (modified from Fiorillo et al., 2018)

CONCLUSIONS

Several markers such as water temperature, electrical conductivity, sinkholes genesis and distribution, piezometer data seem to support the hydraulic behaviour of groundwater typified by ascendant flow. The flow net of karst aquifer feeding Grassano springs has been drawn using MODFLOW tools. The groundwater flow 2D model can be considered a simple tool to understand groundwater circulation affecting Rio Grassano karst aquifer, providing a possible scenario of groundwater behavior.

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Response of the main springs of the Sibillini Mountains area to the 2016-2017 seismic sequence

Davide Fronzi[1], Francesca Banzato[2], Costanza Cambi[3], Roberto Checcucci[4], Lucia Mastrorillo[5], Francesco Mirabella[3], Torquato Nanni[1], Marco Petitta[2], Alberto Tazioli[1], Daniela Valigi[3]*

*[1] Università Politecnica delle Marche, Dipartimento di Scienze e Ingegneria della Materia, dell'Ambiente ed Urbanistica (SIMAU), Ancona, Italy. *Corresponding email: d.fronzi@pm.univpm.it*

[2] Università degli Studi di Roma La Sapienza, Dipartimento di Scienze della Terra, Roma, Italy

[3] Università degli Studi di Perugia, Dipartimento di Fisica e Geologia, Perugia, Italy

[4] Regione Umbria, Servizio Risorse Idriche e Rischio Idraulico Perugia, Italy

[5] Università degli Studi Roma Tre, Dipartimento di Scienze, Roma, Italy

ABSTRACT

The dynamic of groundwater systems feeding several springs of the Sibillini mountains was deeply affected by nine Mw 5.0–6.5 seismic events occurred in central Italy starting from August 2016.

The strongest shock (Mw 6.5) occurred on 2016 October 30th about 5 km NNE of Norcia Town, 9 km below the surface (Chiaraluce et al., 2017), as a result of upper crust normal faulting on the nearly 30-km-long Mt. Vettore-Mt. Bove fault system (Civico et al., 2018; Porreca et al., 2018), a NW-SE trending, SW-dipping fault system cropping out on the western slope of Mt. Vettore, the highest peak of Sibillini Mountains.

Soon after this event, it was observed a general increase of springs and rivers discharge and groundwater levels both in the Visso and Norcia areas, west of the Sibillini Mountains (Petitta et al., 2018). In this area, both discharges and groundwater levels are still nowadays higher than they were before the seismic sequence.

Discharge data of the main springs located east of the Sibillini Mountains were analysed to verify whether the general increase observed on the western side was associated to a decrease on the eastern area. The results of the analysis show that the springs located on the eastern side of Mount Vettore fed by the Basal aquifer (Calcare Massiccio), experienced a significant long-term discharge decrease. The effect of the seismic events on discharge values recorded on the springs SE of Mount Vettore, fed by shallower aquifers (Maiolica and Scaglia), is not of the same kind, since a long-term reduction of average discharge has not been recorded.

The analysis of the historical discharge series of the Pescara spring (SE of Mt. Vettore), and its relationship with the local 12 months SPI index (SPI-12), shows that the very low discharge values recorded at the end of the 2017 depletion period are not associated with SPI as low as documented in the past for similar discharges. This consideration suggests that the very low discharges recorded in 2017, could be also due to the earthquake effects. This hypothesis is supported by the fact that the Maillet depletion coefficients determined for the post-earthquake recession periods are higher than those determined before the seismic events.

Keywords: earthquake hydrogeology, spring discharge, carbonate aquifers

METHODS

The work is based on the analysis of discharge measurements of the main springs located in the Sibillini Mountains area and on the analysis of historical rainfall series.
Discharge data of the eastern springs are measured by the CIIP S.P.A. of Ascoli Piceno.
Historical rainfall series, available from the Centro Funzionale Multirischi Protezione Civile Regione Marche since 1962, were used to calculate the 12 months SPI Index (McKee et al., 1993), to determine whether the low discharge values could be related to severe droughts.

RESULTS

The results of the analysis showed that the discharge of two springs located North-East of Mount Vettore, Foce di Montemonaco and Sassospacato springs, significantly decreased, in the long term, after the 2016-2017 seismic sequence. These springs are both fed by the basal aquifer, (Calcare Massiccio and Corniola formations).
Data of Pescara and Capodacqua springs (eastern side of Sibillini Mountains), fed by the shallower aquifer (Maiolica and Scaglia) do not show an evident long lasting decrease of average discharge after the seismic sequence.
Nonetheless, as far as the Pescara spring is concerned, it was observed that in 2017 the minimum discharge reached at the end of the depletion period is about 25 L/s. Since 1962, the only year in which the discharge has been (slightly) lower than this is 2007.
The analysis of SPI index, determined on the historical rainfall series recorded in Arquata del Tronto, showed that the SPI-12 value reached in 2017 is not as low as it was when similar low-discharge values were reached in the past. This consideration suggests that the very low discharge recorded in 2017, could also be linked to the earthquake effects. This is in accordance with the higher Maillet depletion coefficient values determined for the post-earthquake recession periods, with respect to those calculated for the pre-earthquake ones (Fig. 1).

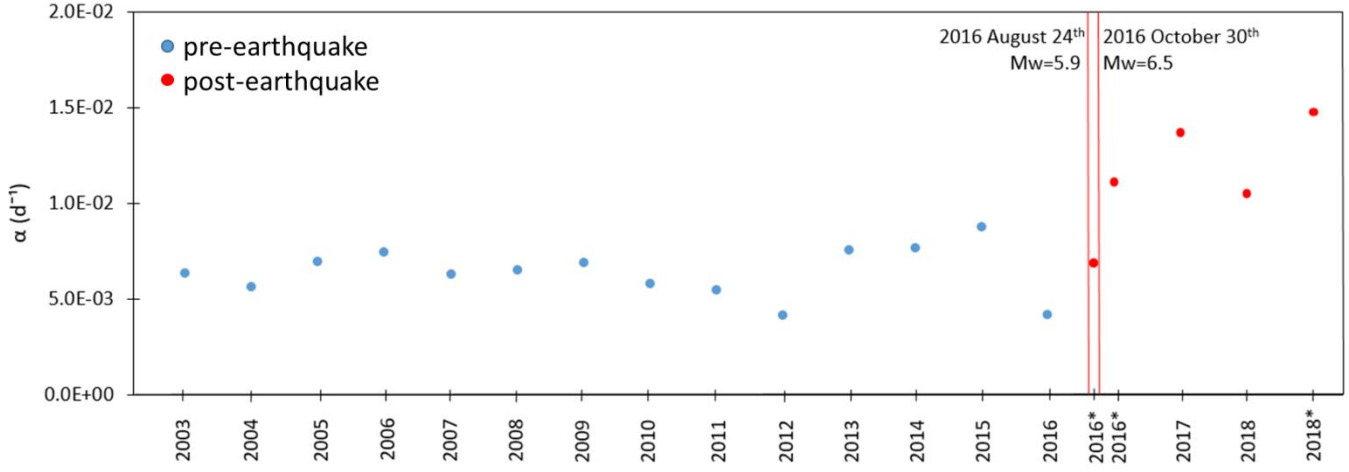

Fig. 1 - Maillet depletion coefficients for the Pescara Spring (2003-2018).
**The values in the same year (2016 and 2018) are determined in different depletion periods.*

CONCLUSIONS

The 2016 October 30th earthquake had strong effects on the dynamic of groundwater systems. A general increase of springs and rivers discharge and groundwater levels can still now be observed in the Visso and Norcia areas. On the eastern side of the Sibillini Mountains, the mean discharge of the springs located at the base of Mount Vettore, and fed by the Calcare Massiccio and Corniola aquifer, significantly decreased after the earthquake and still sits lower than it was before. The earthquake effects on the eastern springs fed by the Maiolica aquifer are not so evident. The mean discharge of these springs did not change significantly and possible earthquake effects can only be observed on depletion periods.

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Process-based resource vulnerability assessment on the example of Gömör-Torna Karst, Hungary and Slovakia

Veronika Iván[1], Judit Mádl-Szőnyi[1]*

*[1] József & Erzsébet Tóth Endowed Hydrogeology Chair, Department of Geology, Eötvös Loránd University, Budapest, Hungary. *Corresponding email: iv.veron@gmail.com*

ABSTRACT

Karst aquifers, especially with highly developed conduits are very complex and heterogeneous hydrogeological systems. In these systems indispensable water resources are stored. Due to the special characteristics of karst systems, the quality of karst water may easily be degraded as a result of anthropogenic impacts. The high sensitivity of these resources thus requires an effective and accurate protection strategy. As a preventive tool, vulnerability assessment supports decision making in land use, environmental and water management. Groundwater vulnerability maps synthesize the relevant lithological, pedological, hydrogeological, meteorological, hydrological and geomorphological information in a visual and easy-to-understand way. Parallel to the increasing popularity of the most commonly used parametric approaches, more and more authors emphasize the importance of the reliability and comparability of groundwater vulnerability assessments and the conceptual problems caused by those vulnerability indicators which do not have physical meaning (Wachniew et al. 2016). Focusing on the development of physically based or process-based approaches helps to overcome this problem (Dassargues et al. 2015; Popescu et al. 2015). The recent study presents a process-based karst groundwater vulnerability approach on the example of the Gömör-Torna Karst (known also as Aggtelek Karst and Slovak Karst). It is an unconfined transboundary aquifer located on the border of Hungary and Slovakia. The aquifer consists of Triassic carbonates, partially covered with Quaternary clayey sediments.

Keywords: groundwater vulnerability, karst aquifers, process-based vulnerability, geophysics

METHODS

In a preliminary study the semi-quantitative, parametric Slovene Method (Ravbar and Goldscheider 2007) was applied on the test site for intrinsic vulnerability assessment (Iván and Mádl-Szőnyi 2017). Revealing the contrast between the rough evaluation and the importance of the aquifer fracturation as well as the overlying clayey sediments, supplementary field and laboratory investigations were presented. For the investigation of sediment thickness and dissolutionally enlarged fractures Radio-magnetotellurics (RMT, 20-300 kHz) and Vertical Electric Sounding (VES) were applied (own measurements and data from Gruber et al. 2015). By means of sieving-hydrometer and laser-diffraction methods, the grain-size distribution of the soil and sediment samples were analysed and their hydraulic conductivity was calculated. Based on these supplementary studies a comprehensive, process-based resource vulnerability assessment was carried out and applied for particular areas. The

methodology was based on the Time-Input method of Kralik and Keimel (2003). Adapting the methodology to the characteristics of the test site, several modifications were applied, e.g. the effect of swallow holes and sinking streams were incorporated into the evaluation. The density of fractures was derived from the RMT results.

RESULTS

The process-based vulnerability assessment is suitable for handling the high heterogeneity of the karst area. It resulted a detailed intrinsic resource vulnerability map with fine resolution. The vulnerability is expressed in real travel time values, which ranges from few hours to 68 months from the surface to the water table. The highest vulnerability can be observed where the clayey sediment coverage is absent and the aquifer is strongly fractured, or where is possibility for concentrated infiltration.

CONCLUSIONS

The adapted and modified method is suitable for the evaluation of karst areas of the region and provides reliable information for resource vulnerability. Instead of dimensionless vulnerability categories, the vulnerability is expressed in real travel time values. Therefore, the methodology provides suitable tool for natural conservation purposes and land use planning. The study was supported by the Geogold-Hungária Ltd. and the Aggtelek National Park. This result is part of a project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 810980.

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The impact of geomorphologic structure on rain water infiltration and groundwater recharge in semi-arid zone

Or Letz[1], Roey Egozi[2], Ofer Dahan[1]

*[1] Ben Gurion University of the Negev, The Zuckerberg Institute for Water Research, Hydrology and water resources, Israel. *Corresponding email: or.letz@gmail.com*

[2] Soil Erosion Research Station, Ministry of Agriculture & Rural Development, Israel

ABSTRACT

The geomorphologic structure of the rock and soil outcrops is an important parameter in rainfall-runoff-groundwater recharge relation characterization in watersheds (Eagleson, 2002). These relations determine the groundwater recharge rate and are difficult to characterize, especially in semi-arid zones (under 300 mm per year). In spite of the aridity conditions, it is considered an important replenishment area of the southern part of the Yarkon-Taninim (Y-T) aquifer (Dafni et al. 2010). The Y-T is one of Israel's most important resources of fresh water, providing ~25% of the country's fresh water (Hydrological Service, 2014). The main objective is to characterize the impact of the geomorphologic structure on percolation and groundwater recharge.

Keywords: replenishment area, geomorphology, vadose zone, groundwater recharge

METHODS

Examining the impact of typical geomorphic settings on groundwater recharge. A first order stream (10.7 acres) which is characterized with two main geomorphic setting was selected: (1) Rocky slopes and (2) Man-made soil terraces along the stream channel. The study area was instrumented with a monitoring setup which includes: (1) meteorological station, (2) two vadose zone monitoring systems (VMS) (Dahan et al., 2009; Rimon et al., 2011) for the rock hillslopes and soil terrace, and (3) a flume in the outlet of the watershed, measuring the runoff generation. The VMS provides high-resolution measurements of variation of rock/sediment water content as well as frequent sampling of rock/soil pore-water for chemical and isotopic composition at multiple depths ranging from land surface to 8 meters below ground level. The chemical and isotopic composition of the vadose zone porewater was used to estimate the water infiltration conditions and identification processes taking place during rain water percolation. The flume at the basin outlet provided runoff discharge following rain events.

A combination of continuous monitoring of the rain pattern, water content across the unsaturated zone, variations in concentration of environmental and artificial tracers, allowed characterization of the link between rain regime to deep infiltration and groundwater recharge with respect to the typical geomorphologic setting.

RESULTS

Water content variation, stable water isotopes and artificial tracer's migration reveal quick and deep infiltration of rainwater during storm events and slow infiltration that continued until the end of the summer (September – October) with limited evaporation effects under rock hillslopes. A sharp increase in water content and sharp depletion in $\delta^{18}O$ indicate on rainwater percolation and limited enrichment of $\delta^{18}O$ indicate on limited evaporation effect. In addition, significant similarity was found in the isotopic signature of the rain, water samples under the hillslope and in groundwater.
In the second geomorphological unit, man-made terrace, it was found that the infiltration is limited under semi-arid conditions. The wetting front reached to shallow depth of ~1.5 meters. Apparently, water emerged at the middle of the cross-section by lateral flow from the margin of the terrace. The $\delta^{18}O$ and the artificial tracer's experiment indicate on vertical and lateral flow.

CONCLUSIONS

The rock outcrops on the surface create funnels for collecting the local runoff and delivering them into high permeability fractured zones where the water penetrated directly to the deep sections. In contrast, the bare soil areas such as hilltops or man-made terraces in streams with highly developed soil cross section, reveal limited infiltration. The main conclusion is that the rocky hillslope has higher recharging potential compared to the soil terraces, and a significant effect on deep infiltration and groundwater recharge. Preserving these rugged, rocky deposits in Southern Judea Mountain with their natural land cover is essential for groundwater recharge.

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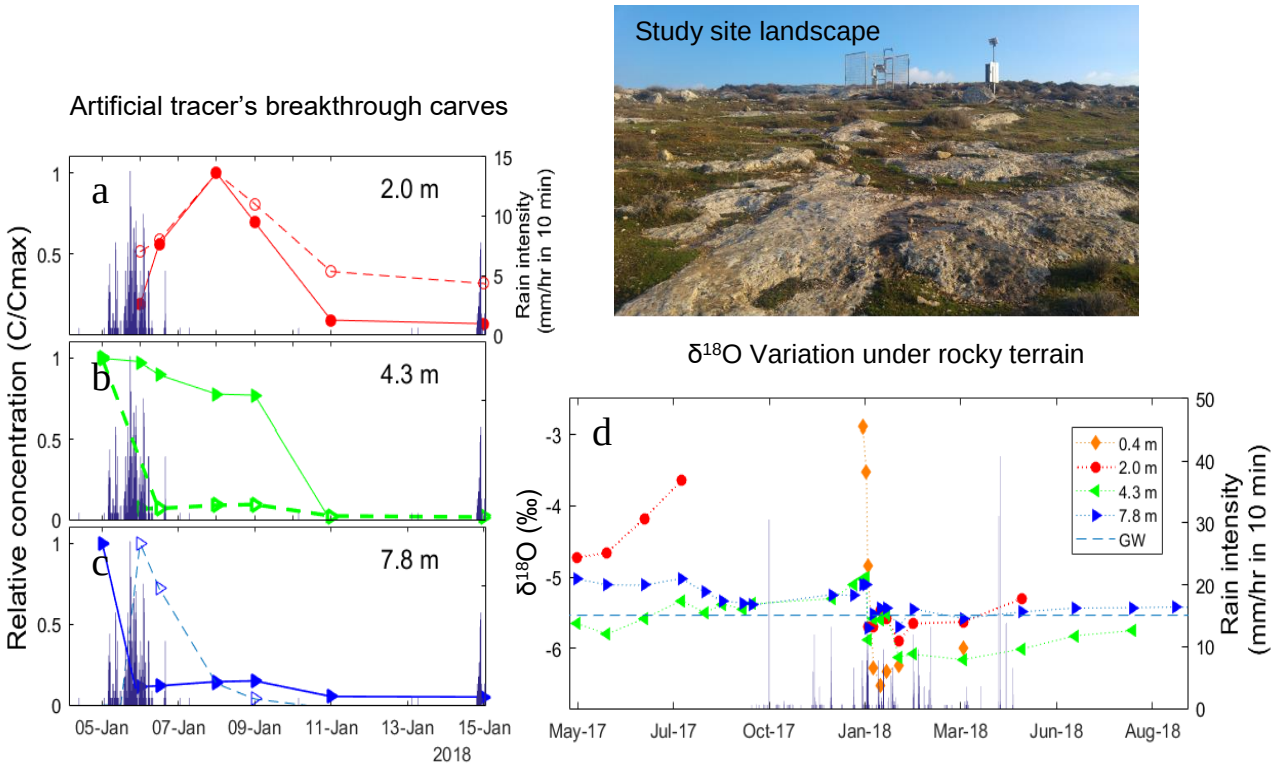

Figure: Artificial tracers experiment (a, b & c) and $\delta^{18}O$ variation (d) under the Rocky hillslope unit. In graphs a, b & c, the relative concentration of the two tracers (hollow shapes – Uranine and a full shapes Naphthenate) indicate a connection between the surface and the deep cross-section. The calculated tracers' arrival time was 3-60 cm/hr. In graph d, the $\delta^{18}O$ variation indicate evaporation effects in the shallow depths (0.4 and 2 meters), while in the deepest cross-section limited evaporation was observed. A similar isotopic composition was found in the deepest cross-section and in the groundwater.

Spring discharge monitoring network in a high-alpine setting: an example from the Pale di San Martino (Dolomites Mountains, Italy)

Giorgia Lucianetti[1], Roberto Mazza[2], Lucia Mastrorillo[2], Piergiovanni Partel[1]*

[1] Ente Parco Naturale Paneveggio Pale di San Martino, Primiero San Martino di Castrozza (TN), Italy.
**Corresponding email: giorgia.lucianetti@uniroma3.it*

[2]Università degli Studi Roma Tre, Dipartimento di Scienze, Roma, Italy

ABSTRACT

The complex physiography of the high-alpine environments does not favour the installation of hydrogeological measurement points, thus alpine catchments are frequently ungauged (De Jong, 2015). Given the increasing water demand, monitoring records of spring discharge are becoming a key tool for a sustainable water management and for water resources forecasting. In 2018, a monitoring network for spring discharge was set-up in the Paneveggio-Pale di San Martino Park in the Dolomites Mountains. The fixed relationships between stage and discharge known as rating curves (Rantz, 1982) are currently under development, but the first preliminary results indicate a good statistical significance. Of great importance is the capability of the stage-discharge relation to be applicable both to baseflow and to extreme flow conditions. This situation is not common as discharge measurements are usually missing in the definition of the upper and lower end of the rating curve (Braca, 2008). In this study, during the monitoring period, particular care has been taken to perform the measurements during both low flow and extreme flow conditions.

The sensors installed in the spring houses, and particularly at the main karst spring, were able to register the extreme event which occurred between October 27 and 29 of 2018, known as storm "Vaia". In particular, the manual measurements previously performed during high-flow periods, allowed to quantify the peak discharge related to the extreme event.

Keywords: springs, rating curve, hydrograph, Alps

METHODS

Automatic water level and temperature loggers were installed in six spring houses and one sensor was placed in the Canali Stream, at the closure of the sub-catchment. Manual monthly measurements were performed over the same time period since the beginning of 2018 in order to establish a relationship between the different water levels and the associated discharges. The ISO regulation 1100-2 (ISO, 1998) recommends at least 12-15 discharge measurements during the period of analysis. Up to now, fourteen discharge measurements have been performed during the monitoring period in order to build the rating curves. For extrapolating the stage-discharge relationship, a graphical extrapolation was performed. All the measured data as pairs of water level and discharge were plotted into one graph and the curve of best fit was drawn.

RESULTS

Graphical extrapolation of the rating curves has been performed for the monitored springs. An example is shown in Fig.1. For the Pradidali spring, a polynomial fitting function was chosen as the best function. The maximum water level reached during the storm Vaia event (417 mm) is also represented in the figure as a red cross symbol. The corresponding discharge was calculated from the fitting function. This value is close to the largest measured discharge, which was observed during the high flow snow-melting period in June 2018. The curve also includes discharge measurements performed during minimum baseflow conditions, in the month of March 2018. Therefore, the obtained rating curve shows a large range of validity, from baseflow to extreme flow conditions. On the other hand, for the sensor installed in the stream, the extreme event resulted in a sudden instability of the river bed geometry and in particular in the filling of the channel with vegetation, affecting the previously developed rating curve.

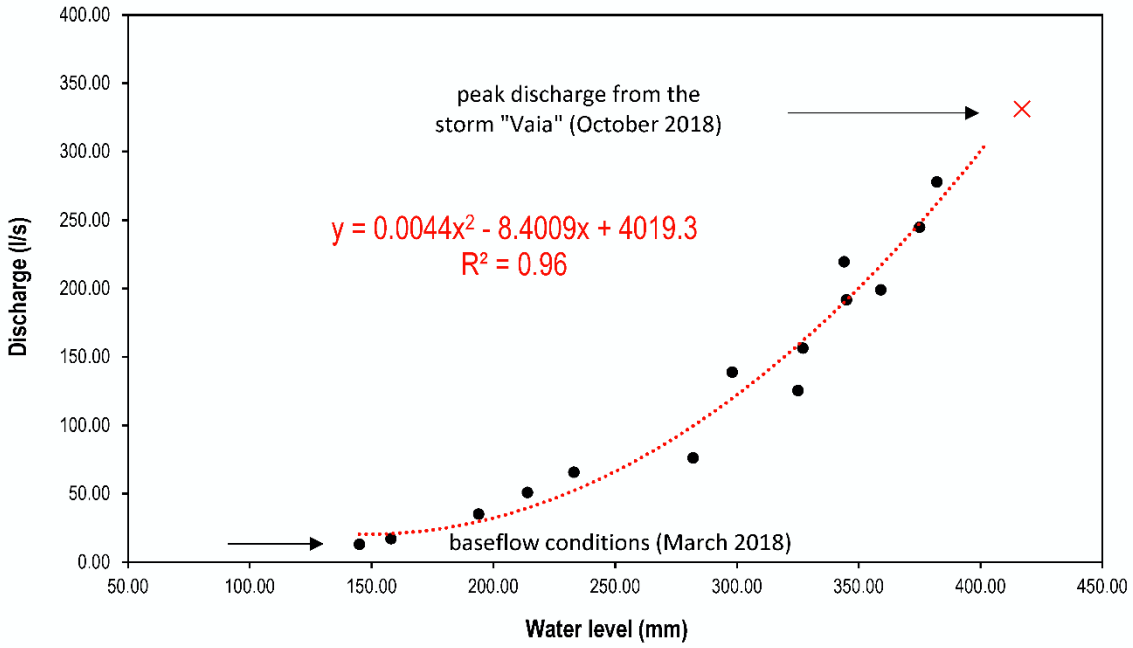

Fig.1 - Stage-discharge rating curve of the Pradidali karst spring. Water level-discharge pair for the storm Vaia is also represented in the figure. The discharge was extrapolated from the fitting function.

CONCLUSIONS

This study shows that for new gauging stations, many discharge measurements are needed to develop the stage discharge relation throughout the entire range of flow data. In particular, for springs in alpine settings, which are characterized by a large flow variability, monthly measurement of discharge in high flow and baseflow conditions are necessary to acquire hydrogeological information in case of extreme weather events. The opportunity to investigate extreme hydrological conditions, such as droughts and floods, depends on the range of validity of the rating curve.

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The Pilato Lake (Sibillini Mts., Central Italy): first results of a study on the supposed variations of its hydrogeological conditions induced by the seismic sequence 2016-2017

Lucio Martarelli[1], Rossella Maria Gafà[1], Paolo Maria Guarino[1], Gennaro Maria Monti[1], Luca Maria Puzzilli[1], Angelantonio Silvi[1]*

[1] ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale, Servizio Geologico d'Italia, Roma, Italy.
**Corresponding email: rossella.gafa@isprambiente.it*

ABSTRACT

The Pilato Lake has glacial origin, is located in the Sibillini Mountains, Central Italy (e.g. Boni et al., 2010; Amoruso et al., 2014) and houses a particular endemism unique in the world: the small crostaceous Chirocephalus marchesonii.

In the context of a research agreement with the Monti Sibillini National Park, ISPRA is carrying on some studies aimed to evaluate the effects of the 2016–2017 Central Italy earthquakes on the hydrogeological conditions controlling the lake's evolution.

The study, started in July 2018, aims primarily at the reconstruction of the subsoil setting beneath the valley hosting the lake, both in terms of geological and hydrogeological boundaries. In order to define the conceptual model of groundwater circulation and, thus. to evaluate the emptying and recharge seasonal cycle of the lake, hydrogeological surveys and geophysical investigations were performed.

Keywords: Pilato Lake, Central Italy, earthquake, groundwater circulation.

METHODS

Hydrogeological surveys along the study area were carried out aimed to determine the spring flow rate and chemical-physical parameters (temperature, T; specific electrical conductivity, CE; pH) of the lake's waters. Using a drone survey, a first detailed reconstruction of the morphological setting was carried out, to be compared with other ones to be performed in the future.

The drone photogrammetric survey allowed reconstructing the bathymetry of the basin for calculating the volume of water. For the assessment of variations of the lake level, the coordinates along the edge of the lake were surveyed (Fig. 1).

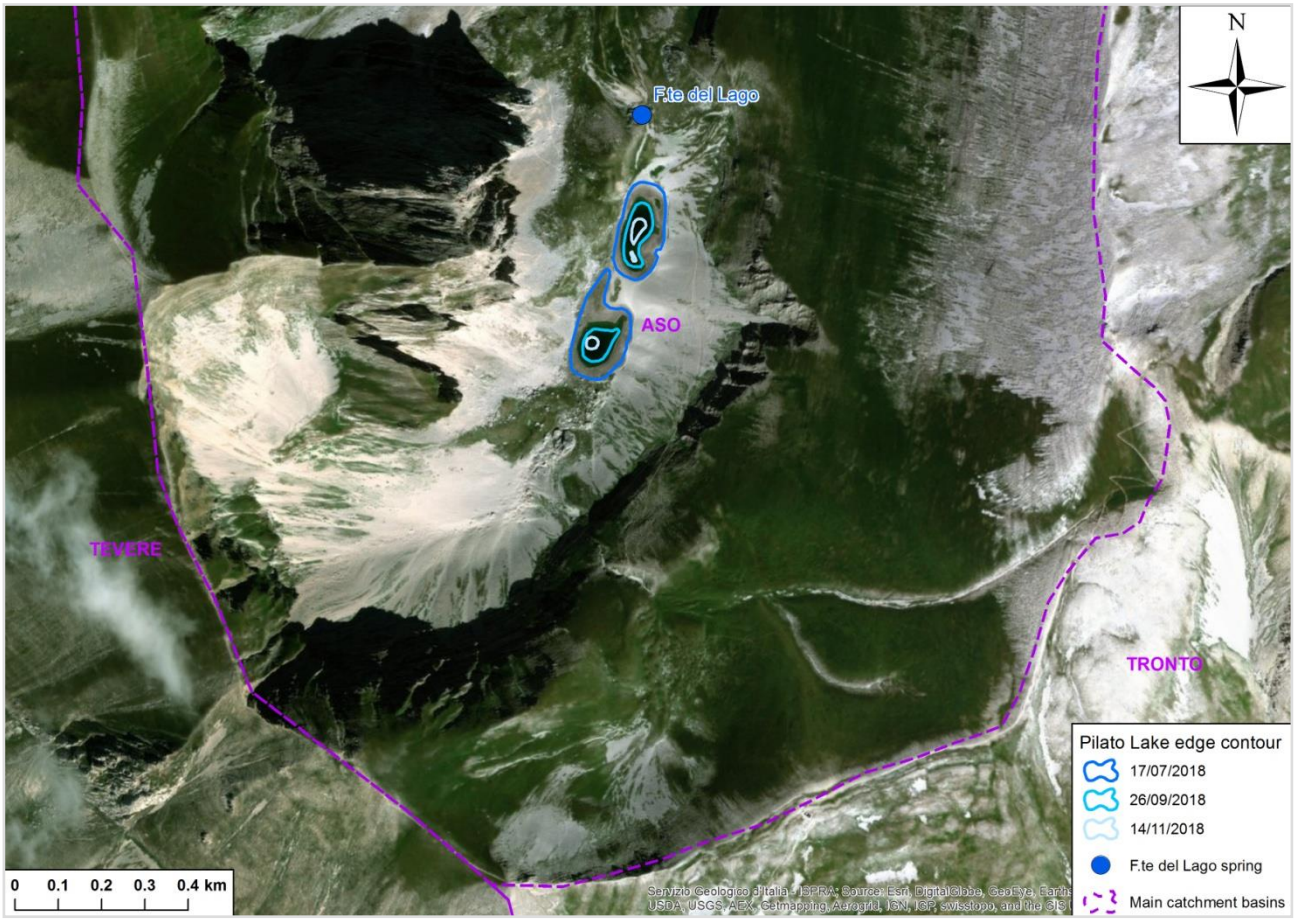

Fig. 1 - Map of location of control points and lake limits in the Pilato lake area

A comprehensive investigation plan, made of seismic and ground probing radar (GPR) surveys was defined. At this stage, two active seismic surveys were carried out for the subsoil characterization in terms of shear-waves velocity (Vs), a parameter directly related to the stiffness of the materials. The seismic surveys allow a preliminary estimate of the thickness of the loose debris deposits over the bedrock.

The climatic characterization was carried out through the analysis of the available data sets from Hydrographical Service of Marche Region and Hydrological Annals. Precipitation and temperature data were acquired (also snow, where available) over a period of at least thirty years, where possible; long-term averages were used to evaluate the deviations from the average of the individual years and the time series were analyzed to assess any long-term trends and cycles, in addition to the seasonal component. Water loss through evaporation from lake surface was also estimated.

RESULTS

The drone photogrammetric survey allowed a preliminary reconstruction of the lake basin bathymetry that allowed, in turn, the calculation of the water basin volumes in the various observed periods, the estimate of evaporation from the lake surface and the comparison with the information relating to previous years compared to the present study.

The velocity profiles of the seismic surveys have estimated the maximum thickness of debris (detrital and glacial sediments on top of calcareous bedrock) equal to about 12-15 m. Further investigations through GPR will be addressed to the better definition of the geological boundaries.
The physical-chemical characteristics of the waters (T=12-13°C; pH=8-9; EC=60-125 µS/cm) are consistent with those of stagnant and slightly oxygenated waters. The low value of EC of the lake's waters is in accordance with the prevailing provenance of the lake's recharge by snow melting and precipitation.

CONCLUSIONS

The research program is still in progress and to date we can propose only preliminary remarks. The hydrogeological survey showed the absence of geomorphological evidence of earthquake ruptures: the crisis situation of the lake level in the summer of 2017 was probably due to the dry meteo-climatic conditions of winter-spring 2016-2017.
The lake level from its maximum flooded quota in May-June 2018 (completion of snow melting) falls down rather rapidly to the elevation of the Fonte del Lago, which acts as an overflow, and then declines more slowly due to evaporation and infiltration through the soil of its bed down to the minimum levels which, in particularly arid years, lead to its drying out.

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Hydrogeological models of potential sites for a deep geological repository in the Czech Republic as part of the site selection process

Marek Vencl[1], Ondrej Mikláš[1]*

[1] Správa úložišť radioaktivních odpadů (SÚRAO) - Radioactive Waste Repository Authority, Prague, Czech Republic.
**Corresponding email: miklas@surao.cz*

ABSTRACT

The Czech Republic plans a single-level deep geological repository (DGR) at a depth of approximately 500 metres in a granite or gneissic rock mass located in a non-seismically active area (Pospíšková et al., 2012). The repository requires specific demands on a hydrogeological system, especially on the flow velocities, directions and retention times, which in the Czech Republic meets a sparsely fractured rock massif. Despite the relative high suitability of the considered environment, there is a lot of issues related to the complexity of the system. SÚRAO is currently considering a total of 9 potential sites, all of which featured crystalline host rock environments and the number of sites will be reduced to just 4 sites for the next phase of geological survey and investigation work. During this process, SURAO is testing sufficient hydrogeological modelling approaches to characterize the host rock and predict the radionuclide transport times (Pačes and Mikšová, 2013).

Keywords: deep geological repository, geological survey, hydrogeological model, ECPM

METHODS

Regional and detailed models of all 9 of the potential sites have been constructed. The groundwater flow and transport models were based on the ECPM (equivalent continuous porous media) approach. The hydrogeological properties of the fractured bedrock was approximated to the continuous matrix, while deterministically identified fault zones were represented as planar features with specific conductivities. The thickness of each layer varied according to the geometry of the geological features. The domain depth was set at 1500 m and the domain was divided vertically into 13 layers. Hydrogeological conductivity was considered to decrease with depth according to eq. 1 (Gustafson and Liedholm 1989):

$$K_z = K_0 \cdot 10^{-(z/c)} \qquad (1)$$

The models were constructed in three different software environments – Modflow (the finite differences method), Flow123D and Feflow (both finite element methods). The models were based on 3D geological models and employed data obtained from hydrological and hydrogeological monitoring and archive data.

RESULTS

The most important results of the simulations consisted of the determination of the hydraulic head field, flow rates and velocities, retention times, drainage areas and flow paths. The maximum flow velocity at the sites at DGR level ranged from 0.2 to 0.7 m/year. The specific discharge from the DGR ranged from 7.9E-03 to 2.7E-02 l/s.km^2. The retention time medians for potential radionuclides in the geosphere were calculated as 1689 – 9149 years. Selected results are shown in Table 1 (Uhlík, 2018). The results of the hydrogeological modelling were subsequently used as input data for radionuclide transport modelling and safety assessment purposes.

	Specific flux (l·s^{-1}k·m^{-2})	**Velocity (m.y^{-1})**	**Pathway length (m)**	**Retention (y)**
Březový potok	$7.9 \cdot 10^{-3}$	0.2	2743	9149
Čertovka	$2.68 \cdot 10^{-2}$	0.6	1333	2463
Čihadlo	$5.56 \cdot 10^{-2}$	0.4	5132	7333
Horka	$1.8 \cdot 10^{-2}$	0.6	3120	5637
Hrádek	$2.3 \cdot 10^{-2}$	0.3	3422	3305
Janoch	$9.41 \cdot 10^{-3}$	0.2	1659	8468
Kraví hora	$1.1 \cdot 10^{-2}$	1.2	2136	5244
Magdaléna	$2.24 \cdot 10^{-2}$	0.3	1333	1689
Na Skalním	$2.52 \cdot 10^{-2}$	0.5	2774	4280

Table 1 - Modelling results

CONCLUSIONS

The Czech Republic is currently involved in the DGR site selection process and now is the right time for the preparation of both a high-quality underground disposal facility design and a safety assessment that includes the detailed hydrogeological characterisation of the host rock.

Hydrogeological investigation studies and mathematical modelling constitute important components of the site selection and description process in terms of providing an idea of the water balance and total flow rate and the identification of drainage and flow paths at the various sites. This information will be included in the safety assessment. Due to the insufficient amount of field data so far available from DGR depths and the computational demands of the higher-scale simulation of fractured systems, the ECPM concept combined with 2D discrete features is being employed.

In the next phase of the site selection process, SÚRAO plans to conduct detailed geological surveys including the drilling of deep boreholes and detailed hydrogeological testing (Procházka, 2010). All the current hydrogeological models will be refined using data from both the geological surveys and the appropriate depth. This phase will also include the construction of detailed DFN models which will allow for the more natural description of flow processes in the fractured rock systems.

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Can geoentropy be used to predict transport in fractured media? Results from preliminary tests

Daniele Pedretti[1*], *Marco Bianchi*[2]

[1] *Dipartimento di Scienze della Terra "A. Desio", Università degli Studi di Milano, Milan, Italy.*
**Corresponding email: daniele.pedretti@unimi.it*

[2]*British Geological Survey, Keyworth, UK*

ABSTRACT

In heterogeneous formations, the predictions of flow and transport are usually complicated by the limited knowledge of the distribution (i.e. the structure) of the aquifer properties, including the hydraulic conductivity (K). Geoentropy (Bianchi and Pedretti, 2017, 2018) is a new approach that combines multiple controls of solute transport in heterogeneous porous media, including connectivity and global variance of Y=ln(K). So far, geoentropy has been successfully applied to porous media, while it has not been demonstrated yet for fractured media. The purpose of this presentation is to illustrate and discuss initial results from the comparison between geoentropy-derived metrics describing the aquifer structure and the time scaling of solute transport in numerically simulated heterogeneous fractured settings. The results suggest that the behaviour of solute transport in heterogeneous fracture media show several analogies with that in porous media, paving the way towards the use of geoentropy for predictions of transport in fractured systems.

Keywords: geoentropy, solute transport, stochastic modelling, fractured media.

METHODS

The approach adopts the code FRACMAN 7.7 (Golder Associates Inc., 2018), which creates synthetic distributions of heterogeneous fractured media based on stochastic distributions of parameters such as fractures lengths, orientations and apertures. The MAFIC algorithm within FRACMAN is then used to simulate steady-state flow along connected fractures and transport of idealized conservative solutes, injected as in a pulse during a tracer test. Constant head boundary conditions are set to create, under homogeneous conditions, a uniform flow field. Only advective transport is considered in this first stage of testing. Transport is resolved using a particle tracking scheme, from which a bundle of 10000 particles is injected in the upstream boundary. The travel time of the particles exiting the system from the downstream boundary is used to determine the solute breakthrough curves (BTCs). The shape of the BTCs is compared with the resulting geoentropy metric H_R (Bianchi and Pedretti, 2017), calculated from the distribution of equivalent porous media resulting from the upscaling of the fractured media to a gridded mesh.

RESULTS

It was found that the shape of the BTCs matches qualitatively the expected distribution of geoentropy metrics for different sets of systems. Low geoentropy index H_R is found for systems displaying higher tailing and that show more connected features than systems with higher H_R and more symmetric arrival times of particles. This is conceptually similar to what found in previous studies on porous media (Bianchi and Pedretti, 2017, 2018), as the tails are influenced by the interconnectedness of the fractures (i.e. preferential flow and channelled transport in porous media) as well as the global variability of Y (low variability of Y means more homogeneity of the velocity fields).

CONCLUSIONS

The results provide insights into the potential use of geoentropy for interpretation and predictions of transport in fractured media. The emerging analogies between fractured and heterogeneous porous media (such as the channelled flow and transport along preferential, well-connected zones) provide the basis to explore more into detail the relationship between geoentropy indexes and the physical properties (e.g. fracture topological statistics) of the subsurface.

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Groundwater flow in the Ischia volcano and implications of thermal water withdrawals

Vincenzo Piscopo[1], Francesca Lotti[2], Luigi Lana[2]*

[1] *Università degli Studi della Tuscia, Dipartimento di Scienze Ecologiche e Biologiche, Viterbo, Italy.*
**Corresponding email: piscopo@unitus.it*

[2] *Kataclima S.r.l., Vetralla (VT), Italy*

ABSTRACT

The conceptual hydrogeological model of the volcano has been updated. It results that the structural setting and wide variety of stratigraphic units are the key factors affecting groundwater circulation in the active volcano. The assessment of the impacts of groundwater withdrawals on the island's hydrogeological system is complicated by interactions of fluids having different origins and composition (meteoric recharge, deep fluids and seawater) in heterogeneous aquifers. The massive pumping supplying the numerous thermal plants present in coastal areas determines the maintenance of quality of the water captured by the wells.

Keywords: volcanic aquifer, thermal water, Ischia

METHODS

This study is aimed to improve the knowledge on the hydrogeology of Ischia combining previous published and unpublished data with new data collection, analysis and processing. The main objectives are to review the conceptual hydrogeological model of the volcano and to examine the present impact of massive withdrawals on the island's groundwater resources.

RESULTS

In the small volcanic island of Ischia, located in a high heat flux zone (about 500 mW/m^2), the structural setting and wide variety of stratigraphic units are the key factors affecting groundwater circulation in the shallow aquifers.

In the resurgent block of Mt. Epomeo, an independent and uplifted basal groundwater circulation compared to the remaining part of the island can be inferred. The marginal faults of the resurgent block constitute the hydrogeological boundaries of this part of the island's aquifer: they represent the preferential ways of ascending deep fluids and partial barriers to the basal groundwater flow from inside to outside.

In the peripheral areas of Mt. Epomeo, groundwater flow is mainly influenced by the nature of the aquifer formations. In the northern, western and southern areas, a continuous basal aquifer and local discontinuous perched aquifers can be distinguished. In the north-eastern area, a single and continuous basal aquifer with the highest permeability in the island results. In these peripheral areas of Mt. Epomeo, the flow and the chemical characteristics of the waters of shallow aquifers depend

not only on natural phenomena but also on the massive groundwater withdrawals supplying the numerous thermal establishments present there.
In natural conditions, the entire hydrogeological system of the island is recharged by infiltration (a total of about 250-290 L/s) and by bottom from deep fluids (at least 90 L/s), and discharge towards the sea and the springs. In the coastal zones of the island, when the pumping from some hundreds of wells is active (a total flow around 600 L/s was estimated during the peak season), a further and significant recharge of the shallow aquifers derives from seawater and from upwelling increase of deep fluids. Although this does not compromise the sustainability of the groundwater withdrawals in quantitative terms, the pumping determines the quality of the water captured by the wells.

CONCLUSIONS

The great variability in the chemical and isotopic compositions of groundwater, explained in the literature as mixing among different end-members (meteoric water, seawater and thermal end-members), is also due to local hydraulic parameters of the aquifers, discharge rates, depth and characteristics of wells from which the water is sampled. The maintenance of quality of thermal waters, as well as their use for an effective volcanic hazard monitoring, cannot disregard the overall control and regulation of flow rate and duration of pumping in the hydrogeologically different sectors of the island.

Grey-box data driven based method for karst spring discharge evaluation

Giuseppe Sappa[1], Francesco Maria De Filippi[2], Silvia Iacurto[1], Gerardo Grelle[1]*

*[1] Università degli Studi di Roma La Sapienza, Dipartimento di Ingegneria Civile, Edile e Ambientale (DICEA), Roma, Italy. *Corresponding email: giuseppe.sappa@uniroma1.it*

[2] Università degli Studi di Roma La Sapienza, Centro Reatino di Ricerche in Ingegneria per la Tutela e la Valorizzazione dell'Ambiente e del Territorio (CRITEVAT), Roma, Italy

ABSTRACT

Nowadays a sustainable management of the groundwater resource is increasingly prominent. Most of groundwater in Central Italy, as in the whole Apennine Mountains chain, is stored in karst aquifers. In the last decades, the most important water resources in Italy are affected by groundwater depletion mostly due to the increasing of anthropogenic activities and the impacts of climate changes. Due to the limited information on temporal patterns of spring discharge in many areas of Italy, the spring discharge forecasting could be a useful tool to predict water lack. Several research studies proposed methods based on relationships between spring discharges and rainfall data. The goal of this paper is to determine the primary factors that govern spring discharge patterns and to develop a grey-box model to evaluate spring discharge.

Keywords: karst spring, groundwater, discharge modelling, water management

METHODS

In the field of simulation models, hydrological physically models are based on physical laws. Equations can be solved by analytical or numerical procedures. Data-driven approaches, instead, do not rely directly on explicit physical knowledge of the process, but they build a purely empirical model based on relationships between input and output variables. Many approaches proposed to analyze the relationships between the rainfall time series over the recharge area and the spring outflow. Research studies, concerning karst springs, employed time-series analysis studying transfer function between rainfall and spring discharge, obtained by black-box models. These ones are often based on continuous and discrete wavelet analysis (Hadi and Tombul, 2018; Salerno and Tartari, 2009), cross-correlation analysis (Fiorillo and Doglioni, 2010; Chiaudani et al., 2017), or machine learning models such as artificial neural network (Granata, F., Saroli, M. et al. 2018). Other approaches for karst spring flow rate evaluation are based on water chemical tracers, due to the difficulty in karst aquifer modelling (Sappa et al, 2017).

In this paper, primary factors governing spring discharge patterns related to rainfall input are modelled by a grey-box model.

The model uses monthly rainfall (P_{-1}, P_{-2},…, P_{-k}) and temperature (T_{-1}, T_{-2},…, T_{-k}) time series as input data. The first step of the pre-processing procedure in order to take into account derived trend and the processed data magnitude. In addition, in order to take into account the evapotranspiration

phenomenon, the temperature values are used in the preliminary non-linear normalization of the effective rainfall.
Input and output data are supposed to be related by a linear relationship having a polynomial form, where the progressive variables, P_i, are the previous monthly rainfall data.
A long time series of available data (at least 60 months) is necessary for the algorithm training in which monthly average flow rates (Q_i) must be known for the first phase of coefficients determination. Subsequently, the model frees from flow rate values validating the accuracy of discharge estimation on a different time window.

RESULTS

The proposed model was applied to several springs of Central Italy, obtaining reliable results. The comparison between estimated (blue line) and measured (green line) discharges of Lupa Spring, in the training window, is presented below (Fig. 1).
It is quite evident the good fitting, especially on the minimum flow rate value, which is the main parameter in the water demand management.

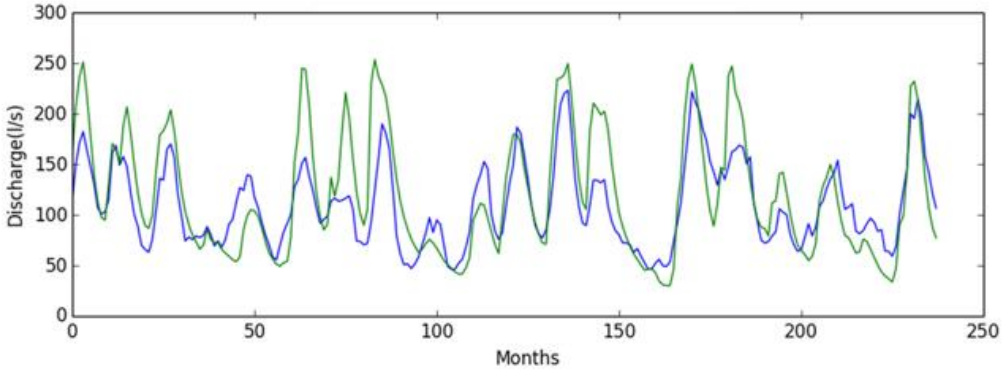

Fig. 1 - Estimated and measured discharges comparison in the training time window (Lupa Spring)

CONCLUSIONS

The presented work highlights the role of the spring discharge prediction and its key role in spring water management, mainly during the dry periods. The model is only rainfall dependent, partially based on the physical nature of the process. Results show that the model is able to evaluate spring discharge data with a satisficing fit. In addition, the case study of the Lupa Spring represents an embryonal phase, in which the improved model will be the core of a computerized self-learning predictive tool for spring discharge management and governance.

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Discharge measurements based on tracer dilution method applied to the hydrogeological study of karst springs in the Mount Albo area (Sardinia NE)

Antonio Maria Sessini[1], Francesco Sanna[2], Giorgio Ghiglieri[1]*

*[1] Università degli Studi di Cagliari, Dipartimento di Scienze Chimiche e Geologiche, Monserrato (CA), Italy. *Corresponding email: antoniosessini@tiscali.it*

[2] Regione Sardegna, Nuoro, Italy

ABSTRACT

This study is focused on the main spring of the karst aquifer of Mount Albo situated in the area of Siniscola, in the province of Nuoro (Sardinia NE). It was developed for the sustainable management of groundwater resources in accordance with current laws: Law n. 183/89, Law n. 36/94 and by Legislative Decree n. 152/2006. The Groundwater of Mount Albo's aquifer is a great relevance resource for the territory and requires studies and safeguards to preserve its quality and quantity. Mount Albo is a mountain chain elongated for about 30 km along the main direction NE-SW and it's formed by middle Jurassic to lower Cretaceous Limestones and Dolostones, that have been intensely karstified. The aquifer is confined at the base and sideways by the Hercynian Metamorphic Basement. The principal aim of this study was to develop a methodological approach to discharge measurements with the use of tracers. Discharge measurements were performed to improve the knowledge of the karst aquifer. This survey was also used to produce a preliminary rating curve peculiar to the main karst spring of Fruncu 'e Oche in the northeastern part of Mount Albo. Tracer Dilution Method for stream gauging, known since 1863 (Spencer and Tudhope, 1958), has been used with both chemical and radioactive tracers. This technique has increased significantly after the development of fluorescent dyes (Kilpatrick and Cobb, 1985). Recently it has been successfully applied both with saline tracers (Moore, 2004) and with Fluoresceine (Dahlke, 2014; Schnegg et al., 2011). In this survey we have conducted discharge measurements with the tracer dilution method. This procedure consists in the injection of a tracer solution at a specific point upstream and in the measurement of its dilution in the water flow at a known point downstream with field sensors. Tracers used were salt (NaCl) and Fluoresceine dye, also known as Uranine. We used the following Injection techniques: Slug Injection and Constant Injection. In the first method a specific mass of tracers is poured at once into the stream and it is based on tracer's total recovery principle according to which the mass injected into the stream at the injection point must flow all through the measuring point downstream without tracer losses. The second technique, based on the achievement of the steady state, consists in the constant rate injection of tracer solution into the stream by making use of a Mariotte Bottle. Different sensors operated to detect the tracer and register the related time-concentration curve. STS Multi-parametric sensors were used for the saline tracer measurement, Sommer Messtechnik sensors and GGUN-FL-30 fluorometric sensors were used for Fluoresceine. During the observation period 69 discharge measurements were performed with the tracer dilution method; most of them were obtained with the Slug Technique (Fig.). The least used method was Constant Injection because of some complications in the achievement of the steady state due to low turbulence and water turbidity. Therefore, the results observed with the slug injection technique using salt and Fluoresceine tracers

have been compared. Regarding to the medium value as the most accurate, a relative error of less than 2% occurred among these results due to the lack of an absolute reference value. To conclude, despite non-ideal conditions and the relative error, the discharge measurements obtained can be considered more accurate than a merely visual estimation and confirm the good reliability of this method. In the future, the implementation of a weir for continuous flow measurements will allow a more refined approach to the dilution method for stream gauging with the estimation of absolute error.

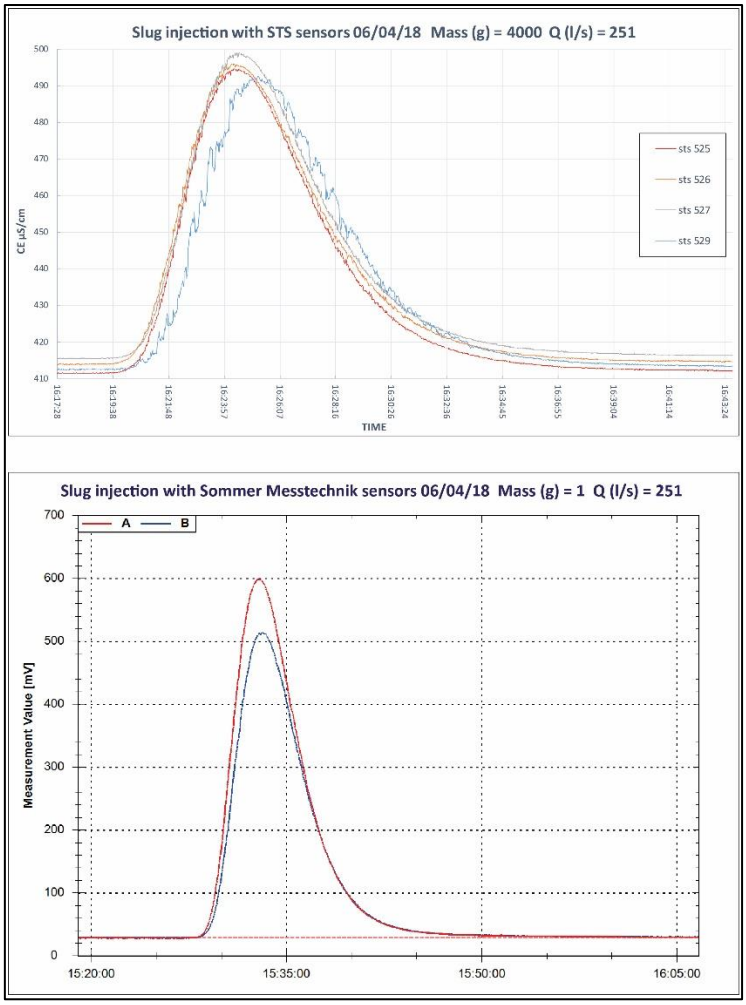

Fig. 1 - Examples of Slug Injections graphs with saline tracer and Fluoresceine dye

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A detailed geological reconstruction as a tool for the reliable numerical model implementation: The Euganean Geothermal System case study (NE Italy)

Filippo Torresan[1], Leonardo Piccinini[1], Paolo Fabbri[1], Marco Pola[2], Mauro Cacace[3], Dario Zampieri[1]*

[1] Università degli Studi di Padova, Dipartimento di Geoscienze, Padova, Italy.
**Corresponding email: filippo.torresan.1@phd.unipd.it*

[2] Croatian Geological Survey, Department of Hydrogeology and Engineering Geology, Zagreb, Croatia

[3] Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Telegrafenberg, Potsdam, Germany

ABSTRACT

In the twenty-first century the use of natural geothermal resources is significantly increased and their renewability help the reduction of greenhouse gases emissions and the human footprint. A strategy for the sustainable utilization and exploitation of these resources is required in order to preserve them for the future generations. A reliable way to evaluate the future exploitation scenarios is represented by the numerical models in which the geological features of the geothermal system are considered. This approach is used in the case of the Euganean Geothermal System (EuGS) in which approximately 150 wells are active and exploit an amount of 14.9×10^6 m^3 of thermal water per year with a temperature between 63°C to 87°C.

Keywords: Euganean Geothermal System, geological reconstruction, unstructured mesh

METHODS

The Euganean thermal water represents one of the most important water-dominant, low-enthalpy geothermal resources in the southern Europe (Fabbri et al., 2017). It is exploited in the Euganean Geothermal Field (EuGF), located to the SW of Padova (Veneto Region, NE Italy). It covers an area of about 25 km^2 and represents the outflow area of the EuGS that extend for about 100 km in the central part of the Veneto Region. Balneotherapy and recreational purposes are the main utilizations of the thermal water and the related tourism industry produce an income of about 300 million € per year (Fabbri et al., 2017). These data testify the important role played by this natural resource on the economy of the Veneto Region. Consequently, numerical models will be used both to evaluate the renewability of the geothermal system and to define plans for the sustainable exploitation in order to be able to preserve it for the future generations.

The reliability of the results of a hydrogeological numerical model is strictly related to the robustness of the implemented geological setting. In order to represent the main geological features that characterize the analyzed geothermal system with a good resolution, a detailed geological reconstruction was performed. The modelled area was set to 115 km long and 50 km wide while the depth was set to 9 km. Deep wells data, some of which reach depth greater than 4 km, were used to define the geological units that characterize the study area and their spatial continuity. The geological

formations were subdivided into 8 chronostratigraphic units taken into account their hydraulic proprieties. This discretization was used in order to redefine all the available geological sections that were implemented into the MOVE software in order to perform a geological reconstruction.
With the aim to preserve the geometry of both geological units and faults into the hydrogeological numerical model, an unstructured mesh was employed. This is a particular aspect because the modeled system is characterized by a complex structural setting that allow the development of the geothermal system. The unstructured mesh was built through the use of the open-source software MeshIt (Cacace and Blöcher, 2015).

RESULTS

The unit's discretization utilized for the geological reconstruction is constituted by: (i) Pre-Permian phyllites and micashists; (ii) Permian clastic and evaporitic-carbonate rocks; (iii) Early Triassic to Middle Triassic dolostone and limestones rocks; (iv) Late Triassic Dolostone; (v) Lower Jurassic to Lower Cretaceous limestones; (vi) Upper Cretaceous to Eocene marly-limestone; (vii) Eocene to Miocene clastic rocks, secondary limestone and mudstone, interrupted by Paleogene volcanic bodies; (viii) Quaternary cover, usually alluvial sediments. In particular, the units (iii) and (iv) host the thermal water reservoir.
The performed geological model of the EuGS was validate through the use of deep wells data and geological sections that were not used during the geological reconstruction. In addition, the model validation was also performed through the comparison with different works in which the complex geological setting of the modeled area was detailed discussed (Fantoni and Franciosi, 2010; Pola et al., 2014). Finally, the geological model was used to validate the proposed hydrogeological conceptual model (Pola et al., 2015) taken into account the real distribution of the geological units in the entire domain. Subsequently, through the use of the MeshIt software, an unstructured mesh of the geothermal system was performed. This mesh is constituted by an amount of 5.428.339 tetrahedrons.

CONCLUSIONS

The use of numerical simulations in geothermal systems can be a useful tool to assess sustainable exploitation and management of a geothermal system. In order to obtain a reliable numerical model, a detailed geological reconstruction of the analyzed system is required. The results achieved by the geological reconstruction of the EuGS are useful to explain the main geological processes that allow the development of this geothermal resource. The related unstructured mesh will be implemented into the Feflow software in order to carry out coupled simulations of fluid flow and heat transport. This represent an important step for the assessment of a management plan for the sustainable utilization and exploitation of the Euganean thermal waters.

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Karst connectivity identification: combining a long-lasting cross-hole hydraulic test and the stochastic inversion for large-scale aquifer characterization

Michela Trabucchi[1,3], Daniel Fernàndez-Garcia[1,3], Jesús Carrera[2,3], Xavier Sanchez-Vila[1,3], Alvaro Hernandez[4], Corrado Torre[4]

*1 Universitat Politècnica de Catalunya (UPC), Department of Civil and Environmental Engineering (DECA), Barcelona, Spain. *Corresponding email: trabucchi.michela@gmail.com*

2 Institute of Environmental Assessment and Water Research (IDAEA), CSIC, Barcelona, Spain

3 Associated Unit: Hydrogeology Group (UPC-CSIC)

4 Sociedad Química y Minera de Chile (SQM)

ABSTRACT

The preservation of groundwater resources is mainly influenced by flow and transport dynamics that in turn, depends on the heterogeneity of the porous medium. In particular, it is growing the interest for the role that connectivity structures play in the characterization of heterogeneity, as these features are extremely important for the hydraulic behaviour of a system (Renard and Allard, 2013). In evaporitic brine filled aquifers (as salt flats of the Central Andes), the connectivity is mainly due to dissolution structures (wormholes), which are key elements to be identified as they may affect the system in both environmental and economic terms. In this context, we want to characterize the structure, heterogeneities and hydraulic properties in the Salar aquifer at the large scale (tens of Kms). More specifically, we ask the question of whether it is possible to characterize the large-scale hydraulic connectivity structure of such system with a cross-hole hydraulic test combined with the stochastic inversion problem.

Keywords: heterogeneity, cross-hole hydraulic test, stochastic inversion, connectivity, scale effect

METHODS

To reach our goals we first carried out a long-lasting cross-hole hydraulic test, continuously monitoring the response in the whole aquifer. Once the data is filtered, we developed a flow numerical model and applied the stochastic inversion (Alcolea et al., 2006) to understand the aquifer heterogeneity. As the inverse problem solution is non-unique, independent data (e.g. isotopes and mixing ratios) are compared with the model outputs in order to better identify the most reliable solutions. Still, to analyse the scale effect we collect data relative to local scale measurements (packers and hydraulic tests), comparing the different sets with model outputs.

RESULTS

The outputs of the combined application based on cross-hole hydraulic test data and the stochastic inversion problem are analysed. We obtained good fittings and low objective function values, which reflect the quality of the models. Remarkably, the estimated hydraulic conductivity fields (from both conditional estimation and conditional simulation) show the presence of high conductivity zones characterizing the domain. The comparison with independent data display consistency. Finally, examining the estimated permeability sets at different scales, we observed a marked scale effect of the hydraulic conductivity up to the regional scale.

CONCLUSIONS

The combined methodology allowed us to reproduce and capture the overall behaviour of the system. Estimated fields and independent data allowed to make reliable assumptions on the existence and location of high conductivity zones. Still, the observed scale effect suggests that the aquifer is probably characterized by preferential flow zones that control the flow dynamics at large scale.

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Hydrologic balance estimation in the Mucille (NE Italy) test site

Philippe Turpaud[1], Luca Zini[1], Chiara Calligaris[1]*

[1] Università degli Studi di Trieste, Dipartimento di Matematica e Geoscienze, Trieste, Italy.
**Corresponding email: calligar@units.it*

ABSTRACT

The Mucille area (Ronchi dei Legionari, Northeastern Italy) is subject to frequent flooding after abundant precipitations. Although this area has always been exposed to such hazard, these inundations become problematic since 2001 as they more frequently affect housing and recreational areas, leading the population to believe that the swallow holes draining the area stopped functioning. The increased frequency of intense rainfall events led the municipal technicians to involve the Department of Mathematics and Geosciences of the University of Trieste to assess the situation. The Mucille karstic depression is fed by a spring area and drained by two swallow holes one of which is permanently active while the other functions only during floods. The Mucille springs represent the westernmost drain of the Classical Karst aquifer (Cucchi et al., 2015; Zini et al., 2013). About 24 hours after the onset of heavy rains, the whole depressed area is flooded. About 8 days later, the water level begins to decrease, coming back to its initial height in about fifteen days.

Keywords: hydrologic budget, karst area, flooded residential area, hazard

METHODS

During floods, while springs and swallow holes discharges measurements are impossible, the extension of the flooded areas has been mapped. The obtained flooded surface together with high resolution DEM coverage allows to calculate the volume of surface water. Combined with water table levels registered in an adjacent piezometer, this volume can be computed over time. Consequently the hydrologic balance (inflow minus outflow) can be estimated during the whole event (Fig. 1).

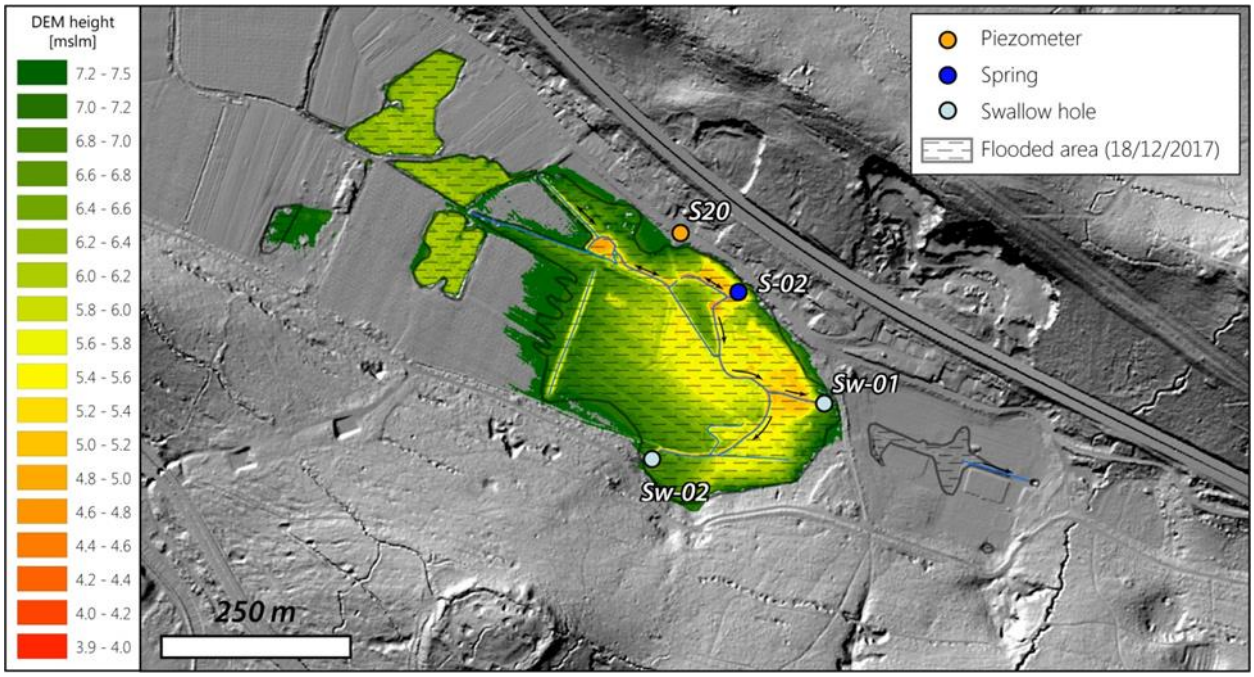

Fig. 1 - Elevation model of the Mucille depression. The observed flooded area validates the use of the DEM for volume calculation. The volumes extracted from DEM permit the elaboration of a hydrologic balance model.

RESULTS

The first day of the flood that occurred during December 2017 (100 mm of rain in less than 48 hours), the difference between the inflow and the outflow averaged about 900 l/s. The following day it decreased to 280 l/s. The next 5 days the water balance was close to equilibrium. From the eighth day on, outflow became predominant resulting in a negative budget between -240 and -80 l/s.

CONCLUSIONS

This study provides evidences fundamental for the design of measures to mitigate the risk. It estimates the discharge of the swallow holes, confirming their efficiency. Nonetheless it also emphasises the need to improve their draining capacity, especially considering the unsuspected high outflow of the springs at the onset of the flood.

Acknowledgements

Studies and research have been funded by Ronchi dei Legionari municipality in the framework of the agreement with the DMG finalized to reconstruct the hydrogeological model of the Mucille di Selz park area.

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The lateral groundwater exchanges from Mt. Maggiore aquifer and Riardo Plain hydrogeological system

Stefano Viaroli[1], Emilio Cuoco[2], Lucia Mastrorillo[1], Vittorio Paolucci[3], Dario Tedesco[2], Roberto Mazza[1]*

[1] *Università degli Studi Roma Tre, Dipartimento di Scienze, Roma, Italy.*
**Corresponding email: stefano.viaroli@uniroma3.it*

[2] *Università degli Studi della Campania, Luigi Vanvitelli, DiSTABiF, Caserta, Italy*

[3] *Ferrarelle S.p.A., Riardo (CE), Italy*

ABSTRACT

The results of recent hydrogeological researches highlighted the presence of an approximately 500 L/s lateral inflow in the Riardo Plain aquifer from the surrounding carbonate ridges (Viaroli et al., 2018; 2019). One of the possible sources of groundwater could be the Mt. Maggiore ridge, which bounds the Riardo Plain at south.

The carbonate hydrostructure of Mt. Maggiore (approximately 100 km^2) is able to store 4.6 m^3/s, 3.6 m^3/s of which flows out in correspondence of the Triflisco and Pila springs (Boni et al., 1986). The destination of the remaining 1 m^3/s of groundwater is still matter of debate. The aim of the present investigation is to increase the knowledge about the hydrogeological settings of Mt. Maggiore and to identify the presence of lateral groundwater exchanges between the fractured aquifer and the surrounding plains.

Keywords: carbonate aquifer, groundwater budget, regional hydrogeology

METHODS

A detail hydrogeological survey has been carrying out since June 2018 with the aim of monitoring the possible natural outflows from the Mt. Maggiore aquifer.

Discharge measurements were monthly performed on the Triflisco and Pila springs and on the Savone River, in the stretch flowing in correspondence of the western boundary of the Mt. Maggiore ridge. Fifteen discharge sections where fixed for the seasonal measurement of the baseflow. Detailed hydrogeological survey on wells and springs is still ongoing and it is covering both the carbonate structure and the surrounding plains.

Simultaneously a chemical and isotopic monitoring of the groundwater has been proceeding. Chemical analyses are made on the groundwater samples collected from wells and springs. Groundwater sampled from wells and springs have been analyzing for major and trace elements.

Monthly isotopic analysis (^2H and ^{18}O) are executed on rainwater samples collected at different elevations (approximately 530 and 300 m a.s.l.) and on groundwater samples collected from 4 wells and 4 springs located along the boundaries of the Mt. Maggiore structure.

The experimental data are also integrated with the geological, hydrogeochemical and isotopic information available in the previous researches carried out in this area.
In the next steps, the managing water authorities for drinking and irrigation proposes working on the Mt. Maggiore aquifer will be engage in order to evaluate the use of the groundwater resource

RESULTS

Despite to the data acquisition phase is still in progress, it is possible to define some preliminary results that will have to be confirmed by the development of the research

- The Triflisco spring, monitored from June 2018, is characterized by a mean discharge of approximately 1850 L/s with standard deviation of approximately 150 L/s.
- The Pila spring is dried due to the activity of the well field, located upward on the southern flank of the Mt. Maggiore. Groundwater outflows were still detected downstream the original spring with a mean discharge of approximately 300 L/s.
- 3 streambed springs were identified along the Savone river, but the recharge dynamics are still uncertain
- The hydraulic head measurements allowed to define different aquifer levels probably related to the presence of different aquifer sections inside the carbonate structure.
- The sampled groundwater showed similar facies and did not highlight differences on the chemical composition.
- The results of the isotopic analyses will give precious information only after a year of monitoring.

CONCLUSIONS

The preliminary phase of the research does not allow the definition of significant conclusions. The first hydrogeological evidences suggest, anyway, the presence of different sections of the Mt. Maggiore aquifer and different discharge directions.
A deeper aquifer feeds the basal spring of Triflisco (approximately 30 m a.s.l.), whereas an upper circulation probably flows northward toward the Riardo Plain at an elevation of approximately 110 m a.s.l.
This interpretation needs to be validated in the next steps by the isotopic results and by the structural analysis of the fractured aquifer.

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Identification and characterization of the karst areas of the Friuli Venezia Giulia Region (NE Italy)

Luca Zini[1], Chiara Calligaris[1], Furio Finocchiaro[1], Paolo Manca[2], Chiara Piano[2], Michele Potleca[3], Maurizio Ponton[1], Luca Terribili[1]*

[1] Università degli Studi di Trieste, Dipartimento di Matematica e Geoscienze, Trieste, Italy.
**Corresponding email: zini@units.it*

[2] Servizio Geologico, Direzione centrale ambiente ed energia, Regione Friuli Venezia Giulia, Trieste, Italy

[3] Protezione Civile Regione Friuli Venezia Giulia, Italy

ABSTRACT

According to Derek and Williams (2007) a karst area can be defined as an area comprising terrain with distinctive hydrology and landforms that arise from a combination of high rock solubility and well developed secondary (fracture) porosity. These areas are characterized by epigean and hypogean karst features. The Department of Mathematics and Geoscience of the University of Trieste and the Geological Service of the Friuli Venezia Giulia Region have developed a multi-year project with the aim of identifying and outlining the regional and cross-border karst areas and karst aquifers.

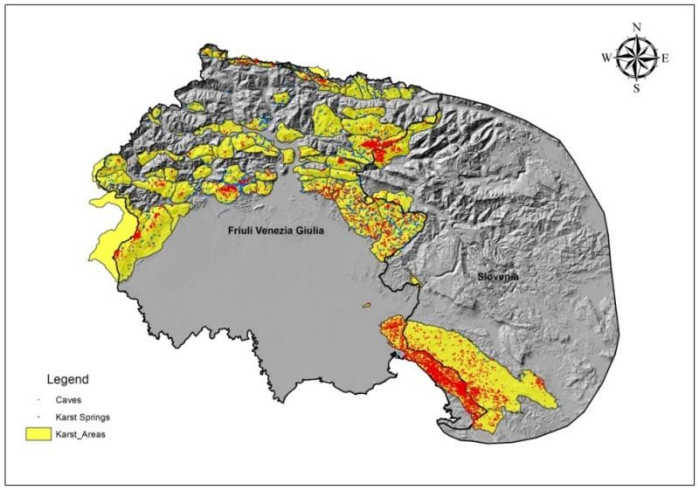
METHODS

In order to create and apply a protocol allowing to outline the karst areas, three different criteria were defined. The presence of karstifiable lithologies is the main discriminant, and in the Friuli Venezia Giulia Region (FVGR), carbonates represent the 40% of the whole entire regional territory. The second criteria is morphological. The outlie of the karst areas has been realised in those areas where epigean and hypogean karst features are present. For the entire region, a database containing all the data regarding the presence of caves is available. Thanks to the active speleological groups, in the FVGR during the last fifty years 8000 caves have been identified and inventoried. Concerning the epigean karst features, thanks to the DTM at 1m of resolution available for the whole regional territory, every single identified karst area, has been verified analyzing the surface morphology. In several areas sinkholes and dolines were recognized as well as other surface morphologies. The last criterion used has been the hydrogeological one: springs in karstifiable lithologies or close to them are a promising indicator of the presence of conduits or fractures characteristics of karst aquifers.

RESULTS

During the first year of the project 121 karst areas were preliminarily identified and outlined for a total surface of 3120 Km^2 corresponding respectively to 40% of the total area and to 64% of the area of the mountain territory of the FVGR. The karst areas in carbonate lithologies (69 areas) cover an area of 2691Km^2 equal to 34% of the regional territory and 55% of the mountain territory, those where evaporitic lithologies outcrop (45 areas) spread over 66 Km^2 equal to 0.84% of the regional territory and 1.4% of the mountain territory while those not purely karstic (7 areas) cover the 4.6%

of the regional territory and 7.4% of the mountain territory with a surface of 361Km^2. 2601 karst springs were also identified with variable discharges from a few liters per minute up to more than a hundred of m^3 per second.



CONCLUSIONS

The identification of karst areas and aquifers is a first important step for the development of future projects aimed at the protection of karst aquifers and their potential hydro potable exploitation. These type of aquifers are particularly vulnerable to pollutants because of their specific characteristics, first of all the high permeability, the low filtration capacity and the high flow rates velocity. Characteristics that allow pollutant dissolved in water to travel long distances in short periods thus putting the quality of the water resource at risk.

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Contaminated Sites

Conveners:

Prof. Domenico De Luca (Università degli Studi di Torino)

Dr. Michele Pellegrini (Syndial S.p.A.)

Dr. Ivana La Licata (Politecnico di Milano)

Modelling contaminant transport in geological media: challenges and perspectives

Marco Bianchi

British Geological Survey, UK

KEYNOTE LECTURE

Numerical modelling of solute transport processes in the subsurface is still used in a wide range of engineering applications such as the design of remediation strategies for groundwater pollution or risk assessments of the impact of human activities on groundwater quality. These applications rely heavily on producing accurate predictions of transport behaviour, which is a difficult task especially in geologic media. The talk will briefly discuss the challenges concerning solute transport modelling in this type of media, with a focus on the sources of uncertainty affecting predictions. These sources include conceptual model uncertainty, input parameter uncertainty, and the uncertainty related to the choice of the mathematical model. Examples from published works will be presented to suggest possible ways to reduce the effect of these uncertainties and significantly improve predictability.

Methodological approach for the assessment of groundwater contamination by transition metals leached through waste rock dumps: the C.na Pecorara muck dump site case study (HV/HC "Terzo Valico" project)

Alessandro Baietto[1], Paolo Perello[1], Alberto Scuderi[2], Luigi Marini[3]*

[1] GDP Consultants – Engineering Geology, Saint Christophe (AO), Italy.
**Corresponding email: baietto@gdpconsultants.eu*

[2] Consorzio COCIV – Consorzio Collegamenti Integrati Veloci, Genova, Italy

[3] STEAM S.r.l., Pisa, Italy

ABSTRACT

A methodological approach for the risk assessment of the potential contamination of groundwater by transition metals leached through waste rock dumps is presented. The method, which includes the execution of sequential extraction tests on transition metals, chemical speciation studies, reaction path modelling and hydrogeological mass transport modelling in both the unsaturated and saturated aquifer zones, has been successfully applied to the C.na Pecorara muck dump site in the context of the HV/HC "Terzo Valico" project (within the Rhine-Alpine corridor of the Trans European Network-Transport).

Keywords: dump sites, transition metals, reaction path and mass transport modelling

METHODS

The groundwater migration of transition metals, also commonly termed as "heavy metals", leached from mucks disposed in dump sites is a process that requires a detailed analysis in the framework of the environmental impact studies. In this context, it is important to thoroughly examine the risks of potential contamination of pre-existing groundwater wells and, more in general, to assess the risk of qualitative deterioration of nearby shallow aquifers. A reliable assessment of the contamination risk must consider the fate of the leaching metals, since they are generated by the interaction of meteoric waters with the excavated muck material, until they percolate in the vadose zone and continue their migration and dispersion in the saturated zone of the aquifer.

The proposed methodological approach includes the accomplishment of speciation studies of the transition metals, reaction path modelling and hydrogeological mass transport modelling in both the unsaturated and saturated aquifer zones. To apply the proposed method, valid both for natural and backfill materials, it is necessary to carry out a set of chemical analyses on the muck material, including sequential extraction tests. The discussed method is applied to the C.na Pecorara quarry in Tortona (AL), which is the disposal site of the debris produced by the excavation of one of the tunnels being part of the HV/HC "Terzo Valico" project. This study has been carried out to evaluate the hazard that the wells adjacent to the disposal site might be contaminated by Chromium VI, Nickel and Cobalt resulted from leaching and percolation of meteoric waters that interacted with the disposed muck material.

RESULTS

In the C.na Pecorara case study, the accomplishment of sequential extraction tests and the speciation of transition metals were used to implement a simulation of the reaction path process governed by the kinetics of dissolution of primary solid phases and precipitation of secondary solid phases. The reaction path modelling helped to define the temporal fate of Chromium VI, Nickel and Cobalt (Figure 1A). Combining these results with the simulation of the seepage process in the vadose zone it was possible to determine the time period after a leachate starts percolating in the unsaturated zone down to the groundwater surface (Figure 1B). Finally, the transitional groundwater flow and transport contaminant modelling was used to define the fate of the plume of contaminants, allowing to exclude the occurrence of a risk of contamination of potable groundwater wells by these metals, even after long-lasting periods (Figure 1C).

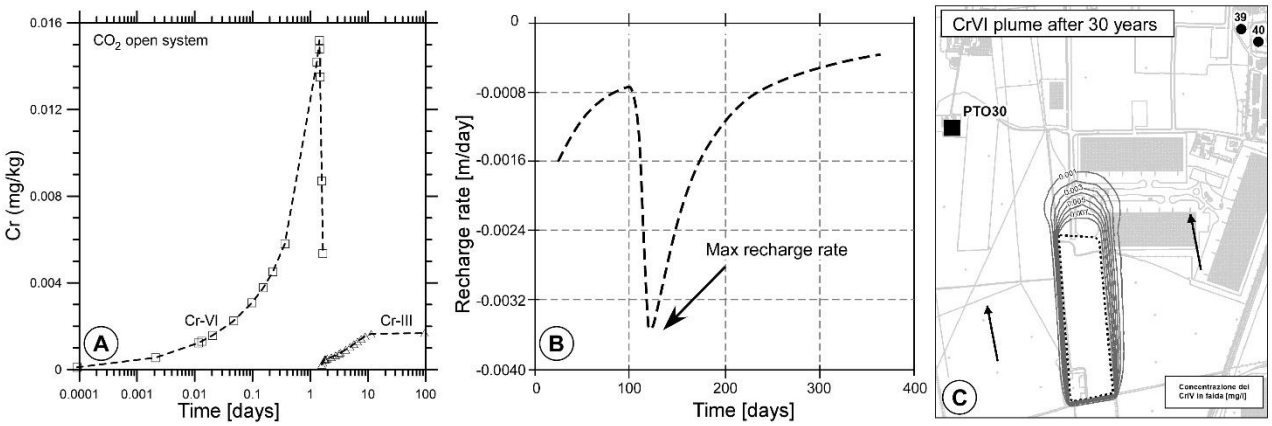

Fig. 1 - A: evolution of the Cr-VI concentration after the reaction path modelling, B: groundwater recharge rate computed with the seepage modelling of the vadose zone, C: Cr-VI plume after 30 years computed with the groundwater flow and transport contaminant modelling.

CONCLUSIONS

Despite the assumptions and simplifications that might be necessary to undertake the geochemical and hydrogeological modelling, the proposed method allows one to assess the risk of groundwater contamination in a more reliable way compared to the sole application of the leaching tests, which are usually carried out in compliance with the legislation. Therefore, this method can be successfully used, in combination with leaching tests when these are required, to provide a reliable forecast of the potential risk of contamination of groundwater by transition metals (heavy metals) leaching both through natural and backfill materials stored in dump sites.

Assessment of soil buffer capacity on nutrients and emerging contaminants at two blue infrastructures for the provision of water-related agroecosystem services

Alessio Barbagli[1], Benjamin Niklas Jensen[2], Muhammad Raza[2,3], Christoph Schüth[2], Rudy Rossetto[1]*

[1] Scuola Superiore S. Anna – Istituto di Scienze per la Vita, Pisa, Italy.
**Corresponding email: rudy.rossetto@santannapisa.it*

[2] Technische Universität Darmstadt - Institut für Angewandte Geowissenschaften, Darmstadt, Germany

[3] IWW Water Center, Mülheim an der Ruhr, Germany

ABSTRACT

Soil capacity to attenuate pollutants and allowing infiltration is critical for designing and setting up Managed Aquifer Recharge and large scale phyto-treatment schemes. Within this work, the buffering capacity (on nutrients and pharmaceutical compounds) of two soils and its evolution under continuous infiltration of Treated WasteWater (TWW) were evaluated.

Keywords: Soil Column Test, Managed Aquifer Recharge, Phyto-treatment plant, Agro-Ecosystem services, Diclofenac, Carbamazepine

METHODS

Soil samples were collected from two test sites (Sant'Alessio Induced RiverBank Filtration plant, IRBF, Rossetto et al. 2015; and San Niccolò phyto-treatment plant, Rossetto et al., 2014) with large differences in geochemical composition and used as medium in soil column tests. High differences in the behaviour of the two soil were detected, in particularly related to the organic carbon contents (48 % and 0.9 % for the soil from the phyto-treatment test-plant and for the soil from the IRBF plant respectively).

Three columns (50·Ø9 cm) for each soil type were specifically designed to minimize the pharmaceutical adsorption. Secondary Treated WasteWater (TWW) was continuously infiltrated from bottom-to-top with a constant flow of about 0.5 L/d for 6 months. The TWW used for the experiment came from a local wastewater treatment plant, weekly collected and infiltrated. Diclofenac and Carbamazepine were spiked in the input TWW during the last 4th month of the test, to evaluate their adsorption and degradation. Water quality was investigated by means of periodic water sampling from each column. To evaluate the whole dataset and understand the difference between the two soils tested, Principal Component Analysis (PCA) was applied. PCA is a statistical tool to identify pattern and reduce dimension of large variable set to smaller components with minimum loss of original data variation and information.

RESULTS

For some compounds (NH^{4+}, PO_4^{3-}, Fe, Mn, NPOC, SO_4^{2-}) the soil characteristics drastically changed the infiltrating water quality. The PCA allowed to identify the common processes, by grouping

compounds, that significantly influenced the water quality during the filtration process. The buffer effect was different in the two type of soils and for the two pharmaceuticals tested. Diclofenac removal was related to adsorption and degradation processes and it was lower than the buffer of Carbamazepine in both soils. Nevertheless, since no apparent degradation of Carbamazepine was detected in both soils, its persistence in the soil may have a larger impact in case of desorption (Barbagli et al., 2019). Furthermore, changes in time in the buffer effect of the soils were observed during the test, meaning that the soil characteristic were altered.

CONCLUSIONS

The experiments presented here allow getting further insights on soil capacity, related to its physico-chemical characteristics, to buffer peri-urban water related potentially negative effects on the beneficial result provided by MAR and large scale phyto-treatment plant. The results highlight the importance of the soils or sediments to be used as medium in such nature-based solutions for their operations. They also offer an approach to, e.g., tailor man-made soil layers in infiltration basins. We strongly suggest that soil characteristics and test duration are carefully considered in designing these infrastructures, when nature-based processes are the choice for dealing with water management issues.

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Anaerobic and aerobic bioremediation of chlorinated solvents and hydrocarbons plumes from an old landfill in the Venice lagoon environment

Giovanni Pietro Beretta[1], Lucia Cavalca[2], Martina Bertolini[2], Sarah Zecchin[2], Giovanni Buscone[3], Laura Ledda[3], Laura Ferrari[3], Giacinto Carnevale[3], Gerardo Bozzetto[4], Jacopo Terrenghi[5]*

[1] *Università degli Studi di Milano, Dipartimento di Scienze della Terra "A. Desio", Milano, Italy.*
**Corresponding email: giovanni.beretta@unimi.it*

[2] *Università degli Studi di Milano, Dipartimento di Scienze per gli Alimenti, la Nutrizione e l'Ambiente, Milano, Italy*

[3] *Tauw Italia S.r.l., Milano, Italy*

[4] *Nuova Alba S.r.l., Milano, Italy*

[5] *Indipendent geologist, Italy*

ABSTRACT

An old industrial waste landfill with a surface of 16 ha in the surroundings of the Venice lagoon has produced heavy hydrocarbons and chlorinated compounds groundwater contamination. Microbiological and chemical results of a two field tests have confirmed the feasibility of bioremediation and have allowed the facilities design. An organic substrate, able to increase the reductive dehalogenation, was injected and recycled in anaerobic barrier near the landfill; air sparging was performed and nutrients injected in order to increase hydrocarbons degradation in aerobic barrier downgradient. Hydrogeological investigation and microbiological analysis were carried out to verify the effectiveness of the reclamation in anaerobic environment, having achieved chlorinated compounds degradation values of almost 24 kg/day. Further studies are underway to improve the aerobic barrier.

Keywords: bioremediation, contaminated groundwater, chlorinated solvents, hydrocarbons

METHODS

A 16 ha industrial wastes landfill located near the Venice lagoon (Dogaletto, VE) is elevated above ground level to a maximum height of about 11 m a.s.l.. From a geological point of view, the landfill area is characterized by the Mestre Unit and Dolo Unit, i.e. alluvial deposits consisting of sand, silt and clay (Beretta and Terrenghi, 2016; Provincia di Venezia, 2008). Based on many geological and hydrogeological investigations, the conceptual model of subsoil is characterized by an alternation between sandy and silty clay horizons; sandy aquifer horizons have a hydraulic conductivity in the order of 10^{-4} m/s and the aquitards/aquicludes having hydraulic conductivity less than 10^{-8} m/s. The groundwater contamination plume coming from the landfill, covers a surface of 17 ha and is contaminated by high concentration (up to 500-600 mg/l) of chlorinated ethenes and ethanes (CE, CA), BTEX, Chlorobenzenes and total petroleum hydrocarbons (TPH). In anaerobic conditions, highly chlorinated ethenes are easily dechlorinated by bacterial organohalide respiration with the

concomitant accumulation of the more toxic vinyl chloride (VC), which can be metabolically and co-metabolically oxidized in aerobic conditions (Weatherill et al., 2018). The use of sequential anaerobic/aerobic systems has been shown to perform complete degradation of chlorinated ethenes to ethanes. TPH can be efficiently degraded by aerobic bacteria, via sequential oxidative reactions and a final cleavage of catechols that enter TCA cycle. The enhanced bioremediation was tested in series anaerobic/aerobic barriers, respectively for CE,CA and for BTEX, Chlorobenzenes and TPH degradation, directly downstream of the landfill and at end of the plume. The positive outcome of the experimentation in test sites has allowed us to design and implement the plume bioremediation, after the approval of the Public Authorities (PA). Test site was expanded with 390 m long anaerobic barrier to degrade CE and CA by injection (20 wells) and recycle (19 wells) of a redox substrate, and 500 m long aerobic barrier to degrade BTEX, Chlorobenzenes and TPH by air sparging (43 wells), water extraction (18 wells) and water and nutrients recycling (35 wells). The effect of bioremediation on hydrochemistry was monitored by means of piezometers placed upgradient and downgradient the barriers (transects). Microbial populations were analyzed in order to determine the effect of the treatments. Phylogenetic and metabolic biomarkers were monitored on site by quantitative PCR analysis (qPCR) on DNA extracted from groundwater samples and cultivation of TPH degrading bacteria, during two years. The structure of microbial community was analyzed by Illumina NGS technique.

RESULTS

In the anaerobic active barrier, the addition of substrate improved the degradation rate of CE and CA between upstream and downstream until 98%. Chemical data were mirrored by an increment of metabolic genes for reductases: tceA from 10^4 to 10^6 and vcrA from 10^4 to 10^7 gene copy number/L of groundwater, and of organohalide respiring bacteria Dehalococcoides from 10^5 to 10^6 gene copy number/L. After two-year treatment, glucose-fermenting bacteria Bacteroidetes increased with respect to Dehalococcoides genus, indicating that Bacteroidetes were involved in the creation of the reducing power used for reductive dehalogenation. In the aerobic active barrier, where optimal concentration of oxygen have been reached, VC and TPH decreased (from 11’2000 to 310 µg/L and from 500 to 219 µg/L, respectively) although TPH-degrading bacteria were present in the order of 10^1 MPN/L.

CONCLUSIONS

The overall data demonstrate that active CE-degrading bacterial populations were present at the site. The addition of organic substrate improved CE reductive dechlorination as evidenced by chemical and microbiological data, whereas increasing of VC was observed only in certain circumstances due to lacking of injection of substrate, confirming the effectiveness of the system when optimally operated. Efficacy of the anaerobic barrier in the degradation of CE was about 82.5%, ranging between 69% and 98% in the various transects. Low efficacy in the aerobic barrier was likely due to high incoming load and difficulty to revert the environmental from reductive to oxidant. This will be improved with further interventions. The monitoring system led to a significant reduction in the plume

in two years of operation of the barriers. Based on results of Phase 1, a Phase 2 design was submitted to the PA and approved to improve effectiveness of both barriers.

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In situ containment of PFAS in groundwater using Colloidal Activated Carbon

Marcello Carboni[1], Paola Goria[1]*

*[1] REGENESIS, Torino, Italy. *Corresponding email: mcarboni@regenesis.com*

ABSTRACT

With the increasing awareness to the widespread contamination associated with PFOA, PFOS and other PFAS compounds, there is an established need for treatment options that can address the large, dilute plumes that these contaminants commonly form.

At the present time, the accepted remediation method for these contaminants is to use pump and treat systems equipped with activated carbon. The costs associated with running these systems and replacing the carbon can be quite high. For that reason, the ability to implement an in situ barrier of activated carbon that can cut off and contain these plumes for many years with a single application affords a beneficial means to decrease or avoid the operating and maintenance costs of existing above-ground systems. This talk examines the use of a colloidal activated carbon that readily distributes within the subsurface, providing a method for injecting an in situ barrier of activated carbon for PFAS treatment. The same technology can treat efficiently a large variety of organic contaminants in groundwater, such as chlorinated solvents, TPH, BTEXS, PAH, pesticides, etc.

Keywords: colloidal activated carbon, liquid activated carbon, PFAS, PFOA, PFOS, in situ sorption, groundwater, plume treatment, adsorption, innovation

METHODS

Laboratory studies were conducted to measure the adsorption isotherms for PFOA and PFOS with a distributable form of colloidal activated carbon. The isotherm data was then used in an adapted version of the BioChlor model in order to estimate the expected adsorption longevity that a barrier of the colloidal carbon can provide for PFOA and PFOS considering the flux and the concentration. Additionally, a 5m sand column experiment was conducted to determine the ability of the colloidal activated carbon to flow and deposit in an aquifer.

RESULTS

The measured PFOA and PFOS isotherms were fit to the Freundlich equation and the isotherm parameters were determined. The isotherm measurements included a demonstration that a dose of the colloidal activated carbon could reduce 100 μg/L of PFOA and PFOS to below the 2016 revised US EPA health advisory limits of 0.07 μg/L.

Using the measured isotherm parameters within the BioChlor model, it was shown that a 50 μg/L plume of either PFOS or PFOA traveling with a velocity of 37m/yr could be contained and meet US EPA limits with a single barrier of the colloidal activated carbon for up to 8 years.

CONCLUSIONS

The results obtained have allowed to apply successfully the technology on real sites. The final part of the talk will present a case study of the first ever in situ treatment of PFAS on a commercial site in Canada. IN SITU Remediation Ltd used PlumeStop on the impacted site, rapidly removing the PFAS contamination from the groundwater through sorption. The PFAS concentrations have since remained at non-detect for over 15 months, with conservative modelling by Grant Carey of Porewater Solutions estimating that the longevity of the PlumeStop treatment will be 100 years or more.
Data will also be provided from lab tests completed on PFAS impacted groundwater from a European site, with evidence of precursor reduction. Reference will then be made to ongoing applications in North America and Europe.

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TRA-KD: an improved tool for particle tracking simulation based on the Kolmogorov-Dmitriev theory

Alessandro Comunian[1], Gianluca Cannizzaro[2], Francesca Giacobbo[3], Mauro Giudici[2]*

[1] *Università degli Studi di Milano, Dipartimento di Scienze della Terra "A.Desio", Milano, Italy.*
**Corresponding email: alessandro.comunian@unimi.it*

[2] *Gran Sasso Science Institute (GSSI), L'Aquila, Italy*

[3] *Politecnico di Milano, Dipartimento di Energia, Milano, Italy*

ABSTRACT

A great number of particles is required to properly model transport using particle tracking tools based on the Kolmogorov-Dmitriev theory of stochastic branching processes, and this entails high computational costs. These tools would benefit from a high-performance computing environment, but unfortunately the available implementations are not parallelized. Therefore, in this work a novel parallelized particle tracking simulation tool (TRA-KD) is proposed to overcome this limitation and to test and implement more appropriate and efficient algorithms.

Keywords: particle-tracking, Kolmogorov-Dmitriev, Continuous Time Random Walk

METHODS

TRA-KD is implemented in Fortran 95 with a Continuous Time Random Walk (CTRW) approach, and it is parallelized using the Message Passing Interface (MPI) paradigm. The reliability of the results obtained with TRA-KD is verified thought the comparison with analytic solutions of the Advective-Dispersive equation (ADE). In addition, the results of the TRA-KD simulations are systematically compared with the results obtained by a code based on a deterministic implementation of Lagrangian particle tracking. The comparisons between the two codes are performed on diverse case studies, including 1-D, 2-D and 3-D heterogeneous aquifer analogues, ranging from laboratory scale to the aquifer scale. Moreover, a novel approach was implemented to better handle particle transitions along different directions and in 3D, by extending previous approaches (Marseguerra and Zio, 1997; 1998).

RESULTS

The breakthrough curves obtained with TRA-KD are in good agreement with the curves obtained with a deterministic Lagrangian implementation of particle tracking. Nevertheless, some comparisons enlightened the need to handle particles that were trapped when crossing particularly low conductivity regions.

Other simulations tests were also useful to partially explain the asymmetries observed during laboratory experiments (Berkowitz et al., 2009), where the relationship between the diameter of the columns and the grain size of the filling material plays a key role.

Besides, the tests made considering an analytic solution to compare the reliability of the different approaches used to implement cells transitions, demonstrate a clear advantage of the new approach, that takes properly into account the diagonal transitions.

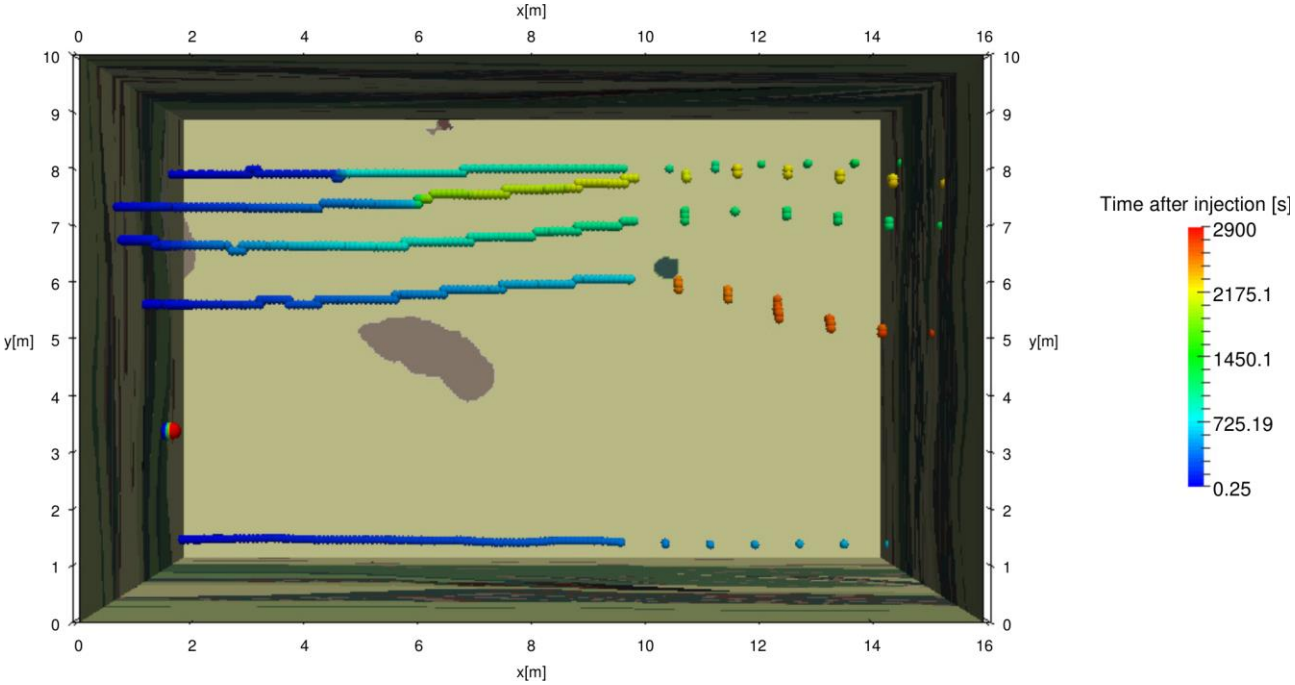

Fig. 1 - Trajectories of particles simulated with TRA-KD within a high resolution aquifer analog

CONCLUSIONS

This work demonstrates the usefulness of the newly developed CTRW particle tracking tool TRA-KD, which provides results comparable with the results of deterministic particle tracking approaches, within a reasonable computation time. In addition it is also demonstrated the applicability of TRA-KD to a diverse range of transport simulation, at different scales and dimensions.

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The 'Polluter Pays Principle': a multidisciplinary approach under legal and technical perspectives

Dario Covucci[1]

[1] *Partner, LCA Studio Legale, Milan, Italy. Corresponding email: dario.covucci@lcalex.it*

ABSTRACT

The 'Polluter Pays Principle' is a cornerstone in environmental law and since 1987 has been set out in the Treaty of the European Communities and in several national legislations. Under this general principle the polluter – *i.e.*, the party responsible for contamination – is under the legal obligation to remedy environment and pay damages suffered by environmental resources. However, experience, at least in Italy, shows that this principle is hard to be implemented and requires multiple competences.

THE 'POLLUTER PAYS PRINCIPLE' IN THE PRISM OF THE CLIENTS' INTERESTS

Legal advisors often provide assistance to clients that may be either polluters or not.

It may happen, on one hand, that a client, when transferring a site (or a company managing a site) that it had contaminated, represented to buyer an environmental situation that resulted to be more serious than disclosed at a later stage; or it has been claimed by public or private entities to have polluted the others' properties; or, which is even worse, is charged of environmental crimes.

In this range of cases, counsel must design a legal defence to prove that the client is not liable for contamination, other entities have polluted the site, or public authorities (or private claimants) have not discharged their burden of proof properly.

On the other hand, the client may be negotiating the acquisition of sites and real properties affected by potential or actual contamination; or it may claim damages and indemnities against the seller that breached environmental warranties; or, again, it wishes to recover remediation costs that it paid in advance and outside a legal obligation.

In this second range of cases, instead, the counsel's effort is even harder: it must help the client both to take legal actions against the polluter, mitigate further contamination events, and build up relationships with public authorities (also to exclude any sort of liability). Furthermore, environmental liability is personal: this means that, even when a site was managed by several operators and in different time periods, counsel must evidence to what extent *each* operator contributed to the same contamination.

WHY ENVIRONMENTAL LAWYERS AND CONSULTANTS MUST WORK TOGETHER

Therefore, it is of the utmost importance that legal and environmental advisors work together to define the best legal and technical strategy consistently with the clients' interests.

There is a variety of scenarios where a multidisciplinary team proves to be highly recommended (if not required):

a) In M&A and real estate transactions involving sites environmental consultants usually carry out an in-depth environmental due diligence (EDD). Lawyers negotiate and draft contracts including environmental representations and warranties and indemnity clauses. Both the advisors must point out critical issues that could result in actual costs, lack of authorizations, potential liabilities (especially third party's claims).

- Definition of a 'baseline' as at the Closing Date allows lawyers to understand the real environmental status, analyse risks of liabilities and impact on purchase price, find and improve solutions for unknown contamination; in a word, to protect the client's interest.

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b) The Italian Decree no. 152/2006 requires the polluter to perform safety measures and remediation activities in coordination with public authorities (Article 242). If polluter fails to do so, the private party that owns and/or manage a contaminated site has the right, not the duty, to notify public authorities of the potential contamination and start a remediation procedure (Article 245). Nobody can require a site owner/manager to remedy environment at its own costs. If no polluter is identified, however, public authorities can perform remediation and then seek costs reimbursement to the private party.

   Furthermore, the private party that suffered costs/damages due to contamination must take all reasonable efforts to identify the polluter, otherwise no compensation/cost recovery can be granted in civil actions.
   In both cases, when assisting a private party, legal counsel have to plead that a causal link between the polluter's activity and actual contamination can be established. It suffices that the alleged polluter is more likely to be liable than not; however, to prove it can be challenging.
   Uncertainties and difficulties may arise when: (1) the site was (or is being) managed (i) by two or more operators, (ii) in different periods over time, (iii) nearby other production sites; (2) different operators (on the same site and/or over time) may have used the same substances, manufactured similar products; (3) contaminants are subject to degradation in the environmental matrices; and/or (4) contamination is 'historical' and evidence is missing or traces back to an old time.
   Environmental forensics techniques can be extremely helpful to: (a) reconstruct historical production process and the past environmental status; (b) locate present and past primary/secondary sources and keep them separate by operator; (c) 'date' contaminants – or the same contamination – and link it to a past operator.

c) When liability cannot be excluded, the client may be interested in a settlement agreement or to contain costs. Legal and technical advisors can help design and develop proposals for safety and/or remediation actions that are (i) proportionate to the actual liability and/or (ii) alternative to financial compensation or measures sought by public and private counterparties.

CONCLUSIONS

All the above considered, the 'Polluter Pays Principles' involves very complex and difficult issues that entail a multidisciplinary approach.
A combination of legal and technical expertise is very advisable, if not required, to manage environmental liabilities in a highly efficient way and provide the best assistance to clients.

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A methodological approach for the identification of sulphate sources in the Portoscuso area (south-western Sardinia)

Stefania Da Pelo[1], Chiara Porru[1], Riccardo Biddau[1], Rosa Cidu[1], Carla Ardau[1], Cristina Buttau[1], Franco Frau[1], Maria Filippini[2], Gianfranco Mulas[3]*

[1] *Università degli Studi di Cagliari, Dipartimento di Scienze Chimiche e Geologiche, Monserrato (CA), Italy.*
**Corresponding email: sdapelo@unica.it*

[2] *Alma Mater Studiorum Università di Bologna, Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Bologna, Italy*

[3] *Comune di Portoscuso, Portoscuso (CI), Italy*

ABSTRACT

Several detrimental effects due to intense industrial activities affect the groundwater of the Portoscuso area (SW Sardinia, Italy) such that the Italian Government has designed the whole territory as a contaminated site of national interest (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 shows sulphate concentrations exceeding the background value of 450 mg/L calculated for the area (Vecchio et al., 2011). In order to verify the origin of sulphate, multidisciplinary investigations were carried out on the geochemical features and stable isotope ratios in groundwater.

Keywords: groundwater, sulphate contamination, isotopes

METHODS

A 3D hydrogeological conceptual model was elaborated for the aquifers. Two hydrogeological and hydrogeochemical surveys were carried out in 2015 and 2018, including a piezometric and chemical-physical survey of 122 piezometers, which allowed defining the main flow direction of groundwater. Forty-seven piezometers were sampled for the geochemical investigations and analysis of δ^2H, $\delta^{18}O$ of water. Twenty samples of the 2015 campaign were selected based on sulphate concentration to perform investigation on dissolved stable isotopes of sulphate ($\delta^{34}S_{SO4}$ e $\delta^{18}O_{SO4}$) up gradient and down gradient from potential sources of pollution. Three samples of rain were collected upstream and downstream of the industrial area considering the prevailing winds from NW, for a complete geochemical and isotopic characterization. The sampling of rainwater was carried out by ARPA Sardegna according to the method set out in Annex IV appendix 2 of Presidential Decree 203/88.
The δ^2H_{H2O} and $\delta^{18}O_{H2O}$ were measured using Wavelength-Scanned Cavity Ringdown Spectroscopy (L2120-i, Picarro). The isotopic characterization of $\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$ was carried out at the University of Barcelona, Spain. The samples were prepared precipitating the sulphate as $BaSO_4$. The $\delta^{34}S_{SO4}$ analysis was performed with an elemental analyzer coupled in continuous flow with a Finnigan Delta C IRMS mass spectrometer (Carlo Erba). The $\delta^{18}O_{SO4}$ was analysed in duplicate

samples using a ThermoQuest elementary high temperature conversion analyser coupled in continuous flow with a Delta X IRMS Finnigan MAT mass spectrometer. This method was also applied to the rain samples. Only for 2 rain samples was possible precipitate sufficient $BaSO_4$ to determine sulphate isotopic composition.

RESULTS

The stable isotopic composition of the water (δ^2H_{H2O}, $\delta^{18}O_{H2O}$) shows that most of the samples lie between the SIMWL (Southern Italy Meteoric Water Line, Giustini et al., 2016) and the GMWL (Global Meteoric Water Line), highlighting the meteoric origin of the recharge waters.

However, some samples align along a straight line crossing the δ^2H and $\delta^{18}O$ values measured by Mongelli et al. (2013) for the sea waters of northern Sardinia. This suggests the presence of salinization processes due to marine intrusion.

For the interpretation of $\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$, data were plotted together with the isotopic composition of the main sulphate sources (Mongelli et al., 2013; Petitta et al., 2011) (Figure 1), and the main flow direction in the aquifer was taken into account. It appears that the origins of the sulphate are various and influenced by several factors. Part of the sulphate sources is likely of natural origin (sea spray and decomposition of marine organic matter) and part of anthropic origin (e.g. dissolution of sulphides probably coming from the waste rock from coal exploitation, atmospheric sulphate of industrial origin). Mixing processes likely occur in groundwater.

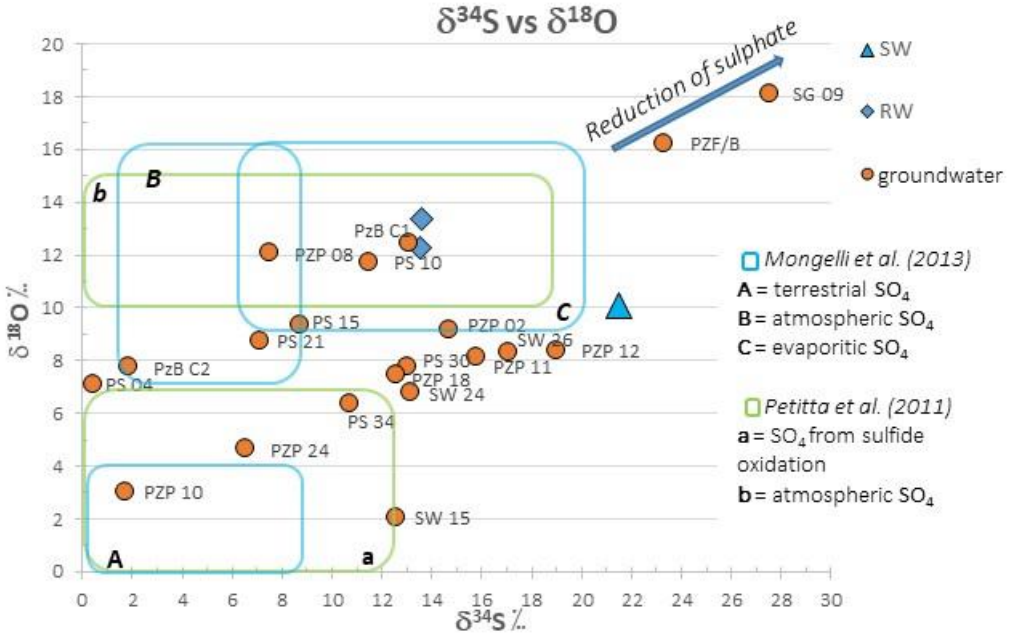

Fig. 1 - Sulphur against oxygen isotopic composition of sulphate in groundwater and rain waters (RW) from the Portoscuso area. Sea Water (SW) isotopic composition from Mongelli et al. (2013) is also provided.

CONCLUSIONS

The integrated approach of hydrogeological, geochemical and stable isotope analyses have provided information on the origin of sulphate in the groundwater of the Portoscuso area. It appears that the origins of the sulphate are various and influenced by several factors, both natural and anthropogenic. Further investigations on the isotopic composition of atmospheric particulate and leachate from waste rocks are running in order to verify the presented hypothesis.

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Groundwater remediation technologies on petroleum hydrocarbons contaminated sites in Italy: a multi-disciplinary statistical analysis

Mara Dal Santo[1], Giuseppe Alberto Prosperi[1]*

*[1] Stantec, Centro direzionale Milano 2, Segrate (MI), Italy. *Corresponding email: mara.dalsanto@stantec.com*

ABSTRACT

A multi-disciplinary statistical analysis was performed on 170 contaminated sites spread throughout the Italian territory. The sites are interested by different past or present activities, for example they are: fuel station, fuel depots, oil refineries and chemical/pharmaceutical plants. The extension of the areas vary from 1.000 m^2 to 3.500.000 m^2.

The groundwater of the sites has been impacted by petroleum hydrocarbons and chlorinated solvents. For each site one or more remedial technologies have been chosen and performed in order to remediate groundwater for example: plant solutions, monitoring natural attenuation and use of chemical reagents for In Situ Chemical Oxidation or Reduction, or oxygen release compounds to enhance the bioremediation, or surfactants.

Keywords: groundwater remediation, remediation technologies, contaminated site, chemical reagents for remediation.

METHODS

Data collection on the remediation performances extends from 1995 to present day and includes 170 contaminated sites on Italian territory.

The main factors evaluated with the analysis were: efficiency, time to obtain remediation, field of applicability based on site-specific hydrogeological features, cost and feasibility of the remediation in comparison with threshold limits (according to D.Lgs. 152/06 and DM 31/15). A statistical approach was used.

Particular attention was dedicated to innovative technologies of chemical injection of reagents, to their design, applicability, efficiency in terms of contaminant reduction and the concern coming from possible formation of byproducts and wells occlusion.

RESULTS

The multidisciplinary analysis allowed to identify Pump and Treat as the most selected technology from 1995, followed by a combination of Air Sparging/ Soil Vapor Extraction (AS/SVE) and Pump and Treat systems.

Multi-Phase Extraction (MPE) systems followed by AS/SVE+P&T were identified as most expensive technologies considering the installation, operation and maintenance per year, but it was verified that, especially MPE, where applicable, has a very good grade of contaminant extraction.

From the other side, Monitoring Natural Attenuation was identified as cheapest technology followed by application of chemical reagents (oxygen release compound, ISCO and surfactants).

Regarding chemical reagents, it was confirmed that use of these technologies can be successfully applied also into low hydraulic conductivities aquifers if wells injection mesh is sufficiently dense.

CONCLUSIONS

During the years, the remediation approaches went through serious changes. Although traditional solution as P&T plants have been the most selected to remediate from 1995, in these last years, innovative technologies (for example use of chemical reagents) have been more appreciated by the designers and by public authorities and extensively applied because they are in some cases more effective or sustainable, cheaper or quicker.

Efficiency, time to obtain remediation, field of applicability based on site-specific hydrogeological features, cost and feasibility of the remediation in comparison with threshold limits were analyzed with a multi-disciplinary statistical approach.

Above all considerations, it turns out to be crucial the choice of the proper technologies according to site-specific conditions. A focused choice of remediation technology is more advantageous and remediates the site to remedial objective without rebound effects while minimizing one or more of the factors of interest (for example: time of operation and costs).

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Chemical reagents applications as innovative remediation technologies for petroleum hydrocarbon impacted groundwater in Italy

Mara Dal Santo[1], Giuseppe Alberto Prosperi[1]*

*[1] Stantec, Centro direzionale Milano 2, Segrate (MI), Italy. *Corresponding email: mara.dalsanto@stantec.com*

ABSTRACT

Innovative technologies with injection of chemical compounds were applied in order to remediate 30 contaminated sites with petroleum hydrocarbon impacted groundwater. The reagents used can be classified as three main technologies: enhanced bioremediation products with oxygen released, In Situ Chemical Oxidation (ISCO) and surfactants. The analysis on these applied technologies allowed to better understand how to conduct the design, execution and monitoring phases of the remediation.

Keywords: contaminated site, groundwater remediation, remediation technologies, chemical reagents for remediation, bioremediation, ISCO, surfactants.

METHODS

30 contaminated sites with petroleum hydrocarbon impacted groundwater were remediated using chemical reagents. The design, execution and monitoring phases were analyzed in detail.

For the design phase, lab data on soil and groundwater samples were collected in order to understand the size and the magnitude of the contamination and to verify heavy metals content. The use of different calculation methods and their impact on the design were investigated, for example: calculation starting from application areas, or from porosity, or from oxidant demand.

For the execution phase different methods of application of the reagent were explored, for example injection into the monitoring wells, direct push injection into the soil, aspersion into excavation, filter socks application. For each method the pros and cons were evaluated.

And at last for the monitoring phase, chemical-physical parameters and lab analysis on groundwater were collected in order to verify remediation effectiveness, contaminant reduction and potential issues as byproduct formation or increase of the contaminant concentration.

RESULTS

The analysis of the results allowed to better understand how to conduct the design, execution and monitoring phases. First of all, it turns out to be relevant to accurately design the remediation project, by choosing the proper reagents based on site specific conditions, on the contaminants of concern of the impacted site, and on the regulation target to be reached, considering also the presence of utilities or underground tanks. The design should be conducted using a calculation form (for example the calculation of oxidant demand) and performing laboratory tests and pilot tests on site. A precise design allowed to have the maximum benefit in terms of contamination reduction. The application

methods were also analysed; in particular the application into devoted wells network – and not into monitoring network - was found to be more efficient.
A frequent monitoring program is to be introduced with a view to analysing the trend and the effectiveness of the remediation but also to detect a possible byproduct formation or an increase in contaminant concentration. Beside the chemical analysis, it was observed that the measure of physical-chemical parameters in the monitoring program is a valid support to verify the efficiency of the remediation and the effectiveness of the reagents.

CONCLUSIONS

In the wide range of remediation technologies, chemical injections proved to be a solid alternative to plant technologies, very effective also in fine aquifers. The analysis on these applied technologies allowed to better understand how to conduct the design, execution and monitoring phases of the remediation.
For 69% of the analysed sites, chemical injections led to a significant reduction of the contamination within 1 year from the application.

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A three-dimensional multicomponent reactive transport model to assess the role of subsurface heterogeneity on arsenic mobility in the shallow aquifer of the Venetian Alluvial Plain

Nico Dalla Libera[1], Paolo Fabbri[1], Daniele Pedretti[2], Leonardo Mason[3], Leonardo Piccinini[1], Fabio Tateo[4]*

[1] *Università degli Studi di Padova, Dipartimento di Geoscienze, Padova, Italy.*
**Corresponding email: nico.dallalibera@phd.unipd.it*

[2] *Università degli Studi di Milano, Dipartimento di Scienze della Terra "A. Desio", Milano, Italy*

[3] *Agenzia Regionale per la Prevenzione e Protezione del Veneto (ARPAV), Venezia, Italy*

[4] *Consiglio Nazionale delle Ricerche (CNR), Padova, Italy*

ABSTRACT

High concentrations of arsenic in groundwater threaten the health of millions of people worldwide. In Italy, arsenic is found in aquifers from north to south and is associated to different geological settings (i.e. volcanic areas and alluvial plains). The shallow aquifer of Venetian Alluvial Plain (VAP) is notoriously affected by arsenic contamination, with concentrations exceeding the WHO limit (10 μg/L). This issues poses a risk for locals, as the aquifer is exploited for agricultural purposes. The processes controlling arsenic mobility and the scale of the problem in the VAP remain unclear. Little is known about the implication of the variability of the physical and mineralogical properties of the aquifer facies on the arsenic mobility. The present work presents the result of a numerical analysis focused on the evaluation of the extension of arsenic contamination as linked to the subsurface heterogeneity of the site. A three-dimensional (3D) multicomponent reactive transport model was combined with a geostatistical reconstruction of the subsurface heterogeneity to quantify the transient arsenic geochemical behaviour. The model focuses on a well-characterized area of the VAP, the "Western Agricultural Areas" (WAA), where monitored piezometers provide time series of arsenic concentrations (as well as the behaviour of the key parameters, such as redox potential, iron and ammonia). The results show a strong dependence of heterogeneity with the arsenic concentrations in groundwater. It was found that zonation of redox conditions linked to localized aquifer recharge and random distribution of organic matter are key aspects that control the extension of the problem in the WAA, as in the VAP. It is concluded that a careful characterization of the geological heterogeneity and hydrological behaviour of the VAP must be considered when aiming at reducing the risk of arsenic exposure of the local population and helping stakeholders on risk assessment.

Keywords: Arsenic contamination, subsurface heterogeneity, 3D reactive transport model.

METHODS

The study is based on a numerical analysis that combines two types of models. The first type is a geostatistical model that reproduces the heterogeneities of the WAA. The model is built using the code spMC (Sartore et al., 2016), a transitional probabilities-based approach that allows for a detailed reconstruction of the subsoil materials distribution based on local well logs stratigraphy. The second model is based on the multicomponent reactive transport code PHAST, which enables to resolve the main geochemical processes involved in the mobility of arsenic. The spMC model provides the spatial distribution of key hydrogeological parameters and geochemical information feeding PHAST. Initial solution, type and amount of equilibrium phases, kinetics reactants and sorption surfaces are tuned using the code PHREEQC based on monitored time series of concentrations and mineralogical data from sediments characterization.

RESULTS

The model suggests that the distribution of arsenic around the study area is patchy and seasonally dependent, consistently with previous observation on the site (e.g. Dalla Libera et al., 2018). The distribution is linked to localized mechanisms such as the degradation of organic matter (OM), the reductive dissolution of ferric hydroxides (HFOs) and the oxygen ingress from the vadose zone. A correlation is observed between recharge events and redox variation of the aquifer. The hydrogeological system tends to reducing conditions due to a diffuse presence of OM-bearing sediments. The different thickness of vadose zone and the heterogeneity in materials permeability control the effectiveness of oxygen ingress into the aquifer, varying the redox potential and all the related processes that can foster arsenic release. The central part of WAA shows an increase of redox potential during the monitored wet period due to clustered rainfall precipitation. Each event produces a decrease of dissolved arsenic linked to precipitation of HFOs, on which arsenic is bound. On the other hand, the northern and southern parts of WAA show a reduced system due to both OM degradation and a low oxygen ingress. In those zones, arsenic variation could be linked to processes of incongruent dissolution of arsenic-bearing minerals (e.g. scorodite) or arsenic sulphur re-precipitations (Harvey et al, 2006), although no experimental evidences occur to support this hypothesis, requiring more investigation.

CONCLUSIONS

A 3D reactive transport model was developed to show the strong control of subsurface heterogeneity on arsenic release. In the study area, the distribution of different geological materials can foster or inhibit arsenic mobilization, influencing the redox condition and the redox-dependent reactions. While the geological materials are generally ubiquitously involved in similar water-rock interactions, the influence of heterogeneity-controlled localized recharge during rainfall events, and the associated oxygen ingress, locally reduces arsenic mobilization. Where recharge is not effective in oxidizing the aquifer, arsenic remains mobile.

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Multiphase flow and solute transport modelling of a hypothetical methane leakage into a shallow aquifer

Andrea D'Aniello[1], Massimiliano Fabbricino[1], Daniela Ducci[1], Domenico Pianese[1]*

[1] Università degli Studi di Napoli Federico II, Dipartimento di Ingegneria Civile, Edile e Ambientale, Napoli, Italy.
**Corresponding email: andrea.daniello@unina.it*

ABSTRACT

Public concerns regarding the potential environmental impacts induced by unconventional gas production operations have recently risen. Therefore, understanding the flow behaviour of stray gases and predicting their fate in the subsurface is crucial to assess the environmental safety of unconventional gas exploitation. In this work, a real-world case is presented to show the potential extent and effects of a hypothetical methane leakage into a shallow aquifer from a deep geothermal well. Multiphase flow and solute transport simulations were performed to assess the vulnerability of the aquifer.

Keywords: methane, natural gas, well integrity failure, multiphase flow, solute transport, numerical modelling.

METHODS

Numerical simulations were performed with GDAn (D'Aniello, 2017), a 2D finite element model meant for the analysis of groundwater (D'Aniello et al., 2019a; D'Aniello et al., 2019b), multiphase flow (D'Aniello et al., 2018; D'Aniello et al., 2019b), and solute transport in porous media (D'Aniello et al., 2019b). Governing equations are those of unsteady-state water saturated groundwater flow (Bear, 1972; Istok, 1989), multiphase flow of immiscible fluids in porous media (Abriola and Pinder, 1985; Parker et al., 1987), and the advection-dispersion equation (Istok, 1989).

RESULTS

Numerical analysis showed that migration of gaseous methane can be extremely fast. Moreover, gaseous methane moves predominantly vertically upwards, close to the well. However, a horizontal spreading becomes appreciable as the source strength increases. The groundwater hydraulic gradient in place does not impact gaseous methane migration, and the shape of the gaseous plume remains symmetric. Conversely, dissolved methane is affected by the groundwater flow field (Fig. 1) and covers greater distances in considerably more time.

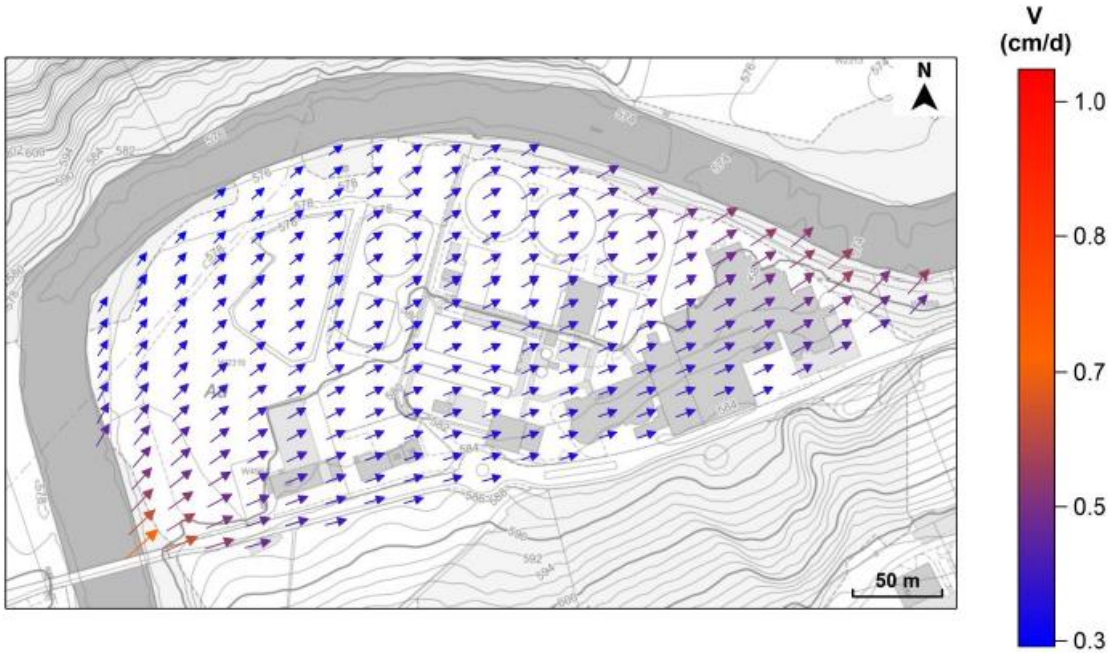

Fig. 1 - Plan view of the site and predicted groundwater flow field.

CONCLUSIONS

The analysis showed that the risk of contamination for local water resources might be limited in this site. However, a concern exists for the risk of explosion in the close vicinity of the well. Indeed, predicted maximum gaseous infiltration rates are comparable to those reported for other sites, and maximum dissolved methane concentrations may overcome in few years the action levels associated with explosion hazard. Until now, quality checks at the well suggested no leakage issues. However, monitoring activities are strongly advised to ensure the safety of the site before abandonment.

Acknowledgements

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The landfill leachate impact on groundwater hydrogeochemistry in fine deposits: a multidisciplinary study

Diego Di Curzio[1], Sergio Rusi[1]*

*[1] Università degli Studi "G. d'Annunzio" di Chieti-Pescara, Dipartimento di Ingegneria e Geologia (InGeo), Chieti, Italy. *Corresponding email: diego.dicurzio@unich.it*

ABSTRACT

The leachate is one of the most important potential source of groundwater contamination (Kjeldsen et al., 2002), especially when the landfills are partially lined or unlined (Stefania et al., 2018).

The interaction between the leachate and the environmental media, in addition to spreading toxic compound in groundwater, leads to several hydrogeochemical and biological changes that, in turn, affect the natural conditions of aquifers (Christensen et al., 2001). These changes also involve compounds that are generally considered slightly or not polluting, such as the major ions (i.e. Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-+CO_3^{2-}), notwithstanding the Concentration Limits of Contamination (CLC) required by the current environmental legislation (i.e. D.Lgs. 152/06).

In this general framework, the main objective of this research is to get a deeper insight into these processes, related to the leachate/groundwater interaction, in a landfill site where the CLC exceedances are limited.

Keywords: landfill leachate, hydrogeochemical changes, groundwater, aquitard

METHODS

The selected study area is a landfill located in Central Italy, within the scarcely permeable plio-pleistocenic clayey deposits, that present a superficial alteration (silty-clayey lithologies). The groundwater flow, in fact, takes place within the altered and fractured shallow portion of the bedrock. At the base of the landfill, there is a stream that, even if with a small discharge, flows toward a regional alluvial aquifer.

The hydrogeological characterization has been performed deepening different features: (1) the geological features have been described in detail, even with respect to the landfill volume, by means of geognostic boreholes; (2) the groundwater flow has been investigated by the hydraulic head time-series analysis and the permeability tests performed in site; (3) the chemical analyses of surface water, groundwater and leachate, analyzed as water (i.e. the same units and detection limits), have been compared to assess the contamination extent and to interpret the changes to the natural environment related to leachate leaks in the aquifer.

RESULTS

The preliminary results highlight that the clayey bedrock alteration (up to 15 m thick) favors, where the landfill is unlined, the mixing between leachate and groundwater that flows toward the stream. The hydraulic conductivity of this alteration is an order of magnitude higher (~10^{-8} m/s) than the clayey bedrock one (~10^{-9} m/s).

The contaminated groundwater, in addition to showing CLC exceedances related to some organo-chlorinated solvents (e.g. Vinyl Chloride, found even in the leachate), are characterized by high concentrations of redox-sensitive compounds (e.g. Fe^{2+} e Mn^{2+}), due to the anoxic conditions caused by the dissolved organic matter. Furthermore, even the major ions appear very different from those of the natural groundwater (Fig. 1). Indeed, the contaminated groundwater is enriched in Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}+CO_3^{2-} and depleted in in Ca^{2+} and Mg^{2+}. This effect can be considered a combination of intermediate redox conditions, that bring to the S species oxidation, and mixing and/or cation exchange, attributable to the clayey minerals in the aquifer.

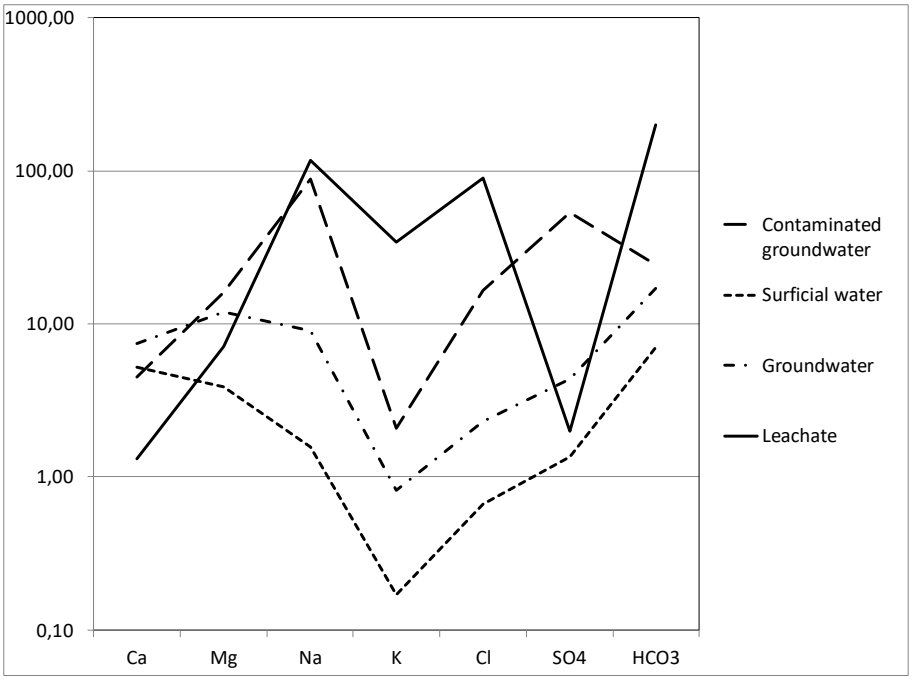

Fig. 1 - Schoeller-Berkaloff diagram showing examples of surface water, natural groundwater, contaminated groundwater, and landfill leachate chemical analyses.

CONCLUSIONS

The multidisciplinary approach has enabled to clarify a complex environmental problem. In particular, the comparison between the chemical analyses of the landfill leachate, analyzed as water, and the natural and contaminated groundwater has allowed to get a deeper insight into the hydrogeochemical processes that change the groundwater chemistry when a landfill leachate contamination occurs.

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Evaluation of the performance of a hydraulic barrier by a Monte Carlo method

Giovanni Formentin[1], Mariangela Vitiello[1], Alberto Francioli[2], Jacopo Terrenghi[2]*

[1] *Tethys S.r.l., Milano, Italy. *Corresponding email: giovanni.formentin@tethys.srl*

[2] *HPC Italia S.r.l., Milano, Italy*

ABSTRACT

A gasoline leak caused the contamination of a shallow alluvial aquiferin a urbanized area Northern Italy.

A rapid intervention was conceived to stop the spreading of contamination: a hydraulic barrier has been placed downstream of the source to collect both the floating oil and the contaminated groundwater.

A numerical model has then been built using MODFLOW-2000 (Harbaugh et al. 2000) to assess the performance of the existing barrier, and to design another hydraulic barrier able to stop the hydrocarbon plume already dispersed downstream.

A preliminary model was built and calibrated against groundwater levels measured in 41 monitoring wells. Hydraulic conductivities in pilot points, recharge zones and constant head BCs were calibrated. The non-uniqueness of the calibrated parameters led to identify 283 alternative parameter sets, all able to represent the observed heads within an absolute average error of 10 cm. These sets, generated with the Null space Monte Carlo method (NSMC) (Tonkin and Doherty, 2009), served to build 283 models, used to simulate the dispersion of solved contamination through forward particle tracking with MODPATH (Pollock, 2012).

The particle paths from all simulations were collected and analysed altogether, leading to the identification of contamination paths likely not captured by the hydraulic barrier. This information can be fruitfully used to improve the placement of monitoring wells and, if the presence of contamination paths is confirmed, to optimize the barrier.

Keywords: MODFLOW, MODPATH, PEST, Null space Monte Carlo, hydraulic barrier

METHODS

The non-uniqueness of the determination of quantities tied to groundwater flow affects, with different degrees, all the real-case situations where the knowledge of the hydrogeological setting is affected by uncertainty. This uncertainty is then passed on to the predictions of interest. Therefore, the uncertainty of each model prediction is characterized by a probability density function with a mean, which is the approximation to the prediction of minimum error variance, and a standard deviation that provides the uncertainty of the model prediction (Herckenrath et al., 2011).

The available methods for quantifying uncertainty in predictions by use of a calibrated model (Tonkin and Doherty, 2009), can be linear (i.e. implying a linear relationship between parameters and predictions, which rarely holds in real cases (Moore and Doherty, 2005)) or nonlinear, such as Monte

Carlo methods. The Null space Monte Carlo method allows to produce a multitude of calibration-constrained stochastic parameter fields, by use of which the variability in the predictions of interest, deriving from lack of information on the model parameters, can be estimated.
A MODFLOW-2000 model has been built to represent a shallow alluvial aquifer and has been calibrated with PEST (Doherty, 2015). Then, NSMC has been applied by generating 283 alternative models. Forward particle tracking with MODPATH has been used to simulate the plume in each model; although this method only accounts for the advective processes, it is way easier than the implementation of a transport model, for which additional information, unavailable in the present case, shall be collected. Moreover, it is assumed that the dispersion determined by uncertainty in model parameters supplies for mechanical dispersion and diffusion not represented in MODPATH.

RESULTS

The NSMC method allowed to generate 283 alternative models, all calibrated against head measurements gathered in 41 monitoring wells in the area of interest. A number of 50 particles were released from the spill area, to represent the dispersion of solute hydrocarbons in the aquifer. The paths followed by a total number of 14150 particles were collected and analysed in a GIS.
A path has been found that escapes the first line of wells. Two more wells downgradient capture most of these particles. Nevertheless, some of them flow through two different paths (Fig. 1). This signals the possibility for the hydraulic barrier to be improved (e.g. increasing the pumping rates), or at least to verify the existence of those paths by increasing the number of monitoring wells and the sampling frequency.

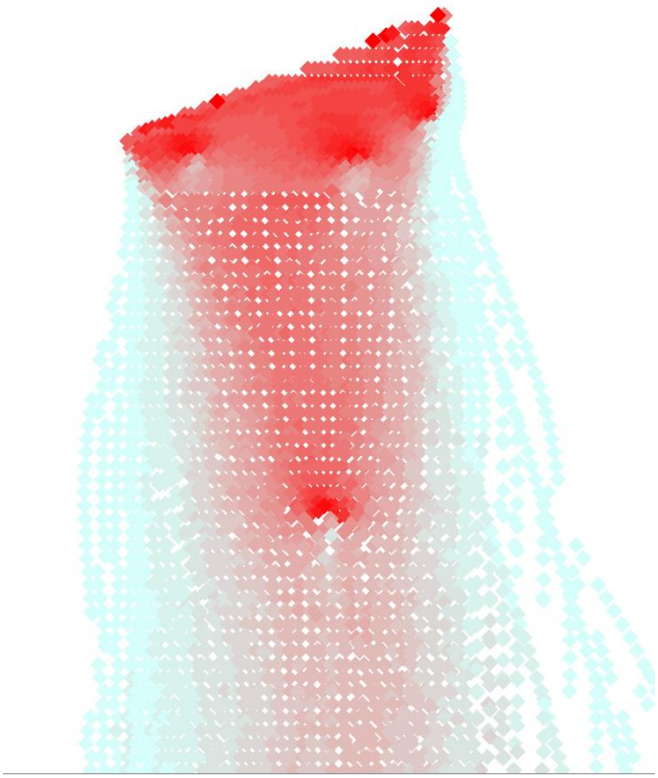

Fig. 1

CONCLUSIONS

Numerical models are built in almost every case where a hydraulic barrier needs to be installed in contaminated sites. They are often built under deterministic assumptions, i.e. calibration provides the set of parameters that minimize a statistic of the difference between observation and their model counterparts.

This study shows that uncertainty in parameters, which is always present due to the impossibility to know perfectly the hydrogeological setting, adds to other sources of error (e.g. measurement errors, structural noise, simplifications) that could potentially lead to designing interventions that do not guarantee the required performance.

A stochastic analysis, such as the NSMC analysis here described, could enhance the knowledge about the variability in model predictions and guide the expert in designing effective interventions.

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3D case-studies of VOC contaminated sites in the city of The Hague, The Netherlands - Using data visualization techniques to better understand the 'black box'

Willem Havermans[1], Michiel Pluim[2]*

*[1] Stantec B.V., Delft, The Netherlands. *Corresponding email: willem.havermans@stantec.com*

[2] Municipality of The Hague, The Netherlands

ABSTRACT

Contaminated sites and the extent to which contaminants have spread are often difficult to comprehend and are therefore often underestimated. Consequently, these incomplete insights may result in unfitting remedial measures, cost overruns, and remedial target levels that are difficult to achieve.

While contaminated sites may look like a black box with unknown distribution pathways, many insights can in fact be gained through closer data-analysis of readily available bore hole information, groundwater flow directions and soil and groundwater concentrations. Manually interpreted and handmade site maps often do not give a full and complete picture, whereas automated interpolations and visualizations of pollutant data can give a faster and far better reproducible way to identify and explain the extent of soil and groundwater contaminations and the ways they have spread. Through the combination of this information, a previously unseen level of detail can be found and presented in three dimensional models, with fourth and fifth dimensional additions of time and money, making it easy to understand and make strategic decisions around for everyone involved: consultants, stakeholders and regulators alike.

Keywords: 3D visualization, groundwater contaminations, spreading, atomized soil data interpretation

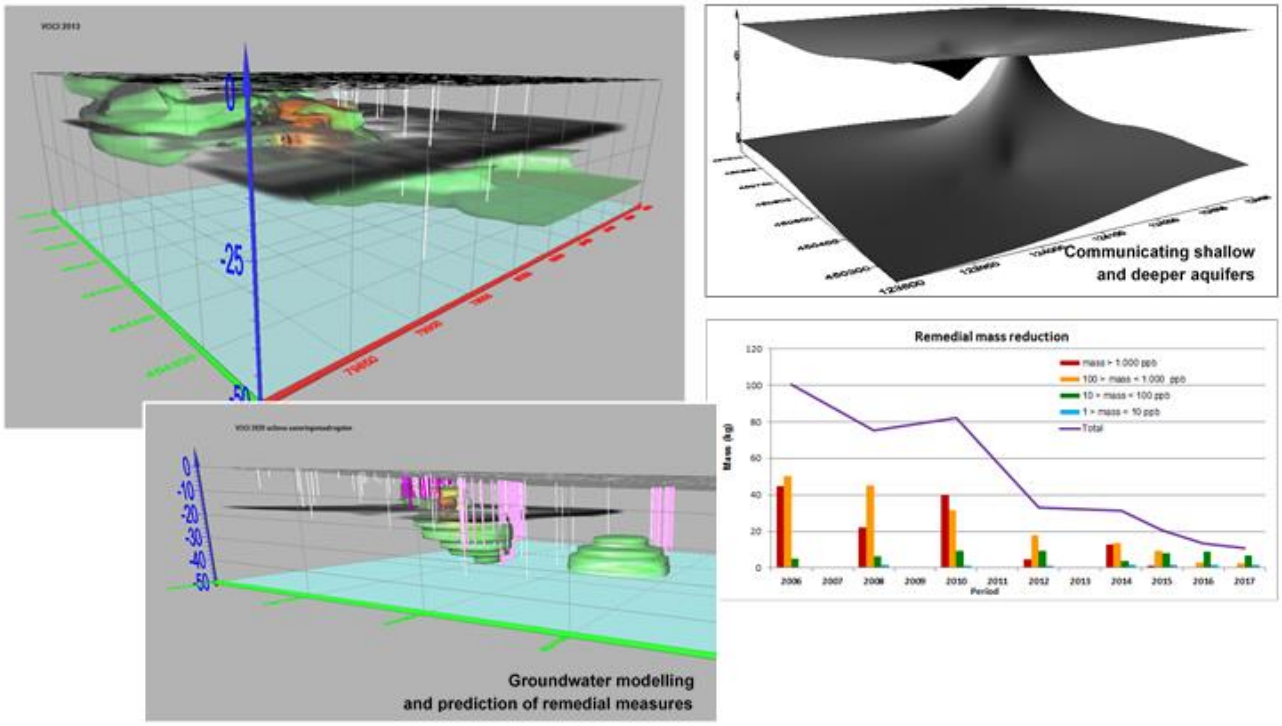
METHODS

Put into practice, this method has a proven added value because of its expedient simplification and evaluation of large amounts of monitoring data. Examples of its application can be seen in the in situ remediation projects that Stantec carries out for the city of The Hague in the Netherlands. Here, the visualizations have been used at various locations to provide necessary insights into the extent of a contamination, and the pattern in which the contaminants have spread over time - the fourth dimension. Knowing the pathway of contaminated groundwater and understanding the spreading behaviour allows us to quantify the annual changes of contaminated soil and groundwater volumes. Subsequently, annual changes of contaminated soil volumes and contaminated masses can be judged by regulators and consultants as being an acceptable risk or if there is reason for concern. When used together in combination with the insights gained from groundwater modelling software and fate transport, this method can be used to present and compare the results of predicted contamination

behaviour and remediation performance over time; answering the question whether a groundwater plume is stable or if it is necessary to intervene to avoid any further migration.
As an important fifth dimension, financial implications are included in the visualization so that more informed decisions can be made. Thanks to our model, we can generate various hypothetical scenarios that allow us to strike the right balance between available budget and desired outcome of remediation and monitoring efforts.

RESULTS

As a rule of thumb, these interpolations, quantified volumes and mass calculations have taught us that more than 75% of the mass of a groundwater contamination is concentrated to 10 - 30% of a site's contaminated soil volume. Economic decisions can then be made for which areas are most beneficial and cost effective to remediate, based on levels that have been agreed upon by local authorities. All this is achieved by using this innovative decision tool, which we have developed based on readily available information obtained from routine soil investigations that is within reach of any soil consultant. This has led to the tool's use in a variety of instances, such as for review of ongoing remediations that have shown to stagnate and are no longer cost effective. Through this tool, light can be shed on the progress that has been made in remedial measures, which can then be compared with the predetermined and approved levels that were agreed to be met, but difficult to achieve in practice.



CONCLUSIONS

Several case-studies of contaminated sites in the city of The Hague, The Netherlands and monitoring data, obtained over more than a decade, have been successfully evaluated by using the 5D-approach. This approach showed us the lessons learned and gave us a better insight in the way how to interpret site monitoring data and the cost effectiveness of in situ remediations.

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Evaluation of the large-scale permeability of the substrate of a physically contained area and development of a system for the dynamic management of hydraulic gradients to neutralize contaminant diffusive flux

Elena Leale[1], Christine Ballarin[1], Emanuele Candiani[1], Andrea Moroni[1], Giovanni Russo[1], Mario Manassero[2], Sara Puma[2]*

*[1] AECOM URS Italia S.p.A., Milano, Italy. *Corresponding email: elena.leale@aecom.com*

[2] GE Engineering, Torino, Italy

ABSTRACT

The solutions adopted to test the hydraulic effectiveness and to manage in the long term a physically contained area to neutralize contaminant diffusive flux at a former chromium-plating plant in North Italy, where soil and groundwater are heavily contaminated by Hexavalent Chromium, are presented. After encapsulation of the area by means of a slurry wall and a capping, extensive hydraulic testing was carried out through two long-term, large-scale pumping tests. The data collected in about 200 days of testing were used to draw conclusions on the hydraulic properties of the aquifer of the low permeability substrate, and to develop a practical method to assure, in the long term the containment of the residual Cr VI mass inside the confined area.

The method was applied successfully thereafter and the results of the first year of monitoring confirm the expectations made.

PROJECT BACKGROUND INFORMATION

Underneath the site there is a high permeability sand and gravel aquifer, 10-11 m thick. Low permeability clayey deposits lay beneath the aquifer.

Long-term isolation of the most contaminated area (about 1.100 m^2) was achieved by a 12 m deep slurry wall installed around the former production lines, wedged 2.00 m inside the low permeability formation. The area was then covered by a HDPE waterproof capping, 2.5 mm thick. The most contaminated soils inside the wall were then excavated down to 7,5 m below ground level, after the installation of a structural concrete wall, realized inside the encapsulated area.

METHOD

In addition to controls made on each slurry panel on depth, panel overlap, verticality and permeability tests of the slurry mixture, after completion of the works, extensive hydraulic testing was carried out by means of two large-scale pumping tests (dewatering of the encapsulated aquifer and long-term recovery).

During the tests the water level recovery rate was faster than it could be expected on the basis of the permeability of the slurry wall (measured during the construction phase and lower than 5×10^{-11} m/s) and the permeability the clayey substrate, investigated during design phase by in-situ permeability tests and laboratory geotechnical tests.

Data collected on pumped volumes, drawdown and recovery rates, were used to obtain indirectly hydraulic properties of the aquifer and of the substrate, such as effective porosity and actual permeability at large scale of the low permeability substrate.
In addition, an experimental relation between induced drawdown within the confined area and upward groundwater flow through the bottom of the confined area was derived.

RESULTS

Together with laboratory data obtained on the hydraulic properties of the slurry wall, the information collected were used to study the significance and role of Cr VI diffusive mass flux either through the slurry wall and through the bottom of the area, due to the elevated concentration gradient.
Once the mass flux due to diffusive phenomena had been determined, by means of a contaminant flow balance, the value of the negative hydraulic gradient that must be maintained to neutralize contaminant diffusive phenomena, was determined.
The experimental relation between induced drawdown within the confined area and upward groundwater flow through the bottom of the confined area was used to provide operative indications for the future management of the physical confinement system.

CONCLUSIONS

To date, the groundwater levels and concentration both internally to the system and externally are continuously monitored and the results of the first 12 months of monitoring confirmed the correctness of the experimental relation between induced drawdown within the confined area and upward groundwater flow through the bottom of the confined area.
In addition, considering that concentration gradients have varied in time due to contaminant mass extraction within the encapsulated area, the amount of the negative hydraulic gradient necessary to neutralize contaminant diffusive flux was regularly updated.
The results of the chemical analyses carried out show a significant decline of Cr VI concentrations either inside and outside the confined area; the presence of the slurry wall introduces a significant discontinuity in the quality of groundwater, with a difference in concentration between the inside and the outside of different orders of magnitude.

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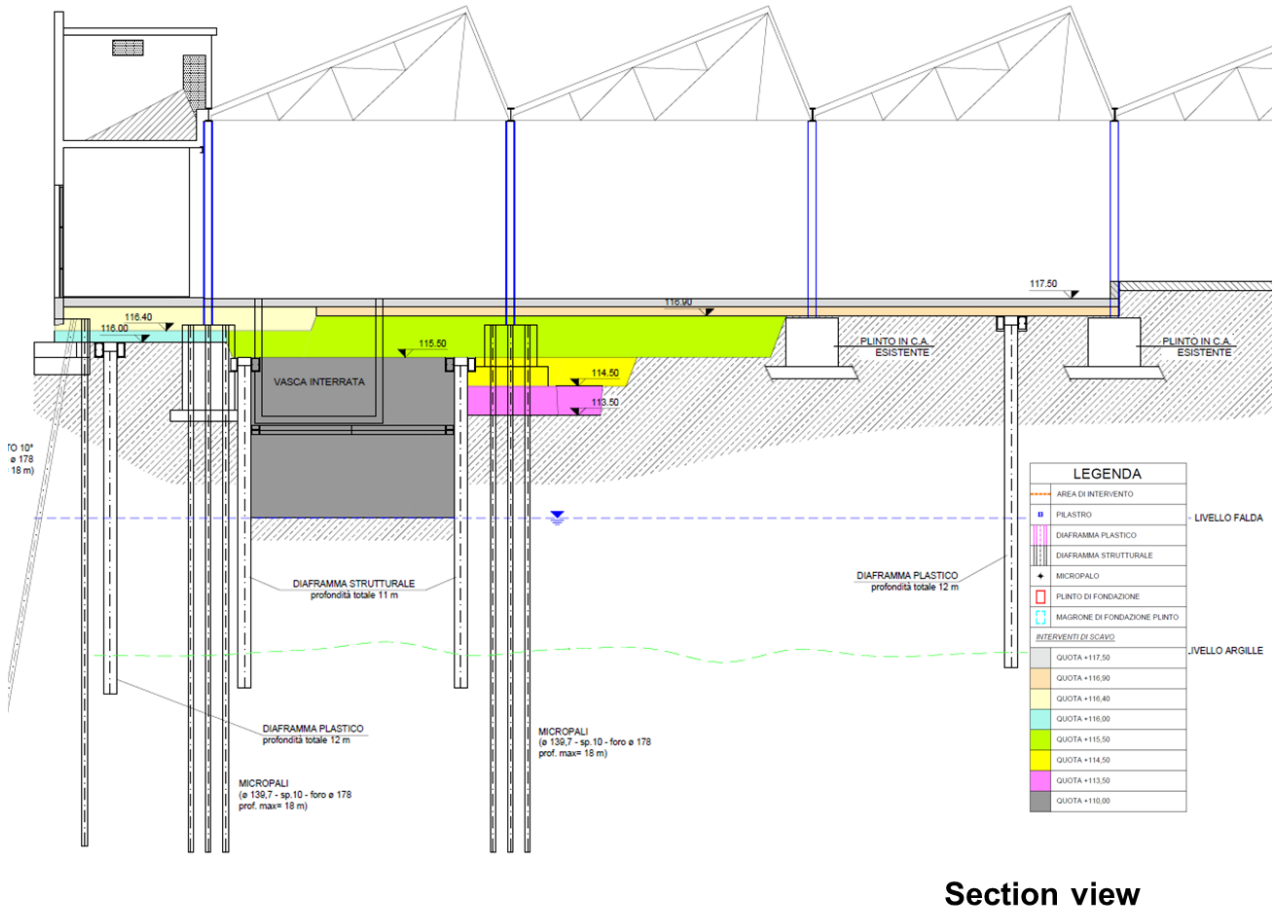

Fig. 1 - Section view of the realized physical containment

Full-scale application of EHC® Liquid technology for the ISCR and ERD treatment of an aquifer contaminated with Tetrachloromethane and Chloroform

Alberto Leombruni[1], Patrizia Trefiletti[2], Mauro Consonni[2], Linda Collina[3], Matteo Avogadri[4], Aldo Trezzi[4], Caterina Di Carlo[5]*

[1] *PeroxyChem LLC - USA. *Corresponding email: alberto.leombruni@peroxychem.com*

[2] *Tethys S.r.l., Milano, Italy*

[3] *SGI Engineering S.r.l., Torino, Italy*

[4] *Ramboll, Milano, Italy*

[5] *Solvay Specialty Polymers, Milano, Italy*

ABSTRACT

EHC® Liquid Reagent is an *in situ* chemical reduction (ISCR) product for the treatment of impacted groundwater. It is a cold-water soluble formulation that is specially designed for injection via existing wells or hydraulic injection networks for the treatment of a wide range of groundwater contaminants. EHC Liquid creates strong reducing conditions and promotes both biotic and abiotic dechlorination reactions. EHC Liquid is composed of two parts: EHC Liquid Reagent Mix, an organo-iron compound, and ELS® Microemulsion, which are easily combined and diluted for injection. Organic carbon addition in the saturated zone is well-known to promote conventional enzymatic reductive dechlorination reactions. This happens because the carbon in the subsurface will support the growth of indigenous microbes in the groundwater environment. As bacteria feed on the soluble carbon, they consume dissolved oxygen and other electron acceptors, thereby reducing the redox potential in groundwater. As bacteria ferment the ELS microemulsion, they release a variety of volatile fatty acids (VFAs) such as lactic, propionic and butyric, which diffuse from the site of fermentation into the groundwater plume and serve as electron donors for other bacteria, including dehalogenators. Lecithin itself is composed primarily of phospholipids, which have both hydrophilic and hydrophobic regions in their molecular structure. As a result, ELS emulsions tend to be stable emulsions, expectedly more stable than with only hydrophobic compounds. Further, phospholipids support remediation by providing essential nutrients (carbon, nitrogen, phosphorus) to bacteria. The soluble organo-iron compound is comprised of a ferrous iron (Fe^{2+}) that can form a variety of iron minerals (e.g. magnetite, pyrite) that are capable of reducing contaminants as they oxidize further to the ferric (Fe^{3+}) state via one electron transfer. The ferric ion can be "recycled" back to ferrous as long as other electrons from supplied carbon and indigenous carbon are available.

The site is situated in a highly industrialized area of northern Italy, where groundwater is historically contaminated with tetrachloromethane (> 10 ppb), chloroform (> 10 ppb), hexavalent chromium and, to a lesser extent, PCE and TCE. In the intervention area and downstream of it, 10 standard Pump & Treat wells were located, designed to accelerate the removal of various contaminants. The presence of active pumps inside, or in the immediate vicinity, of the area affected by EHC® Liquid injections,

however, could have compromised their effectiveness. This is due to the increase in groundwater speed and the removal of the injected emulsion. For this reason, a strategy has been planned to shut down some wells and reduce the flow rates of the others, in order to guarantee the maintenance of an adequate action of the latter. A detailed evaluation of the influence of P&T infrastructure, and the consequent action plan, was based on hydrogeological tests carried out in the field. This included simulations by a mathematical flow model, which allowed the design engineers to identify an optimal configuration pumping, in order to achieve aforementioned purposes.

RESULTS

After approximately 12 months from injection of EHC® Liquid into the groundwater in the main source area, the concentrations of CT and CF contaminants are rapidly reduced, compared to the pre-treatment concentrations, until the target values of treatment are reached in the main piezometers monitoring in the area, also highlighting the establishment of clear and enhanced biotic and abiotic reducing conditions.

Testing phytoscreening in a shallow aquifer contaminated by chlorinated ethenes

Carlotta Leoncini[1], Maria Filippini[1], Adele Lo Monaco[2], Simona Gagni[2], Renata Emiliani[2], Roberto Riberti[2], Francesco Caridei[3], Alessandro Gargini[1]*

[1] *Alma Mater Studiorum Università di Bologna, Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Bologna, Italy. *Corresponding email: carlotta.leoncini2@unibo.it*

[2] *Agenzia Regionale per la prevenzione, l'ambiente e l'energia dell'Emilia-Romagna (Arpae), Bologna, Italy*

[3] *Ecosurvey® - 3000 S.r.l., Bologna, Italy*

ABSTRACT

Phytoscreening is a hydrogeological application that has proven to be effective in reflecting the extent and severity of subsurface contamination by chlorinated ethenes (Limmer et al., 2013), being advantageous as inexpensive, time-saving, and capable of reaching remote locations. Volatile organic compounds (VOCs) are absorbed by the roots, either directly from groundwater or from soil gas/water and carried through the xylem cells of the plant. By drilling the inner core of the tree, micro-cores can be obtained and analysed but the accuracy of the method for quantitative analysis is still under discussion (Duncan and Brasseau, 2017). The case study presented herein focuses on a poplar grove, growing over a shallow mainly silty unconfined aquifer contaminated by tetrachloroethene (PCE) and trichloroethene (TCE), along with their degradation products dichloroethene (DCE) and vinyl chloride (VC). The experiment has been set to compare contaminants concentrations in tree tissues with those measured in groundwater. This study, part of a wider project involving different sites also contaminated by chloroethenes, aims to deepen the knowledge of the contaminants fate in trees, distinguishing over different hydrogeological conditions and various plant species.

Keywords: trees, groundwater, chlorinated ethenes

METHODS

Seven poplars were selected nearby existing piezometers in order to have reasonable correspondence between tree and groundwater sampling locations. An incremental borer was used to drill the trees at a fixed height in the trunk. The tree cores were analysed with a closed-system purge-and-trap process (EPA method 5035A), commonly used for assessment of VOCs in solid materials, followed by a gas chromatography–mass spectrometry analysis (EPA method 8260). Besides, specific compounds detector tubes were inserted in the residual tree-holes. This technique was developed by ARTA Abruzzo (Luchetti and Diligenti, 2015) and used to assess the "in vivo" gaseous phase concentrations of chloroethenes directly on-site.

RESULTS

The results show that the poplars located inside the area of the known groundwater plume do have a record of contamination, which means there is a correspondence, in terms of either areal occurrence of the contaminated aquifer or types of detected compounds, between tree cores and groundwater samples (figure 1). Furthermore, the cores analysis identified all the degradation products of the chlorinated ethenes series, which were rarely found in former literature. In general, the study reported a relatively low correlation between the concentrations found in trees and corresponding groundwater concentrations, being relatively higher only for those contaminants with lowest volatility (TCE and PCE).

Fig. 1 - Comparison between the total chlorinated ethenes concentrations in groundwater and in the tree core samples.

CONCLUSIONS

The ability of trees to detect groundwater contaminations by chlorinated ethenes and to assess plume delineation is confirmed. Phytoscreening applicability for quantitative analysis is discussed according to site-specific hydrogeological variables (porosity and thickness of the unsaturated zone, chloroethenes occurrence and properties, etc.) and seasonality. Deeper understanding of the interactions between trees and groundwater could make phytoscreening a useful tool to characterize aquifers contaminated by chloroethenes.

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Hydrogeological data from contaminated sites. Millions of numbers without soul

Lotti Francesca[1]

[1] *Kataclima S.r.l., Vetralla (VT), Italy. Corresponding email: f.lotti@kataclima.com*

ABSTRACT

More and more we assist to the advancement of graphical tools to visualize data in the contaminated site context: 3D views, Augmented Reality, 3D videos, complex 3D model simulations, etc. It is known that presenting data in a nice attractive way, gives the impression that data are trustable and "real" (Csinger, 1992).

Periodic monitoring of water levels, pumped discharges, groundwater quality, besides an extensive set of other data, are required for each contaminated site by the regulatory context (DLgs 152/06; ISPRA, 2006). The typical situation that a hydrogeologist faces at the start of a project is receiving 1 or 2 Gb of material pertinent to the site. Data are often chaotic, unorganized, redundant, with unknow coordinate system and… in pdf files. Sometimes the only way out is to inspect the site and get aware of the situation by person. But, unfortunately, walking through the site can open new unexpected scenarios.

Keywords: data quality check, contaminated site auditing, relational DB

METHODS

At the very beginning of every project, a considerable amount of time is devoted to get the most out of the available data. This implies to dispone of the data in an organized way. One option is to use pre-built hydrogeological databases such as the QGIS plugin Midvatten (Källgården and Spångmyr, 2018) or to build your own DB.

The second fundamental aspect is to verify on the field the quality of data, the possible sources of error and/or interference with the recorded data (Fig. 1).

RESULTS

Results from this approach are presented from different experiences in contaminated sites projects.

The use of a relational DB allows to avoid the typical anomalies of data organized in non-relational tables, i.e. the so-called deletion, update and insertion anomalies. When populating the DB, some simple rules have been respected to avoid these anomalies, which impact on the global errors associated with data. The DBs were "normalized" to the 3rd Normal Form (NF) according to the following steps:

1. Remove multivalued attributes (1st NF);
2. Remove partial dependency (2nd NF);
3. Remove transitive dependency (3rd NF).

An example of DB structure is reported in Fig. 1.

Concerning the field audits, the most recurrent data bias encountered can be synthetically listed as follows:

- Dewatering of cellars;
- Presence of underground pools/caves and/or leaky pools and pipes;
- Presence of unauthorized pumpings inside/outside the site;
- Piezometers/wells not sealed;
- Presence of excavations with the bottom reaching the groundwater level, but not monitored/considered;
- Rivers forgotten/excluded from conceptual models;
- The position of measurement of the depth to water does not correspond to the point of absolute elevation measurement;
- Missing absolute elevation measurement;
- Broken phreatimeter or out of calibration;
- Errors in points distances and elevations;
- Absence of clear labelling of the name in many points (points are often inverted);
- Pumping wells with broken counters.

The direct site inspection (even one day) can save up a considerable amount of time in later stages of work.

CONCLUSIONS

Data collected in contaminated sites is typically used to build and calibrate models, which are used to make predictions and assist decisions about remediation options and dimensioning. Getting aware of the data quality is of paramount importance and can be achieved though:
Organizing all the available data in a relational DB in GIS environment;
Performing a data quality check through statistical and geostatistical techniques;
Visiting the site to individuate the data origin and the sources of noise affecting the collected data;
Common sense would require this course of actions to be obvious, further processing the data only after several iteration of the previous steps (Fig. 1).

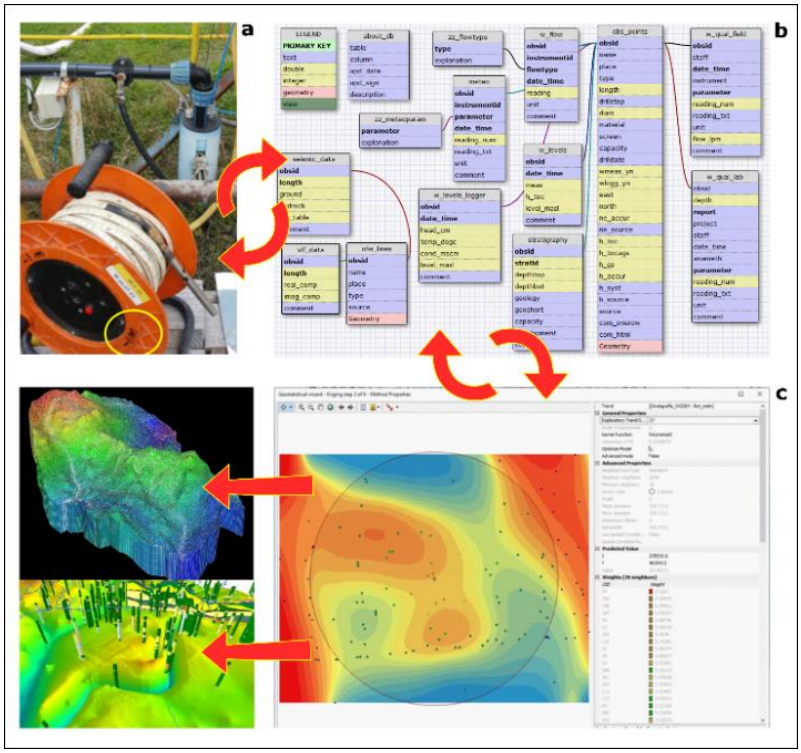

Fig. 1 - a. Broken phreatimeter with 1 m of cable missing (not always recorded by the field operator); b. default structure of the Midvatten SQLite DB (open source QGIS plugin); c. final results of data processing.

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Numerical simulation of Groundwater Circulation Wells: a stochastic approach to evaluate their effectiveness

Lotti Francesca[1], Alessandro Battaglia[2], Luca Ferioli[2], Marco Petrangeli Papini[3], Vincenzo Piscopo[4]*

[1] *Kataclima S.r.l., Vetralla (VT), Italy. Corresponding email: f.lotti@kataclima.com*

[2] *ERM, Milano, Italy*

[3] *Università degli Studi di Roma La Sapienza, Dipartimento di Chimica, Roma, Italy*

[4] *Università degli Studi della Tuscia, Dipartimento di Scienze Ecologiche e Biologiche, Viterbo, Italy*

ABSTRACT

Groundwater circulation well (GCW) techniques can provide an effective remediation tool in areas unfavourable to traditional technologies. Hydraulic barriers may be problematic, especially where concentrated hot spots of contamination are present in low permeability layers, or where the treatment costs of the pumped groundwater are unaffordable.

Dimensioning and evaluating the effectiveness of a full-scale GCW system is nevertheless hard to be achieved via analytical methods, mostly because of the vertical component of groundwater flow induced by GCW. A numerical approach is herein presented, which involved the use of MODFLOW-USG with Quad-Tree refinement and pinched-out layers. Simulations where performed in probabilistic mode, in order to include the uncertainties emerged in the previous calibration phase of the numerical model. GCW design parameters including GCW spacing, screen length, screen placement, and circulation flow rate were defined according to the higher probability to capture and remediate the contamination plume.

Keywords: Groundwater Circulation Wells, Numerical Modelling, Uncertainty Analysis, PEST

METHODS

All the available data were digitalized and organized in a geodatabase. Statistical, geostatistical and temporal processing of data were performed to isolate measurement errors and other outliers. The numerical model was built with MODFLOW-USG (Panday et al., 2013), calibrated through the pilot points technique in PEST, run in parallelized mode with PEST_HP (Doherty, 2015). The preliminary calibration step generated the so-called master model. The following step was to generate other 125 equally calibrated models applying the Null Space Monte Carlo technique (Doherty, 2015; Doherty et al. 2010) to explore the uncertainties of the model results. A schematic workflow of the followed procedure is described in Fig. 1, compared with the classical approach. Contaminant dispersion has been simulated by particle tracking using the code mod-PATH3DU (Muffels et al., 2016).

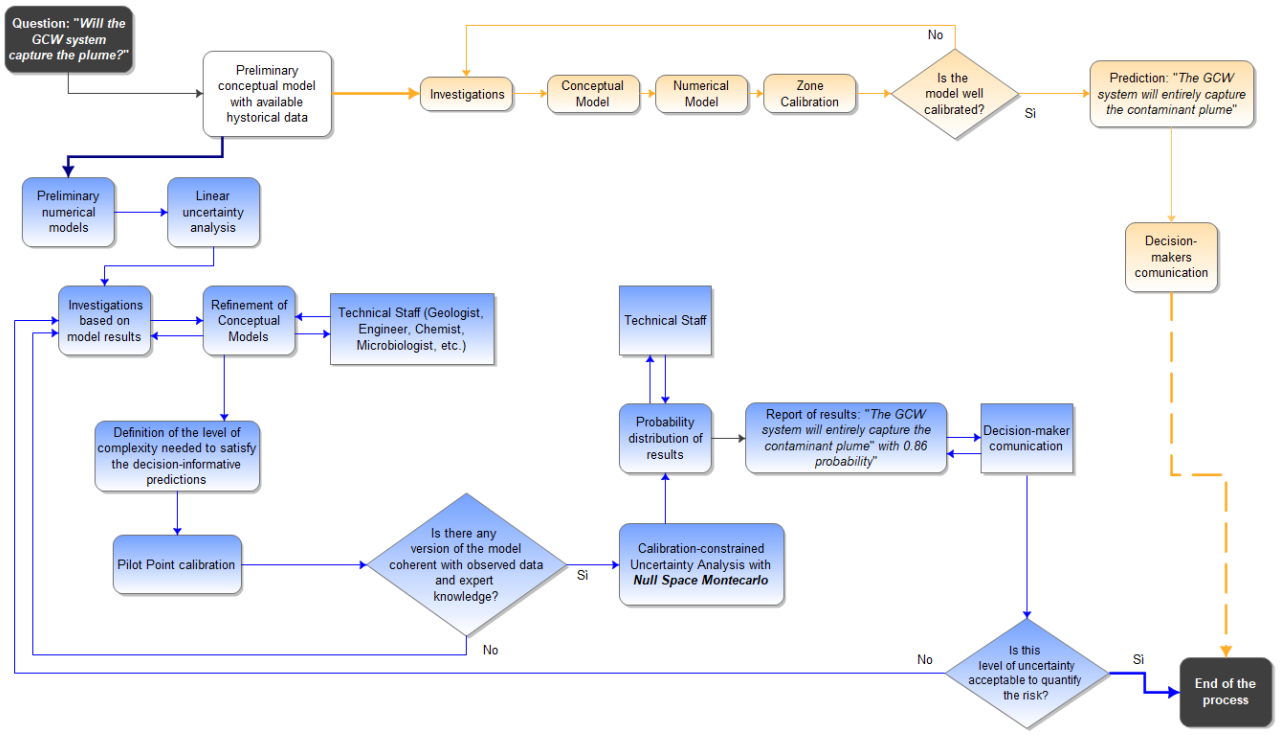

Fig. 1 - Numerical modelling approached followed to assess the GCW effectiveness

RESULTS

The numerical analysis showed the optimized number, relative distance and circulation discharges of the GWC to install. Probabilistic results assessed a very low probability of the contaminant to escape the GCW system, suggesting the position and number of monitoring wells to prevent any ineffectiveness of the system at the real operational field conditions.

CONCLUSIONS

Groundwater circulation well (GCW) techniques can provide an effective remediation tool in areas unfavourable to traditional technologies. A numerical approach was tested in a contaminated site; probabilistic simulations were performed in order to dimension the system at an acceptable level of risk of unsuccess. The uncertainties emerged in the previous calibration phase of the numerical model were quantified and included into the GCW design, according to the higher probability to capture and remediate the contamination plume.

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Compositional fingerprinting tools for hydrocarbon contaminated site characterization: source apportionment and spill dating applications at two field case studies

Marchesi Massimo[1], Patrizia Trefiletti[2], Alberto Francioli[3], Rodolfo Ferrari[3], Roberto Ferrari[4]*

[1] *Isotope Tracer Technologies Europe S.r.l., Milano, Italy. *Corresponding email: massimo.marchesi@it2europe.com*

[2] *Tethys S.r.l., Milano, Italy*

[3] *HPC Italia S.r.l., Milano, Italy*

[4] *Pool per l'Assicurazione della Responsabilità Civile e Ambientale, Milano, Italy*

ABSTRACT

From small to large scale impacted sites, (i) potential multiple sources of contamination, (ii) presence of containment and remedial systems such e.g. Pump and Treat (P&T), (iii) variation with regards responsibility due to changes on operational or managing stakeholders over time are few among the multiple complexities when assessing contaminants apportionment. Compositional fingerprinting tools can be applied to hydrocarbon contaminated sites to get insights into type of products or oil, approximate age of spills, degree of weathering (Hurst and Schmidt, 2005) and to distinguish anthropogenic/petrogenic from natural contributions in soils and water, all essential information for a more reliable conceptual model development (Vecchiato et al, 2017).

The present study investigates the origin of hydrocarbon in groundwater, sediment and LNAPLs at two selected contaminated sites different for site history and scale by compositional fingerprinting tools. Site #1 represents a coastal area in North of Italy, mainly impacted by a pump distribution system of bunker/crude oil, operative in the past. It is within a large operative commercial port and industrial area with different potential contamination sources. This Site is impacted by LNPALs and groundwater with elevated C>12 hydrocarbon concentrations. Site #2 represents a small lakes area with a suspected gasoil spill in the vicinity, eventually impacting the water and particularly the sediment qualities in terms of total C>12 hydrocarbons.

The approach at both sites turned to be reliable in contaminants' dating and source apportionment including, where applicable, type of products and spill dating (Site #1) and identification between petrogenic versus natural origins (Site #2).

Keywords: fingerprinting, groundwater, source and fate allocation.

METHODS

GC-MS analysis allowed to characterize biomarkers (e.g. stirenes, terpenes) homologue compounds distributions (e.g. n-alkane, alkylcyclohalkanes, isoprenoids), the presence of additive (e.g. MTBE, ETBE), specific markers (e.g. sulphur content), and ratios (e.g. nC17/pristane, BE/TXs, carbon preference index) typical of certain petrogenic oil or refined fractions (such crude oil, gasoline, jet

fuel), anthropogenic (e.g. digestate and sewage sludge amendment) and natural hydrocarbons (e.g. such wax leaf, fatty acids and fatty alcohol in sediments).
Site #1 located along the coast, was active in the past in the oil distribution. Upgradient the site and in the vicinities other activities are present such gasoline stations and oil and organic product disposal and stock facilities which could have contribute to the contamination, particularly in groundwater. Samples from LNAPLs (within the site only), groundwater (for the site and the nearby areas) and a creek were collected for fingerprinting compositional analysis during three sampling campaigns in 2018.
Site #2, located in a pristine environment, experiences a small gasoil leak in 2014 from a tank at a distance of several hundred meters from the lake areas. Sediments' samples from Lake A and Lake B were collected for fingerprinting compositional analysis after hydrocarbon extraction by Soxhlet techniques.

RESULTS

In Site #1 were conducted, in three phases, compositional fingerprinting surveys with the purpose of characterizing the product and groundwater contamination inside the site, to create a starting baseline and to assess their relationships with the contamination detected nearby, identifying third party contributions. Results demonstrated of the presence of very degraded crude\bunker oil, with spills most likely occurred over 20 years ago and surely not recently within the site. In the vicinities of the property, external areas showed a different origin of hydrocarbons in groundwater, probably not related to the pump distribution system of bunker oil but more to recent upgradient gasoline spills.
Data from Site #2 clearly showed a predominant natural hydrocarbon component rather than petrogenic origin. Almost no n-alkanes, IPAs or other hydrocarbon were found while mostly other compounds were detected such as fatty acids. Particularly, the carbon preference index (CPI) showed an unusual distribution of odd over even number of carbon compounds, significantly different from ranges of CPI typical of petrogenic hydrocarbons.

CONCLUSIONS

The use of compositional fingerprinting tools is essential when elaborating a conceptual model of contaminated sites impacted by hydrocarbons. By the use of these techniques can be possible to get important insights with regards the source of contamination such type of product released, spill dating and eventually in distinguishing between natural versus anthropogenic/petrogenic origin.

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Multi-isotopic approach for the groundwater flow and contaminants characterization in a complex contaminated site: Ex-ACNA di Cengio (SV)

Michele Pellegrini[1], Massimo Marchesi[2,3], Luca Alberti[3]*

[1] Syndial servizi ambientali S.p.A. - Business Service Ambientali, Fano (PU), Italy.
**Corresponding email: michele.pellegrini@syndial.it*

[2] Isotope Tracer Technologies Europe S.r.l., Milano, Italy

[3] Politecnico di Milano, Dipartimento di Ingegneria Civile e Ambientale (DICA), Milano, Italy

ABSTRACT

Stable isotopic investigations represent a crucial tool for groundwater flow characterization. The use of environmental isotopes related to water molecule (^{2}H and ^{18}O) has been applied for decades for the identification of groundwater recharge areas (elevation and localization), as well as ^{3}H (tritium) and ^{14}C-DIC (dissolved inorganic carbon) used to estimate average groundwater residence times (Clark and Fritz, 1997). Differently of more recent application are the investigations named Compound-Specific Isotope Analysis (CSIA), used since the end of 90's (Hunkeler et al., 1999) for the characterization of pollutants related to volatile organic compounds (VOCs). Since then and up to the present day, the use of CSIA has seen a crescendo of scientific applications and developments, especially in forensic chemistry, until it is currently considered an indispensable tool for the characterization of complex contaminated sites, such as the site of Cengio (SV).

Keywords: stable isotopes, CSIA, groundwater, contamination

METHODS

In the case of Cengio geochemical and isotopic characterization have been carried out in order to better understand the relations between the areas inside the industrial site, delimited by a slurry wall, and the areas outside it. Specifically, three distinct objectives were pursued:

- the characterization of the main sources of recharge of the hydrogeological system;
- the characterization of the aquifer water/matrix relationships, in order to better define the groundwater flow pathways;
- the identification of the origin of the organic contaminants detected on site and the relationship of these between the external and internal sectors to the slurry wall.

In order to pursue these objectives, the environmental isotopes ^{2}H and ^{18}O of the H_2O molecule for groundwater were investigated, taking into consideration also the rainwater and those of the Bormida River. At the same time, the analysis of ^{3}H and ^{14}C-DIC were carried out in order to obtain an estimate of the average residence times of groundwater and thus better understand the conceptual model of groundwater water circulation.

The distribution of the major ions together with the isotopic analysis of ^{34}S and ^{18}O in sulphates (SO_4^2), were used for the evaluation of the interaction between groundwater and the solid matrix of the aquifers involved.
Finally, the analysis of ^{13}C (CSIA) concerned the volatile organic compounds (VOCs), specially the compounds of the family of chloroethylenes and chlorobenzenes. For the monochlorobenzene (MCB), ^{37}Cl-CSIA analysis were also performed for a combined approach, the so-called dual isotope approach ^{13}C ^{37}Cl.

RESULTS

The isotope investigations carried out aimed to identify any differences among the origin of the contaminants as well as their relationship (a) with the groundwater that flows into the different sectors of the Cengio site and (b) with the different aquifer matrices. The results of geochemical and isotopic investigations in the waters present in the marls in general showed a very small groundwater flow circulation. Geochemical and isotopic investigations on SO_4^2 confirmed the separation of the internal environment with respect to the external areas. Particularly significant are the dual isotope CSIA results (^{13}C ,^{37}Cl), mainly for PCE and MCB (Fig. 1), that highlighted the lack of correlation between the contamination found within the areas internal with respect the slurry wall and the one outside.

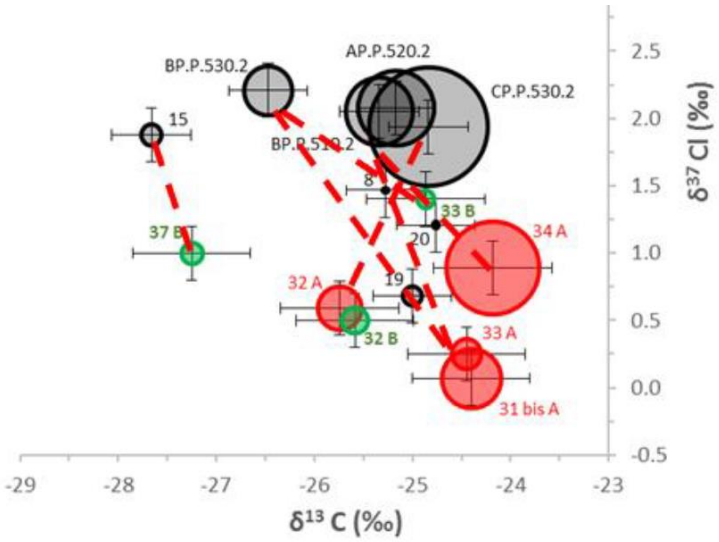

Fig. 1 - Double isotope ^{13}C and ^{37}Cl for the MCB. The size of the circles is a function of concentration. In green the filling material, in red marl rocks, in gray the corresponding internal monitoring points. With a dotted line in red have been highlighted the values of ^{13}C and/or δ ^{37}Cl depleted in areas outside the slurry wall if compared with the corresponding internal monitoring points

CONCLUSIONS

The present isotope approach has allowed to identify different origins for the polluted analysed, also as a function of time. Furthermore, it was possible to highlight the potential biodegradation processes underway in some sectors rather than in others. Allowing to improve the conceptual site model

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An interdisciplinary approach to evaluate the Natural Attenuation as potential remediation action

Pietro Rizzo[1], Emma Petrella[1], Anna Maria Sanangelantoni[1], Marco Ghirardi[2], Fulvio Celico[1], Maria Giovanna Tanda[3], Andrea Zanini[3]*

[1] *Università di Parma, Dipartimento di Scienze Chimiche, della Vita e della Sostenibilità Ambientale, Parma, Italy.*
**Corresponding email: pietro.rizzo2@studenti.unipr.it*

[2] *Comune di Parma, Parma, Italy*

[3] *Università di Parma, Dipartimento di Ingegneria e Architettura, Parma, Italy*

ABSTRACT

Downtown the city of Parma, in the shallow aquifer, there is a contamination of chlorinated hydrocarbons (mainly constituted by perchloroethylene). Within the AMIIGA project (INTERREG Central Europe), the Municipality of Parma evaluated the natural attenuation as potential remediation action.

From September 2017 to February 2019, in order to accomplish this task, several actions were carried out including drilling seven new monitoring wells and seven monitoring campaigns for collecting water samples for: chemical, isotopic, microbiological and metagenomic analyses. This work summarizes the obtained results.

Keywords: Natural attenuation, PCE, AMIIGA Project

METHODS

The study area is located in the Po plain. The aquifer system consists of several permeable horizons intercalated by low-permeability clays and silts. The present work is focused on the shallow permeable horizon that directly interacts with the urbanized territory of the City of Parma. Preliminary results were shown in Zanini et al. (2018).

Considering the complexity of the problem, a multistep approach has been adopted. First step: the analysis of the available data regarding the monitoring network, piezometric levels and chemical analysis. Moreover, all the potential contaminant sources, inside the study area, were listed. Second step: new investigation actions were designed in order to improve the aquifer characterization and knowledge. Third step, seven monitoring wells (MWs) were drilled in order to improve the monitoring network. During the drilling, the borehole logs were collected with the aim at improving the knowledge of the study area. Fourth step: seven sampling campaigns have been carried out from September 2017 to February 2019 collecting over than 60 water samples. In order to have a complete overview of the hydro-geochemical and hydro-ecological processes: chemical, isotopic, microbiological and metagenomic analyses were carried out.

Simultaneously a numerical groundwater flow model at large scale has been developed in order to: quantify the mean flow and identify its direction, estimate the mean hydraulic conductivity of the aquifer and reproduce the seasonal variations of the water table.

RESULTS

The new borehole logs allowed the reconstruction of a reliable conceptual model. Beneath the ground surface, the stratigraphic sequence begins with deposits made by silt and clay, whose thickness progressively increases from 1 to 19 m moving northward. Below this horizon, the confined "shallow aquifer" (gravels and sands with discontinuous clay lenses) whose thickness is up to 30 meters, at least can be found. Beneath the "shallow aquifer", a continuous bed of fine-grain-sized deposits has been found. The results of the isotopic analyses allowed to state that the aquifer is recharged upgradient of the urbanized area.

Chlorinated solvents in concentration higher (PCE up to 22 μg/L) than the legal limits (1.1 μg/L) occurred in groundwater in some MWs. The highest concentrations were detected in a known contaminated site, as well as downgradient starting from this site. In single observation wells, the PCE concentration varied over time, therefore suggesting possible PCE pools located in the transition zone between the lowest and the highest hydraulic head measured during the observation period. The spatial distribution of PCE suggests the existence of multiple pools. At the same time, the rapid decrease of concentration downgradient suggests effective dilution due to dispersion and/or attenuation due to microbial degradation.

CONCLUSIONS

Analysis of the samples from the most contaminated MWs unveiled a community containing a higher percentage of methophiles belonging to different genera (Methylobacter, Methylocella, Methylococcus, Crenothrix), all known for being endowed with methane monooxygenase. The presence of these bacterial genera suggested that the most probable pathway of biodegradation of the chlorinated solvents (e.g. PCE) could be an oxidative (co-metabolic) dehalogenation by means of methane monooxygenase. Moreover, the samples of two MWs contained a number of sequences belonging to the Rhodoferax genus known to be a vinyl chloride (VC) utilizing bacterium (Paes et al. 2015). This may indicate a possible reductive pathway in anaerobic niches of the plume leading to incomplete degradation and transport of the contaminant in the aerobic zone where Rhodoferax can use it. VC was never found among contaminants.

From the analyses in a couple of MWs also emerged the Dechloromonas bacterial genus with non-negligible values. This bacterial genus is able to use PCE and nitrates as electron acceptors in an anaerobic respiration process. Therefore, the possibility that some portions of the aquifer may be in hypoxia or anoxia conditions favouring anaerobic degradation of the chlorinated solvents can not be excluded.

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Innovative tools for the analysis of biological processes for the remediation of contaminated aquifers

Claudio Sandrone[1], Andrea Campi[1], Giulia Spini[1]*

*[1] BAW S.r.l., Saluzzo (CN), Italy. *Corresponding email: biotech@baw-env.it*

ABSTRACT

The reclamation of contaminated groundwater and soil is generally a long and complex activity. The numerous variables involved in the reclamation process usually make it difficult to choose a remediation technique that is always effective in all conditions, so it is a common practice to rely on small-scale pilot tests, which allow the evaluation of the effectiveness of a technique before applying it on a large scale.

The complexities of the definition of a conceptual site model increase even more with those techniques based on microbial activity, greatly affected by site-specific conditions and environmental variables. Moreover, in these cases, it is often difficult to set up field and/or laboratory tests able to provide representative and reliable information on the biological degradation phenomena occurring on site.

To date, a wide range of molecular biological tools and services - called Molecular Biological Tools (MBT) as a whole - with the aim of facilitating the characterization, understanding and management of biological processes exist on the market. In detail, Bio-Trap® samplers by Microbial Insights, Inc. are the fundamental tools for many analytical, microbiological and genetic determinations. These devices, once colonized by site microorganisms, constitute real in-site microcosm studies, able to provide information on microbial communities, progress of biodegradation processes, health status of microbes, etc. These data proves extremely useful for a better management of the site during the characterization phase, in the selection of the remediation technique and up to the performance monitoring.

In the case of a shallow aquifer contaminated by MtBE and EtBE, MBT provided conclusive information of extreme importance. Previously a laboratory biodegradation test was conducted to assess the best conditions to stimulate the biological degradation of contaminants and if the degradation was complete. Then, the SIP® (Standard Isotope Probing) and Census® techniques confirmed the laboratory test results, guaranteeing their representativeness and providing detailed indications on the best technique to accelerate the natural attenuation of contaminants.

Keywords: In-situ bioremediation, Molecular Biological Tools (MBT), Bio-Trap® sampler, In-situ microcosm study, Standard Isotope Probing (SIP®), Census®

METHODS

Bio-Trap® passive samplers represent the essential tool for many future determinations. They consist of a matrix of small beads made for 25% of a composite material called Nomex® and for 75% of powdered activated carbon, yielding elevated specific surface. The sampler, once conditioned with selected contaminants and placed in a piezometer, is easily colonized by the microorganisms of the site; following analyses will evaluate the number of microbial communities installed and their capacity of degrading the contaminants of interest.

Bio-Trap® samplers are used as they are (Standard Bio-Traps®), or they can be "baited" with some amendments (Specialty Bio-Traps®). In the first case, besides serving as biological samplers for groundwater, they can be used to assess the effectiveness of the Monitored Natural Attenuation (MNA) in degrading the contaminants. Instead, Specialty Bio-Traps® may be used to evaluate if the addition of certain amendments could favorably affect the biodegradation, supporting the biological processes. To have a comparison between MNA conditions, these samplers need to be coupled with a Standard Bio-Trap® sampler.

Fig. 1 - Bio-Trap® sampler from Microbial Insights, Inc.

The SIP® analytic technique can conclusively determine if the biodegradation stimulated by the addition of amendments is enhanced in comparison to MNA. This method consists in tracking the degradation of ^{13}C-labelled contaminants. Census®, instead, allows the rapid identification of specific bacteria and enzymes responsible for the biodegradation of a pollutant, indicating the potential effectiveness of different remediation strategies.

RESULTS

In the case study, MtBE was the main contaminant of interest, therefore ^{13}C-labelled MtBE was inserted in three Bio-Trap® units placed on site: one for MNA, one biostimulated (with nutrients) and one bioaugmented (with specific bacteria). The quantification of biomass enriched in ^{13}C at the end of the analyses revealed higher values in the MNA unit. Similarly, the observed decrease of the contaminant mass was higher in the MNA Bio-Trap®.

MtBE underwent degradation in all three units, but SIP® demonstrated that biodegradation was favored under MNA conditions. Census® detected a low to moderate genetic degradation potential in

all three units, showing that in the baited ones the levels of specific MtBE-reducing enzymes and bacteria were lower than in the MNA unit.
In this case, SIP® and Census® demonstrated that the addition of amendments (nutrients or bacteria) did not enhance MtBE degradation compared to natural attenuation conditions.

CONCLUSIONS

Advanced microbial tools for the analysis of biological processes may constitute an important decision support to assess the applicability and the effectiveness of those remediation technologies foreseeing even marginal processes of bioremediation. With a better knowledge of the biological phenomena occurring in a contaminated site it is possible to improve the remedial actions by selecting the most effective technologies and thus reducing the overall costs of remediation. In addition, in specific cases, through these tools it is possible to demonstrate that MNA is already effectively remediating the contamination.

Integrated use of biodegradable surfactants and ISCO reagents for the treatment of hydrocarbon contaminated soils and aquifers

Claudio Sandrone[1], Andrea Campi[1], Giulia Spini[1], Fabiano Maccari[1]*

*[1] BAW S.r.l., Saluzzo (CN), Italy. *Corresponding email: biotech@baw-env.it*

ABSTRACT

In situ reclamation processes of areas contaminated by hydrocarbons are often complex and problematic; many aspects, related to contamination and subsoil's characteristics, represent the factors increasing the complexity of the conceptual model and therefore applying a single technique for the reclamation of the site is usually not resolutive.

The main characteristic of hydrocarbon-contaminated sites is the possible presence of the pollutant itself in the form of different phases: dissolved in groundwater, adsorbed on soil, volatilized or present as a separated liquid phase (NAPL phase). These many possibilities explain why a single technology may not be able to be effective on all the forms of the contamination, and an integrated approach is generally advised

Recently, emerging reclamation technologies have established themselves as valid alternatives to traditional methods, proving to be effective and decisive and allowing the targeting of all the forms of the hydrocarbon contamination. The synergistic application of two remediation techniques as Surfactant Enhanced Remediation® and In Situ Chemical Oxidation (ISCO) proved itself successful in treating soil and groundwater in a former fuel depot contaminated by hydrocarbons in Northern Italy.

Keywords: Integrated approach, synergy, Ivey-sol®, Surfactant Enhanced Remediation (SER®), Provect-OX®, In-Situ Chemical Oxidation (ISCO), Push-Pull™ application

METHODS

The integrated approach of remediation using surfactants and ISCO reagents takes full advantage of the characteristics of the two technologies.

Ivey-sol® surfactants promote desorption of the contaminant fraction adsorbed to the solid matrix, which in general is estimated to represent the 90-95% of the overall contaminant mass. Their action is also very effective in targeting the contaminant free-phase and making it available in aqueous phase, where it is easily removable through pumping. The Push-Pull™ applications of the Surfactant Enhanced Remediation are based on this concept: the reagents are injected into the soil in the Push phase, and later they will be pumped out (Pull) together with the hydrocarbon contamination made more available.

Provect-OX® is a special ISCO reagent, able to promote, after the oxidation phase, the development of microbial processes that complete the degradation of the contaminants, preventing the common problem of the rebound. Its oxidant effect on the contamination is strongly enhanced by the Ivey-

sol®, which previously desorbed the hydrocarbons and made them available for the oxidation reactions.
In short, the Ivey-sol® surfactants are effective in targeting the free phase and the phase adsorbed in the unsaturated soil, making them available for removal or for future treatments. Provect-OX® continues the remediation both in the unsaturated and saturated soil, intervening with strength on the contamination, and finally promoting biological degradation.

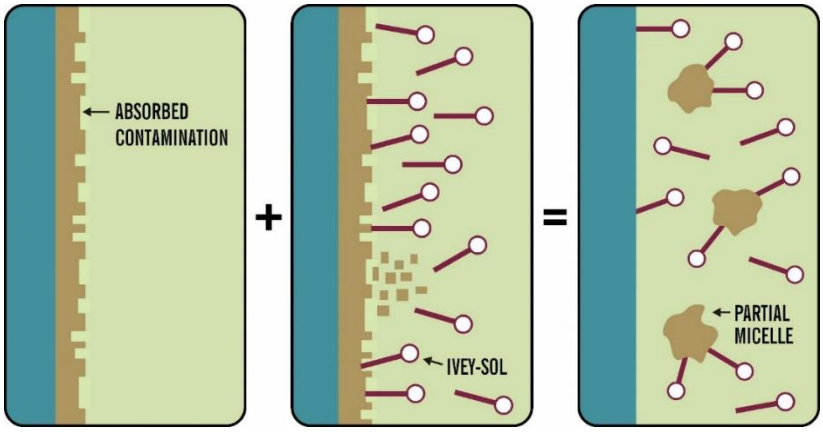

Fig. 1 - Operating principle of Ivey-sol® surfactants

RESULTS

The application of the two technologies yielded the disappearance of the contaminant free-phase and the reaching of remediation goals for total hydrocarbons in groundwater. Moreover, the concentrations of heavy hydrocarbons in the unsaturated soil were drastically reduced by 95%, reaching complete conformity to law limits.
The post-operam monitoring continues for 24 months, to control the biodegradation started after the oxidation phase. To date, no rebound phenomena have been detected.

CONCLUSIONS

The synergetic application of emerging reclamation technologies may be the key to remediate complex sites such as the hydrocarbon-contaminated ones. Each technology has strengths and weaknesses; exploiting the best characteristics of each technique is fundamental to achieve excellent results. The combined use of Ivey-sol® and Provect-OX® products has showed its effectiveness in reclaiming polluted sites for all its environmental matrices.

Hydrogeological characterization of a closed MSW landfill using multivariate statistical analysis and groundwater numerical modelling

Gennaro Alberto Stefania[1], Tullia Bonomi[1], Chiara Zanotti[1], Marco Rotiroti[1], Davide Sartirana[1], Di Martino Giuseppe Raffaello[2], Antonella Perosa[3], Piergiorgio Valentini[3], Letizia Fumagalli[1]*

[1] Università degli Studi di Milano-Bicocca, Dipartimento di Scienze dell'Ambiente e della Terra, Milano, Italy.
**Corresponding email: gennaro.stefania@unimib.it*

[2] Cem Ambiente S.p.a., Cavenago Brianza (MB), Italy

[3] Città metropolitana di Milano, Area Ambiente, Settore Rifiuti e bonifiche, Servizio Coordinamento Tecnico Rifiuti, Milano, Italy

ABSTRACT

This work deals with a groundwater pollution event from a Municipal Solid Waste (MSW) landfill, at present closed and subjected to the post-operative managing since 2003.

The study area is located in the alluvial plain of southern Lombardy region (North Italy), and the landfill is placed on a Holocene alluvial terrace produced by subsequent depositions and erosions phases of the Lambro River (Fig 1).

In 2014, intense rainfalls (up to 1400 mm/year compared to 600 mm/year on average) greatly contributed to increase the leachate level up to overflow the land surface around the landfill. The consequent percolation through the soil induced a deterioration of the groundwater quality. The work aimed to a) define the conceptual model both of the aquifer system and the pollution; b) identify the consequences of the leachate infiltration on groundwater c) understand if a complete natural attenuation (NA) was achieved.

To this end, a hydrogeological and a hydrochemical characterization was obtained using a standard approach coupled to hierarchical cluster analysis (HCA) and numerical groundwater flow modeling.

Keywords: leachate plume, numerical model, groundwater pollution

METHODS

Hydrogeological and hydrochemical data related with the MSW landfill and the nearby areas (coming from the landfill management and the online database of the highway TEEM) were handled using the specific well-database TANGRAM (Bonomi, 2009).

The site characterization consisted of: 1) drawing up lithological cross-sections to define the hydrogeological structure; 2) time and spatial analysis of piezometric data, taking into account also rainfall and hydraulic data of the Lambro river, to define the relationships between groundwater and surface water; 3) time and spatial analysis of chemical data coupled with HCA based on the Ward method and the Euclidean distance in order to discriminate different hydrochemical feature in groundwater and to identify different pollution processes.

A numerical groundwater flow model was built up using MODFLOW-NWT (Niswonger et al., 2011). The model calibration was based on an inverse approach using Pilot Points and SVD-Assist through the PEST code (Doherty, 2010). Besides MODPATH code was used to understand the likely paths that the leachate plume could have followed.

RESULTS

The conceptual model shows the presence of two aquifers: the upper one (10-20 m thick) is mostly composed by fine deposits, except in a N-S oriented structure below the central part of the landfill, where sandy deposits host an unconfined aquifer. The lower, semiconfined aquifer, (10-15 thick) is composed of sand. Hydraulic head data show a gaining behaviour of the Lambro River, and different groundwater flow directions in the two aquifers (i.e. N-S and NE-SO, respectively); changes of flow directions in rainy periods confirm a local lack of separation between them.

The trend analysis of the chemical data, 2014-2017, shows an overall attenuation of the pollution, while the cluster analysis groups chemical data in 8 cluster (Fig. 1) showing that locally (i.e. clusters 2 and 8) groundwater is affected by high Fe, Mn, As concentrations. This s highlights different redox conditions in groundwater, possibly due both to NA or background conditions. As a consequence, a specific monitoring network was suggested.

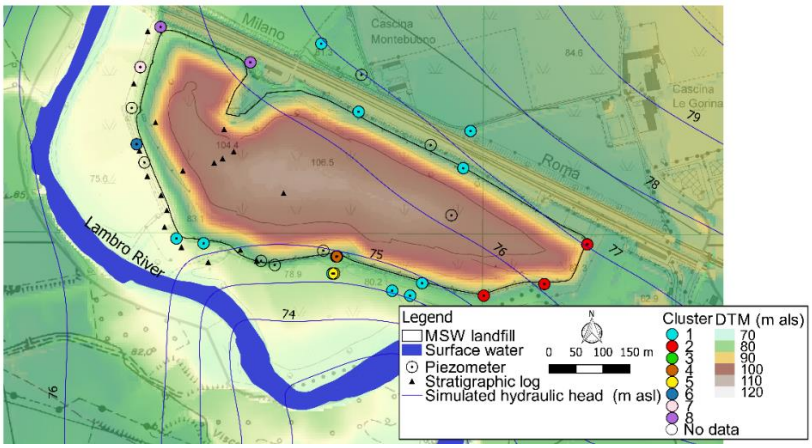

Fig. 1 - Study area with the simulated piezometric map (November 2017) and cluster analysis hydrochemical results (2014-2017)

The groundwater flow model correctly simulates both the piezometric behaviour and the leachate plume flow path. In particular, after reaching the water table, the leachate moves toward the deeper sandy aquifer while, downstream, it moves upward due to the gaining effect of the Lambro River.

CONCLUSIONS

An integrated approach based on the use of different methodologies to elaborate data appeared to be appropriate. In the presented study this approach increased the comprehension of the hydrological system and of the pollution evolution, allowing to a) evaluate the NA phenomena, b) suggest an optimal monitoring network to distinguish pollution and background contamination, c) locate a conformity point as provided by law to verify the downstream groundwater quality.

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How models surprise

Daniel Feinstein

United States Geological Survey, USA

KEYNOTE LECTURE

Groundwater models are constructed objects of knowledge – that is, vehicles of expectation (after Popper). They are certainly not timeless forms of truth … but by representing and interacting with our expectations, they do surprise. I am not claiming that flow and transport models overturn fundamental expectations of physics – the ordinary intermediate-scaled, continuous, Euclidean, Newtonian, field-based physics that is second nature to us (although fundamentally wrong). Rather, in talking with colleagues, I am struck by the ways that our models can 1) extend, 2) disappoint, and 3) complicate our ordinary expectations.

Examples abound in the consulting and academic domains. Consider a site model that points to previously unexpected sources of contamination. Or a calibration process that pinpoints problems with previously accepted data. Crucially, surprises may arise from deficiencies in our understanding of mechanisms (and even our choice of equations), deficiencies which may only become explicit when a model is rigorously subjected to history matching and uncertainty analysis. In a different way, the rising field of statistical modelling trained on physically-based models has great potential for enriching our expectations. Metamodels expose correlations among predictors, even for uncalibrated models, which, in turn, can highlight unexpected patterns of causation. Examples of models that extend, disappoint, and complicate our expectations are examined.

The well-constructed models we make have strengths (they enforce mass balance) and weaknesses (they are incomplete, always departing from the truth). For both reasons they often turn around and act on us in ways that are surprising. An open question: Is it possible to design a model so that it is more likely to defy and reshape hidden assumptions and questionable expectations?

Nullspace Monte Carlo particle tracking to identify source areas of groundwater pollution in the N-W Milano FUA (AMIIGA Project-CE No 32)

Luca Alberti[1], Loris Colombo[1], Giovanni Formentin[2], Pietro Mazzon[1]*

[1] Politecnico di Milano, Dipartimento di Ingegneria Civile e Ambientale (DICA), Milano, Italy.
**Corresponding email: loris.colombo@polimi.it*

[2] Tethys S.r.l., Milano, Italy

ABSTRACT

The Italian Decree no. 152/2006 requires local administrations to identify the subjects that caused contamination of soil and groundwater. This is a compulsory step to enable the characterization and remediation of a contaminated site, and yet, in old industrial areas impacted by multiple sources, it can prove very challenging.

The aim of the present study is to propose a stochastic methodology to locate potential sources while taking into account the uncertainties in time (using a transient numerical flow model) and in space (with a forward particle tracking from a site suspected to host buried wastes) in the N-W sector of the Milano Functional Urban Area (FUA). The methodologic probabilistic framework (developed within the AMIIGA project package funded by Interreg Central EUROPE) could be used for a historical reconstruction of releases from contaminated sites (under uncertainties) in order to apply the guiding principle in the European environmental legislation (European Parliament, 2016), the Polluter Pays Principle.

Keywords: contaminated sites, organo-chlorinated solvents, null space Monte Carlo, particle tracking, Modflow

METHODS

In Functional Urban Areas (FUAs), Management plans need to take into consideration both point sources (PS, corresponding to areas releasing plumes of high concentrations, i.e. hot-spots) and multiple point sources (MPS, consisting in a series of unidentifiable small sources clustered within large areas) that cause diffuse groundwater contamination. For the former category, according to the fourth part of the Decree n°152/2006 (IEC, 2006) in case they are suspects linked to historical analysis or evidence, if the analytical results overtake the limit concentration (1.1 µg/l for Tetrachloroethene in the italian law), the site is "potentially contaminated".

Tools developed within the AMIIGA Project (i.e. WEBGIS, multivariate and cluster analysis) were applied to FUA in order to reconstruct the historical activity in a specific spatial and temporal context.

In order to reconstruct the main groundwater flow direction and the advective transport of the contaminant in a pilot area in the North-Western part of Milano FUA, a numerical multi-layered transient model was implemented and calibrated with Modflow (Harbaugh et al., 2000). Withdrawal from 4997 wells has been considered as a major source of uncertainty in contaminant directions

(PEST, (Doherty, 2014)). In this sense, the deterministic approach is not able to consider the uncertainties due to calibration parameters and targets affected by data entry error (i.e. chemical analysis provided by laboratory) and by historical documentation (archives' research provided by Province, Region, Sanitary Authority and Environmental Protection Agency).
For this reason, adopting in PEST a Nullspace Monte Carlo (NSMC, (Tonkin and Doherty, 2009)) analysis, several sets of hydraulic conductivity fields were generated, all respecting the measured transient head targets. Considering the effect of heterogeneity in hydraulic conductivity distribution within the aquifer, using MODPATH (Pollock, 1994) and placing a number of particles as starting points in a suspected contamination site, 400 forward MODPATH runs were performed starting by a stochastic set generated by the NSMC procedure and minimizing the objective function (composed by the head targets in monitoring wells).

RESULTS

Collecting the particle positions in each cell of the multi-layered aquifer for the most suitable realizations (a selection was based on an acceptable threshold objective function, i.e the value obtained with the deterministic model), the stochastic forward tracking technique was able to obtain: 1) a probabilistic map of source location and time of source activation 2) the wells likely to be impacted downstream of the suspected source and 3) the correlation between the time frequency of passing particles and the observed concentration time-series in the suspected wells.

CONCLUSIONS

Identification of the sources of groundwater contamination is crucial to enable remediation of contaminates sites, where groundwater concentrations are higher than the threshold limit valued fixe by the Decree no 152/2006 in Italy. The identification is always very complex and very difficult to be solved in old industrial areas where contamination can be very dated. Following a criterion of the "most probable than not", a probabilistic methodology was developed in order to quantify the sources of uncertainty affecting groundwater flow over time (abstraction rate from wells and contamination spill in the suspected area) and the uncertainties linked to the hydrogeological model (hydraulic conductivity and vertical discretization). The obtained maps correlate and reconstruct the historically contaminated wells with the "potential source areas", thus enabling public authorities to focus their investigations of actual contamination sources.

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Water resources provided by the major aquifers in the Province of Siena within the framework of the Provincial Territorial Plan (PTCP)

Piero Barazzuoli[1], Fausto Capacci[2], Jenny Migliorini[2]*

[1] Università degli Studi di Siena, Dipartimento Scienze fisiche, della Terra e dell'Ambiente, Siena, Italy

*[2] Independent professional geologist, Siena, Italy. *Corresponding email: capacci10@unisi.it*

ABSTRACT

The management of water resources, particularly for drinking water purposes, is no longer delegated to individual Municipalities or to consortia between municipalities, as the community, national and regional legislation has identified the Authorities and Basins, in their various capacities, which pursue the same water resource management objectives.

Faced with such a strategic issue such as water, local administrations in Tuscany must necessarily contribute to determine the planning strategies as defined by the spirit of the Regional Law 65/14. This work therefore, falls within the scope of research finalised to a disciplined management of water resources within the framework of the Territorial Plan.

The area subject to research includes the entire territory of the Province of Siena, within which, when drawing up the Provincial Territorial Plan, we assessed the surface and groundwater resources of the whole territory, with particular reference to those which concern the aquifers which are most significant (CISS – Significant Groundwater Bodies) for the Tuscan Region, and therefore, strategic for the Province itself.

Finally, we compared this groundwater resource with the total demand for water in the provincial territory in order to assess the sustainability of the activities linked to said demand.

Keywords: water resources, planning, management

METHODS

The evaluation of the total water resources in the provincial territory and their division in surface and groundwater was carried out with the criteria proposed by Barazzuoli et al. (1995), which are based on the one hand on the average parameter values of the Water Balance of River Basins (P=Er+D+Ie) and, in particular, on the estimate of excess water (Ws), and on the other on the infiltration values (Iti) and the groundwater runoff (Dsott) for Hydrogeological Systems (Iti=Dsott).

In order to assess the renewable water resource in the hydrogeological systems in question, we carried out *an indirect evaluation of the total infiltration (Iti)* using the calculation procedure based on the potential infiltration rate (C.I.P. in Celico, 1988), which consists in infiltration percentages based on the degree of permeability of the lithotypes which constitute the analysed hydrogeological system, in relation to Ws.

This type of assessment was structured over various stages:

1st - Definition of the degree of permeability of the various lithotypes and choice of pertinent C.I.P.;

2nd - Elaboration of an isoline map of the average annual Ws;
3rd - Evaluation of the Ws related to each hydrogeological system examined;
4th - Calculation of the total infiltration in each area examined through the relation: Iti = Ws*C.I.P.*S (S=*surfacing water of the hydrogeological basin*).

RESULTS

Based on average values (for the years 1967-2006) of the hydro-climatic parameters collected and elaborated whilst reporting the water balance throughout the provincial territory, we have acquired all the useful elements in order to assess the significant groundwater bodies (CISS) within the Province of Siena, through the procedure based on the C.I.P. The individual assessments are reported in Table 1.

AQUIFER NAME	P	Er	Ws	CIP	Iti
CARBONATE AQUIFER OF MONTAGNOLA SENESE AND OF PIANA ROSIA	106	74	35	0.9	31
CARBONATE AQUIFER OF POGGIO DEL COMUNE	31	22	9	0.9	8.3
CECINA AQUIFER	2	2	1	0.6	0.4
CARBONATE AQUIFER OF THE COLLINE METALLIFERE	7	4	3	0.9	2.7
ELSA AQUIFER	24	18	7	0.4	2.7
VAL DI CHIANA AQUIFER	137	101	37	0.3	10.9
CARBONATE AQUIFER OF MOUNT CETONA	15	9	6	0.9	5.1
AMIATA AQUIFER	94	50	50	0.9	45.3

Table 1 - Final results obtained from the estimate of surface and groundwater resources of the main aquifers in the provincial territory (Years 1967-2006); values expressed in 10^6 m^3/year

For some of these aquifers (*Montagnola Senese and Mount Amiata*), these indirect evaluations are confirmed by the results of hydrological studies which assessed the resource directly either based on the piezometric water levels or their range or on the mean water flow of the springs they feed.

CONCLUSIONS

The groundwater resources assessed with the C.I.P. were then compared with the total water demand (Drinking, Irrigation and Manufacturing consumption) of the Province of Siena; for which an average total water requirement equal to approximately $77 \cdot 10^6 m^3$/year, corresponding to about 2435 l/s, has been defined.
Referring to previous assessments, it is possible to state that as matters currently stand, the sole groundwater resources referring to said aquifers are, on average, widely sufficient to meet said water demand. The data obtained for the water supply and demand have also led to formulating a critical analysis of the situation in the Province of Siena in relation to the current water resource management. Implementing summary sheets reporting all known information concerning significantly important aquifers (CISS) lying, wholly or partially, within the province's territory, has been a useful means to

define direct and indirect intervention strategies by the Provincial Council on the strategic topic of Water Resources Management.

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Hydrogeological setting of a Rome city sector: shallow groundwater in the right bank of Tiber River inside the G.R.A highway

Adele Clausi[1], Roberto Mazza[1], La Vigna Francesco[2], Isidoro Bonfà[2]*

[1] *Università degli Studi Roma Tre, Dipartimento di* Scienze, *Sez. Geologia, Roma, Italy.*
**Corresponding email: ade.clausi@stud.uniroma3.it*

[2] *ROMA CAPITALE, Dip. Tutela ambientale, Uff. Geologia e Idrogeologia Ambientale, Roma, Italy*

ABSTRACT

This paper presents a detailed hydrogeological study of a Rome city sector, in the right bank of Tiber River, approximately inside the GRA highway and focused on the east of "Rio Magliana" stream.
A hydrogeological model of the subsoil of this city sector, more detailed than the most recent Hydrogeological Map of Rome (1:50.000 scale - La Vigna and Mazza, 2015) has been possible to obtain by means of the geologic-stratigraphical analysis, performed starting from the data provided by Environmental Protection Dep. of Roma Capitale (Municipality of Rome) and through the analysis of historical topographic and thematic maps of this sector. Moreover, the most superficial aquifer bodies has been identified.

METHODS

An extensive bibliographic research, aimed to recovering as much data as possible to homogeneously cover the study area, has been performed in order to build the conceptual groundwater model.
Most of data have been provided by technical reports of the notified sites stored in the Environmental Protection Dep. of Roma Capitale's database, by the Ventriglia's work (2002) and by the historical topographic and thematic maps of Rome as well. The historical maps was very useful because they report the presence of ancient springs and fountains, nowadays mostly erased by the anthropic urban texture. The cartography analysis has been also supported by targeted field observations.
Subsequently the archived data have been elaborated by means of constructing detailed hydrogeological cross sections (1:10.000 scale). The water table contours' elaboration was manually performed by means of triangulation methodology and then improved with visual methodology, by comparing the springs' elevations with the morphology shape. The spatial analysis and the overlapping operations of the several drawings were performed by means of ESRI Arcgis 10.1 and Adobe Illustrator CC 2017 software.

RESULTS

The obtained hydrogeological cross-sections highlighted that in the northern sector of the study area the upper volcanic deposits have an important thickness and base oneselves on a fine cineritic deposits called, on the geological map (Funiciello et al. 2008), "*Tor de' Cenci* Unit".
Going towards the central and southern areas, the volcanic deposits thickness is reduced and the underlying "*Ponte Galeria* Formation" becomes thicker with the "*Pisana* Member", a stratigraphic

member made up of three different lithofacies (Pgl $_{3a}$, Pgl$_{3b}$, Pgl $_{3c}$). In the study area the "Sandy-clay lithofacies" (PGL$_{3b}$) (*Argille a Venerupis senescens* Auctt.) presents a certain continuity. This stratigraphic setting also in conjunction with the water table available data and the springs' elevations, allowed to suppose that the "*Tor de Cenci* Unit", in the northern sector of the study area, and the "Sandy-clay lithofacies" of the "*Pisana* Member", in the southern sector, can assume the role of aquicludes of their upper aquifers, which can been identified in the geological formations of: volcanic tuffs "*Tufi varicolori di Sacrofano*" and "*Tufi di La Storta*" in the first case (upper shallow aquifer), and the sedimentary "Sandy lithofacies" ("*Sabbie Salmonate*" Auctt) in the second case (lower shallow aquifer).

CONCLUSIONS

The hydrogeological conceptual model of the analysed sector allowed to detect the presence of two overlapping shallow aquifers bodies, the first in the upper volcanic deposits of Sabatini Mts, and the second in the most superficial sandy sediments of the "*Ponte Galeria* Formation" that sometimes can result confined.

Both circulations are separated from the underlying deeper regional aquifer, except for the sectors where the stratigraphic setting does not allow hydraulic separation and therefore determines a single groundwater circulation.

This hydrogeological setting has been represented in a detailed Hydrogeological Map 1:25.000 scale. The detection of these shallow aquifers contributes to the basic knowledge for the protection of local water resources, especially from the anthropic pressure factors that insist on this area.

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A preliminary method for the assessment of groundwater flooding susceptibility in urban and rural areas

Silvio Coda[1], Vincenzo Allocca[1], Domenico Calcaterra[1], Pantaleone De Vita[1], Diego Di Martire[1]*

*[1] Università degli Studi di Napoli Federico II, Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse, Napoli, Italy. *Corresponding email: vincenzo.allocca@unina.it*

ABSTRACT

Groundwater flooding susceptibility (GFs) can be expressed as the probability of spatial occurrence of groundwater flooding, given a set of hydrogeological and geo-environmental local conditions. Groundwater flooding (GF) is "*the emergence of groundwater at the ground surface away from perennial river channels or the rising of groundwater into man-made ground, under conditions where the normal ranges of groundwater level and groundwater flow are exceeded*" (McDonald et al., 2008, 2012). The impact of GF can be severe on rural and urban environments, cultural heritage, socio-economic activities and human health. McDonald et al. (2008) identify three scenarios of GF in the UK, triggered by: i) water table rising above the land surface in response to prolonged extreme rainfall in unconfined and consolidated aquifers; ii) rapid response in groundwater levels to precipitation and limited storage capacity in shallow and unconsolidated sedimentary aquifers; iii) groundwater rebound (GR) induced by reduction in groundwater abstraction due to a decrease of industrial activities in large aquifers underlying urban centres.

Legislation about flooding risk management has been introduced in Europe by the Directive 2007/60/EC, which has been subsequently adopted in Italy by the Legislative Decree 49/2010. This law has recognised the importance of assessing, preventing and reducing flooding hazard and risk.

In order to provide a useful contribution to scientific debate on a global and current issue of the Urban Groundwater Science, in this study we attempt to develop a methodology for the assessment of GFs associated with GR, by empirical estimate of a GFs index based on the hydrogeological, geomorphological, hydraulic and land use characteristics of an aquifer. An area of about 14,3 km^2 in the eastern part of Naples (southern Italy) was selected to test the method. Since 1990, the test area has been affected by GR due to the reduction in groundwater pumping (Coda et al., 2019), while since 2007 GF impacts on buildings and agricultural lands have been recorded for a total count of 55 cases. The effectiveness of the method proposed has been verified by comparing the susceptibility classes with the results of hydrogeological monitoring and spatio-temporal distribution of flooded areas.

Keywords: groundwater rebound, groundwater flooding susceptibility, urban and rural area, Italy.

METHODS

A parametric and semiquantitative methodology was developed, considering intrinsic factors controlling the GFs. The approach used takes into consideration five predisposing parameters for calculating the GFs index, by the following empirical equation:

$$\text{GFs index} = [A \times U \times R \times L \times D]$$

Where, A is type of saturated aquifer, U is hydraulic characteristic of unsaturated medium, R is type of groundwater-surface water interaction, L is land use type, and D is depth of water table. A score range was applied to each selected parameter by means of a heuristic approach. In raster GIS environment, for each cell in which the area is discretized, the GFs index was calculated by product of scores assigned to each parameter. The GFs index varies from 0,001 to 1.2 and is divided into five classes. The method was applied to a porous multi-layered aquifer system located in the eastern peri-urban area of Naples, characterized by volcaniclastic and alluvial deposits, where a considerable geological database is available and a continuous hydrogeological monitoring in the 2015-2018 period was carried out (Coda et al., 2019).

RESULTS

The GFs index map (Fig. 1) showed that the zones with low and very low susceptibility have an extension of 5,2 km^2 (36,6 %), while the moderate susceptibility area has an extension of 2,0 km^2 (14 %). The remaining part of the area is extended for 7,1 km^2 (49,4 %) and shows a high and very high susceptibility. Of a sample of 55 flooded sites, monitored in the period 2013-2018, 64% and 36% were collocated in the very high and high susceptibility classes respectively.

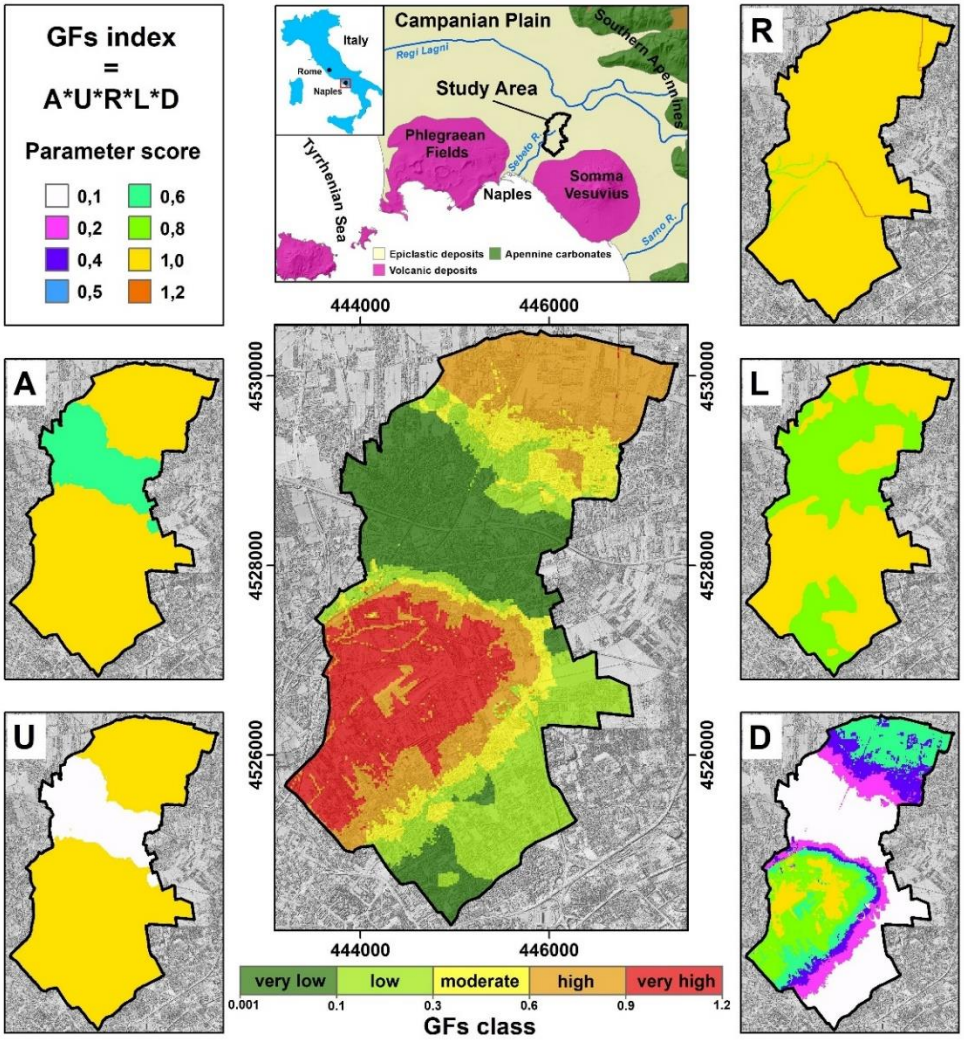

Fig. 1 - GFs index map of the area study

CONCLUSIONS

The method is apparently applicable to investigate GFs in areas affected by GR-induced GF. The GFs index map can be considered the first step to implement hazard and risk maps and a new tool to assist the local Authorities in addressing the problems derived from GF. For this reason, we suggest testing other urban and rural aquifers affected by GR-induced GF, using this methodology to compare outcomes and improve it.

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Hydrothermal management of an ATES system in Wallonia, Belgium

Guillaume De Schepper[1], Marco Riboni[1], Tanguy Robert[2,3]*

[1] AQUALE s.p.r.l., R&D Department, Noville-les-Bois, Belgium.
**Corresponding email: m.riboni@aquale.com*

[2] University of Liège, Urban and Environmental Engineering, Liège, Belgium

[3] F.R.S. – FNRS (Fonds de la Recherche Scientifique), Brussels, Belgium

ABSTRACT

In the context of energy transition, new building constructions often include air conditioning energy-saving technologies based on sustainable energy sources, such as aquifer thermal energy storage (ATES) systems. An open-loop well doublet ATES system was designed and is under implementation in the interest of a new administrative building in the city of Liège, Belgium, along the Meuse river. This ATES system will be the very first operational in Wallonia (southern Belgium) and will presumably be the reference case for future ATES developments in this region. Potential thermal impact on the local aquifer, based on thermal needs from the future building, was simulated and quantified with a 3D groundwater flow numerical model.

Keywords: groundwater, geothermics, aquifer thermal energy storage, hydrogeological modeling

METHODS

The targeted alluvial aquifer reservoir was thoroughly characterized with several boreholes drilled and field experiments performed. To determine the hydraulic properties of the aquifer, a step-drawdown and a long-term constant rate pumping tests were performed on ATES wells. In addition, the transport parameters of the aquifer were estimated with a dye tracer test (Na-naphtionate) and a heat tracer test. Collected field data were the basis for developing a 3D groundwater flow heterogeneous numerical model coupled to heat transport by means of FEFLOW (Diersch, 2014). It was automatically calibrated with the state-of-the-art pilot points method (Renard, 2007; Doherty, 2015; Doherty, 2016). Transient simulations were run over a 10-years period for assessing the future ATES system impact on the local aquifer.

RESULTS

The numerical model was used here for simulating and assessing the future ATES system impact on the local alluvial aquifer. A 5 K temperature difference between both wells, corresponding to the minimal temperature difference needed by the groundwater heat pump to be efficient, was applied and respected throughout the simulation process. In addition, the air cooling period is much longer than the air heating period, resulting in a longer warm water storage period. As a result, a significant thermal recycling effect of the ATES open-loop well doublet is foreseen (see Fig. 1). Yet, the groundwater temperature rise doesn't exceed 25°C after a 10-years operational period, with an initial

14.5°C groundwater temperature. Hence, the ATES system efficiency doesn't seem to suffer from this thermal recycling effect.

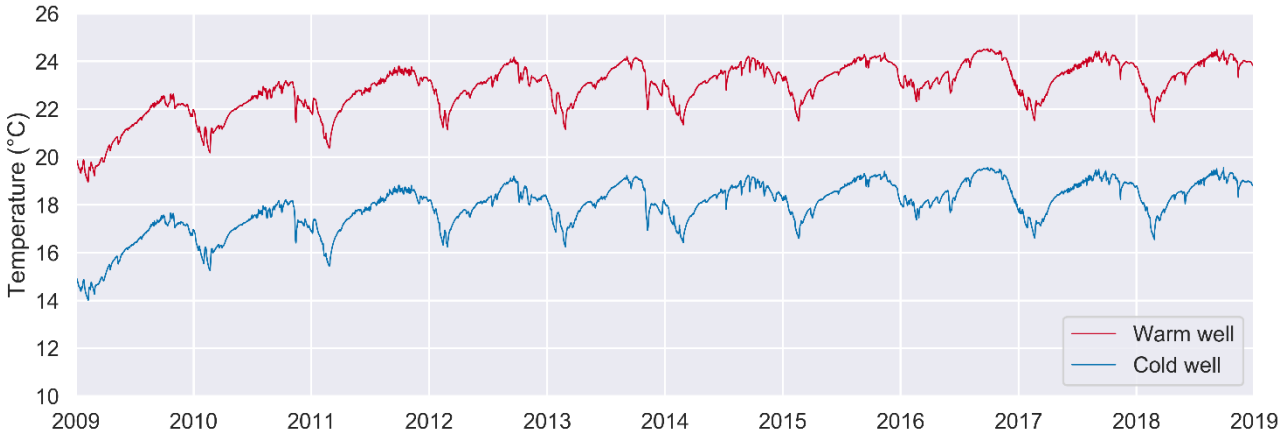

Fig. 1 - Simulated groundwater temperature evolution at the ATES wells (warm and cold wells) over the 10 years simulation period.

CONCLUSIONS

The thermal impact on the aquifer is limited to the vicinity of the building and the system efficiency seems suitable for long-term thermal energy production. This ATES system will be the very first one in Wallonia, while other regions of Belgium already have numerous operational systems (Possemiers et al., 2014; Fleuchaus et al., 2018).

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Evaluation of hydrofacies connectivity and hydraulic properties by using facies and sequence stratigraphy analysis: the case of the Palatine Hill, central archaeological area of Rome

Cristina Di Salvo[1], Luca Laudati[1], Marco Mancini[1], Mattia Marini[2], Salvatore Milli[3,1], Massimiliano Moscatelli[1], Francesco Stigliano[1], Maurizio Simionato[1], Gian Paolo Cavinato[1]*

[1] Consiglio Nazionale delle Ricerche, Istituto di Geologia Ambientale e Geoingegneria (CNR-IGAG), Roma, Italy.
**Corresponding email: cristina.disalvo@igag.cnr.it*

[2] Università degli Studi di Milano, Dipartimento di Scienze della Terra "A. Desio", Milano, Italy

[3] Università degli Studi di Roma La Sapienza, Dipartimento di Scienze della Terra, Roma, Italy

ABSTRACT

This study shows the preliminary results of a hydrofacies analysis of the terrains constituting the Palatine Hill (Central Archaeological area of Rome), by means of a geological reconstruction based on facies and sequence stratigraphy analysis coupled with a hydrogeological monitoring. The distribution of sedimentary deposits reflects processes acting within the depositional environment. Understanding the facies distribution and their internal variations as well as their hydraulic properties is essential for characterizing the behavior of aquifer systems. Facies models thus provide some predictability in the distribution of sedimentary terrains and, in turn, hydrofacies. Groundwater level monitoring allowed detecting differences of how facies influence the hydrogeological response.On this basis, a groundwater conceptual model was built, useful to understand the dynamics in an area characterized by a very complex geological setting, having a high historical and archaeological value.

Keywords: hydrofacies, sequence stratigraphy, groundwater level monitoring

METHODS

Despite its small dimension (0.26 square km), the Palatine Hill exhibits a complex stratigraphic architecture related to the Pliocene and Quaternary evolution of the Roman Basin. The latter hosts the Pleistocene to Holocene Tiber succession, and shows a stratigraphic framework which is the result of the close interaction between tectonic uplift, volcanic activity and glacio-eustatic sea-level fluctuations (Milli, 1997). The infill of Roman Basin is characterized by several depositional units constituting low rank depositional sequences, within of each fluvial and fluvial-palustrine-lacustrine and coastal and shelfal depositional systems occur. In the Rome area these sequences form a complex stack of multiple-incised valleys (Milli, 1997; Milli et al., 2008; Mancini et al., 2018), filled by fluvial deposits interbedded with volcaniclastic deposits. This implies a high variability on texture and porosity (i.e., hydrofacies), due to the rapid vertical and lateral variations of the sediment occurring in the fluvial environments. The alternation of depositional and erosional phases determines the overlapping and/or lateral contact between different hydrofacies, which, on turn, brings variations in

the confining conditions of aquifers, the inflow and recharge rates and the response to hydrological stresses. The ultimate objective of hydrofacies analysis is to capture the three-dimensional hydrogeological structure or architecture of aquifer systems and create more realistic groundwater models, with a greater predictive capability. At first, sequences were detected by the well logs parametrization, and cross sections were built to form a fence diagram. Groundwater level oscillations were recorded every 1 hour in 5 monitoring wells (September 2011 - April 2012). Three groundwater circulations were detected: sub-surficial (A-30 m a.s.l.), shallow (B-around 17 m a.s.l.) and deep (C-around 10.5 m a.s.l.). Data were interpreted in the light of Palatino sequence stratigraphy architecture, and the multiple groundwater levels were associated to the corresponding sequences. Differences in the timing and magnitude of aquifers response to the storm and Tiber River floods were detected, probably related to different confining conditions, connectivity between facies and storage coefficient values.

Depositional sequence	Litostratigraphic units (Mancini et al., 2013)	Hydrofacies (aquifer?)	Monitoring wells
PG6	VSN		Not monitored
PG5	FTR	A-subsurficial, 30 m a.s.l.; B-(shallow), 17 m a.sl.	22p; 16 ms
PG4	PPT, PPI	B-(shallow), 17 m a.s.l.	23 CH1
PG3	CIL	C-(deep), 10.5 m a.s.l.	23 CH0; 8 ms

RESULTS

The deepest aquifer C (PG3), with base level very close to the valleys of Holocene tributaries shows a rapid and impulsive hydrological response to Tiber river flood; this suggests a strong connection and high transmissivity;

The shallow aquifer B is hosted in sequences PG4 and PG5 and is monitored in two distinct wells. The response to rainfall-floods are smoothed with respect to aquifer C, and occur with different magnitude in the two sequences. This suggests a weak connection with tributaries; differences in texture and porosity imply different storage coefficient for the two sequences.

The subsurficial aquifer A is hosted in the PG5; however, differently from aquifer B, it does not show any connection with river floods. This can be due to a different thickness of PG5 in this portion of the hill, as well as scarce connection with Holocene tributaries valleys.

CONCLUSIONS

This works represents the first results to a hydrofacies analysis approached by means of facies and sequence stratigraphic analysis in the centre of Rome. Results show that the facies analysis and the sequence stratigraphy approach provide a better understanding of local groundwater flows; it is very helpful in avoiding erroneous interpretations of piezometric data in complex geological contexts, since allows to account for interconnectedness of aquifers and their confining condition. The model can set the base for further groundwater modelling, in which the values of hydraulic and solute-transport parameters can be assigned by means of the hydrofacies-based model grid cells, and may be subsequently adjusted during the model calibration process.

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Preserving archaeological heritages from flood hazard: use of 3D geological models as a base for conceptual hydrogeological scheme in the area of the Coliseum (Rome)

Cristina Di Salvo[1], Marco Mancini[1], Massimiliano Moscatelli[1], Francesco Stigliano[1], Maurizio Simionato[1], Gian Paolo Cavinato[1]*

[1] Consiglio Nazionale delle Ricerche, Istituto di Geologia Ambientale e Geoingegneria (CNR-IGAG), Roma, Italy.
**Corresponding email: cristina.disalvo@igag.cnr.it*

ABSTRACT

Historical city centers must often deal with problems related to the preservation of archaeological heritages from natural risks. The case study lies in the historical center of Rome, in the area of the Anphitheatrum Flavium (Coliseum), the most important testament of the Roman Empire hosting the highest number of annual visitors in Italy (6.5 Mln during 2016). Such high touristic flow is responsible for a raising of exposition to hazards such as floodings and, consequently, an increase of the total risk. During the last years, the Central Archaeological Area of Rome experienced many flooding cases, due to intense storm events (Di Salvo et al., 2018). During the 10/20th/2011 storm, Floodwater elevation in the Coliseum reached 6 m from the ground of the hypogea. The comprehension of surface water-groundwater dynamics together with the anthropic modification of the hydraulic system is fundamental for understanding of flood mechanism e planning mitigation actions.

Keywords: Historical city centre, Rome, Coliseum, groundwater, flood hazard

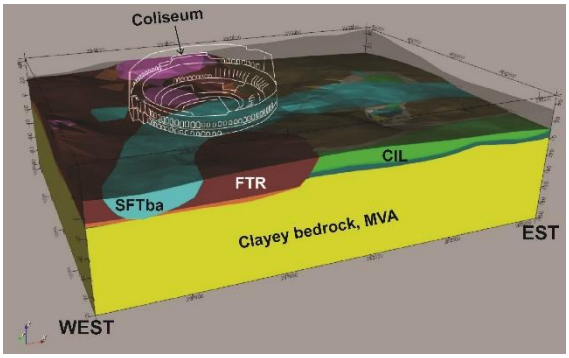
METHODS

Borehole data were interpreted in order to homogenize the log descriptions. Despite the existence of previous conceptual hydrostratigraphic frameworks (Capelli et al., 2008; La Vigna et al., 2016), lithostratigraphic units were divided or grouped into complexes, by using a lithological criterion, accounting for hydraulic conductivity values and the stratigraphic sequence hierarchy (Fig. 1). Pleistocene sequences (the clastic CIL and FTR formations, Mancini et al., 2014) are distinct complexes in the model. Indeed, even if lithological differences can be scarce, the geometries, recharge areas and flowpaths of the two formations are different. This means that also the groundwater contribution to the Arena from these two aquifers could be different, in terms of discharge and response time to rainfall and river stage fluctuation. Three cross sections were initially drawn and used as input data for a 3D hydrostratigraphic model.

Non marine Syntherms [1] and 3rd order marine Sequence [2]	Formation [1]	Lithotypes	Hydrostratigraphic complex
Tiber River Synthem (MIS 5-1)	Anthropogenic layer (Holocene)	hm: dominant masonry hb: dominant infill	h
	Alluvial deposit (Tiber River depositional system, Upper Pleistocene-Holocene)	SFTba 1: gravels SFTba 2: sands SFTba 3: silts and clay	SFTba 1 SFTba 2 SFTba 3
Quartaccio Synthem (MIS 10-9)	Aurelia Fm. Villa Senni Fm.- Pozzolanelle Villa Senni Fm.- Tufo Lionato (355 ± 2 ka[3])	AEL: sandy-silty VSN2: poorly cemented, welded coarse scoriaceous ashes VSN1 a: lithoid tuff VSN1 b: poorly cemented, welded coarse scoriaceous ashes	VTA-Q
Fosso del Torrino Synthem (MIS 12-11)	Pozzolane nere Fm. (407± 4 ka[3])+ LTT La Storta Fm. (416± 5 ka[3]) Pozzolane Rosse Fm. (457± 4 ka[3]) Fosso del Torrino Fm.	PNR: Black massive and chaotic pyroclastic unit LTT: Ashy and scoriaceaous pyroclastic deposit RED: massive semicoherent deposit with up to 24 cm diameter FTR 1: sandy gravels FTR 2: silty sands and sandy silts FTR 3: clayey silts and silty clays	VTA-S FTR 1 FTR 2 FTR 3
Villa Glori Synthem (MIS 14-13)	Tufi stratificati varicolori di Sacrofano Fm. (488± 2 ka[3]) Prima Porta Unit (518 ± 5 ka[3]) Palatino Unit (520 ± 8 ka[3]) Valle Giulia Fm.	SKF: pyroclastic deposit with interbedded volcano- sedimentary PTI: lithoid tuff PPT: lithoid tuff VGU 1: gravels VGU 2: silty sands, sandy silts and clays	PTI-VGU
Flaminia Synthem (MIS 16-15)	Santa Cecilia Fm.	CIL 1: gravels CIL 2: interbedded silty sands and sandy silts CIL 3: Clayey silt	CIL 1 CIL 2 CIL 3
Vatican Sequence	Monte Vaticano Fm. (Lower - Upper Pliocene)	MVA	MVA

← *Fig. 1*

Fig. 2
↓



RESULTS

The 3D view enables different perspectives of the geology, allowing understanding at best the aquifer geometries and the lithological contacts between complexes (Fig. 2). The older Pleistocene sequence (CIL Fm) spreads on the eastern portion of the model, while is absent in the western part. Conversely, the youngest sequence (FTR Fm) covers the western portion while is lacking in the eastern part. The thickness of these sequences progressively reduces toward the center of the model, (i.e., the center of the Anphiteatrum), where are missing or eroded, and the Holocene valley (SFTba Fm) directly overlays the clayey bedrock. Piezometric measurements show a groundwater head flow directed from East to West. A shallow groundwater domain, collecting local rainfall infiltration, surface runoff and overland flow is hosted into the uppermost portion of the SFTba Fm and the anthropic Backfill deposit; a deeper, confined one occurs into the CIL and FTR Fm. The gravel bed at the base of SFTba (Sftba 1) acts as a drain for groundwater uprising from the Pleistocene aquifers, ensuring the hydraulic continuity. An upward groundwater transfer between the deep and the shallow domains cannot be neglected, likely occurring through the sandy portions of the alluvium (SFTba 2). Thanks to this double system, both surface water and groundwater are collected from the east, north and south toward the center of the arena, and then are drained westward. The anthropic modifications of the hydrological system took advantage of this particular setting, tending to manage and control the inflow-outflow rates. In the case of intense storms, increased runoff and piezometric head can result in an increased upwarding flow. In a condition of Tiber flood, the channels and sewers can be overwhelmed, and the increased inflow results in hypogea flood.

CONCLUSIONS

The aim of this work was to furnish a conceptual model useful for further flood hazard mitigation studies in the area of the Coliseum. The geological model allows optimizing the management of stratigraphic information; the 3D visualization speeds the process of stratigraphic setting evaluation. The model was helpful in detecting geological limits and computing volumes and thicknesses, evaluating the geometric relationships between hydrogeological complexes. The conceptual model, together with historical-archaeological information and observations, allowed formulating hypothesis about the dynamics of groundwater and surface water inflows to the arena. In order to plan action for a proper management of stormwater, groundwater inflows and outflows should be quantified by means of a proper long-term monitoring.

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Evaluation of nitrate trends in groundwater: a case study in a groundwater body in southern Italy

Daniela Ducci[1], Renata Della Morte[2], Adolfo Mottola[3], Giuseppe Onorati[3], Giovanni Pugliano[2]*

[1] Università degli Studi di Napoli Federico II, Dipartimento di Ingegneria Civile, Edile e Ambientale, Napoli, Italy.
**Corresponding email: daniela@unina.it*

[2] Università degli Studi di Napoli Parthenope, Dipartimento di Ingegneria, Napoli, Italy

[3] Agenzia Regionale Protezione Ambientale della Campania (ARPAC), Napoli, Italy

ABSTRACT

A procedure for trend analysis has been adopted, applying the guidelines proposed by ISPRA (Italian Institute for Environmental Protection and Research), according to the spatial and temporal dimension of the available dataset. For calculating the statistical significance of the upward trend of time series, the Mann-Kendall method has been used, while, for estimating the value of the trend and for predicting the nitrate concentrations in 2021 and 2027 (terms of the first and second planning cycles in Italy), the Sen method has been applied.

The trends of the time series of nitrate concentrations has been evaluated for 16 sampling points located in a groundwater body of the Campania region (southern Italy), classified at bad quality status due to nitrate concentration and therefore defined "at risk".

The study indicated that the location of the sampling points presenting upward trends seems to be strictly related to the land-use (population density, agricultural practices, efficiency of the sewer system, etc.).

Keywords: groundwater quality, nitrate pollution, nitrate trends, Italy

METHODS

The present study used, for the trend analysis, the groundwater bodies (GWB) quality monitoring network of the Environmental Protection Agency of Campania (ARPAC). With the aim to establish the chemical status classification (Directive 2006/118/EC and Italian D.lgs. 30/2009), ARPAC samples and analyses groundwater of the monitoring network points, at least twice per year (http://www.arpacampania.it/web/guest/365).

The examined GWB, the Volturno-Regi Lagni plain (P-VLTR), is the largest of the Campania region (southern Italy) and it is formed by two porous aquifers: the shallow and not continuous phreatic aquifer (10–20 m of silty-sandy alluvial-pyroclastic deposits), with low-moderate permeability, and the main aquifer (60–70 m of coarse-grained sandy sediments), with moderate-high permeability. These two aquifers are separated by the Campanian Ignimbrite (39 ky B.P.) tuff, with a maximum thickness of 50–60 m.

Since the previous century, a severe contamination by nitrate (more than 50 mg/L) has been recognized in the P-VLTR GWB (Corniello et al., 1990), also in the main, protected aquifer. The

nitrate concentration measurements were selected from 16 monitoring well, collected between 2003 and 2017 and with approximately 2 nitrate analyses per year.
The nitrate trends in each monitoring point were calculated by adopting the guidelines suggested by the Italian Institute for Environmental Protection and Research (ISPRA 2017), based on the D.M. Env. (2016).
The procedure provides, after to ascertain the consistency of the data set for each monitoring point, the evaluation of the increasing trends statistically significant (p-value = 10%) for each monitoring point and the estimation, for the points showing an increasing trend, of the effective value of the trend (angular coefficient) and the calculation of nitrate concentrations in the future (2021 and 2027 scenarios).
The nitrate trends of the time series were performed by using the non-parametric Mann-Kendall test (MK). In case of presence of an increasing trend, the effective value of the trend was estimated using the non-parametric Sen approach. Using the Sen's slope (variation of the nitrate concentration per year), it is also possible to estimate nitrate concentrations in the future, i.e. nitrate concentrations at year N.

RESULTS

In the period 2003-2017, the nitrate concentration (mean value) is higher than 37.5 mg/L in eight wells. The results showed that nitrate had not detected change in the majority of wells (56%). Three wells had a statistically significant decreasing trend. No reversal trends have been individuated. Statistically significant increasing trends were observed at four wells, corresponding to a percentage of 25%, located in the southern part of the GWB, whith mean nitrate concentrations > 50 mg/L (Ducci et al. 2019).
For these four wells with an increasing trend, the nitrate concentrations at 2021 and 2027 (terms of the first and second planning cycles in Italy), calculated using the Sen's slope, are higher than 50 mg/L.

CONCLUSIONS

Chemical data of the groundwater monitoring network of ARPAC allowed the identification of the presence of nitrate pollution in the examined alluvial-pyroclastic GWB and its evolution. The results of the temporal analysis of nitrate concentration indicated that the trend analysis done following the ISPRA approach is very effective.
The southern sector of the study area, affected by high values of nitrate, present upward trends in four wells, confirming the results highlighted in Ducci et al. (2019), where the data set was smaller. This sector presents high population density and intensive agricultural land-use. Three wells have a statistically significant decreasing trend and the remaining 9 wells do not have a trend that was statistically significant. No reversal trends have been individuated and that confirms the absence of strong changes in the land-use in the examined years (2003-2017).
In the four wells showing the increasing trend, the nitrate concentrations in 2021 and in 2027 will be higher than 50 mg/L, if the land-use management does not clearly change toward a sustainable development.

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Groundwater quality assessment downstream Mediouna landfill (Casablanca Morocco)

Ahmed Fekri[1], Chakib Marrakchi[1], Ouafa El hammoumi[1]*

[1] University Hassan II of Casablanca, Faculty of sciences Ben M'Sik, LGAGE.
**Corresponding email: ahmedfekri13@gmail.com*

ABSTRACT

Groundwater monitoring program around a landfill area is usually undertaken to understand the hydro geological conditions in order to determine groundwater quality, to describe the occurrence and distribution of pollution and to delineate contaminant plume in aquifer at long term. The groundwater quality degradation represents a significant threat to public health and environment. Furthermore, the fractured aquifer presents a higher vulnerability especially toward landfill pollutants.

The Mediouna landfill located 10 km SE of Casablanca is sited on fractured hard rock. This unlined landfill without any system to collect the leachate and gaz has a capacity volume of nearly three million m^3. It started on 1983 in the abandoned quarries of sandstone.

The first investigations on a potential groundwater contamination have been carried out three years later. Two close wells showed a brow water color with high values of some heavy metals.

The present study aims to develop an understanding conceptual model to delineate pollution plume downstream the landfill. The assessment of groundwater quality is monitored trough three hydro chemical monitoring campaigns carried out on 2001, 2011 and 2014.

Leachate's sample and 13 wells groundwater's water have been selected from up and downstream of the landfill (Fig. 1) (Smahi et al., 2013). Key parameters, such pH, electric conductivity and majors elements have been measured as well as chemical oxygen demand for organic pollution indication.

The statistical treatment using Principal Component Analysis has identified three well water groups according to their dissolved elements. A first group characterized by high mineralization and organic matter, the second characterized by low concentration of mineralization and total absence of organic matter. The third group shows middle concentrations of both, mineralization and organic matter.

As results, (i) the front of pollution is progressing toward Casablanca city, related to a structural control mainly by the lineaments. The high values are registered close to the landfill and they decrease far of it (ii) the mineral pollution is progressing downstream faster than the organic one.

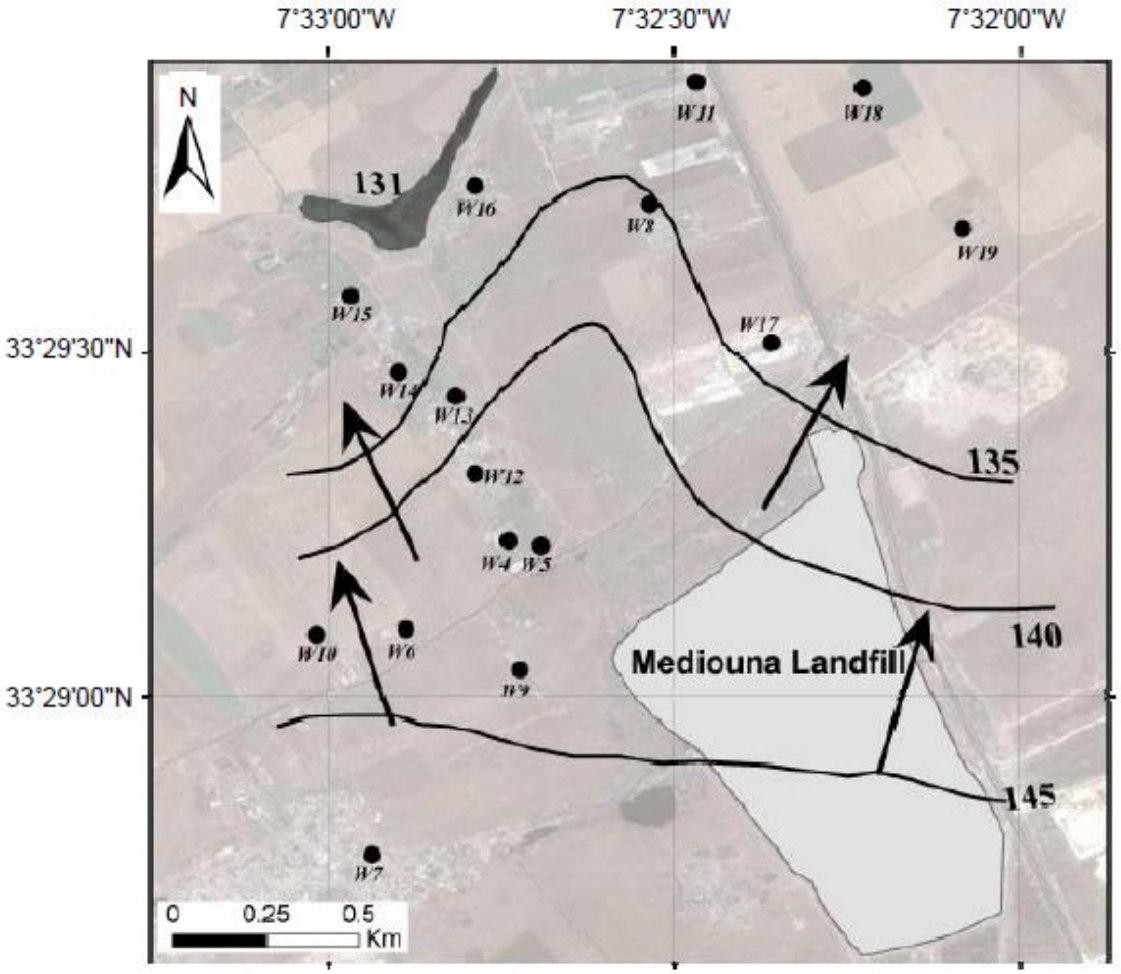

Fig. 1

Keywords: landfill, pollution, groundwater, Mediouna, Casablanca

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Follow-up investigation on groundwater flowpath at regional scale using a multi-isotopic approach: the case study of Lombardy region

Maurizio Gorla[1], Agata Cristaldi[1], Alessandro Lacchini[2], Davide Lo Monaco[1], Valentina Marinelli[2], Simona Pascariello[1], Chiara Righetti[1], Chiara Sbarbati[2], Roberto Simonetti[1], Marco Petitta[2], Ramon Aravena[3]*

[1] *CAP Holding, Ufficio Progetto PIA e Bonifiche - Direzione Ricerca e Sviluppo, Milan, Italy*

[2] *Università degli Studi di Roma La Sapienza, Dipartimento di Scienze della Terra, Roma, Italy.*
**Corresponding email: chiara.sbarbati@uniroma1.it*

[3] *University of Waterloo, Earth and Environmental Department, Waterloo, Ontario, Canada*

ABSTRACT

In the last 50 years environmental isotopes were widely used as a valuable tool to investigate and to understand the source, the travel, the residence time and the processes involving groundwater along a flowpath.

Against this backdrop, the present study is focused on the enlargement of knowledge about groundwater flowpaths, renewable rate and related percentage use in a wide area of Lombardy region through a multi-isotopic approach. Specifically, water stable isotopes (^{2}H and ^{18}O) aimed to trace water flowpath, sources and recharge of groundwater (Petitta et alii, 2011; Carucci et alii, 2012), tritium helped to understand the transit and turnover time of water within a system (Sbarbati et alii, 2015), nitrogen isotopes (^{15}N and ^{18}O in nitrates) allowed to assess, where present, the possible contamination origin (Petitta et alii, 2015; Caschetto et alii, 2017; Sbarbati et alii, 2018), while sulfates isotopes (^{34}S and ^{18}O) focused on deep and shallow contribution to groundwater flow.

The follow-up investigations have been developed in the framework of a research collaboration between the "Water Alliance", which represents a group of water utilities distributed in different Lombardy's provinces, and Sapienza University of Rome.

The research started from the results obtained from a previous isotopic characterization of aquifers tapped for drinking water in the provinces of Milano and Monza-Brianza, performed during 2015 and 2016 by CAP Holding in synergy between hydrogeological lab of Sapienza University (Gorla et alii 2018).

The obtained results confirmed the multi-isotopic approach as a relevant tool to assess origin, ages, vulnerability of groundwater resources and impact of human activities, useful also to improve the sustainable management and protection of tapped groundwater resources used for drinking purposes by Water Alliance members.

Keywords: multi-isotopic approach, groundwater resources, water utilities, Lombardy region

METHODS

A groundwater sampling survey has been performed in November 2017 by water utilities of the Water Alliance in cooperation with hydrogeology lab of Sapienza University. Each supplier selected a defined number of wells and springs having similar hydrogeological characteristics and distributed along a possible regional flowpath, oriented North-South (Fig.1). In particular, 48 samples have been collected for groundwater stable isotopes and tritium, while 28 samples have been selected for nitrate and sulfates isotopes. In addition, 2 water analysis along Adda River have been have been carried out. Oxygen and hydrogen isotope analyses in water have been performed in the Isotope Laboratory of the University of Parma, instead tritium, nitrogen and sulfates isotopes have been analyzed in the Environmental Isotope Laboratory of the University of Waterloo.

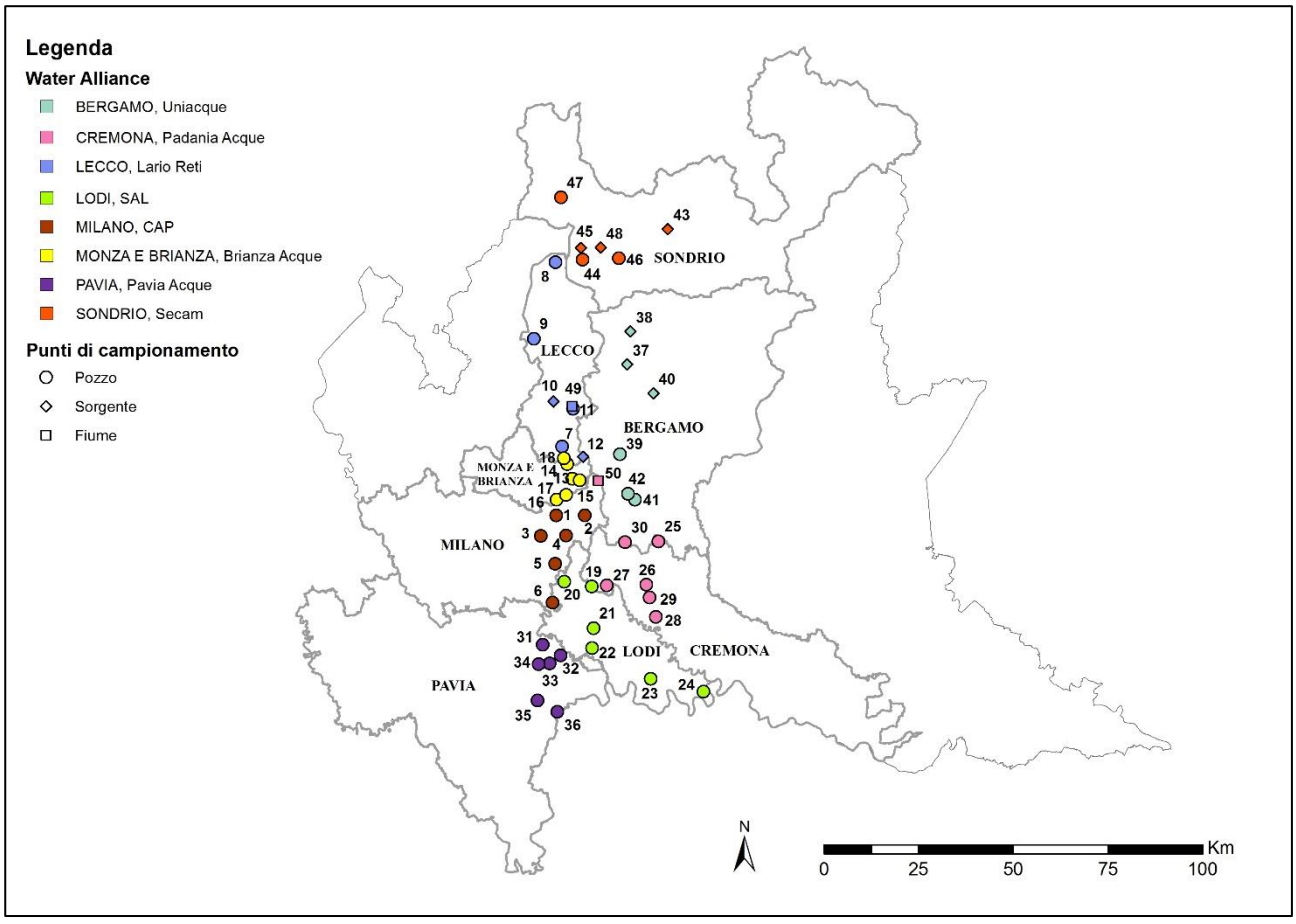

Fig. 1 - Location map of groundwater and surface water samples collected in November 2017.

RESULTS

Groundwater stable isotopes range between -11,2‰ e -8‰ for $\delta^{18}O$ and between -78‰ and -53‰ for δD, with the more depleted values for springs located at high elevation. These depleted isotope signals highlight the influence of topographic effect on meteoric recharge. The same aspect has been identified from tritium results, where these samples reach the maximum concentration values, typical of young water continuously influenced by meteoric recharge. Concentrations values in the other samples vary between 0,8 and 7,3 T.U, similar to those obtained during the previous study (Gorla et

alii 2018). Concerning nitrogen and sulfates isotopes, data range respectively between +0,7 and +23,3‰ for $\delta^{15}N$, and between -0,1 and +11,6‰ for δ18O; while sulfates vary between, +0,5 and +15‰ $\delta^{34}S$ and between +5 and +12‰ for $\delta^{18}O$. Nitrogen results as for the previous study confirm the possible anthropogenic origin of nitrate in groundwater, while sulfates origin can be attributable both to marine origin and oxidation processes, partially influenced by human activities.

CONCLUSIONS

Results obtained from 2017 preliminary sampling survey, interesting a wide area of Lombardy region, allowed to improve the knowledge about groundwater conceptual model from province to regional scale. The study also confirmed the utility of the multi-isotopic approach in defining origin, ages, vulnerability of groundwater resources and impact of human activities, offering a useful tool for improving the sustainable management and the protection of tapped groundwater resources used by different water providers.

The present study lays the foundation for a wide characterization extended to the whole Lombardy region, to define a clear hydrogeological conceptual model necessary for the correct management of groundwater resources tapped for drinking use.

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Implementation of satellite-based data for improving predictions of arsenic contamination in groundwater in the Red River Delta in Vietnam

David Haaf [1, 2], Licia C. Pollicino[3,4], Stefania Stevenazzi[3], Marco Masetti[3], Son V. Nghiem[5], Michael Berg[1], Lenny H.E. Winkel[1,2]*

[1] *Eawag, Swiss Federal Institute of Aquatic Science and Technology, Duebendorf, Switzerland.*
**Corresponding email: david.haaf@eawag.ch*

[2] *ETH Zurich, Institute of Biogeochemistry and Pollutant Dynamics, Zurich, Switzerland*

[3] *Università degli Studi di Milano, Dipartimento di Scienze della Terra "A. Desio", Milano, Italy*

[4] *Politecnico di Milano, Dipartimento di Ingegneria Civile e Ambientale (DICA), Milano, Italy*

[5] *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA*

ABSTRACT

Natural arsenic contamination of groundwater aquifers is globally widespread, and particularly poses a problem in regions where groundwater is the main source of drinking and cooking water. Arsenic poisoning can lead to a myriad of serious health effects such as diseases of blood vessels, diabetes and cancers.

The aquifers of the Red River Delta in Vietnam are highly contaminated with arsenic and it has been estimated that in this area, around 3 million people are affected by high arsenic concentrations (> 10 µg/L, WHO guideline value; Winkel et al., 2011).

Previously, predictions of arsenic contamination in the Red River Delta were established via geospatial modelling using arsenic measurements, as well as surface and 3D-geology. Based on these predictions, probability maps of arsenic at specific depths were created. By comparing these depth-resolved probabilities to measured arsenic concentrations, a drawdown of arsenic-enriched waters from Holocene aquifers to previously uncontaminated Pleistocene aquifers was observed. This finding indicated that arsenic contamination has been exacerbated by excessive groundwater pumping rates (Winkel et al., 2011). Furthermore, in a study conducted in the Mekong delta, it was hypothesized that groundwater extraction causes interbedded clays to compact, thereby releasing water containing dissolved arsenic that is subsequently transported to deeper aquifers (Erban et al., 2013).

Such human-induced changes cannot be captured by the previous predictive models based on natural predictive parameters mentioned above, leading to erroneous predictions of the arsenic content in areas affected by urbanization, especially in deeper aquifers.

To improve predictions in human-affected regions we are using satellite data and remote sensing techniques that enable detection of changes of urban and suburban extents (Nghiem et al., 2009) and vertical build-up (Mathews et al., 2019). Those data and techniques in combination with geochemical and environmental data can help in i) resolving mechanisms behind arsenic mobilization in aquifers due to increased pumping rates and ii) making predictions of arsenic contamination more accurate, especially in areas characterized by increased groundwater pumping.

Keywords: groundwater, arsenic, geospatial modelling, pumping, urbanization

METHODS

To cope with this environmental issue, the Weights of Evidence Bayesian-based model can be considered a reliable methodology to gain a thorough comprehension of the spatial correlation between the occurrence of high arsenic concentration and factors potentially influencing deep aquifer contamination. The advantage of this modelling technique consists in the possibility of quantitatively defining the importance of chemical parameters and urban change patterns in controlling the deep aquifer susceptibility to arsenic pollution. These results have been achieved by analysing quantitative statistical parameters (weights, contrast) of each class by which each factor has been previously subdivided.

In addition to the chemical parameters observed in the Pleistocene aquifer (redox potential and iron concentration) the examined factors included: i) arsenic concentration in the Holocene aquifer and ii) satellite QuikSCAT (QSCAT) data processed with the innovative Dense Sampling Method (DSM; Nghiem et al., 2009) used to quantify urbanization in terms of building volume patterns and their rates of change in a decadal time span.

RESULTS

A direct correlation was found between arsenic contamination in the Pleistocene aquifer and: i) negative values of redox potential and ii) high iron concentration in the deep aquifer, iii) high arsenic concentration in the Holocene aquifer and iv) highly urbanized areas.

All these factors were combined to generate a predictive probability output, expressed as susceptibility map of the Pleistocene aquifer to arsenic contamination. The performance of this map was evaluated through the application of the same procedures adopted in previous groundwater vulnerability studies (e.g. Sorichetta et al., 2011).

CONCLUSIONS

The relationship between high arsenic concentration and chemical parameters detected in the deep aquifer has proved to be consistent with the outcomes derived from the analysis performed by Winkel et al., 2011.

The analysis on DSM data indicates that the excessive groundwater withdrawal, resulting from the high demand of water in intensive urban areas, has a strong impact on the quality deterioration of the Pleistocene aquifer. An extensive and excessive groundwater pumping can induce a vertical downward migration of chemical components leading to prevailing anoxic conditions and/or downward transport of arsenic contaminated waters from the shallow to the deep aquifer. Moreover, it could be the cause of the release of dissolved arsenic stored in deep interbedded clays into adjacent aquifers, suggesting clay-compaction as one of the factor affecting arsenic contamination in the deep aquifer. These results provide preliminary information on the nature of deep groundwater arsenic and on the sources responsible for its mobilization.

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Assessing aquifer vulnerability to seawater intrusion accounting for surface water bodies

Nerantzis Kazakis[1], Gianluigi Busico[2], Nicolò Colombani[3], Kostantinous Voudouris[1], Micòl Mastrocicco[2]*

[1] Aristotle University of Thessaloniki, Dept. of Geology, Thessaloniki, Greece.
**Corresponding email: kazakis@geo.auth.gr*

[2] Università degli Studi della Campania, Luigi Vanvitelli, DiSTABiF, Caserta, Italy

[3] Università Politecnica delle Marche, Dipartimento di Scienze e Ingegneria della Materia, dell'Ambiente ed Urbanistica (SIMAU), Ancona, Italy

ABSTRACT

Salinization of coastal aquifers is a common problem worldwide. Overexploitation of these aquifer systems often alters the exchange with surface water bodies, making saline water propagate in surface water bodies. GALDIT methods is one of the most applied and modified methods for the assessment of seawater intrusion vulnerability (Chachadi and Lobo-Ferreia, 2007; Kazakis et al., 2018). Here we show a modification of the standard GALDIT method accounting seawater intrusion from superficial water bodies. The proposed extension named SUSI (Superficial Seawater Intrusion) include six new parameters to GALDIT application (Elevation, Vadose zone hydraulic conductivity, Torrents, Rivers, Lagoons, and Wetlands), providing a better description in the salinization of coastal aquifers due to seawater intrusion.

Keywords: seawater intrusion, vulnerability, groundwater

METHODS

A modification of GALDIT index including superficial seawater intrusion has been applied in two coastal area of Greece and Italy, characterized by the presence of some lagoons, permanent rivers and torrents (Epanomi area and Po River Lowland). Six new parameters have been added to the six pre-existent of the typical methods: 1) Vadose zone hydraulic conductivity, 2) Elevation, 3) Torrents, 4) Rivers, 5) Wetlands, and 6) Lagoons. Each parameter was classified into 4 classes ranged from Very Low to High and weights were defined using Analytical Hierarchy Process (AHP) (Kazakis, 2018). The modified GALDIT method was validated using the single-parameter sensitivity analysis for both the study area giving highest weights to groundwater type, groundwater level, distance from the shore, vadose zone hydraulic conductivity and elevation.

RESULTS

The application of standard GALDIT methods for the two study area only represents the first 1 km of coastline as affected from high risk of seawater intrusion, while the rest of both the site characterized by medium vulnerability, mainly due to the negative piezometric heads values. The modified methodology (Fig. 1a for Epanomi area and 1b for Po River lowland), instead, offered a better discrimination of the vulnerability for seawater intrusion. highlighting also the zone where saline surface water bodies interact with groundwater, remarking how superficial water bodies can be a preferential way for seawater intrusion.

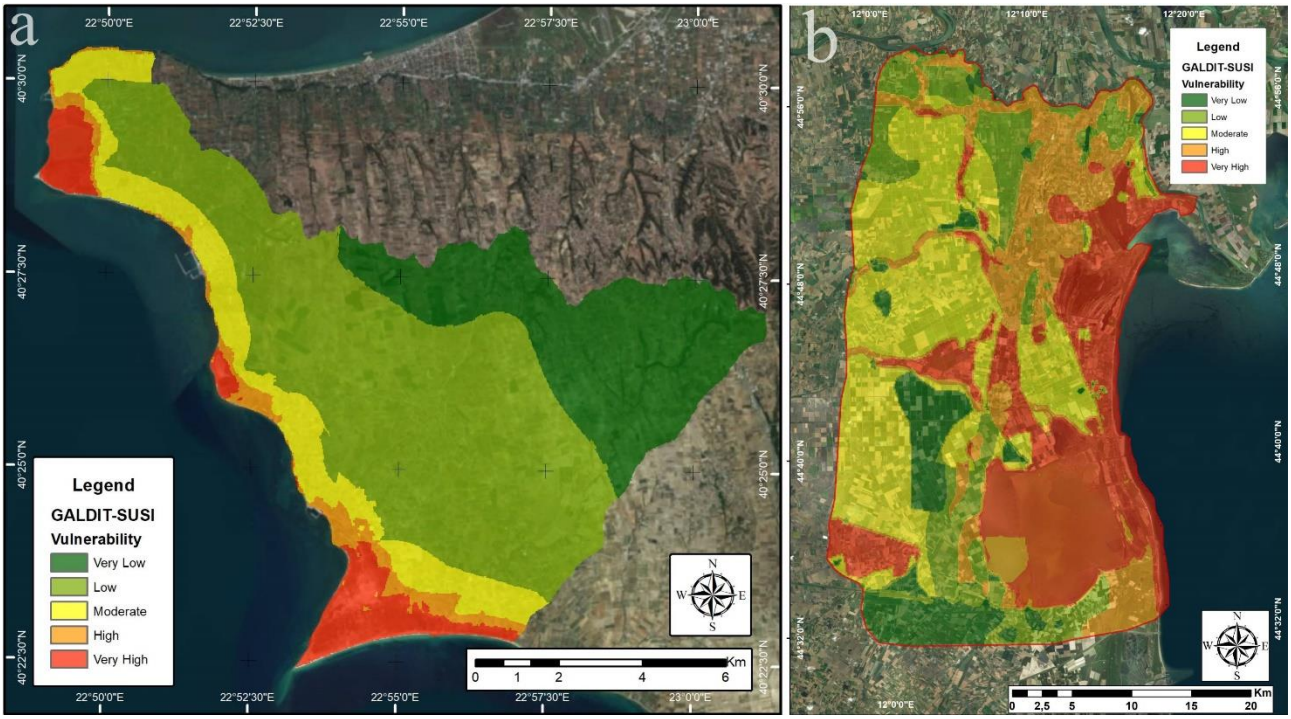

Fig. 1 - Seawater intrusion vulnerability map for Epanomi (a) and Po River Lowland (b).

CONCLUSIONS

The results highlight the main drawback of the standard GALDIT application, which shows a low discrimination capacity to map the vulnerability to saltwater intrusion in low-lying areas where surficial water bodies abound. The modification is easily applicable and adaptable to different hydrogeological situation.

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Monitoring the effectiveness of the hydraulic barrier from Castelluccio (Tuscany central Italy). A shallow aquifer with a marked anthropogenic boron contamination

Marta Lazzaroni[1], Orlando Vaselli[2,3], Luca Rossato[1], Luciano Giannini[3], Barbara Nisi[4], Stefania Venturi[2]*

[1] *Environmental Geologist. *Corresponding email: martalazzaroni0@gmail.com*

[2] *Università degli Studi di Firenze, Firenze, Italy*

[3] *Consiglio Nazionale delle Ricerche, Istituto di Geoscienze e Georisorse (CNR-IGG), Firenze, Italy*

[4] *Consiglio Nazionale delle Ricerche, Istituto di Geoscienze e Georisorse (CNR-IGG), Pisa, Italy*

ABSTRACT

In 2009, several residents from the small village of Castelluccio (eastern Tuscany) observed an increasing degradation of plants and flowers in their own gardens. The causes were related to anomalous concentrations (up to 57 mg/L) of boron in domestic wells. The geologic setting of the study area, characterized by sedimentary rocks, could not justify the high B contents, thus suggesting an anthropogenic origin of the contaminant. From 2010 to 2013, new geochemical surveys (Venturi 2013; Venturi et al., 2015) carried out in piezometers drilled on purpose evidenced boron concentrations larger than 120 mg/L. In February 2015, a hydraulic barrier was set up in the eastern part of the Castelluccio area. The geochemical monitoring considered in this work refers to the period 2014-2018 and focuses the attention on groundwater from a piezometer where the highest contents of boron were recorded, this site likely being the closest one to the contamination area. The groundwater pumped from the hydraulic barrier are used in industrial activities. The geochemical surveys suggested that the barrier works in reducing the boron concentrations, although they are still above the limit set by the Italian law.

Keywords: groundwater remediation, pollution, boron, contaminated land, shallow aquifer

METHODS

Groundwater coming from thirteen wells and piezometers in the area of Castelluccio (Arezzo, Italy) were monitored from 2014 to 2018 on a three-weeks or monthly basis. Temperature, pH, electrical conductivity and boron contents (analyzed by ICP–MS) were determined. Particular attention was paid to groundwater collected from the piezometer PZ02A that was likely representing the site closest to the source of contamination.

RESULTS

The concentrations of boron in the 13 monitored points ranged from 0.11 to 251 mg/L (most samples showing boron contents >1 mg/L), the highest values recorded before the activation of the hydraulic barrier in the piezometer PZ02A (the nearest to the contamination source). In February 2015, the

hydraulic barrier, was operating and after a month the boron concentrations at PZ02A decreased to 100 mg/L. In April 2015a decrease was recorded although the concentrations of boron remained relatively high (ca. 60 mg/L). This suggests that the contamination source close to PZ02A was still active.

In order to estimate the amount of boron pumped from PZ02A, a simple calculation was applied by considering a flow rate of 0.75 L/min (according to the company and a mean boron concentration value of 100 mg/L (Lazzaroni, 2017), as follows:

$$100\ (mg/L) \times 0.75\ (L/min) \times 60\ (min) \times 24\ (h) = 108\ g/day\ of\ B$$

If we extrapolate this value for 10 years (from 2009 to 2018), we estimate almost 0.39 ton could have been recovered by simply considering the boron content occurring in PZ02A. These values are not computed in our calculation since no specific flow rate data are available. It is to remark that that the boron source has not been clearly defined and the results shows a general and diffuse contamination.

The Castelluccio Boron in numbers	
100 mg/L	the medium value
4.5 g/h	quantity of Boron in the aquifer for hour
0.108 kg/gg	quantity of Boron in a day in the aquifer
39.42 kg/yr	quantity of Boron in a year in the aquifer
0.39 ton	quantity of Boron in aquifer from 2009 to 2016

CONCLUSIONS

This study evidenced a general and diffuse contamination of boron in the Castelluccio area. The installed hydraulic barrier was able to efficiently minimize the diffusion of the contaminant in the area, though still persisting in the monitored wells/points. The hydraulic barrier will be maintained for the years to come to verify whether significant decreases of the boron concentrations will be registered since the target is to achieve contents < 1 B mg/L (D.Lgs 52/2006). To achieve this goal, is necessary identify the contamination source, thus allowing to prepare new remediation strategies.

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Evaluation of the deposition, infiltration and drainage of the atmospheric pollutants in the vadose zone

Marco Masetti[1], Corrado Camera[1], Daniele Pedretti[1], Stefania Stevenazzi[1]*

[1] Università degli Studi di Milano, Dipartimento di Scienze della Terra "A. Desio", Milano, Italy.
**Corresponding email: stefania.stevenazzi@unimi.it*

ABSTRACT

In the last decades, a large effort has been carried out to reduce atmospheric pollutant emissions in Europe. However, despite the progresses of the last 30 years (Rogora et al., 2016), water and soil acidification, nutrition unbalance in forest trees, and eutrophication in surface waters are still of great concern.

In particular, nutrients that fall on the ground from the atmosphere represent a minor component of the total nitrogen input to soils, especially when compared to agricultural, civil and industrial inputs (EEA, 2005). Although often underestimated, this source apportionment becomes a part of leaching from the soil to groundwater. Therefore, the overarching goal of this study is to identify anthropogenic background values of pollutants in groundwater, not related to direct sources of contamination (e.g., industrial wastes, leakages from sewage systems, fertilizers).

Keywords: nitrogen cycle, monitoring, unsaturated zone

METHODS

In June 2018, an instrumented field site has been settled to reconstruct the path of nitrogen through: 1) atmospheric emission; 2) wet and dry depositions; 3) infiltration through the ground surface and the vadose zone; 4) addition to groundwater storage.

The field site is located within a well field of the public manager of the integrated water service of the Province of Milan, in northern Italy. The well field is located in the plain, 20 km east from the City of Milan.

The instrumented field site is constituted of a meteorological station, 6 soil moisture sensors, 6 tensiometers and 3 suction cups. Soil moisture sensors, tensiometers and suction cups have been settled at three depths (20 cm, 40 cm, 80 cm) to evaluate the soil characteristics and responses to precipitation events along the soil profile.

The instruments are equipped with a solar panel and a data logger, which allows collecting data every ten minutes. Water in the suction cups is manually collected after each rainfall event.

The field site is located 25 m upgradient respect to a water well monitored in continuum by a multiparameter probe. This probe allows measuring several parameters: groundwater depth, temperature, pH, EC, turbidity, DOC, TOC and nitrate concentration.

RESULTS

In situ tests at the field site allowed evaluating an infiltration rate of 1.5×10^{-4} m/s, which is compatible with a silty sand and gravel deposit. The monitoring campaign allowed calculating an arrival time of rainfall of about 9-13 hours, from the topsoil to groundwater table (about 7 m below ground).

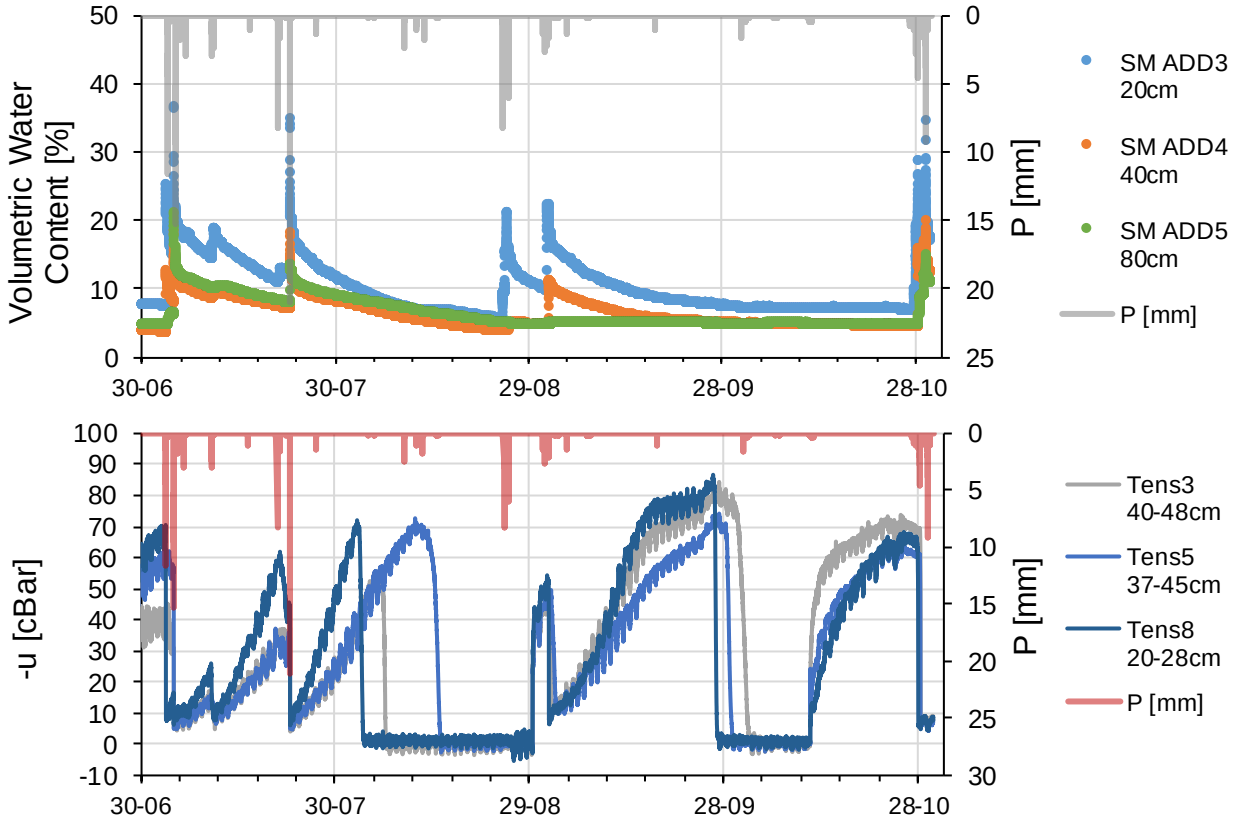

Fig. 2 – Volumetric water content (upper graph) and pore pressure (lower graph). Tensiometers have been restored some times during summer, due to long dry periods.

CONCLUSIONS

Results from the monitoring campaign allows a better understanding of the nitrogen cycle from the atmospheric emissions to rainwater precipitations to soil and groundwater, adding useful information about the amount of nitrogen involved in the process.

Moreover, it will be possible to calibrate a numerical model, which could help in identifying the impacts of atmospheric emissions on groundwater quality in different environmental contexts (e.g., natural, urban and agricultural areas).

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How long will it take? Estimating groundwater recovery time from nitrate contamination in the highly impacted Lombardy plain (northern Italy)

Arianna Musacchio[1], Marco Rotiroti[2], Viviana Re[1], Harald Oster[3], Barbara Leoni[2], Enrico Allais[4], Elisa Sacchi[1]*

[1] *Università di Pavia, Dipartimento di Scienze della Terra e dell'Ambiente, Pavia, Italy.*
**Corresponding email: arianna.musacchio01@universitadipavia.it*

[2] *Università degli Studi di Milano-Bicocca, Dipartimento di Scienze dell'Ambiente e della Terra, Milano, Italy*

[3] *Spurestofflabor, Wachenheim, Germany*

[4] *ISO4 s.n.c., Torino, Italy*

ABSTRACT

Groundwater nitrate contamination represents a main environmental issue in Europe, despite the regulations implemented during the last 30 years. Therefore, to effectively address this persistent issue, the estimation of the time gap between the implementation of conservation measures and the observation of measurable improvements is fundamental. In the framework of INTEGRON project (CARIPLO Foundation #2015-0263), groundwater dating was performed and correlated to changes in groundwater quality in the Lombardy plain (northern Italy). The study area is currently one of the most impacted by nitrogen input in Europe, due to both agricultural and civil sources. In the northern sector of the plain nitrate concentrations often exceed the "concern" threshold of 25 mg/L, meanwhile the southern plain presents lower values. The overall aim is to estimate the time required for management actions to become effective, combining groundwater dating with different techniques and nitrate trend analysis.

Keywords: nitrates, residence time, trend analysis, INTEGRON project.

METHODS

Analyses of temporal trends of nitrate concentrations were performed on 162 wells of the Regional Environmental Protection Agency monitoring network. By applying a Mann Kendall test, significant trends were detected and their magnitude estimated (mg/L/year). To assess groundwater residence time, in the northern sector of the plain, eight transects of 4-5 wells, aligned along the flow lines, were identified and sampled for CFCs, SF_6 and $T/^3He$ during two sampling campaigns (2017-2018). Groundwater samples were analysed also for major anions and stable water isotopes ($\delta^{18}O$, δ^2H).

RESULTS

According to trend analysis, from 2006 to 2016 nitrate concentrations mostly remain stable. Only 29.7% of wells shows a detectable decrease (~-0.5 mg/L/y), whereas 42.8% indicates no trends. More than 27.5% of wells still shows a significant increase of nitrates (~+0.3 mg/L/y). In the shallow aquifer, increasing trends are mostly observed in wells already exceeding the regulatory limit of 50

mg/L (Musacchio et al. in press). As regards groundwater residence time, the occurrence of CFCs and SF_6 in all samples indicate post-1940's infiltration components. However, exceeding concentrations of CFCs species prevent their use for absolute groundwater dating. Two out of three studied CFCs species are mostly in excess, as reported in the trilinear plot (Fig. 1; Darling et al. 2010). SF_6 model ages range between 2 and 29 years. In the western sector of the area, a significant correlation between groundwater age and nitrate content was detected. In the eastern sector stable isotopes indicate the dilution of groundwater nitrate content due to irrigation practices.

CONCLUSIONS

In the northern Lombardy plain, a short turnover time, probably reduced by irrigation practices, characterizes groundwater circulation. Thanks to the ongoing analysis of $T/^3He$ both the estimation of nitrate residence time and the evaluation of current management practiced will be improved.

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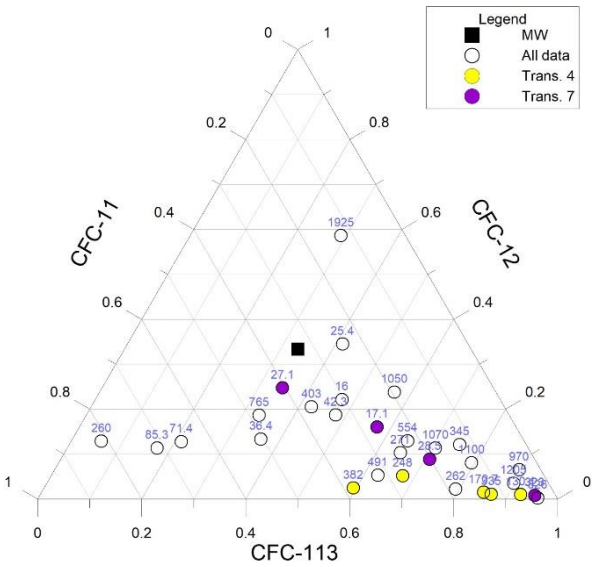

Fig. 1 - Full symbols = transects (possible flow/dilution lines);
MW = modern air equilibrated water; numbers = sum of all CFCs in pmol/L.

A Bayesian approach for the assessment of shallow and deep aquifers susceptibility to point sources contamination in the Province of Milan, Italy

Licia C. Pollicino[1,2], Marco Masetti[1], Stefania Stevenazzi[1], Maurizio Gorla[3], Agata Cristaldi[3], Chiara Righetti[3]*

[1] *Università di Milano, Dipartimento di Scienze della Terra "Ardito Desio", Milano, Italy.*
**Corresponding email: licia.pollicino@unimi.it*

[2] *Politecnico di Milano, Dipartimento di Ingegneria Civile e Ambientale (DICA), Milano, Italy*

[3] *Gruppo CAP, Ufficio Progetto PIA e Bonifiche - Direzione Ricerca e Sviluppo, Milano, Italy*

ABSTRACT
In densely populated areas, urban and industrial activities are responsible for groundwater quality deterioration due to point sources contamination (Kuroda and Fukushi, 2008). In the Province of Milan (Northern Italy), the available water-quality data indicate the occurrence of high PCE+TCE and chromium concentrations in the unconfined shallow as well as in the confined deep aquifers. To cope with this problem, statistical methods can represent reliable tools to provide key information for groundwater management and protection.

Keywords: shallow and deep aquifers, point sources contaminants, urban areas, statistical methods

METHODS
Among the various techniques, the Weights of Evidence (WofE; Bonham-Carter, 1994) technique was identified as one the most appropriate method to assess the susceptibility of aquifers to contamination (Sorichetta et al., 2011). In this study, the WofE technique was used to assess aquifer susceptibility to PCE+TCE and chromium contamination of the shallow and deep aquifers in the Province of Milan (Northern Italy).WofE was used to quantitatively evaluate the degree of spatial correlation (i.e., weights) between pollutants occurrence and factors potentially controlling the qualitative status of the aquifers.
For the shallow aquifer analyses, the investigated factors include: i) groundwater depth, ii) hydraulic conductivity of the unsaturated zone, iii) groundwater velocity, iv) degree of confinement and v) the distribution of industrial settlements, representing potential sources of PCE+TCE and chromium contaminations.
For the deep aquifer analyses, the examined factors include: i) thickness of the fine sediments between shallow and deep aquifers, ii) distribution of pollutant concentrations in the shallow aquifer and iii) potential leakages from the shallow aquifer system to the deep one represented by the presence of wells screened in both aquifers (multi-aquifer wells).
The investigated factors, resulting statistically and physically significant, were combined to generate four maps representing the shallow and deep aquifers susceptibility to PCE+TCE and chromium pollution (Fig. 1). Each map was validated using a series of validation procedures proposed by Sorichetta et al., 2011.

RESULTS

The WofE analysis performed on shallow aquifer showed a direct correlation between point sources contamination and i) high values of both groundwater velocity and hydraulic conductivity of the unsaturated zone, ii) low values of groundwater depth, iii) a medium or medium-high degree of confinement, iv) a high presence of industrial activities.

The WofE analysis carried out on deep aquifer outlined a direct correlation between point sources contamination and i) a limited thickness of the fine sediments layer between shallow and deep aquifers, ii) areas with high PCE+TCE and chromium concentrations in the shallow aquifer, iii) a high presence of multi-aquifer wells.

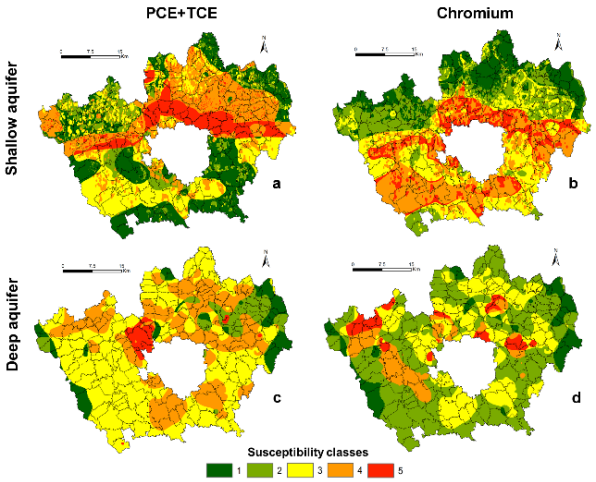

Fig. 3 - Susceptibility maps.

CONCLUSIONS

Although the WofE method has been widely used in shallow aquifer vulnerability analyses to non-point sources (e.g., Stevenazzi et al., 2017 and included references), it has also proved to be effective for evaluating the quality deterioration of both shallow and deep aquifers due to point sources pollutants.

The WofE technique has allowed defining the hydrological and land use conditions that have a high impact on groundwater pollution by identifying the range of factor values that strongly influence the occurrence of point sources contamination in each aquifer.

Moreover, the results have highlighted that the shallow aquifer can be considered as a secondary source responsible for the development of contamination phenomena within the confined deep aquifer. In particular, heterogeneities in the fine sediment separating the two aquifers and inappropriate design of wells (multi-aquifer wells) can favour the vertical movement of the pollutants towards the deep aquifer.

Those results together with the final susceptibility maps can represent an extremely useful support to be used by stakeholders and decision makers for an appropriate management and protection of the groundwater resource.

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Modelling the interactions between groundwater and the underground infrastructures using MODFLOW-USG and ArcGIS Pro: the case study of Milan metropolitan city

Davide Sartirana[1], Gennaro Alberto Stefania[1], Mattia De Amicis[1], Tullia Bonomi[1]*

[1] Università degli Studi di Milano-Bicocca, Dipartimento di Scienze dell'Ambiente e della Terra, Milano, Italy.
**Corresponding email: d.sartirana1@campus.unimib.it*

ABSTRACT

Since the beginning of the 1990s, following an intense phase of industrial dismantling, the area of the current metropolitan city of Milan (440 Km²) has been subject to the rise of groundwater level that has generated problems of interference with the underground infrastructures (parkings, metropolitan lines, etc.). The growth in the use of three-dimensional models for groundwater flow, combined with an exhaustive database of the underground employment by the infrastructures, allows today to be able to predict and to manage the effects of changes in the hydrogeological system on the anthropized one. This work aims at better understanding the interactions between the underground infrastructures and the groundwater flow.

Keywords: underground infrastructures, groundwater, Milan, 3D

METHODS

The first step was the construction of two databases about the study area: the first one regarding all the information about the underground infrastructures, defining a methodology of identification which involved the use of some elements contained in the DBT (Topographic Data Base); the second one dealing with groundwater heat pumps authorized at July 2014.

All this information was implemented in ArcGIS Pro, an ESRI 3D software: each element was extruded according to its real height and volume at its own proper absolute altitude; in this way the real occupation of the underground was figured (Fig. 1).

A numerical groundwater flow model was then developed, using Modflow-USG (Panday et al.,2013). An unstructured grid, built with the technique of the quadtree refinement, was realised. The model grid has 3495050 cells, with a maximum size of 100*100 and a minimum one of 12.5*12.5, divided in 13 layers, with a medium thickness of 5 meters for the first 8 layers, and 10 meters for the deepest 5. The underground infrastructures were included in the model as boundary conditions using the Horizontal Flow Barrier (HFB) package (Attard et al.,2016). The heat pumps and wells were simulated with WELL package. Recharge was simulated in 5 zones defined on different land uses.

The simulated piezometric map was superimposed with spatial urban data in ArcGIS Pro (Fig. 1) in order to provide a comprehensive 3D representation of the results. ArcGIS Pro was also used for evaluating the most suitable locations for future works of subservices, in relation to the current situation, with the purpose of using the numerical model as a management tool for water decision making (Vazquez-Suñè et al., 1999).

RESULTS

The model has returned preliminary results which enable to observe the interactions between groundwater flow and the underground infrastructures. 4 metro lines (the fifth one will be added for a future scenario) and the passing railway were represented; 153 underground parkings, identified using the methodology mentioned above, were inserted. 886 heat pumps and 412 wells were included as WELL. The overall effect of the infrastructures is well visible locally. Piezometry was well detailed near the encumbrances. The number of cells was highly reduced in front of using a structured grid. Groundwater heat pumps operating mechanism (pumping and reinjection wells) was correctly represented. The Horizontal Flow Barrier (HFB) package has properly simulated the underground infrastructures and their behaviour. The model is still under development; the first simulations promise good results, although the time of simulation is high.

CONCLUSIONS

Using an unstructured grid in an urban context allows to well represent the underground infrastructures, especially the metropolitan lines. ArcGIS Pro is a very useful product to represent the data of the study area in a 3D environment and can be used also as an instrument for future predictions about the underground vertical development of Milan's city. The integration of these tools represents a valid support for all the municipal administrations and the stakeholders whose need is to consider groundwater as one of the topics in city planning and to manage the resource in a sustainable way.

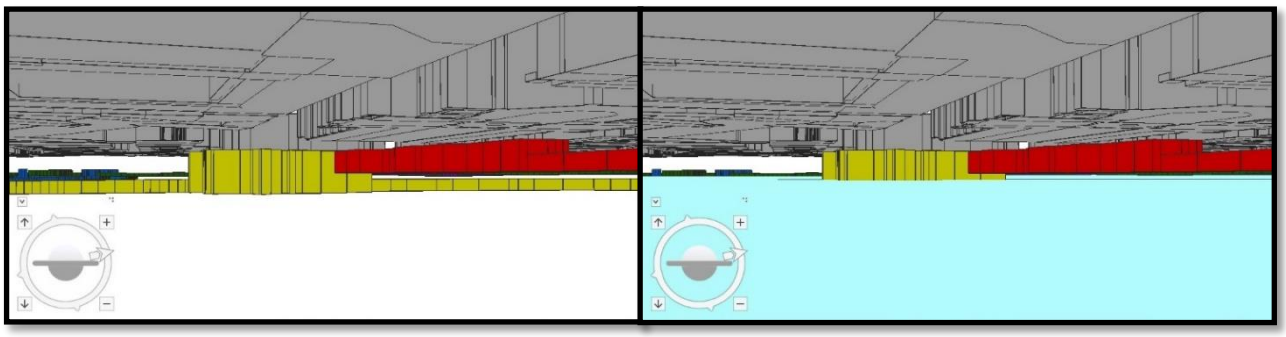

Fig. 1 - On the left, the database information is implemented in ArcGIS Pro: the elements in grey represent the bottom of superficial buildings, whose information derives from the DBT (Topographic DataBase); the yellow element is the M3 line at Duomo station; the red one is the M1 line at Duomo; on the right, the superimposition of Modflow-USG outputs in ArcGIS Pro at Duomo stations is visible in light blue.

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Groundwater modeling and isotope investigations for the Water Safety Plan implementation in Milan metropolitan area

Laura Scesi[1], Luca Alberti[1], Martino Cantone[1], Mariachiara Caschetto[2], Paola Gattinoni[1], Ivana La Licata[1], Massimo Marchesi[1,2], Angelo Ortelli[1], Gabriele Oberto[1], Marta Gangemi[3], Angela Manenti[3], Matteo Monti[3]*

[1] *Politecnico di Milano, Dipartimento di Ingegneria Civile e Ambientale (DICA), Milano, Italy.*
**Corresponding email: luca.alberti@polimi.it*

[2] *Isotope Tracer Technologies Europe S.r.l., Milano, Italy*

[3] *MM S.p.A, Servizio Idrico, Milano, Italy*

ABSTRACT

Natural groundwater resources are subject to steadily increasing water demand for agriculture, domestic and industrial use. Effective allocation requires accurate knowledge of the aquifer dynamics. Groundwater numerical models are useful tools for groundwater management, but the increasing required accuracy of the models predictions entails an improvement of the hydrogeological conceptual model (Alberti et al, 2016). A flow and transport model focused on the Milan Metropolitan area has been developed to forecast the impact of changes in the withdrawal conditions and climate changes effects on groundwater availability. In addition, a chemical and multi-isotopic characterization of groundwater resources has been carried out in order to improve the existing hydrogeological conceptual model. The study is part of the Water Safety Plan (WSP) that the Milano's water manager (MM SpA) is implementing with the aim to manage and preserve the groundwater quantity and quality. Results highlighted the worth of the approach adopted in the hydrogeochemical characterization and in the groundwater pollution assessment including source and fate of organic contaminants.

Keywords: isotopes, groundwater modelling, water management

METHODS

A groundwater flow model focused on the Milan Metropolitan area has been implemented to assess, for forecasting purposes, the impact of changes in withdrawal conditions on the hydrogeological system, in order to provide useful information for the management of the underground water resource. The model has been implemented through MODFLOW2005 code (Harbaugh et al., 2005) and together through MODFLOW-USG in order to assess the advantages and compare the results of a classical finite difference grid with a Voronoi mesh. The calibration was done initially through a trial and error approach and then using an assisted calibration of parameters adopting the code PEST (Doherty et al., 2005). During the numerical model implementation about 60 sampling locations (wells and piezometers) were selected among the three o main aquifers within the Milan Metropolitan area – A (shallow, depth < 40 m) B (intermediate, 40 m below ground level, b.g.l.) and C (deep, below

100 m b.g.l.). Samples were collected for major ions, trace element, Volatile Organic Compounds (VOCs) including chlorofluorocarbons (CFCs), ^{3}H- ^{2}H-, ^{18}O- H_2O, ^{13}C-CSIA and ^{37}Cl-CSIA on chlorinated solvents analyses. Results of the chemical and multi-isotopic survey have been interpreted in order to validate the transport model.

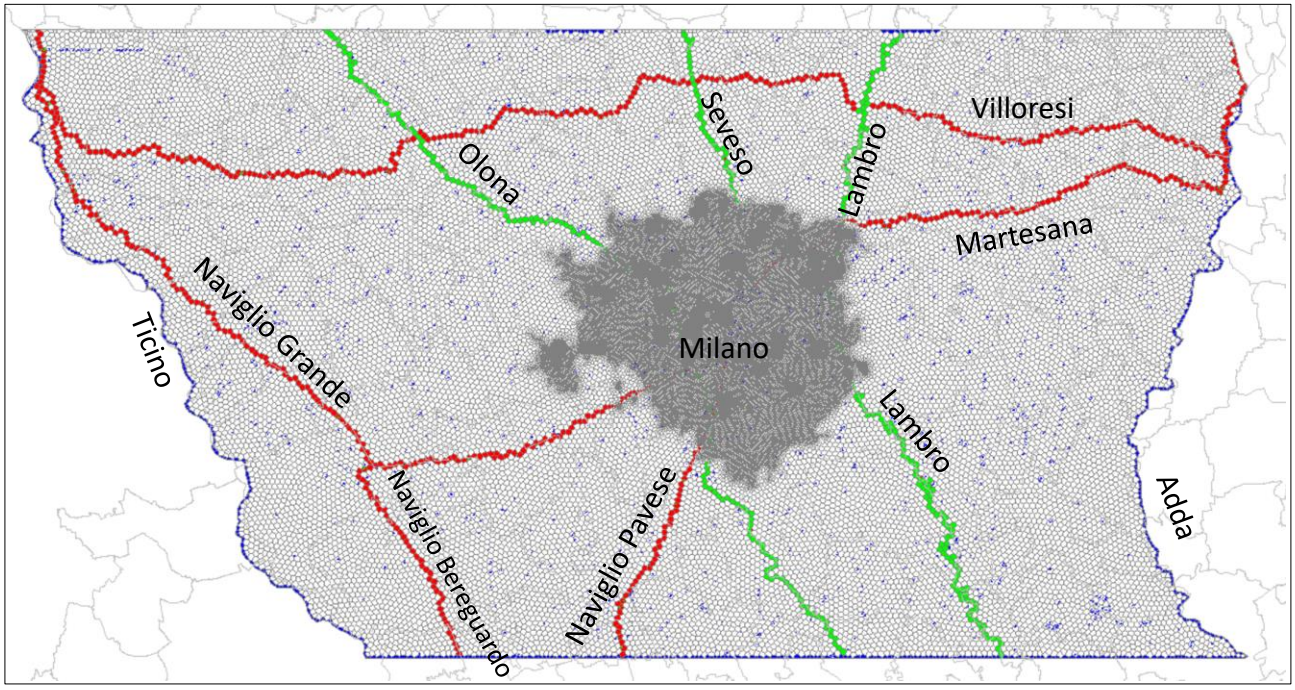

Fig. 1 - Numerical flow model implemented using a Voronoi mesh. Rivers inside the model are represented in green (in blue the ones at the bouondary: Ticino and Adda), channels are shown in red while blue points are wells.

RESULTS

Once implemented and calibrated the flow and transport model on Milan Metropolitan area, it has been validated using the results of the isotopic survey carried out in the same area. The combined use of chemical indicators, environmental stable isotopes (^{2}H, ^{18}O – H_2O), CFCs and ^{3}H-H_2O allowed a better understanding of the groundwater flow dynamics in terms of recharge areas, relationship among shallow, intermediate and deep aquifers and residence times. In particular, the combined use of ^{3}H-H_2O together CFCs led to a precise residence time estimation for groundwater in the intermediate aquifer (B) same as for the deep aquifer (C) where waters are characterized by longer residence times.

^{13}C-CSIA and ^{37}Cl-CSIA were very useful for VOCs groundwater pollution assessment, in particular for perchloroethylene (PCE). Significant $\delta^{13}C$- and $\delta^{37}Cl$- PCE differences were found in the proximity of polluted areas allowing discretizing responsibilities (sources allocation) and distinguishing between plumes and background (diffuse) contaminations. ^{13}C-CSIA and ^{37}Cl-CSIA results for trichloroethylene (TCE) and dichloroethylene (cis-DCE) better constrained the role of natural attenuation processes in containing and mitigating the contamination. ^{13}C-CSIA and ^{37}Cl-CSIA results will be used for the next transport model implementation helping in a better

understanding of the conceptual model with regards of several contaminated areas within the Milan Metropolitan area.

CONCLUSIONS

Only through a correct understanding of the aquifer dynamics together with the assessment of the fate of contaminants, will water practitioners be enabled to successfully manage water resources and to put in place prevention and/or mitigation measures to avoid additional deteriorations. The proposed case study reveals how isotope applications, coupled with hydrogeological investigations and flow and transport models, can turn in a fine-tuned tool essential in the management and risk assessments within a WSP in urban areas such as the Milan Metropolitan area.

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Atmospheric nitrogen deposition in a highly human impacted area in northern Italy

Stefania Stevenazzi[1], Marco Masetti[1], Corrado Camera[1], Massimo Tiepolo[1], Elena S. Ferrari[1], Roberto S. Azzoni[2]*

[1] *Università degli Studi di Milano, Dipartimento di Scienze della Terra "A. Desio", Milano, Italy.*
**Corresponding email: stefania.stevenazzi@unimi.it*

[2] *Università degli Studi di Milano, Dipartimento di Scienze e Politiche Ambientali, Milano, Italy*

ABSTRACT

Nitrogen can enter the water cycle through atmospheric depositions on ground and water surfaces, leakages from point and diffuse sources (i.e., sewage treatment plants or sewage systems, fertilizer and manure applications), and erosion processes affecting nitrogen rich soils (EEA, 2005). However, integrating all nitrogen forms, processes and scales is still a major challenge for the understanding and the management of the nitrogen cycle.

Keywords: air pollution, ammonium, nitrate, precipitation

METHODS

A monitoring experiment was set up to collect wet atmospheric depositions in a human impacted area with multiple land uses, representing different emission sources (i.e., extended urban areas with residential buildings and industrial activities, high traffic roads and agricultural activities).

Wet deposition is measured at 17 sites, homogeneously distributed in the western sector of Lombardy Region (northern Italy), in the surroundings of Milan. Rainwater collection was executed almost at each single rainfall event at all the sites, starting from February 2017 to February 2019. In summary, 16 precipitation events were monitored and 155 rainwater samples were collected, involving, on average, 10 sites each time. After collection, samples were analysed for pH, electric conductivity, ammonium, nitrate, nitrite, major cations (calcium, magnesium, sodium, potassium), and major anions (sulphate, chloride, fluoride). The physico-chemical parameters were analysed according to their spatial distribution and temporal variation to identify similarities or differences among samples according to the location of the monitoring sites and the season when rainwater samples have been collected. Moreover, rainwater chemistry was compared to atmospheric pollution, derived from air quality data from ground-based stations and pollutant emissions data provided by the Regional Environmental Agency (ARPA Lombardia), to identify a quantitative correlation between emissions and depositions.

Maps of deposition of nitrate and ammonium were obtained by multiplying precipitation maps with concentration maps (Rogora et al., 2016). These maps have been transformed into nitrogen deposition maps ($N\text{-}NO_3^-$ and $N\text{-}NH_4^+$), in order to obtain a map of total nitrogen depositions.

RESULTS

Results show a direct relationship between high levels of air pollutants (e.g., NO_2, SO_2, NH_3) and relatively high contaminant concentrations (e.g., NO_3^-, SO_4^{2-}, NH_4^+) in rainwater samples. Consequently, rainfalls sampled in autumn-winter or during the fertilisation period (April-July) show higher contaminant concentrations respect to those sampled in spring-summer or before the fertilisation period. In addition, the chemical composition of rainwaters reflects local meteorological conditions and local emission sources.

In fact, samples collected in urban or agricultural areas show higher concentrations of specific chemical species (e.g., Ca^{2+}, NO_3^-, NH_4^+) in comparison to those collected in rural areas or close to natural environments (i.e., Alps and Como Lake).

Such results allowed estimating wet nitrogen depositions, as nitrate and ammonia, in the study area. The average concentrations of nitrate and ammonia in precipitation during the monitoring period were 5 mg L^{-1} and 2.5 mg L^{-1}, respectively (Fig. 1).

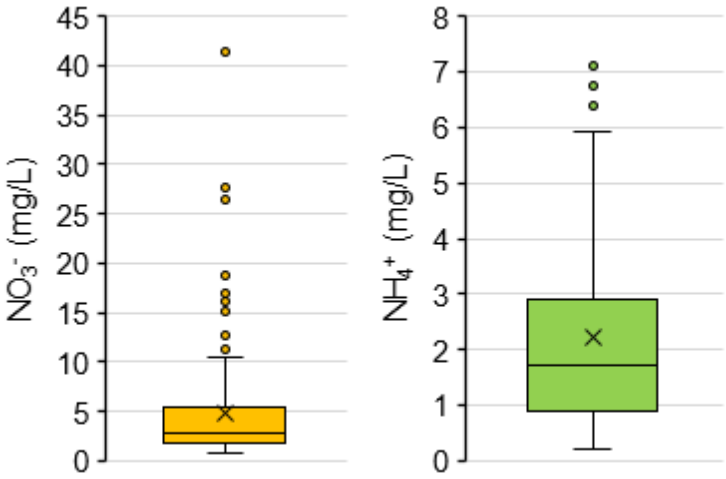

Fig. 4 – Nitrate (left) and ammonium (right) concentrations in rainwater samples.

Consequently, given an average annual precipitation of about 800 mm for the period 2016-2018, a wet deposition of inorganic nitrogen equal to 9 kg (NO_3^--N) ha^{-1} yr^{-1} and 15.5 kg (NH_4^+-N) ha^{-1} yr^{-1} was estimated. Considering both the variability of the spatial or temporal distributions of precipitations and the variability of concentrations of nitrogen compounds in rainwaters, the total amount of nitrogen depositions can range between 20 and 30 kg ha^{-1} yr^{-1}.

CONCLUSIONS

As leaching of nitrogen compounds from soils generally increases at nitrogen deposition rates higher than 10 kg ha^{-1} yr^{-1} (Butterbach-Bahl et al., 2011), this study suggests that the nitrogen atmospheric input to soils should not be neglected when evaluating the impacts of nitrogen sources to terrestrial and aquatic ecosystems, as well as to groundwater resources.

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Thermodimensional assessment of GWHPs: compare with analytical and numerical simulations approach

Glenda Taddia[1], Stefano Lo Russo[1], Elena Cerino Abdin[1], Martina Gizzi[1]*

*[1] Politecnico di Torino, Dipartimento di Ingegneria dell'Ambiente, del Territorio e delle Infrastrutture (DIATI), Torino, Italy. *Corresponding email: martina.gizzi@polito.it*

ABSTRACT

Is there a simpler methodology respect the numerical simulations that allows to define the dimensions of the thermal plume?

METHODS

A Groundwater Heat Pump system (GWHPs) is a technology that withdraws water from a well or a surface water source, 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).

The increasing implementation in several urban areas of the world of the open-loop groundwater heat pump systems for cooling and heating buildings which discharge into the aquifer could potentially cause, even in the short term, a significant environmental impact associated with thermal interference with groundwater, particularly in the shallow aquifers.

The discharge of water at different temperatures compared to baseline (warmer in summer and colder in winter) poses a number of problems especially in the more densely urbanized. The national and regional current legislation related to withdrawals and discharges into aquifers, despite design a framework suitable for the protection of groundwater and allow to decide the best configuration of the plant with a case by case approach, make the administrative procedures quite complex. In effect, timing for obtaining permits are not always consistent with the timelines for urban planning and buildings construction.

Currently, in order to constantly verify the possible impact of the geothermal plant about some activities or pre-existent uses, the competent authorities require 1) a specialized hydrogeological investigations and characterization of the subsoil at the considered site; 2) the processing of a complex numerical model that simulate propagation mode and estimate the thermal plume size which develops in the shallow aquifers.

However, as to develop a simulation model it is required the use of complex, expensive and time consuming numerical calculation tools, we focused the analysis about the possibilities to apply available analytical formulae for predicting the size, the thermal plume speed propagation and the occurrence of thermal feedback phenomena.

In 2009, Banks was one of the authors to deal with the potential external risk to other aquifer users located down-gradient of the doublet, in the path of the thermal plume emanating from the recharge well.

Assuming that 1) the doublet spacing is *2d*; 2) the wells fully penetrate the aquifer; 3) the aquifer is homogeneous with a uniform thickness *m*, he demonstrated that there is minimal risk of internal feedback if:

$$d > d_{critical} = \frac{Q}{mU\pi} \qquad (1)$$

where *U* is the regional Darcy velocity.

In 2011, Banks also derived 2D analytical solutions for thermal plume evolution: plume length (L_{pl}) for long distance can be approximated as Eq. 2; the maximum down-gradient width (W_{pl}) was given by the following Eq. 3:

$$L_{pl} = v_{th}t = \frac{v_e}{R_{th}}t = \frac{U}{neR_{th}}t \qquad (2)$$

$$W_{pl} = \frac{Q}{mU} \qquad (3)$$

where v_{th} is the thermal advective velocity; v_e is the groundwater effective flow velocity (m/s); *t* is the simulation time; R_{th} is the thermal retardation coefficient and *ne* is the effective porosity.

In this research work, the Politecnico di Torino open-loop geothermal system was modelled by using the finite-element code FEFLOW® 6.2 (Diersch, 2010), performing a heat-transport simulation over an operating time of (153) days (May to September) and estimating the average cooling thermal-load P(t) at the end of the monitored period (t).

Subsequently, the simulated values of thermal plume L_{pl} and W_{pl} were compared with those obtained by applying 2D analytical formula provided by Banks in 2011 (Eq. 2-3).

RESULTS

In this first phase, the results obtained from the simulations of GWHP plant (May-September) were compared to the analyses obtained through the analytical method, maintaining an equivalent thermal load for both cases. From the results, it was possible to define that the analytical methodology derives to be comparable with the most complex and expensive methodology of numerical simulations.

CONCLUSIONS

The analytical formulae result to be a good option for simplifying the national and regional current legislation related to withdrawals and discharges into aquifers about the open-loop geothermal systems.

A next step of this work will be to establish what is the best value of Q and T (daily or monthly average) and what is the statistical relationship among them, in order to obtain an optimal comparison between the simulated and the analytical data.

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Using water level and temperature coupled data series to improve hydrogeological parametrization in a complex alluvial system

Luca Vettorello[1], Andrea Sottani[1], Francesco Trevisan[2]*

*[1] Sinergeo S.r.l., Vicenza, Italy. *Corresponding email: lvettorello@sinergeo.it*

[2] Veneto Acque S.p.a., Mestre (VE), Italy

ABSTRACT

The project of a new pumping station for drinking water supply, designed to reach an overall extraction rate of about 2 m^3/s, required an in-depth analysis of the hydrogeological resource, in order to estimate the sustainability of the groundwater exploitation. This study describes the first session of investigations, including pumping tests, automatic monitoring activities and numerical modeling of groundwater flow and heat transport. The research aims to improve the knowledge of the aquifer properties in a complex hydrogeological system, located in the Veneto alluvial plain.

Keywords: pumping test, hydraulic conductivity, numerical model, heat transport

METHODS

Several pumping tests have been conducted in the 9 new wells, progressively activated with different configurations, recording groundwater level and temperature with dataloggers in 12 observation wells, 2 monitoring stations in the river and 1 installed in the lake. During the planning step, a FEM numerical model has been used to calculate the expected drawdown in local unconfined aquifer and, consequently, the maximum extension of the zone of influence. Therefore, the model prediction has been compared to the following experimental observations, acquired during the pumping test. The monitoring network has been kept in operation for about 1.5 year, collecting water level and temperature data series. In this way, different types of observations have been used to progressively calibrate the mathematical model, gradually adding information about porous media heterogeneity and new levels of complexity, from hydraulic conductivity distributions to heat transport transient simulations, concerning water exchange processes between Brenta river, Camazzole lake and the phreatic aquifer.

RESULTS

Initial prediction of maximum expected drawdown was compared to following pumping test observations at the highest extraction rate, obtaining a maximum residual of 0.13 m, a medium absolute error of 0.054 m and a normalized RMS error of 12.53%, with an observation range of 0.53 m. These results have been achieved with a homogeneous parameter distribution, assigning a constant value of hydraulic conductivity (6.0E-03 m/s) to the entire mesh. Afterwards, the pumping tests analytical interpretation provided hydraulic conductivity values, ranging from about 3.7E-03 to 1.8E-02 m/s. This parametric variability has been introduced in the numerical model, firstly considering a

simple kriging interpolation of field results and then verifying the parameter distribution through a series of pilot points calibrations, automatically conducted with PEST and validated by different campaigns of phreatic level measurements. This way, the long-term groundwater monitoring allowed to optimize initial results, to refine hydraulic conductivity distribution and to extend the overall water resource characterization to a larger domain. After the series of steady state simulations, average distributions of conductivity and other less sensitive hydraulic parameters were used as inputs for the following transient simulations, combining flow and heat transport to evaluate model reproduction of monitoring trends. The most interesting results have been achieved simulating the heat exchange process between the river-lake system and the downgradient aquifer, in order to confirm the previously defined hydraulic properties.

CONCLUSIONS

Sustainable management of groundwater resources of public interest must be based on an accurate knowledge of the natural system hydrogeological properties. However, all the information needed to design and implement a rational groundwater exploitation is never completely available. In this case study, characterized by a complex hydraulic system, the traditional parametrization of the aquifer, based on pumping tests interpretation, was integrated with other analysis tools. This approach takes into account the high seasonal thermal gradients, which locally occur in water exchanges between surface and underground flows. The fundamental aim is to contribute to the development of interpretation methods, useful to improve the characterization of aquifer parameters heterogeneity and to enhance the reliability of model estimates and forecasts.

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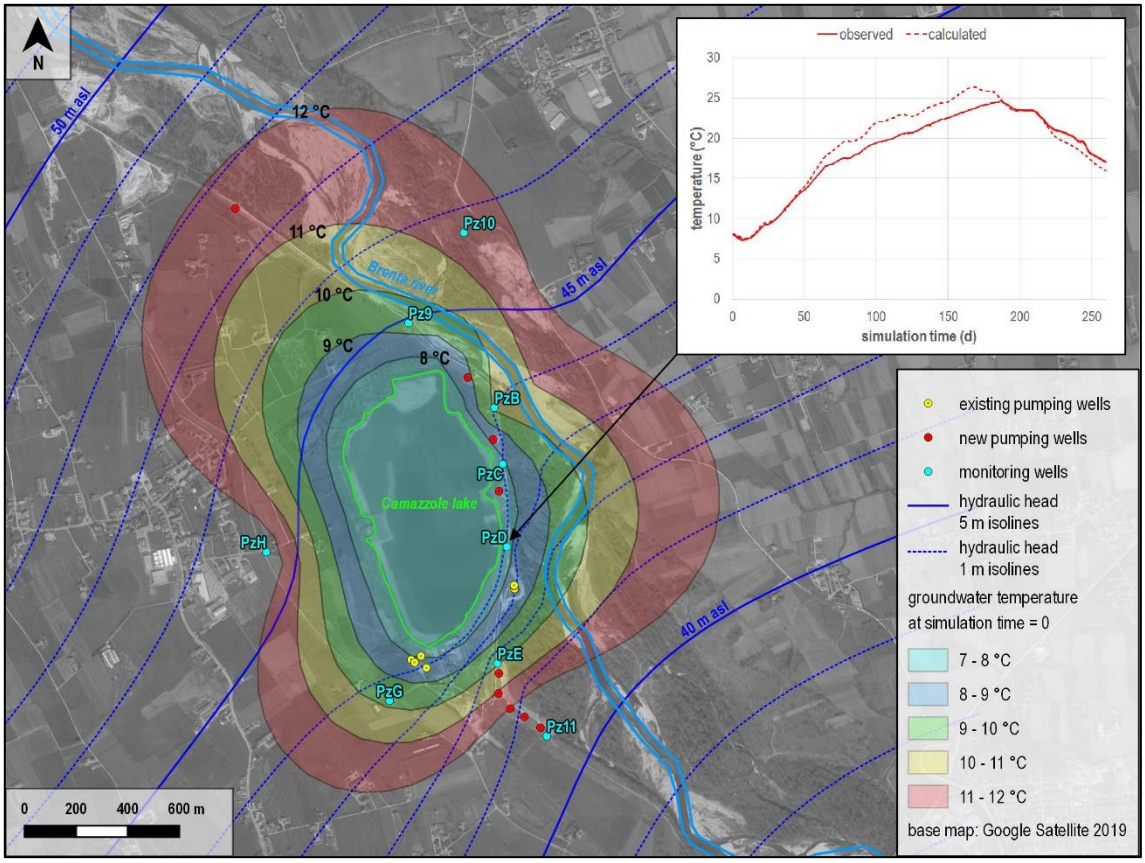

Fig. 5 - Initial distribution of groundwater temperature around the Camazzole lake and transient simulation results in PzD monitoring well during the first period of groundwater exploitation

Aquifer vulnerability in parts of Yenagoa, Southern Niger Delta, Nigeria

Willabo A. Miepamo[1], Bisong Andy Etta[1], Ebi Oborie[1], Justin Ikirigo[1], Bethel Okpomu[1]*

[1] Federal Polytechnic Ekowe, Bayelsa State, Department of Science Laboratory Technology, Nigeria.
**Corresponding email: Sutaria4life@yahoo.com*

ABSTRACT

This study on aquifer vulnerability assessment in certain parts of Yenagoa, Bayelsa State, Southern Niger Delta, Nigeria, adopted the use of DRASTIC method based on geographic information system (GIS) model to delineate areas susceptible to contamination. Seven hydrogeologic parameters were applied for the aquifer vulnerability evaluations which include depth to water table, net recharge, soil media, impact to vadose zone, aquifer media, topography, and hydraulic conductivity. Data relating to the seven hydrogeologic parameters of the model were obtained and transformed in the model into seven maps by GIS to develop the DRASTIC vulnerability map which shows the three different forms of aquifer vulnerability namely high, moderate, and low zones. The communities within the high vulnerable zones include Swali, Agudama, Ovum, Igbogene, Okutukutu, Onopa and Okolobiri. Those within the moderate vulnerability zones are Kpansia, Etegwe, Yenezue, Azikoro, Opolo, Tombia, Biogbolo and Akenfa and in the low vulnerability zones, we have Amarata, Yenezuegene, Edepie, Azikoro, Akenfa and Okaka. The high vulnerability zones ranking was attributed to very low depth to water table, high net recharge, high hydraulic conductivity and permeability of gravelly sand in the aquifer media. The moderate vulnerability zones were due to high net recharge, low porosity of silt/clay in vadose zone, silty-loam in soil media and high hydraulic conductivity. The low vulnerable zones were influenced by impermeability of clay-loam in the soil media, low porosity of silty clay in the vadose zone and low topographic slope percent.

Keywords: aquifer, vulnerability, DRASTIC

METHODOLOGY

Data for Depth to Water Table was be obtained using a dip meter to take readings of water level in all study locations during drilling borehole. Aquifer, vadose zone and soil data was taken in course of drilling the boreholes and put in a polythene bag and sent to the laboratory for hydrometer test. Topography Data was obtained using software called ARC-GIS. Hydraulic Conductivtiy Data was obtained by carrying out a pumping test on newly drilled boreholes. Net Recharge Data was obtained from the Nigerian Metrological Agency.

Drastic vulnerability index was obtained using the equation below:

$$DI = D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W = \text{Pollution Potential}$$

RESULTS

The results of this study is represented below in (Fig1) aquifer vulnerability map show low, medium and high vulnerable areas with respect to their DRASTIC vulnerability index.

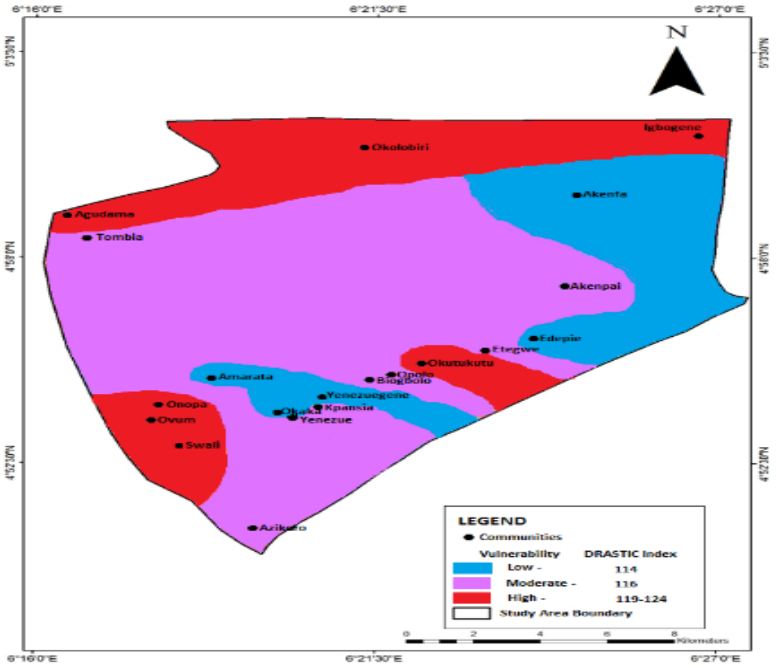

Fig. 1 - Aquifer vulnerability map showing high, moderate and low areas

CONCLUSION

Based on the findings of this study, the aquifer vulnerability map (Fig1) above indicates the DRASTIC index and communities. The red color zone represent communities where the aquifers are highly vulnerable. The shaded purple color is the moderately vulnerable aquifer zone. The blue shaded zone is the low vulnerable zone where aquifers are less vulnerable and finally recommendations were made to stakeholders, community and government with respect to high vulnerable aquifer areas on how groundwater can be protected and properly managed.

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Geochemical study to identify the source of nitrate in the carbonate aquifer (southern Italy)

Livia Emanuela Zuffianò[1], Pier Paolo Limoni[1], Giorgio De Giorgio[1], Maurizio Polemio[1]*

[1] Consiglio Nazionale delle Ricerche, Istituto di Ricerca per la Protezione Idrogeologica (CNR-IRPI), Bari, Italy.
**Corresponding email: l.zuffiano@ba.irpi.cnr.it*

ABSTRACT

The attention of local communities and authorities was focused on the level of groundwater nitrate of a wide coastal karstic aquifer, not far from the town of Bari (southern Italy), worried about the potential effect of unsecure landfills.

The study considered each potential source of nitrate, considering the type of local land use: mineral fertilizers, septic waste, animal manure and landfill leachate.

The hydrochemical investigation was conducted on groundwater of the limestone aquifer and on leachate samples. The most important chemical parameters (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, NO_3^{-}) and some minor constituent (Fe, Mn) are taken into account.

In particular, the environmental isotopes of hydrogen (H), carbon (C), nitrogen (N) and oxygen (O) were used to identify the groundwater provenance and geochemical reactions.

The stable isotopes oxygen-18 (^{18}O) and deuterium (^{2}H) were used to investigate the origin of water in the aquifer system in the study area.

The combination of NO_3^- concentration with $\delta^{15}N\text{-}NO_3^-$ and $^{18}O\text{-}NO_3^-$ in water also provides valuable information for identifying different sources of NO_3^- to the coastal aquifer. Samples of groundwater and leachate were analysed for ^{13}C and Tritium (^{3}H). Previous studies have demonstrated that the biogeochemical processes within the landfill environment can produce a unique composition for these isotopes, therefore they can be utilized successfully to delineate leachate influence.

Key words: nitrate, nitrogen and oxygen isotopes, karstic coastal aquifer, Italy, Apulia

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