Italian Chapter

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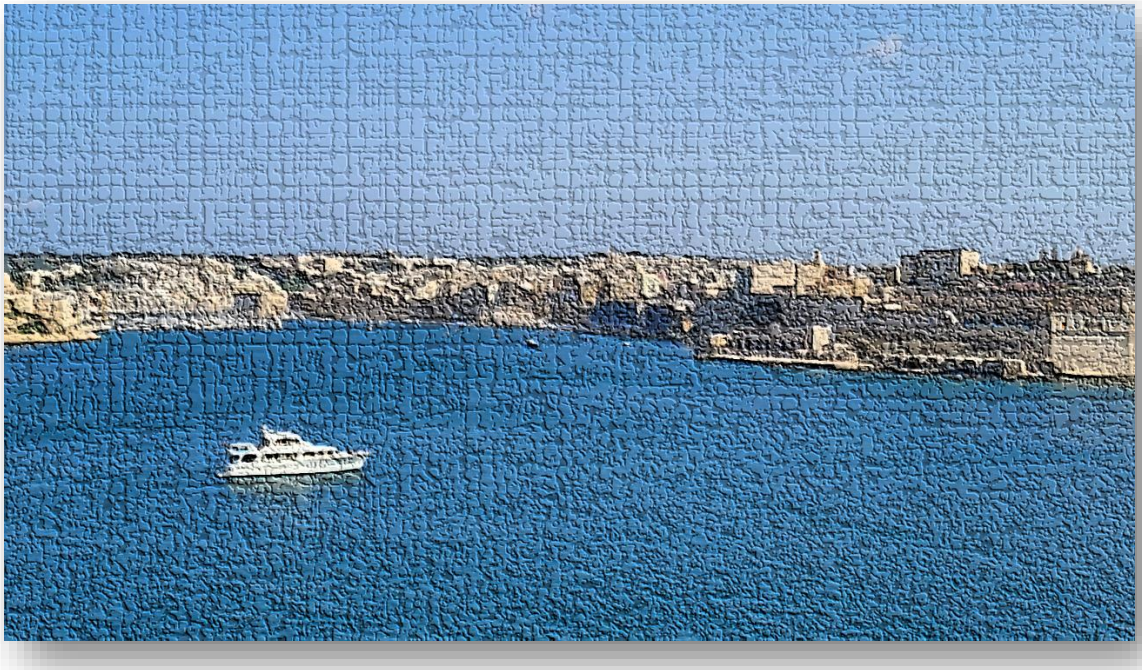
National Meeting on Hydrogeology

THE ENERGY &WATER AGENCY



6th Edition of FLOWPATH

the National Meeting on Hydrogeology

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Conference Proceedings Book

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Preface

The Italian Chapter of the International Association of Hydrogeologists (IAH) is pleased to present you the proceedings of the abstracts submitted to the 6th Edition of FLOWPATH, the National Meeting on Hydrogeology. The congress take place on 14th-16th June 2023 in Malta.
Following the tradition of the previous editions of FLOWPATH, the conference is an opportunity for hydrogeologists and professionals to exchange ideas and discuss different issues on groundwater resources.
The objectives of the conference are:

- ✓ To ensure that hydrogeology can play an important role in supporting the development of groundwater management and protection policies.
- ✓ To strengthen knowledge and research initiatives on emerging challenges to the groundwater environment
- ✓ 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 a sustainable water resources management;
- ✓ To highlight research initiatives undertaken in the Maltese islands, and improve technical cooperation between Maltese and Italian hydrogeologists.

The congress has been structured into four sessions, i.e.:
Session 1: Policies and Practices to Protect Groundwater
Session 2: Special Session on Hydrogeological Studies in Malta
Session 3: Emerging Challenges to Groundwater Quantity and Quality
Session 4: Groundwater Dependent Ecosystems

Each session starts with a Keynote lecture, held by international experts. The members of the Scientific Committee and the Chairs of the four sessions actively contributed to this successful Congress.
This Conference Proceedings book, including one keynote lecture for each session and 90 total abstracts, represents the final step of this Congress. All these abstracts underwent a rigorous peer-review process by the Scientific Committee members and were assigned to oral (45) or poster (45) presentation. The Authors come from Universities, Public Bodies, Private Companies of Italy and some other countries.
In summary, this congress, with more than 150 participants, testified the interest in groundwater resources and their protection with a view to future challenges in the hydrogeological sciences.

Summary

Session 1

Policies and Practices for the Protection of Groundwater

Oral Presentations

Assessment of Groundwater Sustainable Yields through the Use-Drawdown Method

Tony Cauchi[1]

[1]*GHD (Australia)*

Key words: Groundwater,Sustainable Yield,TFN Modelling,Python

Groundwater resources require adaptive planning and management to consider emerging issues, changes to the resource, its use and development pressures, as well as the system response to extraction. Maximising groundwater resource development provides social and economic benefit, which must be balanced with minimising unacceptable impacts to the environment. Estimation of sustainable yields of groundwater resources can be undertaken in many ways, with varying degrees of complexity and error. Transfer Function Noise (TFN) modelling can be used to estimate a relationship between groundwater level condition and groundwater use (extraction) within an aquifer or groundwater catchment. This approach requires very few inputs - time series groundwater level data (records of years are required) and groundwater stresses, primarily groundwater extraction data (volumetric measurements), and when considering unconfined aquifers, climate data.

TFN modelling has the benefit of not requiring complex and expensive numerical groundwater modelling, and utilises existing and accepted groundwater theory and functions that can be programmed through automated script based processes (Python package Pastas). The outcome is that large spatial areas can be iteratively assessed relatively rapidly, providing a variety of statistics used to assess uncertainty in the models (such as goodness-of-fit and root square mean error) as well as 95% confidence interval bands on the model outputs.

Once an acceptable goodness of fit is achieved (between measured and modelled data), an empirical relationship between drawdown and groundwater use can be obtained. This relationship can be used to forecast groundwater use scenarios to estimate drawdown under a range of potential future scenarios. Using the empirical relationship developed, groundwater drawdown can be used to compare against metrics that define groundwater resource sustainability. Thus, the modelling approach presents a useful iterative groundwater resource planning tool.

This method is being applied across the State of Victoria in Australia (an area the size of Italy), simultaneously across 25 confined aquifers, to support planning and policy decisions regarding groundwater, particularly in respect to limits for allocation and sustainable groundwater use.

Optimization of Reservoir Operation Considering Lake-Aquifer Interaction and Conjunctive Use of Surface and Groundwater

Ata Joodavi[1], Rudy Rossetto[1]

[1]Scuola Superiore Sant'Anna, Pisa, Italy

Key words: Conjunctive use, Reservoir management, Optimization model

Managing the conjunctive use of surface-water reservoirs with large amount of leakage loss and groundwater resources is an actual challenge. In this study, a methodology, based on the combination of a numerical groundwater flow model (MODFLOW, Harbaugh et al., 2017) for simulating reservoir-aquifer interaction, and an optimization model, for the reservoir operation-management considering surface/groundwater interactions is presented. The numerical groundwater flow model was developed by means of FREEWAT (De Filippis et al., 2017) software and used to obtain a leakage function representing the reservoir's leakage loss to the aquifer in response to different water levels in the reservoir. The leakage function is embedded to the reservoir mass balance equation in the optimization model. The optimal policy was derived based on maximizing the reservoir's water yield while considering different constraints such as the water demand for drinking and industrial purposes and storage constraints. The modelling method proposed in this study was applied to an off-stream artificial lake in the north-east of Iran. Based on our calculations, the distance between the total demand (12 Mm3/year) and optimal release from the reservoir (5.7 Mm3/year) could be supplied by groundwater via pumping wells while the additional recharge of the aquifer provided by the leakage is 7.26 Mm3/year. The results demonstrate the potential benefits of adopting conjunctive use strategies for water management in a complex environment (Joodavi et al., 2020). Moreover, the modelling method can be adapted to any artificial lake system to enhance its operation, planning and management, as it can provide accurate assessment of the effects of operational releases on lakebed seepage.

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A Reproducible Procedure to Elaborate Long Groundwater Level and Abstraction Rate Time Series Acquired from Data Logger, a Present-Day Necessity

Agnese Redaelli[1], Marco Rotiroti[1], Tullia Bonomi[1], Letizia Fumagalli[1], Mariachiara Caschetto[1], Francesco Esposto[2], Gianfranco Sinatra[2], Mauro Olivieri[2], Silvia Bozza[2], Chiara Zanotti[1]

[1]University of Milano-Bicocca

[2]Acque Bresciane S.r.l

Key Words: Time series, Monitoring networks, Water scarcity, Climate Change

In a climate change context, a sustainable water resource management is crucial and long time series of monitoring data become necessary. Recently, monitoring networks were improved, but the consequent extension of available data requires specific and reproducible procedures to effectively manage future big data. In groundwater studies, water suppliers could be valuable providers of long time series data. Indeed, they often store millions of groundwater level and abstraction rate data with a high temporal resolution, which often lie unexploited due to a missing dedicated operating procedure. In this work, a reproducible procedure to exploit long time series of groundwater levels and abstraction rates from data logger in operating wells is presented. This procedure allows the extraction of hydrogeological information from the data, improving monitoring networks' efficiency and data management. This work relies on over 9 million of hourly data of groundwater level and withdrawal rate of 107 public wells over 10 years (2013-2022). These wells, managed by the water supplier Acque Bresciane S.r.l., serve 50 municipalities in the province of Brescia (N Italy). This method includes a first pre-processing phase consisting of: (1) homogenization of data acquired from different sources, (2) errors and outliers treatment, and (3) data association with the geographical localization and the well's structure. The successive analysis phase allows to (1) separate static from dynamic groundwater levels, (2) classify groundwater levels according to abstraction rate ranges, (3) quantify the available static data and select the groundwater levels associated with the minimum withdrawal class (< 5 L/s), (4) extract and compare pluriannual, annual and seasonal trends of groundwater level, and (5) investigate the groundwater drawdown related to abstraction rates. Nowadays, in-depth analyses and elaborations of high-resolution hydrogeological data from automatic sensors are vital. Such elaborations can support and improve both monitoring networks' efficiency and day-to-day management, pinpointing malfunctioning (errors, sensors' misplacement, etc.) or evaluating the maintenance effectiveness on wells. As a result, a clearer evaluation of wells hydrodynamic behaviors is facilitated, alongside to the identification of tapped aquifer, of the possible interconnections among different compartments, and of the aquifer recharge and discharge assessment, also in climate change context.

Potential and limits of the Po Plain for the development of open-loop Groundwater Heat Pump Systems (GWHPs) in Italy, the case study of Milan and Turin.

Alessandro Berta[1], Glenda Taddia[1], Martina Gizzi[1], Federico Vagnon[1]

[1]Politecnico di Torino (DIATI)

Key Words: Geothermal energy, GWHPs, Shallow aquifer, Italian regulatory

Italy plans to pursue the target of obtaining 30% of final consumption of energy from renewable energy sources (RES) in 2030, by defining a pathway of sustainable growth for RES and the full integration thereof into the system. In this context, Groundwater Heat Pump systems (GWHPs) represent one of the most suitable technologies to be applied in the heating and cooling of buildings in densely urbanised areas, reducing CO2 emissions and environmental pollution. Currently, the share of geothermal heat production, out of the total thermal production from Renewable Energy Sources (RES) in Italy, is limited to 2.1%. It is, therefore, necessary to incentivise and encourage the deployment of geothermal solutions in order to increase the RES percentage and reach the European targets. However, different environmental aspects must be considered to minimize the impact of GWHP systems on the subsurface and shallow aquifers. Therefore, urban planning tools must pursue a rapid deployment of GWHP and ensure adequate long-term protection of the groundwater bodies, through an understanding of the subsoil in the decision-making process. A proper geological and hydrogeological characterization is fundamental and required by regulatory authorities for allowing the correct development of GWHPs. To date, the numerical model is the most powerful predictive tool, and a model calibration is required to perform uncertainty analyses, by connecting the performed model to the real world. For developing realistic numerical models, a set of data is necessary to properly define the fundamental hydrogeological parameters, such as horizontal hydraulic conductivity (Kx, Ky), porosity (η), longitudinal dispersivity (α), and storativity (S). Two case studies were considered: Turin City (Piedmont Region), where more than 50 authorisations for geothermal discharges have been submitted, and Milan City (Lombardy Region), where there are more than 200 geothermal plants. Despite the similar hydrogeological contexts (presence of unconfined, highly productive aquifer), the analysed cities are characterized by different open-loop diffusion rates. The in-force regional and municipal regulatory references to which a new geothermal project must comply (i.e., authorization requests and plant final testing operations) were taken into consideration, highlighting the potential connected to the diffusion of GWHPs and understanding the causes of the different diffusion rate in the mentioned contexts.

Groundwater Resources Management in Mountainous Areas: A Regional Scale Approach in Lombardy Region (Northern Italy)

Stefania Stevenazzi[1], Chiara Zuffetti[1], Corrado Camera[1], Alice Lucchelli[1], Giovanni Pietro Beretta[1], Riccardo Bersezio[1], Marco Masetti[1]

[1]Università degli Studi di Napoli Federico II

Key Word: Groundwater body, Groundwater quality, Groundwater budge, Geological modelling

Groundwater resources management and protection at a regional scale require the identification and definition of groundwater bodies (GWBs) that should represent the hydrogeological reference areas to evaluate the availability and quality of groundwater resources. In mountainous areas, groundwater resources are strategically important to maintain adequate water supply for human consumption and to preserve the functionality of (ground)water dependent ecosystems, also considering the expected growing demand and reduction of resources due to ongoing climate changes. Within this framework, this study presents a regional approach that could support public agencies and water companies to efficiently manage and protect the water resources in mountainous areas.

A 3D hydrostratigraphic model coupled with a water budget evaluation and hydrochemical and isotopic fingerprints was developed to identify and delineate GWBs in a geologically complex Alpine environment. The 3D hydrostratigraphic model integrated the available geological maps and cross-sections and applied the current classification criteria for hydrogeological mapping to the bedrock units, respecting the geometry of their boundaries. The model accounts for the dominant groundwater circulation patterns through the geological units that compose the bedrock water reservoirs. GWBs were identified and verified through the inspection of the 3D hydrostratigraphic model combined with: i) the location of known springs, ii) the knowledge on groundwater circulation (e.g., speleological information), iii) the hydrochemical characteristics, iv) the location of recharge areas identified through isotopic analyses, v) the groundwater budget evaluation.

Sixteen GWBs have been identified all over the 10.290 km² area, showing differences in storage capacity up to four times between GWBs mainly constituted of carbonate rocks and those prevalently composed of crystalline or terrigenous rocks. Groundwater quality in the study domain is generally excellent, with few exceptions. The results of this study allow to: i) identify the most Strategic Storage Reservoir in terms of quality and storage capacity; ii) evaluate the present ground- and surface water availability; iii) detect areas of interest for implementing groundwater monitoring networks; iv) recognise recharge areas of the most relevant springs, to implement protection strategies.

Assessment of Karst Aquifer Spring Potential by 3D Modelling Constrained by Geological Maps and Densely-Space Airborne and Ground Geophysics: the Mountainhydro Project

Alice Lucchelli[1], Gianluca Fiandaca[1], Daniele Pedretti[1], Riccardo Bersezio[1], Matteo Gisolo[2]

[1]Università degli Studi di Milano

[2]A2A Ciclo Idrico S.p.A

Key Words: 3D modelling, AEM surveys, Hydrogeophysics,Hydrostratigraphy

Groundwater represents a crucial source of freshwater supply since it helps to adapt to intermittent water shortages caused by climate change. In the last two years, Northern Italy is facing a period of severe water stress. Mountain areas are particularly affected due to the scarce precipitation and warm winter temperatures that produce a thinner-than-usual snowpack. With these premises, it has become urgent to assess the long-term sustainable use of groundwater resources and to ensure their adequate protection. MountainHydro project consists of a multifaceted approach for the potential assessment of groundwater springs in a karst-fissured setting of the Italian Southern Alps (Valle Sabbia, Lombardy). The project is financed by A2A Ciclo Idrico, within the largest airborne electromagnetic survey (AEM) campaign for groundwater management ever carried out in Italy. It aims to evaluate the resilience and sustainability of water supply to local mountainous communities by springs as a function of climate change scenarios.

The proposed approach is multidisciplinary data-driven, based on stratigraphic, petrophysical, and structural data, ground-based and airborne geophysical data, hydrogeological and hydrogeochemical data.

The 3D geo-structural model is computed after the existing cartography integrated by 1:10.000 original surveys, ad hoc geological cross sections, and field measurements of hydrostratigraphic parameters. Hydrogeological data entails discharges, water stable isotope fingerprints, and hydrochemical characterization. Geophysical surveys, which provide key information on the structural setting at different depths over the exploration area, consist of 4000 line-km of AEM supported by ground acquisitions, i.e. 20 km of electrical resistivity tomography (ERT), 150 km of ground-based time-domain electromagnetic survey (TEM). The combination of several complementary geophysical methods enhances the coverage and reliability of the 3D electrical resistivity model of the investigated area. This approach shall provide unprecedented spatial coverage for the mapping of structural heterogeneities, karst conduits, and other preferential seepage zones. The geological 3D model informed by geophysical data will establish the basis for a 3D finite elements flow model.

Urban Groundwater: How to Classify Cities by a Hydrogeological Point of View?

Francesco La Vigna

Geological Survey of Italy – ISPRA

Key Words: Urban geology, Urban groundwater, Urban resilience, Climate change

Groundwater plays a significant role in cities' resilience and there is a growing body of evidence highlighting its importance in supporting urban living and the impact of urbanism on natural groundwater systems.

There are many benefits obtained from sustainable groundwater use in cities: the economic value derived from productive uses for drinking water, industry, and garden irrigation, as far as for cooling and heating exchange; the ecological value provided by supporting urban groundwater-dependent ecosystems; the option value of storing groundwater as an insurance against future water shortages , as well as against fire hazard. On the other hand, several interdependences exist between some groundwater services and the cascading effects on city life in cases of shock (drought, heavy rain, pollution, energy demand) and chronic stress (climate change). Consequently, although it is a quite rare practice, groundwater should be considered by city planners as one crucial aspect in every resilience assessment and strategy. In agreement with this point of view a first groundwater-city classification is proposed in order to facilitate a more effective city-to-city comparison with respect to, for example, the best practices and solutions that have been put in practice by similar cities in terms of local groundwater resources management. Through the clustering proposed, cities could more easily be grouped worldwide by typology and thus compared with respect to groundwater issues and opportunities in common. Therefore, city planners could more easily assess the relative adaptation strategies and best practices to raise the resilience of cities by the groundwater point of view.

Unconventional Pumping Tests in Carbonate Aquifers, Without Interruption of Drinking Water Exploitation

Sergio Rusi[1], Diego Di Curzio[2], Alessia Di Giovanni[1]

[1]Department InGeo University Chieti Pescara

[2]Department of Water Management, Delft University

Keyword: Pumping Test, Carbonate aquifer, Gran Sasso, Groundwater

The Gran Sasso carbonate aquifer is the largest and most productive in the Apennines. Its hydrogeological structure has been deeply studied since the middle of the last century for springs' characterization for drinking purposes and for drilling of a motorway tunnel. Meanwhile, its hydrodynamic parametrization is less developed and is mainly limited to monitoring the discharge and chemical and isotopic parameters of springs.

Starting from the '80s of the last century, the aquifer has also been exploited through wells especially in its southern portion where it was possible to reconstruct the geological structure and perform pumping tests because of the lowest groundwater table depth.

The aquifer is characterized by secondary porosity, i.e. by fracturing and karst features, and an underlying impermeable marly complex, which represents the basal aquiclude. In such aquifers, it might appear inappropriate to characterize the hydraulic properties via pumping tests, as their reliability is proven in homogeneous and isotropic media. However, the high extent of the aquifer (about 700 km2), the location of the wells, as well as the scarcity of information available and the lack of alternatives forced to estimate some hydrodynamic parameters as in porous aquifers and to test the aquifer experimentally, especially in conditions of maximum pumping even for the evaluation of the influence radius.

Furthermore, since the aquifer testing was performed during the normal activities of abstraction and distribution, it was not possible to perform canonical tests, i.e. with only one pumping well and observing the adjacent wells. However, the high transmissivity of the aquifer, the use of a single pumping well would have not sufficed to induce a drawdown that allowed data processing.

Therefore, the step-drawdown test was obtained by turning on an increasing number of wells over time and keeping fixed the observation points. This kind of test, in addition to avoid interrupting the water supply, allowed:

- estimating hydraulic conductivity and transmissivity;
- estimating drawdown in pumping wells and in observation piezometers in operating conditions;
- evaluating the extension of the perturbation induced to the aquifer both at the test and stress discharges;
- evaluating flow directions in operating conditions.

The Use of Compound-Specific Isotope Analysis (Csia) to Allocate the Potential Sources of Dissolved Chlorinated Solvents Contaminant in Large Urban Areas: Lessons Learned from Few Case Studies

Massimo Marchesi[1], Orfan Shouakar-Stash[1], Luca Alberti[2], Matteo Antelmi[2], Ramon Aravene[3]

[1]*Isotope Tracer Technologies Labs*

[2]*Politecnico di Milano*

[3]*University of Waterloo*

Key Words: Isotope Analysis, Chlorinated Solvents, Urban Area, Source allocation

A Water Safety Plan (WSP) ensures safe drinking-water through good water supply practice from catchment to consumer, in order to (i) prevent contamination of source waters, (ii) to treat the water to reduce or remove contamination and (iii) to meet water quality targets. Thus, isotopic data can give crucial insights both in terms of defining hazards and assessing risks and can play a pivotal role in management and monitoring phases consistently ensuring the safety and acceptability of a drinking-water supply. Stable isotope analyses such as 2H, 18O e 3H - H2O already play a key role in robust water resource management plans; other analysis like Compound-Specific Isotope Analysis (CSIA) can add a valuable contribution with regards groundwater contaminants characterization and management aspects. Within this contribution the origin and pathways of frequently detected contaminants in groundwater such for example tetrachloroethylene (PCE) among others (chloroform CF, trichloroethylene etc.) were investigated by coupling isotope, groundwater flow and transport modeling, and statistical analysis at two major cities in the North of Italy (Lombardy Region) as part of their Water Safety Plans (WSPs). Chlorine and Carbon Compound-Specific Isotope Analysis (37Cl & 13C-CSIA) and 2H, 3H, 18O were applied in different hydrogeological settings to infer additional information's for the development of the conceptual model of the contamination, including source apportionment, remediation and containment actions efficacy evaluation and overall to asses the pathways of such contaminants in groundwater resources, which are used for the water supply systems of these cities.

Session1

Policies and Practices for the Protection of Groundwater

Poster Presentations

Natural Background Level Assessment for Inorganic Compounds in Groundwater in a Contaminated Site: A Roadmap to Contamination Screening Values Definition

Adriana Damato[1], Stefano Ghergo[1], Daniele Parrone[1], Elisabetta Preziosi[1]

[1]CNR-IRSA

Key Words: Monitoring network, Groundwater, Pollution, Arsenic

The Contaminated Site of National Interest (SIN) "Bacino del Fiume Sacco", extends for 72.4 km2 in the Sacco River valley in Central Italy. It was established in 2016 after the detection in 2005 of β-Hexachlorocyclohexane, a byproduct of the now banned pesticide lindane, in cow's milk and then in soil and groundwater. Pollution related to "lindane" is now receding, however other pressures are currently affecting this important industrial area. High concentrations of inorganic substances (Al, As, Fe, Mn and Tl) detected in groundwater have raised questions about the existence of pollution plumes in the valley.

Following the Italian Decree n. 152/06 a contaminated site is established when the Screening Values (CSC) are exceeded and, after an investigation of the site and a site-specific risk assessment, the Target Values (CSR) are exceeded, resulting in unacceptable risks to human health or the environment. For inorganic substances, it is essential to differentiate the natural background levels (NBL) from anthropic pollution: the NBLs express the distribution of an element in the environment produced by natural processes.

This project, funded by the Italian Ministry of Environment through the Regione Lazio and with the collaboration of Regional Agency for Environmental Protection, aims to assess the NBL for inorganic compounds in groundwater to be applied in the 'Bacino del Fiume Sacco' SIN. The research plan involves the collection of 200 groundwater samples in the basin, mainly upstream the contaminated site, seeking for the natural background. A regional water table aquifer flows along the valley, mainly in the volcanic products, alluvial sediments and travertines, with the river draining water from the aquifer for most of its course. The selection of the water points will be mainly driven by the hydrogeological complexes, trying to obtain a monitoring network with an approximate density of one point per 2-3 km2, with greater density in the alluvial complex where most of the CSC exceedances are found. Other selection criteria include land cover, accessibility and state of conservation.

Groundwater will be sampled following established protocols. Lab analysis includes inorganic substances (major compounds and trace elements), some organic compounds (VOC, hydrocarbons) and stable isotopes (δ2H, δ18O, δ13C). The results will be processed with statistical and geostatistical procedures to define NBLs, following the Italian national guidelines.

Data-Driven Monitoring Strategies for Groundwater Quality Protection Through Time Series Clustering of Groundwater Pollution Data.

Chiara Zanotti[1], Marco Rotiroti[1], Agnese Redaelli[1], Mariachiara Caschetto[1], Letizia Fumagalli[1], Camilla Stano[2], Davide Sartirana[1], Tullia Bonomi[1]

[1]University of Milano – Bicocca

[2]A2A Ciclo Idrico Spa

Key Words: Time Series, groundwater quality, clustering, drinking water

Over the past few decades, groundwater quality monitoring networks have grown, and considerable time series of quality data are currently available. Hence, a research effort is required to investigate novel methods for exploiting groundwater quality time series. In this work, time series of groundwater pollution data are exploited with the aim of developing data-driven monitoring strategies, and early warning systems to support groundwater resource management for drinking water purposes. The research area is Brescia municipality (N Italy): an urban area with a complex hydrogeological context and numerous superimposing historical pollution sources. The dataset, provided by A2A Ciclo Idrico Spa, consisted in concentrations of Tetrachloroethylene (PCE), Trichloroethylene (TCE) and Cr(VI) on raw water before any potabilization treatment, from 2009 to 2020 for 68 wells and 16 springs.

Time series exploratory analysis and time series cluster analysis were performed on groundwater pollution data, to identify groups of wells with homogeneous responses to anthropogenic inputs and highlight critical situations. The exploratory analysis was performed through Mann-Kendall test and Sen's slope estimator for the trend identification and quantification.

A multivariate time-series clustering was performed on PCE and TCE, with the Dynamic Time Warping method. The clustering revealed 3 clusters linked to diffuse background contamination and 7 clusters linked to discrete hotspots, distinguished by distinct time profiles. Similarly, Cr(VI) data were subjected to a univariate time series cluster analysis, which revealed 3 background clusters and 7 hotspots, including 4 singletons.

Based on the clustering outputs, data-driven monitoring strategies and early warning systems were designed for each group of wells. For the clusters associated with diffuse background contaminations and those with constant trends, the 95th percentile was used to calculate trigger levels, which represent future threshold values for early warnings. Specific monitoring procedures were suggested for the clusters with pluriannual patterns that were either oscillatory or monotonous based on the direction of the trends.

The outcomes of the work demonstrate how a detailed time series analysis can support the implementation of data-driven monitoring strategies and early warnings for more efficient, site-specific monitoring networks, able to avoid redundant analyses while focusing on relevant trends.

GIS-Based survey and hydrogeological assessment of Operational Extractive Activities in Italy

Matteo Paoletti[1], Lucio Martarelli[2], Chiara Sbarbati[1], Vincenzo Piscopo[1]

[1]Università degli studi della Tuscia

[2]Servizio Geologico d'Italia, ISPRA

Key Words: Groundwater, Quarry, Hydrogeology, Italy

Extractive activities play a key role in the Italian economy but may exert a negative influence on quality and quantity of groundwater resources. For example, dewatering activities may be required to lower the water table, to allow deeper excavation into rock deposit when lateral expansion is limited. Furthermore, quarrying industry could negatively impacts on groundwater physico-chemical equilibrium as well as on its chemical composition (i.e. acidic drainage, increase of heavy metals).

The objective of this research was to create a GIS (Geographic Information System) that could provide statistics on the operational extractive activities in Italy. Specifically, the regional plans of extractive activities (PRAE) of each Italian region were analyzed, in addition to statistical information from regional statistical services. A main issue was the harmonization of this information provided with different accuracy level. These data were georeferenced and correlated with geographic information through the national geoportal to obtain a complete and detailed visualization of the mining activities in the territory. Each quarry was represented by a vector in GIS, including as attributes the following correlated information: the river basin, the lithology and hydrogeological complex, the type of quarry (slope or plain), the percentage infiltration coefficient and the permeability. Finally, a statistical analysis was developed to analyze the collected information and obtain an overview of quarry activities in Italy. It was then possible to identify the most critical hydrogeological areas and assess the impact of quarry activities on these areas. The research aims to safeguard groundwater resources in Italy and to promote a sustainable approach to extractive activities. This project is supported by a grant from PNRR "Geosciences IR" (Missione 4 "Istruzione e Ricerca"—Componente 2 "Dalla ricerca all'impresa"—Linea di investimento 3.1, "Fondo per la realizzazione di un Sistema integrato di infrastrutture di ricerca e innovazione" Finanziato dall'Unione Europea NextGenerationEU—CUP I53C22000800006).

Water Resource Management in Inland and Coastal Areas: Results Of Cooperation Between Italy and Argentina on Qualitative and Quantitative Issues of Groundwater and Surface Water Interactions.

Lucio Di Matteo[1], Daniela Ducci[2], Vincenzo Allocca[2], Domenico Calcaterra[2], Antonella Carosi[1], David Michele Cappelletti[1], Julián Cuello[3], Corrado Cencetti[1] , Daiana Dell'Arciprete[3], Diego Di Martire[1], Giovanni Forte[2], Nora Gómez[3], Luis Guarracino[3], Felipe Herrera[3], Eduardo Kruse[3], Patricia Laurencena[3], Massimo Lorenzoni[1], Sofia Ortenzi[1], Jonatan Pendiuk[3], Leandro Rodrigues Capítulo[3], Leonardo Sánchez Caro[3], Stefania Stevenazzi[2], María Marta Trovatto[3], Daniela Valigi[1], Esteban Villalba[3], Silvina Carretero[3]

[1]*Università di Perugia*
[2]*Università di Napoli Federico II*
[3]*Universidad Nacional de La Plata*

Key Words: Water management, GW-SW interactions, Italy, Argentina

Sustainable use and management of water resources require scientific knowledge about aquifer recharge processes, the interactions between groundwater (GW) and surface water (SW), and accurate estimates of the water budget. These issues are increasingly in the attention of water resource managers, given the growing demand for water for various uses, unavoidable environmental needs, and ongoing climate change effects. The EU Water Framework Directive (WFD 2000/60/EC), to preserve the environmental quality and quantity of water bodies, proposes a holistic approach to reviewing the water budget, considering groundwater and surface water as a single resource. In the framework of the CUIA initiatives (Consorzio Interuniversitario Italiano per l'Argentina), this work illustrates the results arising from the scientific cooperation between the University of Perugia, University of Naples Federico II, and Universidad Nacional de La Plata (Argentina) on topics related to aquifer recharge processes and groundwater-surface water interactions, examining qualitative and quantitative aspects of inland and coastal areas, at different spatial-temporal scales. The application of these aspects in some regions of Italy (the Nera River basin, Umbria, and the Tyrrhenian coastal plains and the carbonate aquifers of Campania) and Argentina (coastal area of the Río de La Plata and the Atlantic Ocean, and Pampean and Puelche aquifers), exploited for multiple uses of water, allow the exchange of experiences and methods on hydrogeological systems with different anthropogenic and environmental needs. In all investigated aquifer systems, the pressure on groundwater and surface water bodies is high, including decreasing recharge, increasing water demand (inland areas), seawater intrusion, or natural/anthropogenic pollution into coastal aquifers. The sharing and integration of hydrogeological information are

particularly useful, considering that some methods proven in specific meteorological-climatic, lithological, morphological, and ecological contexts may not be well represented in other hydrogeological systems. The research aims to promote multidisciplinary studies to understand recharge processes better and strengthen the cooperation between the two countries, focusing on groundwater-surface water interactions in inland and coastal environments.

Groundwater Discharge and Climate Change: The Application of GCMs to Assess Long-Term Effects of Climate Change on Spring Flow Along the Apennines

Tommaso Casati[1], Maria Filippini[1], Antonio Navarra[1], Alessandro Gargini[1]

[1]Alma Mater Studiorum - University of Bologna

Key Words: GroundwaterDischarge, Climate change, GCMs, Forcasting

Global warming affects atmospheric and oceanic energy budgets, modifying the Earth's water cycle with consequent changes to precipitation pattern. The impacts of possible emissions scenarios on surface water have been widely investigated and can be obtained from global climate circulation models, but the net effects of climate change on groundwater discharge are still uncertain at global and local scales. In order to assess future spring flow scenarios, the most critical step is to quantify the recharge-discharge connection.

The main aim of this research is to predict the long-term effects of climate change on the discharge of seven main springs with long hydrologic series of discharge values, located in different hydrogeological settings along the Apenninic chain (Italy). The investigated springs are strategic for either public water supply or mineral water bottling. Apennines stretch along the Italian peninsula in a Northwest-Southeast direction, crossing the Mediterranean area that represent a critical zone for climate change due to a decrease of recharge and increase of frequency and severity of droughts since the last two-three decades. In this communication, the data of two of the chosen spring, called Ermicciolo (42°55'25.8"N, 11°38'29.5"E; 1020 m ASL), discharging out from the volcanic aquifer of Mount Amiata, and Verde (42°05'26.5"N, 14°12'06.3"E; 410 m ASL), discharging out from the Majella Massif, are presented. Statistical and numerical tools have been applied to analyse the time series of recharge-related parameters in the spring's contribution area and of the spring discharge in the time-span 1938-2022.

In order to estimate the impact of climate change on the springs outflow, regional atmospheric circulation models have been downscaled to the spring catchment area and used to derive the expected discharge at 2040-2060 time span, according the build-up data-driven model of the recharge-discharge relationship in the past.

In Situ Detection of Low Permeability Layers for High Resolution Dependent Modelling of Potential Contaminated Sites

Maurizio Barbieri[1], Francesco Maria De Filippi[1], Stefania Franchini[1], Giuseppe Sappa[1]

[1]Sapienza University of Rome

Key Words: Groundwater, Monitoring, Pollution, Modelling

In contaminated sites, the effectiveness of remediation measures are increasingly dependent on previous high-resolution site characterization (HRSC) results. However, in many industrial sites, where high pollution risk related to groundwater is present, the hydrogeological models are often simply based on the stratigraphy results of geological drilling activities related to the groundwater monitoring network design. This approach, even if suitable for modelling groundwater flow (both in undisturbed and disturbed conditions), does not fit when contaminant back diffusion from low permeability lenses and layers occurs within high permeability aquifer. The triggers of the contaminant release might be related to pumping time, changes in flowrates, rapid raising or dropping of water table and they are not often recognized by the stakeholders. These latter tend to proceed by trial and error in order to understand the contamination origin and occurrence, leading to increase working times and costs. In these conditions, a major resolution can be obtained coupling preliminary stratigraphic data with specific in situ activities such as multiparameter and natural gamma radioactivity logs in the monitoring wells. Results coming from these additional investigations help to confirm the location of low-permeability layers and, consequently, to identify the most vulnerable areas towards which groundwater management must be deepen.

In this study, within an industrial site in the province of Benevento (Italy), based on stratigraphy and slug tests a 3D hydrogeological model has been set up and coupled with results of natural gamma radioactivity logs in order to detect the release of Chromium VI from low permeability lenses at specific depths.

Unfolding the Spatial Heterogeneity of the Natural Background Level of Arsenic in Groundwater at the Meso-Scale

Laura Landi[1], Marco Rotiroti[2], Igor Villani[3], Maria Filippini[1]

[1]Alma Mater Studiorum - University of Bologna

[2]University of Milano-Bicocca

[3]Emilia-Romagna Region: Sites Under Remediation

Key Words: Background Level, Arsenic, Heterogeneity, Geostatistics

The geogenic contamination by arsenic in groundwater is a common issue in many areas of the globe due to peculiar geological conditions prompting arsenic mobility. In these geological settings, the Natural Background Level (NBL) plays a key role in order to discriminate between natural or anthropogenic contamination. The evaluation of a reliable NBL that can be effectively exploited at the scale of a polluted site often requires site-specific studies. Conventional regional scale distributions of contaminant NBL in groundwater are indeed limited in their ability to capture natural heterogeneities that affect contaminant mobility at smaller scales.

The aim of this project is to define a strategy to unfold the spatial heterogeneity of the arsenic NBL at the meso-scale (100-1000 km2), considering the crucial role of geological and geochemical heterogeneities. Arsenic concentration data will be collected from monitoring networks of sites under remediation. These networks represent a pervasive source of information in urbanized/industrialized areas, offering a spatial and temporal resolution of data higher than that of large-scale monitoring networks for groundwater quality control. Potential anthropogenic influences on the concentration data will be managed through an accurate pre-treatment procedure supported by the conceptual model of the area of interest. Relying on a geostatistical approach, the most suitable method will be identified to unfold the spatial distribution of the NBL while incorporating the natural heterogeneities as secondary variables. Different methods, such as stratified kriging and co-kriging, will be examined and tested on a proper dataset.

An optimal strategy will be investigated on a pilot area in the eastern Po Plain (Emilia-Romagna Region, Italy) affected by geogenic arsenic contamination in groundwater. Eventually, the same protocol will be tested on a different area, with a forecasting approach of NBL assessment.

The resulting continuous distribution of arsenic concentration at the meso-scale will provide a useful practical tool for groundwater contamination management. In fact, distribution maps of NBL heterogeneities at the meso-scale will allow overcoming the issue of over- or under-estimation of NBL caused by regional scale data and the issue of cost and time consume of site-specific studies.

The Groundwater Component of the Urban Geo-Climate Footprint

Francesco La Vigna

Geological Survey of Italy ISPRA

Key Words: Urban Geology, Urban Groundwater, Resilience

The Urban Geo-climate Footprint (UGF) is a new approach, designed by geologists from the Geological Survey of Italy (ISPRA), based on a tool aiming to classify and cluster cities from a geological point of view.

According to United Nations, cities will soon be places where more than half the world's population will live. They are in constant interaction with geological settings and geographical contexts of the places where they were developed.

This project's basic assumption is that cities with similar geological-geographical settings can have similar challenges to manage, both due to common geological issues and climate change effects on the surface. Having an instrument capable of classifying and clustering cities can be useful for rapid comparison and best practice exchange. The UGF tool, allows this classification activity by extracting an INDEX for the city called UGF INDEX..

Among several parameters contributing to the UGF index calculation there are some related to groundwater which are the groundwater city classification (La Vigna 2022), the evaluation on the existing interaction between the local aquifers and city's infrastructures, the drought risk and the water stress.

New Data and Perspectives from the Groundwater Monitoring Network of the City of Rome (Italy)

Francesco La Vigna[1], Claudio Papiccio[2], Rossella Maria Gafà[1], Lucio Martarelli[1], Isidoro Bonfà[2], Maria Pia Congi[1], Gennaro Maria Monti[1], Mauro Roma[1], Angelantonio Silvi[1], Renato Ventura[1], Valerio Vitale[1]

[1]Geological Survey of Italy (ISPRA)

[2]Roma Capitale (Municipality of Rome)

Key Words: Urban hydrogeology, Monitoring network, Urban groundwater

The Groundwater Monitoring Network of Rome (GMNR) was born on 2014 when the Environmental Protection Department of Roma Capitale (Municipality of Rome) decided to dedicate the more than 200 existing water wells (mainly developed for green areas irrigation) also for monitoring purposes. The GMNR considerably contributed to the development of the new Hydrogeological Map of Rome on 2015 (La Vigna et al. 2015, La Vigna and Mazza 2016). Recently, by an agreement between Roma Capitale and ISPRA (Geological Survey of Italy) the monitoring activities have been strengthen, several new wells have been surveyed and all data are inserted and are available in a web-GIS system and an interactive map.

Each monitoring station visible on the interactive map have a link to a graph showing the trend over time of the measured parameters. In this regard, a system has been developed in order to allow the collection and the entry to the central database of investigated data even in real time by means of portable devices (tablet or smartphone), through a survey form. As a whole, this actually allow the field workers to quickly transmit the measured data - piezometric levels and in situ chemical-physical parameters - from the hydrogeological data collection site to a single online central database.

With the described agreement related to the GMNR, the survey activities are going to lead to a systematic structuring of information relating to the groundwater of the city of Rome, probably developing the first dedicated urban example in Italy, and contributing to enhance the local groundwater resource knowledge and also to increase public awareness in this regard.

Hydrogeological and Hydrogeochemical Characterization of a Semi-Arid Area in Southern Italy

Silvio Coda[1], Vincenzo Allocca[1], Pantaleone De Vita[1], Paola Petrone[1], Nicola Castello[1]

[1]DiSTAR – UNINA

Key Words: Water balance, Groundwater quality, NBL, Southern Italy

The semi-arid regions are intrinsically vulnerable to climate changes and ensuring long-term groundwater availability is a big challenge for the future. In this study, the main groundwater bodies (GWBs) of a semi-arid area of 540 km2 of the Matera province (Basilicata region, southern Italy) have been investigated for the first time.

Four GWBs are present in the study area, in particular a sandy-conglomeratic aquifer (SC), a clayey aquitard (Ar), and two alluvial aquifers in the plains of Basento (AlB) and Cavone (AlC) rivers. For each of them and referred to the period 2000-2021, actual evapotranspiration has been estimated by the Thornthwaite-Mather method and MODIS satellite data, while the groundwater recharge (GR) and average yield (AY) have been estimated by using the potential infiltration coefficients. In the period June 2021-September 2022, a hydrogeological and hydrochemical monitoring was carried out on a network of 49 selected wells, piezometers, and springs. Piezometric levels, discharge springs, and 52 analytes (chemical-physical parameters, organic and inorganic compounds) were determined.

The outcomes show that the greatest groundwater potential results for AlB and AlC, with an AY equal to 6.7 l/s×km2 and 8.1 l/s×km2, respectively. Lower values of AY equal to 4.4 l/s×km2 and 2.0 l/s×km2 have been estimated, respectively, for SC and Ar.

From the hydrochemical point of view, groundwater of SC and AlB are characterized by a dominant Ca-Mg-HCO3 facies. Significant analogies have been found for Ar and AlC, both characterized by facies varying between Ca-Mg-HCO3 and Na-K-Cl-SO4 types. In all the GWBs high concentrations and strong spatio-temporal variability of some inorganic species have been detected. Ar and AlC show the highest concentrations of sulfates, with mean values equal to 276.9 and 499.8 mg/l, respectively. These GWBs are also marked by high concentrations of nitrate with mean values of 70.5 mg/l and 50.8 mg/l. Locally, high values of Fe and Mn have been detected in AlB, in which concentrations of 1000 µg/l are exceeded for both metals. These hydrochemical anomalies can be attributed both to natural and anthropogenic factors, related to hydro-stratigraphical and mineralogical characteristics of aquifers, groundwater redox conditions, as well as to human activities.

The results obtained are preparatory for the assessment of natural background levels in the GWBs.

Application of Different Methods for the Estimation of Natural Groundwater Recharge: The Muravera Case Study

Porru Maria Chiara[1], Arras Claudio[1], Piscedda Fabrizio Antonio[1], Lorrai Mario[2], Maurizio Testa[3], Paolo Botti[3], Stefania Da Pelo[1]

[1]Department of Chemical and Geological Sciences, University Campus of Cagliari, Building A, 09042 Monserrato (Ca), Italy
[2]Regione Autonoma della Sardegna, Servizio tutela e gestione delle risorse idriche, vigilanza sui servizi idrici e gestione delle siccità, via Mameli 88, 09123 Cagliari, Italy
[3]Regional Environmental Protection Agency of Sardinia (ARPA Sardegna)

Key Words: Natural recharge, Soil water balance, Inverse water balance, Water table fluctuation

Evaluation of natural recharge is essential for a sustainable management of groundwater resources, especially in coastal areas where saltwater intrusion phenomena can arise. Direct recharge from precipitation represents the main source to phreatic aquifer; however, in complex hydrogeological systems, further sources as lateral recharge or surface water discharge into the groundwater systems needs to be evaluated for an accurate quantification of available resources.

In this study, several methods are used to estimate natural recharge of the Muravera alluvial aquifer, in south-eastern Sardinia (Italy), where ongoing seawater intrusion problems have led to a critical deterioration of the groundwater resource with severe environmental and socio-economic impacts.

Direct recharge from precipitation is evaluated through the application of two different methods, namely the I) Inverse Water Balance (IWB), and the II) Soil Water Balance (SWB). The IWB approach is based on spatial distribution of simple climatic dataset (precipitation and air temperature) and subsequent evaluation of the infiltration term through the definition of Potential Infiltration Indexes (CIP). The SWB approach, based on a modified Thornthwaite-Mather method, is implemented within a computer code developed by the USGS (Westenbroek et alii 2010); the code calculates spatial and temporal variations of groundwater direct recharge by integrating tabular daily climatological data with gridded datasets containing information about 1) hydrologic soil group, (2) land-use/land-cover, (3) available soil-water capacity, and (4) surface-water flow direction.

To evaluate the occurrence of supplementary alimentation sources, the Water Table Fluctuation (WTF) method is also applied. The methodology, implemented within the ESPERE Macro Excel developed by the BRGM, requires continuous groundwater level measurement, and it assumes that piezometric level rises in unconfined aquifers are directly related to aquifer recharge. Advantages of this approach include its simplicity and an insensitivity to the mechanism by which water moves through the unsaturated zone (disadvantage of the SWB).

Results of the IWB and SWB methods illustrate that the average direct recharge from precipitation, referred to the same decade 2009-2018, are in good agreements and vary between 2.86 and 4.43 Mm3/year, respectively. Results of the WTF, applied to the available 2019-2020 monitoring data, indicates that a supplementary 3 Mm3/year recharge occurs, mostly from the aquifer interactions with the Flumendosa river.

Effective Monitoring Network Design for Evaluation of Nitrate Contamination in the Southern Campidano Aquifer.

Fabrizio Antonio Piscedda[1], Mario Lorrai[2], Maurizio Testa[3], Claudio Arras[1], Francesca Lobina[1], Porru Maria Chiara[1], Alice Murgia[1], Botti Paolo[3], Stefania Da Pelo[1]

[1]Department of Chemical and Geological Sciences, University Campus of Cagliari, Building A, 09042 Monserrato (Ca), Italy

[2]Regional Environmental Protection Agency of Sardinia (ARPA Sardegna), via Contivecchi 7, 09122 Cagliari, Italy

[3]Regione Autonoma della Sardegna, Servizio tutela e gestione delle risorse idriche, vigilanza sui servizi idrici e gestione delle siccità, via Mameli 88, 09123 Cagliari, Italy

Key Words: Nitrate Vulnerable Zones, Monitoring networt, Campidano aquifer

According to the Nitrate Directive, nitrate vulnerable zone (NVZ) should be designed for the mitigation of nitrate (NO3−) contamination caused by agricultural practices, where concentration of NO3- in groundwater exceeds the limit of 50 mg/L.

The vulnerability of aquifers to nitrate pollution, sources of contamination and the groundwater flow field should be carefully assessed prior to the designation of NVZ. Moreover, the effectiveness of the designation of NVZs depends on the adoption of effective monitoring strategies and the representativeness of monitoring wells. In this study, a methodological approach to identify an effective groundwater monitoring network for the designation of a NVZ is proposed.

In the alluvial plain of the Campidano graben (Sardinia, Italy), the monitoring carried out by the regional agency for the environmental protection of Sardinia (ARPAS) revealed exceedances of the 50 mg/L for nitrates. Therefore, a comprehensive hydrogeological survey was performed to examine the hydrogeological context and to provide a designation of the area.

The Campidano graben developed during multiple tectonic phases starting from the the Oligo-Aquitanian and culminated during the extensional tectonics related to the opening of the South Tyrrhenian Basin during Plio-Pleistocene. The basin is filled by transitional to continental deposits structuring a multilayer groundwater system in which the alternations of several aquifer levels and aquicludes gives rise to a complex hydrogeological system. Further complications can arise from improper construction of wells that can allow the mixing of groundwaters coming from different sources, which makes difficult to identify the origin and extent of contamination.

Some 345 points (wells and piezometers) were inspected to collect technical information on well construction characteristics, piezometric level and field physico-chemical parameters of groundwater. Several features of the inspected points were evaluated for defining their suitability as monitoring point, like pressures near the points (i.e. stable or pile of manure at less than 50 m), their state of use (i.e.pump

working) and their accessibility. A score was assigned to each feature, the sum of which determined the high, medium or low suitability for each point to be sampled for chemistry and isotope analyses.

Piezometric heads measured in the 345 wells allow to define the piezometric trends, which were consistent with previous studies. Drainage axes and main and secondary watersheds were identified.

Nitrate values exceeding 50 mg/L were found in 170 samples distributed in points near the main drainage axis corresponding to the Flumini Mannu hydrographic axis, at areas occupied by greenhouse growing and in crop fields. The applied approach defines the most representative points in the multilayer groundwater system and serves to evaluate future suitable measures for the designation of new NVZ in the Campidano area. Regular monitoring will contribute to better management of NVZs, which should result in a reduction in nitrate pollution, protect drinking water sources, and improve water quality in water bodies.

Evaluating the Feasibility of a Managed Aquifer Recharge System in a Coastal Aquifer: First Results of Natural Recharge and Streamflow Simulations Using a Multi-Model Approach.

Pier Andrea Marras[1], Claudio Arras[1], Maria Cristina Porru[1], Fabrizio Antonio Piscedda[1], Mario Lorrai[2], Maurizio Testa[3], Paolo Botti[2], Stefania Da Pelo[1]

[1]Department of Chemical and Geological Sciences, University Campus of Cagliari, Building A, 09042 Monserrato (Ca), Italy

[2]Regione Autonoma della Sardegna, Servizio tutela e gestione delle risorse idriche, vigilanza sui servizi idrici e gestione delle siccità, via Mameli 88, 09123 Cagliari, Italy

[3]Regional Environmental Protection Agency of Sardinia (ARPA Sardegna), via Contivecchi 7, 09122 Cagliari, Italy

Key Words: Aquifer recharge, Managed Aquifer Recharge, SWAT model, SWB

The alluvial aquifer of the Muravera coastal plain, located in the south-eastern Sardinia, is affected by significant saltwater intrusion phenomena, posing a threat for the groundwater resources, already stressed by the increasingly warmer climate. The Flumendosa river, after draining almost 1800 km2 upstream, flows across the plain, where three tributaries (Flumini Uri, Rio Pibilia and Rio Mannu) feed into it. Aquifer overexploitation for irrigation and drinking water purposes, together with the reduction of runoff water due to the occurrence of several dams along the watershed, are leading to a further extension of the saltwater intrusion. For this reason, local authorities are planning the implementation of an early warning system for limiting saltwater edge movement toward the inland. Actions will be driven according to the scenarios simulated by a numerically enhanced conceptual flow and transport model. In this framework, the feasibility of a Managed Aquifer Recharge (MAR) system to increase the aquifer recharge in the plain along with the assessment of sources of freshwaters to feed the MAR system is under evaluation. In this study the contribution of river discharges to the natural recharge of the coastal aquifer was investigated using a multi-model approach: the SWB (Soil Water Balance) model was used to assess the recharge rates, while the SWAT Model (Soil and Water Assessment Tool) was implemented to simulate the water balance, particularly the discharge to the floodplain from the Flumendosa, Flumini Uri and Pibilia rivers. The SWB model was feed with data provided by field sampling and laboratory tests, such as water content, dry density, particle density, porosity, and grain size distribution. The SWAT model was run and calibrated using available streamflow data, measured in different gauges along the rivers, and reservoir release rates, which allowed a correct simulation of river discharges.

First results show that the aquifer recharge variates across the plain: gravel and sandy quaternary deposits have, accordingly to the SWB simulations, the highest infiltration rates. In the floodplain, the Flumendosa river, especially in the driest season, is draining water from the aquifer, meaning a further loss of underground available water.

In the next steps, a detailed simulation of aquifer and rivers exchange dynamics and the assessment of future management scenarios in the context of climate change projections, including the implementation of a MAR system, will be carried out.

Open-Loop Geothermal Systems - the issue of Iron-oxidizing bacteria in aquifers and heat-exchange plant: a case study at the Bologna Technopole

Tommaso Casati[1], Sandra Cristino[1], Luna Girolamini[1], Enrico Dinelli[1], Nicolas Greggio[1], Alessandro Gargini[1]

[1]Alma Mater Studiorum - University of Bologna

Key Words: Geothermal system, Iron bacteria, Heat-exchange plant, Pumping wells

Open-Loop Geothermal Systems are a type of geothermal energy technology that extracts heat from groundwater, using it to provide space heating and cooling in buildings. These systems are important because they produce green energy by utilizing a renewable resource: the groundwater's heat. This study examines an open-loop geothermal system located at Bologna's Technopole, in Italy, which serves to cool the supercomputers at the European Centre for Medium-Range Weather Forecasts (ECMWF). The geothermal system includes four pumping wells and six recharge wells. Two intake wells and three losing wells draw water from the intermediate confined alluvial aquifer (screens around 75 m depth), whereas the other five wells, with the same pattern, involve the deep confined alluvial aquifer (screens around 110 m depth). The first sampling round has identified the high concentration of dissolved bivalent iron and ferrobacteria as the critical issues affecting the system's efficiency. During pumping, these bacteria form concretions in the well filters, leading to partial obstruction.

The research aims to address this issue by conducting chemical and microbiological analyses, video inspections, mechanical and chemical sanitation. The effectiveness of these interventions will be verified by multiple pumping tests ante and post intervention to evaluate improvements in wells efficiency. Furthermore, the study aims to provide the ECMWF with a management plan for the geothermal system, outlining the optimal pumping scheme in order to avoid well filter clogging, limiting turbulence and groundwater aeration. This study provides valuable insights into addressing challenges in open-loop geothermal systems, with practical implications for future projects.

Hydrogeological Asset of the Alpine Regions: Physical and Chemical Characteristics of Groundwaters

Marco Donnini[1], Francesco Frondini[2], Marino Vetuschi Zuccolini[3], Laura Melelli[2], Federica Fiorucci[1], Carlo Cardellini[2], Giovanni Chiodini[4]

[1]CNR-IRPI. Perugia, Italy

[2]Univeristà degli Studi di Perugia. Perugia, Italy

[3]Università di Genova. Genova, Italy

[4]INGV. Bologna, Italy

Key Words: Alps, Groundwaters, Hydrogeochemistry, Geo-DataBase

Groundwaters have a key role in the human life. In Europe 65% of drinking water and 25% of water for agricultural irrigation come from groundwaters. Within groundwater, thermal and mineral waters play an important economic role in the wellness and food market.

In the Alpine region, the ratio of runoff to infiltration is unbalanced in favour of the former, making groundwater supply highly sensitive to climate change. Despite the importance and the vulnerability of groundwaters in Alpine region, quantitative and qualitative studies that involve the entire Alpine region are rare, being difficult conducting studies in an area of more than 200,000 km2 shared among six countries (France, Italy, Switzerland, Germany, Austria and Slovenia).

In this work, we present a geo-database containing more than 3,000 chemical analyses of spring waters (fresh, mineral and thermal) characterised through the main ions (for all springs) and for less than 20% of the data also through the isotopic composition of water and carbon. The DB data were obtained from literature (scientific publications, books, websites...) and from new field samplings collected between 2011 and 2022.

The 15% of springs with a known flow rate (1,480 springs) include all springs with a maximum highest discharge of more than 1,000 l/s (numerically 1% of springs with a known flow rate, 16 springs), the latter representing 75% of the total flow rate in l/s. The geo-database was compared with a GIS-based hydrogeological map of Alps elaborated for the purpose. The map highlights the presence of an inner crystalline core north- and south-bounded by dominant carbonate rocks, while external to the chain are located basins mainly filled by sandstone-type rocks. The more productive springs are located in the calcareous complexes and, secondary, in the external basins. The mineral and thermal springs are mainly located in correspondence of the main tectonic lines and of the basins external to the chain.

We maintain that our work constitutes a useful base knowledge on groundwaters on the whole Alpine region, and provides a tool to characterize, estimate and monitor the groundwater resources in this area,

in line with the goal 6 "ensure availability and sustainable management of water and sanitation for all" of the 2030 Agenda for Sustainable Development of United Nations (https://sdgs.un.org).

3D Hydrogeological Numerical Modelling for the Sustainable Management of Groundwater in the Arborea Coastal Plain (Sardinia, Italy)

Antonio Maria Sessini[1], Manon Lincker[2], Gerhard Schafer[2], Alberto Carletti[3], Claudio Arras[1], Stefania Da Pelo[1]

[1]Department of Chemical and Geological Sciences, University Campus of Cagliari, Building A, 09042 Monserrato (Ca), Italy
[2]Institut Terre et Environnement de Strasbourg (ITES) UMR 7063 CNRS-Université de Strasbourg, France
[3]Desertification Research Centre (NRD), University of Sassari

Key Words: Hydrogeological numerical modelling, Nitrate contamination, Coastal plain, Managed Aquifer Recharge

Along Mediterranean coastal areas, most of the industrial production, agriculture and population are concentrated. The consequent high demand for fresh water leads to groundwater overexploitation, pollution and eventually, saline intrusion. The Arborea plain, located in the central-western coast of Sardinia, is an intensive farming district based on dairy production and agricultural activities. The plain passed through deep reclamation actions in the 1920s, when the insalubrious swamp areas were covered, and a complex network of drainage channels and pumping stations were built to lower the piezometric level and intercept runoff waters. Since 2005 it has been declared a Nitrate Vulnerable Zone (ZVN - 91/676/CEE) because of the high nitrate concentration measured in groundwaters and caused by manure and effluents (Biddau et al.,2018). According to the hydrogeological model of the coastal plain, a phreatic multi-layer aquifer is hosted within the Holocene littoral sands superimposed to a deeper alluvial aquifer hosted in Pleistocene continental deposits. The two aquifers are physically separated by a thick silty clay layer quite continuous northworth and are locally connected in the southern part of the plain because of the gradual thinning of clay deposits (Ghiglieri et al., 2016). To better understand the dynamics of the phreatic aquifer and to study the nitrate source and fate, a steady state and a transient numerical groundwater model have been implemented for the Arborea plain with Feflow 7.4, within the PRIMA-Sustain COAST project. In detail, the main water inputs (precipitation, irrigation), industrial and agricultural abstractions, and exchanges with surface waters, including the drainage channels, have been modelled. Lastly, various nitrate contamination and groundwater management scenarios were simulated. Preliminary results indicate that approximately 58% of the total annual outflow is drained by the ditches, while transport simulations globally underestimate the observed nitrate concentrations. A second groundwater model, now under development at the local scale, wants to simulate the efficiency of a Managed Aquifer Recharge system (MAR) implemented through a

Forested Infiltration Area (FIA). The FIA pilot site has been realized in the south part of the plain by the NRD-UNISS of Sassari University in the framework of the ENI-CBC MED MENAWARA project with the objective of testing new strategies to mitigate the nitrate contamination of the phreatic aquifer.

Session 2

Special Session on Hydrogeological Studies in Malta

Oral Presentations

KEYNOTE LECTURE

Unveiling Malta's Hydrogeological Frontier: Paving the Way for International Research Synergy

Ariel T. Thomas, Aaron Micallef

The talk delves into the recent discovery of offshore freshened groundwater in Malta and its implications for global hydrogeology. This presentation aims to highlight the significance of research collaboration in investigating and understanding this novel hydrogeological phenomenon, which has also been observed in continental shelves worldwide. The talk begins by providing an overview of the groundbreaking findings in Malta, where the presence of offshore freshened groundwater has challenged conventional notions of coastal hydrogeology. Through an exploration of the geological and hydrological context, the talk discusses the unique characteristics and potential resources of this offshore freshwater reserve. Drawing from the Maltese case study, and similar studies on the Atlantic Margin of North America, Canterbury Bight in New Zealand and the East China Sea, the address emphasizes the need for international research synergy in studying offshore freshened groundwater. It underscores the importance of interdisciplinary collaboration, involving hydrogeologists, geophysicists, geologists, and other relevant stakeholders, to comprehensively investigate the occurrence, dynamics, and sustainability of these valuable freshwater reserves. Furthermore, the address aims to foster a platform for knowledge exchange and cooperation among hydrogeologists from different regions who have encountered similar hydrogeological features in continental shelves worldwide. It encourages the sharing of research methodologies, technological advancements, and best practices to unravel the mysteries surrounding offshore freshened groundwater and its potential for sustainable freshwater supply. Through a comprehensive examination of the Malta case study and an exploration of international perspectives, this keynote address seeks to inspire hydrogeologists to embark on a collective journey towards understanding and harnessing the vast potential of offshore freshened groundwater. By facilitating research collaboration, this presentation envisions the establishment of a global network of experts working together to address the scientific, environmental, and socio-economic challenges associated with these remarkable hydrogeological phenomena. In conclusion, the keynote address serves as a call to action, urging hydrogeologists to embrace a new frontier of research and collaboration. By unifying our efforts, we can pave the way for innovative approaches, sustainable management strategies, and transformative solutions that will shape the future of offshore freshened groundwater exploration and utilization on a global scale.

Mapping Saltwater Intrusion Via Electromagnetic Induction (EMI) Measurements in Pwales Valley – Maltese Island

Lorenzo De Carlo[1], Antonietta Celeste Turturro[1], Maria Clementina Caputo[1], Manuel Sapiano[2], Julian Mamo[3], Oriana Balzan[2], Luke Galea[2], Michael Schembri[2]

[1]CNR, Water Research Institute
[2]Energy and Water Agency (EWA)
[3]Institute of Earth Systems, University of Malta

Key Words: Maltese coastal area, Salt water intrusion, Electromagnetic data, 3D modeling

In coastal areas saltwater intrusion causes a depletion of groundwater by reducing freshwater supplies for domestic and agricultural uses and causing severe deterioration of the quality of water resource. This trend, combined with reduced precipitation patterns, as an effect of climate changes, is observed in Pwales Valley – Maltese Island, where the water resource management plays a crucial role for the environmental sustainability of the area, given the importance of intensive agricultural activity along this valley. Accurate and advanced saltwater intrusion observation models able to overcome some limitations of the traditional hydrogeologic techniques (network of regularly spaced wells not always available, multi-depth measurements difficult to be collected) are strongly encouraged. In recent years, non-invasive cost-effective geophysical techniques have been increasingly used for investigating coastal areas due to their high capability to collect measurements over large areas in order to provide areal information at field scale. Specifically, Electromagnetic Induction (EMI) measurements provide subsurface electrical conductivity data that are particularly appropriate for characterizing and monitoring the saltwater intrusion dynamics due to the high sensitivity of such parameter to the salinity. In the study area of Pwales Valley, EMI survey was performed with n. 22 EMI transects, mainly oriented in the North-South direction. CMD DUO (Gf Instruments, Brno, Czech Republic) sensor, based on two electromagnetic coils working at a signal frequency of 925 Hz, was used to collect overall more than 20,000 electrical conductivity data in few days. Each EMI transect was inverted independently for imaging the 2D cross sections within 20-25 m in depth from ground surface. Then, all the 2D inverted models where merged to produce a quasi 3D high-resolution model of electrical conductivity of the Pwales Valley. The results highlighted the spatial extension of the tongue-shape salt water intrusion from east to west along the valley, as well as some geological-hydrogeological peculiarities such as the thickness of the salt wedge and the irregular top surface of the bottom impermeable layer, otherwise undetectable with other techniques. This approach confirms to be a useful tool for an effective geohydrologic characterization of the studied area, essential for planning mitigation actions and/ or adaptation measures to tackle climate changes.

Hydraulic Characterization of Pwales Aquifer in Malta Island

Maria Clementina Caputo[1], Lorenzo De Carlo[1], Antonietta Celeste Turturro[1], Manuel Sapiano[2], Julian Mamo[2], Oriana Balzan[2], Luke Galea[2], Michael Schembri[2]

[1]CNR Water Research Institute

[2]Energy and Water Agency (EWA)

Key Words: Water retention, MAR, lab measurements, Infiltrometer test

Whitin the aim to reduce the water need by increasing water use efficiency and producing additional water resources, the Energy and Water Agency (EWA) of Malta is planning to develop a Managed Aquifer Recharge (MAR) pilot plant in Pwales Valley to improve the quantitative and qualitative status of the groundwater body. For this reason, within a service agreement, signed between EWA and the Water Research Institute (IRSA) of the Italian National Research Council (CNR), a detailed hydraulic characterization of the valley was carried out.

Specifically, hydraulic properties of the rocks that constitute strata atop of the Pwales aquifer were determined by means both of laboratory measurements on samples shipped by the Agency and of field test carried out in the studied area.

The water retention and hydraulic conductivity functions, which relate the matric potential, ψ, and hydraulic conductivity, K, to the water content, θ, respectively were measured using three experimental methods (suction table, WP4-T Dewpoint Potentiameter and Quasi-Steady Centrifuge method) because each of them allows to obtain data points in a specific wet range.

The water retention and hydraulic conductivity functions were measured on samples extracted from blocks of Upper Coralline Limestone formation, that hosts the aquifer, collected in three different quarries: Ghian Tuffieha (GT), Mellieha (ML) and San Martin (SM) areas. The measured water retention and hydraulic conductivity data were fitted with LABROS SoilView Analysis software that allows to accurately describe the functions and obtain the parameters which are crucial for modelling the water flow and transport processes in the critical zone other than providing the hydrogeological characterization of the aquifer useful for environmental applications.

In addition, large ring infiltrometer test was carried out to determine the field saturated hydraulic conductivity, Kfs, and the average infiltration rate.

Knowledge of the hydraulic characteristics of the Upper Coralline Limestone, completely missing in the scientific literature, allows developing a local groundwater-flow numerical model in order to better describe and understand how the water flows from the soil to the groundwater of the valley and visualize different environmental scenarios such as the potential effects of MAR plant in the coastal Pwales groundwater.

Hydrogeological Modelling of a Seawater Intrusion Barrier in the Malta Mean Sea Level Aquifer (MSLA) Coastal/Island Carbonate System

Francesco Demichele[1], Julian Alexander Mamo[2], Michael Schembri[3], Louise Spiteri[4], Mariello Spiteri[4], Manuel Sapiano[3]

[1]EMDP Ltd
[2]University of Malta
[3]EWA
[4]EMDP Ltd. - University of Malta

Key Words: MAR, Saltwater Intrusion, Numerical Modelling, Carbonate Aquifer

The carbonate Malta Mean Sea Level Aquifer (MSLA) is a freshwater lens system floating on water of higher salinity. This basal aquifer system supplies the majority of the water demand of the Maltese Island while population growth challenges the sustainability of this groundwater body due to increased abstraction rates by means of boreholes and pumping stations conveying freshwater through a system of underground drainage galleries. Saltwater intrusion is one of the most wide-spread and important processes that degrades water-quality by rising salinity to levels exceeding acceptable drinking and irrigation water standards and endangers future exploitation of the coastal/island aquifer.

In order to ensure that groundwater can keep play its role well in the future, Managed Aquifer Recharge (MAR) can be implemented to sustain and replenish groundwater supplies by guaranteeing sustainable yields and good status of quality. The evaluation of the feasibility of MAR schemes to improve the qualitative and quantitative status of the Malta MSLA was simulated through numerical modelling. The groundwater flow numerical model of the MSLA was developed through the Life Project (LIFE 16 IPE MT 008). After calibrating and running the model, several scenarios of MAR implementations were simulated leading to the optimal MAR network configuration for the MSLA.

The Malta MSLA MAR network shall be composed of an underground infiltration gallery drilled through the middle of the Island surrounding the drainage galleries and an injection boreholes array to be located in Malta South. Numerical modelling simulations revealed that the diffused infiltration distributed along the infiltration gallery is adequate to restore unexploited conditions of the groundwater body while the localized injection through boreholes would halt seawater ingression by locally increasing hydraulic heads.

Although the preliminary assessment and modelling of the MSLA MAR network carried out as part of this study are indicative, outcomes of numerical modelling illustrate the positive impacts of the implementation of the MAR network to improve aquifer qualitative and quantitative status established

by the European Water Framework Directive (WFD). Nonetheless, this study aims at developing a regulatory framework on the management of MAR in the MSLA, aligned to Malta's policy outlook and WFD requirements.

This project has received funding from the EU's Horizon2020 programme under the Marie Curie GA 814066

SIGMA: Seismic Imaging of Groundwater for Maltese Aquifers

Dr Matthew Agius[1], Mr. Luca Laudi[2], Prof. Pauline Galea[1], Prof. Sebastiano D'Amico[1]

[1]Department of Geosciences, Faculty of Science, University of Malta

[2]Energy and Water Agency

Key Words: Ambient seismic noise, autocorrelation, cross-correlation, groundwater, islands, Malta

Text of Abstract: The limestone islands of Malta face high levels of water stress due to low rainfall over a small land area and a high population density. We investigate an innovative, cost-effective approach to groundwater monitoring in an island environment by computing auto- and cross-correlations of ambient seismic noise recorded on short-period and broadband seismic stations. While borehole readings give accurate site-specific water level data of the groundwater across the islands, this technique provides a more regional approach to quantitative groundwater monitoring.

We perform the Moving Window Cross-Spectral method to determine temporal changes in seismic velocity (δv/v). Comparison of the δv/v with groundwater levels from boreholes and precipitation show comparable patterns. We find that the variations of the δv/v from autocorrelations are more pronounced than the cross-correlation, and that short-period seismic stations are also sensitive. The δv/v signal deteriorates at longer interstation distances, presumably because paths traverse complexgeology. We conclude that changes in the groundwater level found beneath very small islands even as small as 3 km2) can be detected seismically. Low-cost, easy to deploy seismic stations can thus act as an additional tool for groundwater monitoring especially in places with limited natural water reservoirs, like rivers and lakes, and infrastructure.

Numerically Enhanced Conceptual Modelling (NECoM) Applied to the Malta Mean Sea Level Aquifer

Francesca Lotti[1], Iacopo Borsi[2], Enrico Guastaldi[3], Alessio Barbagli[3], Paolo Basile[4], Lorenzo Favaro[4], Adrian Mallia[5], Rachel Xuereb[5], Michael Schembri[6], Julian Alexander Mamo[6], Manuel Sapiano[6]

[1]SYMPLE

[2]TEA Sistemi

[3]Center for GeoTechnologies, University of Siena

[4]STEAM

[5]Adi Associates Environmental Consultants

[6]Energy and Water Services(EWA)

Key Words: Data gap, Numerical Modelling, GW Management, Seawater intrusion

Conventional hydrogeological practice is to formulate a conceptual model, which is often the basis of a numerical model. The numerical model is then used to test groundwater management strategies. A workflow is proposed, employing the numerically enhanced conceptual model (NECoM) of the Mean Sea Level Aquifer (MSLA) on the island of Malta. The Malta MSLA is overexploited and under threat of salinization. Data (heads, chloride concentrations, electrical conductivity logs, tidal tests and qualitative analyses) were assimilated into a fast-running numerical model. Simultaneously, strategies for optimal acquisition of further data were examined through themodelling process. Themodel was delivered through the Energy andWater Agency, with suggestions for flexible model deployment. These workflows will, hopefully, spawn model improvements through further revision of the base concepts. The model allows the agency to make predictions, which have uncertainties that are quantified and reduced through data assimilation as new data become available. Contemplated management plans can therefore be properly assessed before implementation. The proposed NECoM approach can be generalized since it bases model usage on the premise that modelling should make maximum use of existing data by assimilating its information content, thereby highlighting the uncertainties of decision-critical predictions that remain because of data insufficiency. Thus, the presently disjointed process of modelling on the one hand, and data acquisition on the other, can be better aligned. Conceptual and numerical model development become parallel, rather than sequential, activities. Together, they enable predictions of future system behaviour for which bias is reduced and uncertainties quantified.

COST Action (OFF-SOURCE, CA21112) - Offshore Freshened Groundwater: An Unconventional Water Resource in Coastal Regions?

Hiba Wazaz[1], Aaron Micallef[1], Claudia Bertoni[2], Wei-Li Hong[1], Michela Giustiniani[3], Katrin Schwalenberg[4], Ariel Thomas[1], Elizabeth Quiroga Jordan[5]

[1]Department of Geosciences, University of Malta

[2]Department of Earth Sciences, University of Oxford

[3]National Institute of Oceanography and Experimental Geophysics, Sgonco TS, Italy

[4]Federal Institute for Geosciences and Natural Resources, Hannover, Germany

[5]Ruden AS, Engelsviken, Norway

Key Words: Offshore groundwater, COST Action, science networking, water resources

A third of the world faces water insecurity, while freshwater resources in coastal regions are under enormous stress due to population growth, pollution, climate change and political conflicts. OFF-SOURCE is a scientific network funded by the European Cooperation in Science and Technology (COST). It aims to address whether and how offshore freshened groundwater (OFG) – groundwater stored in the sub-seafloor with a total dissolved solid concentration below that of seawater – can be used as an unconventional source of freshwater in coastal regions. Specifically, the Action will identify where OFG is found in waters of COST Member Countries and in which volumes, delineate the most appropriate approaches to characterise OFG, identify the most cost-effective strategy to utilise this resource, and assess the environmental and legal challenges to sustainable OFG use. These activities will be carried out by a gender-balanced and inclusive scientific network, consisting of experienced and early-career scientists and stakeholders from diverse and complementary scientific disciplines. The network will foster cross-disciplinary and intersectoral collaboration between currently isolated fields of research to reduce the gap between science, policy making and society. There are five working groups (WGs) that address the critical tasks of this action: Assessment (WG1), Innovation technologies (WG2), and Utilisation (WG3) of OFG, the Challenges faced by the community (WG4), as well as Training and Dissemination of up-to-date knowledge about OFG (WG5). This interaction will foster new ideas and concepts that will lead to breakthroughs in OFG characterisation and utilisation, translate into future market applications, and deliver recommendations to support effective water resource management. The Action will also provide high-quality training and funded scientific exchange missions for early career investigators, particularly from less research intensive countries, to develop a pool of experts able to address future scientific challenges related to OFG.

Session 3

Emerging Challenges to Groundwater Quality and Quantity

Oral Presentations

Stochastic Simulation for Defining NO_3 and F Background Levels in Different Groundwater Bodies of the Campania Region.

Gianluigi Busico[1], Mozhgan Bordbar[1], Dario Tedesco[1], Micòl Mastrocicco[1]

[1]Università della Campania Luigi Vanvitelli

Key Words: Groundwater quality, Background level, Pollution, Quality maps

The topic of groundwater quality assessment is the most investigated environmental issue nowadays due to the increasing amount of several inorganic compounds in groundwater resources. An important concept in groundwater quality evaluation are the "Natural Background Levels" (NBLs): a relative amount of a given compound used to distinguish between natural and anthropogenic influenced concentrations. NBLs are strictly dependent on the hydrogeolofical conditions of the groundwater bodies. Anyway, human activities may also negatively affect groundwater quality and consequently influence the groundwater base condition. The present research aimed to determine the NBLs and the anthropogenic background level (ABLs) of two pollutants potentially harmful for human health, F and NO3, using an innovative approach based on the gaussian sequential simulation (sGs) algorithm which allow a spatial characterization of statistical results. The study area extends between Caserta and Naples provinces and is characterized by alluvial and/or of volcanic deposits bordered by carbonate reliefs consisting of Limestone and subordinately of Dolostone. The NBL and ABL have been extracted using the post processing sGs median (MED) maps using more than 500 groundwater samples. The geographic areas with by the highest ABL of NO3 resulted to be those characterized by the tuff outcrops, followed by the three alluvial plains of the areas, in the order High Volturno Plain>Garigliano Plain>Low Volturno Plain. Here the agricultural and suburban activities are responsible for groundwater pollution. The lowest values characterize instead limestone, lavas, and flysch deposits. Concerning F NBL, the areas characterized by highest concentrations are those located close to the Roccamonfina volcano and in correspondence to the tuff outcrops followed by the Volturno and Garigliano plains characterized by the presence of reworked volcanic material and receiving recharge by the volcanic aquifers. As secondary product, the probability maps, indicated the tuff region along with the alluvial plain of the High Volturno river as the locations where the highest probability of exceeding NO3 threshold (50 mg/L) will occur. For F instead, the map highlighted the whole Garigliano Plain along with the southern sector of the study area as the locations with the highest probability of exceeding the F threshold (1.5 mg/L). The obtained results represents a useful insight to delineate groundwater protection zone.

Radar Precipitation Data as Functional Input for Deriving the Potential Volume of Water Available for Infiltration: The Pilot Case of Lombardy Region

Andrea Citrini[1], Giovanni Pietro Beretta[1], Corrado A.S. Camera[1]

[1]Università degli Studi di Milano

Key Words: Radar precipitation, Water balance, Infiltration, Lombardy Regio

Since its application in the meteorological field, radar has shown great potential for hydrologic application. Although indirect measures, radar precipitation values have the advantage to be spatially continuous, avoiding errors due to the interpolation of rain-gauge data (often sparse and poorly located). Despite this, radar has not yet achieved the expected success as input for hydrologic models and water balance estimations. In this context, this study aims to assess whether the use of this dataset is cost-effective for estimating the volume of Potential GroundWater Recharge (PGWR), at the annual scale, in the Lombardy Region.

This application included the use of Swiss radar data (1 x 1 km2 resolution) and datasets from 137 weather stations at the annual scale for the 2011-2020 period. At the Italian station locations, radar underestimates the amount of precipitation of about 21%. For this reason, the radar data were corrected by adding the interpolated error calculated at the rain-gauge locations using deterministic interpolation techniques: Thin Plate Spline (RAD+TPS) and Inverse Distance Weighting (RAD+IDW). Using the simplest water balance equation to maximize the operativity of the proposed approach, the PGWR volume was calculated multiplying effective rainfall by potential infiltration coefficients based on the definition of hydrogeological complexes. Finally, the outcomes were evaluated by comparison with the BIG-BANG project (ISPRA).

Although the two methods apply different calculation procedures, the results are comparable and of the same magnitude (on average the precipitation values are around 28.2 Gm3/y while PGWR values are around 6.7 Gm3/y). Comparing the precipitation results, a strong correspondence was found considering the mountain part of the Region (alpine and pre-alpine belt) with differences of only -4% and +3% for RAD+IDW and RAD+TPS, respectively. In the Po Plain, differences reached up to -9% (RAD+IDW) and 29% (RAD+TPS). The volume of PGWR led to similar results with a variation of about -11% (RAD+IDW) and +19% (RAD+TPS) compared to the BIG-BANG project.

The comparison with the national project showed that the use of corrected radar precipitation data as input in a simplified balance formula is a useful solution to efficiently obtain satisfactory results at yearly level. To increase its usefulness for groundwater management (e.g., drought events), a finer temporal resolution (monthly or daily) should be tested.

The Sustainable Yield of a Well in Low Permeability Fractured Aquifers: New Insights from Pumping Tests Interpretation

Chiara Sbarbati[1], Tolossa Dabi Dinagde[2], Francesca Lotti[3], Vincenzo Piscopo[1]

[1]Tuscia University, Viterbo, Italy
[2]University of Lille, Lille, France
[3]Symple srl, Vetralla (VT), Italy

Key Words: Well yield, Fractured aquifers, Pumping tests

The topic of sustainable use of groundwater has been widely discussed over time, but it still represents a crucial issue. Theoretical and practical approaches to the definition of the sustainable use of groundwater have been developed mainly at aquifer scale, but few studies are available on the defining of pumping flow from a single well considering its long-term impact on groundwater, especially in fractured hard-rock aquifers.

These aquifers represent a water supply source in many regions of the world, even if they are considered as low-productive aquifers. Several factors influence the occurrence of groundwater in fractured rocks, such as lithology, geomorphology, tectonics and climate conditions. For these reasons, both regional and local scale hydrogeological studies are necessary to plan the sustainable use of groundwater. When the task is to define the pumping flow from a single well considering its long-term impact on groundwater, few studies are available, especially with regard to fractured aquifers. Although in fractured aquifers the strong heterogeneity complicates the interpretation of the results of the pumping tests, they remain the main method of examining the response of the aquifer to pumping.

In this study six long-term pumping tests, carried out in andesitic and metamorphic fractured rocks aquifers, were deeply examined. The drawdown-time relationship detected through the pumping tests shows different trends that fit with different theoretical models, depending also on the test time. In addition, results show that in such heterogeneous hydrogeological environment, the drawdown-time trend recorded in the pumping well seems to be the key factor for the definition of the sustainable yield of the well, rather than the hydraulic parameters of the aquifer obtained from the pumping tests. The examined cases allowed also to define a simple and inexpensive operational approach to assess the sustainable yield of a single well.

Multidisciplinary Investigation of Groundwater Flow in Unsaturated Slopes Susceptible to Shallow Flowslides

Giovanni Forte[1], Marianna Pirone[1], Rosa Di Maio[2], Claudio De Paola[2], Rosanna Salone[2], Antonio Santo[1], Gianfranco Urciuoli[1]

[1]DICEA-Università degli Studi di Napoli Federico II
[2]DISTARUniversità degli Studi di Napoli Federico II

Key Words: unsaturated soils, groundwater regime, ERT, Flowslides

Shallow flowslides usually start as small slides of soil covers resting on bedrock, which increase in volume and velocity as they move downhill. They represent one of the most dangerous natural hazards worldwide as they occur in many geological settings.

In Campania region (southern Italy), these landslides involve pyroclastic soil covers in unsaturated conditions that are usually triggered by intense rainfalls. The groundwater regime, in terms of pore water pressure and volumetric water content distribution, plays a key role as it influences the shear strength of partially-saturated soils. Therefore, several studies have focused on the hydrogeological setting of the slopes as a predisposing factor for the occurrence of flow-like landslides. It is highly variable over time and space depending on the rainfall regime, the soil hydraulic properties and the presence of local geological and stratigraphic factors affecting groundwater flow paths.

In this study, a multidisciplinary approach based on geological, geophysical and geotechnical investigations is proposed with the aim of identifying the role of the local stratigraphic setting on the groundwater regime. The study was developed for the Faito test site in the Lattari Mts. (Naples), an area historically affected by shallow flowslides. It consists of loose pyroclastic deposits from the 79 AD Vesuvius eruption, which cover a karst-fractured carbonate bedrock with a natural slope of more than 30° steep.

The stratigraphic setting was characterized by integrating geological logs, soil sampling, 2D and 3D electrical resistivity tomography (ERT) surveys. Several stratigraphic cross-sections were selected to build up 2D geotechnical numerical models for hydraulic response simulation. They were selected to be representative of i) the variability of the different buried soil horizons in terms of depositional setting, continuity and thickness; ii) the role of steep stratigraphic contact between shallower soils and bedrock; iii) the spatial distribution of water content.

The study showed that permeability contrasts of the soil cover and the buried bedrock morphology heavily influences pore water distribution, while ashy material filling the upper karst bedrock provides a hydraulic connection of the groundwater flow infiltrating from the topsoil downward.

New Insights on Groundwater Flow of the Tavo Tapped Karst Springs (Gran Sasso Aquifer, Central Apennines) Using Tracer Tests

Valeria Lorenzi[1], Nadine Goeppert[2], Marino Domenico Barberio[3], Nico Goldscheider[2], Francesca Gori[1], Mauro Manetta[1], Giacomo Medici[1], Marco Petitta[1], Sergio Rusi[4]

[1]Sapienza University of Rome, Italy
[2]Karlsruhe Institute of Technology (KIT), Germany
[3]INGV, Rome, Italy
[4]University G. D'Annunzio, Chieti, Italy

Key Words: Karst aquifer, Tracer test, Hydrogeology, Flowpaths

The Gran Sasso is a calcareous-karst aquifer of about 1000 km2 of total extension, one of the most representative karst aquifers of the central-southern Apennines. The permeability due to fractures and the karstification of the Gran Sasso calcareous complex are influenced by the stratigraphic and structural elements. They often act as an obstacle to groundwater flow determining different hydrogeological sub-basins and influencing the flowpaths.

Within the framework of the European project KARMA (karma-project.org), a tracer test was carried out in April 2022 in the recharge area of Tavo springs (Vitella d'Oro and Mortaio d'Angri springs). One injection point (Rigopiano ditch) and two selected monitoring points (i.e., Vitella d'Oro spring and Tavo River), located at the north-eastern boundary are considered. We used previous turbidity events which occurred at the Vitella d'Oro spring as basis for planning the tests.

Uranine and Sodium Naphthionate were used as tracers, as they are considered to be toxicologically safe for humans and the environment, a necessary condition for the application in a National Park such as the Gran Sasso Mountain. The monitoring has been performed using two continuously measuring field fluorometers, coupled with discrete water sampling, and charcoal bags at different locations. Both continuous data and discrete ones highlighted the arrival of the Uranine dye 9 h 45 min and 11 h after the injection, at Tavo River and at Vitella d'Oro spring, respectively. The results highlighted that catchment areas are different although the two springs belong to the same regional Gran Sasso aquifer. Besides, by analysing the charcoal bags, we inferred the superimposition of two local flowpaths, a shallow and fast one, and a deeper and slower one, both feeding the Vitella d'Oro spring. The results obtained show how the springs are particularly sensitive to both basin-scale variations and local conditions, placing them as vulnerable to discharge reduction/exhaustion in a potential climate change scenario.

Modelling Transient Groundwater Flow Dynamics in the Tabriz Unconfined Aquifer Near Urmia Lake (Iran)

Mattia Gaiolini[1], Zahra Abdollahi[2], Bakhtiar Feizizadeh[3], Gianluigi Busico[4], Micòl Mastrocicco [4], Nicolò Colombani[1]

[1]Marche Polytechnic University
[2]AREEO, Zanjan, Iran
[3]University of Tabriz
[4]University of Campania "Luigi Vanvitelli"
[5]Marche Polytechnic University

Key Words: Numerical modelling, groundwater flow, remote sensing date, evapotranspiration

Since 1995 a worrying decline in the Urmia Lake water level has been registered due to climate change along with unsustainable management of water resources. The drying up of the lake has led the groundwater resources to experience quality deterioration and quantity depletion. To properly evaluate trends of water fluxes and quantify the groundwater losses in the surrounding area of Tabriz (Iran) a MODFLOW-NWT groundwater flow model has been implemented via Processing Modflow 11 graphical user interface. The hydrogeological units were reconstructed using more than 300 stratigraphic core logs model, while model boundary conditions and stresses were implemented with specific remotely sensed data downloaded from national and worldwide (MODIS from NASA and ECMWF from COPERNICUS) databases and a transient simulation was carried out over a simulation period of sixteen years (2000-2016). Very good performances were achieved, and the model showed a good ability to describe groundwater fluctuations over simulation time providing an accurate estimate of groundwater balance. The evapotranspiration turned out to be one of the major causes of the groundwater decline, playing massive contribution in the groundwater outflow and showing an increasing trend over the simulation time. The role of the spatialization of both recharge and evapotranspiration extinction depth was investigated without finding significant differences in model performance indicators, but considerably affecting the groundwater budget. A scenario without human stressor was explored producing a significant water table increase at locations near to pumping wells, but no significative changes in the groundwater budget compared to the baseline scenario. This pointed out the climate change as the major driver of groundwater depletion in the study area, although it must be stressed that surface water diversion from upland basins was not considered in this analysis. The implementation of such numerical models is crucial to gain a better understanding of the area and could represent an important tool to support decision making for future sustainable management and to design a proper restoration plan.

Climate Change Resilience in The Poor Hydrogeological Setting of the Northern Apennines: The Case of the Nadìa Spring

Maria Filippini[1], Tommaso Casati[1], Enrico Dinelli[1], Michele Failoni[1], Francesca Stendardi[1], Beatrice Tiboni[1], Alessandro Gargini[1]

[1]University of Bologna

Key Words: spring discharge, drought resilience, Northern Apennines, multi-tracer test

The Nadìa spring is a crucial source of drinking water in the Emilia Romagna Region of northern Italy and ranks as the second most productive tapped spring in the area with a discharge up to 70 L/s, whereas most of the other springs have flowrates lower than 5 l/s. Unraveling the factors that prompt the high Nadìa discharge will support management of this resource in the face of future climate changes. To this end, geological and geomorphological observations, hydrological, hydrochemical and isotopic analyses, and a multi-tracer test were conducted at the spring in 2021-2022, during an unprecedented dry period in the Northern Apennines. The spring arises at the base of a calcarenitic fractured aquifer (Pantano Formation, upper Burdigalian-lower Langhian) underlain by lower permeability units. Karst dissolution along structural discontinuities in the Pantano Formation has been suggested in the past to account for increased permeability. The major ion composition of spring water reveals an obvious calcium-bicarbonate hydrochemistry that is consistent with the hypothesis of karst dissolution. An 80 m deep borehole was drilled in the Pantano Formation 7 km away from the spring, showing fractures with decimetric apertures as deep as 60-70 m bgs, which may be the result of karst dissolution. However, the chemical variability over time expected in a karst system due to the drainage of different groundwater fractions (newly infiltrated vs. older groundwater) was not observed. Instead, the hydrograph of Nadìa appears regular and steady, with a discharge ranging between 64 and 45 L/s in the monitoring period. This stationarity is also reflected by the low annual variability of major ions and water stable isotopes. On January 2023, Sodium Chloride and Uranine were injected inside a sinkhole distant 340 m from the spring. A limited amount of tracer was recovered at the spring with sporadic impulses after two weeks from injection. The results suggest that the spring is fed by a peculiarly large reservoir hosting homogenized groundwater. Discharge occurs mostly through pressure transfer with limited input from newly-infiltrated water. A volume of the aquifer representing a reasonable reservoir for the spring was identified based on a geo-structural model of the Pantano outcrop. This hydrogeological set-up ensures resilience of the spring on a seasonal scale whereas the spring may be impacted by climate changes on a decadal scale.

First Hydrogeological Water Balance in the High and Middle Venetian Plain Between Mincio and Tagliamento Rivers (Ne, Italy)

Davide Cappellari[1], Roberto Tonucci[1], Leonardo Piccinini[1], Andrea Braidot[2], Alberto Cisotto[2], Nico Dalla Libera[2], Paolo Fabbri[1]

[1]Department of Geosciences, University of Padova
[2]Eastern Alps Water Authority

Key Words: Hydrogeology, Water Balance, Venetian Plain, NE Italy

In the A.M.A.R.O.N.E. project, funded by the Cohesion and Development Fund (FSC 2014-2020), a first sketchy regional scale water balance in the high and middle Venetian Plain between Mincio and Tagliamento rivers was carried out. The aim of such a project is to improve the conceptual hydrogeological model of this sector of Venetian plain and to define the hydrogeological water balance not only lumped but also distributed using numerical modeling, which will be implemented later in the project. Such a first rough water balance is based on the Coefficient of Potential Infiltration (C.P.I.; Civita, 2005) approach, where the difference between the distributed precipitation (P) and the distributed real evapotranspiration (EVT), i.e. the effective precipitation (Pe), is multiplied by such a C.P.I. coefficient to derive the infiltration. C.P.I is related on the hydrogeological complexes present in the considered area. In the GIS environment, each parameter has been calculated at a pixel scale, allowing us to obtain a first distributed hydrogeological water balance for the high and middle Venetian Plain.

The water balance concerns an area of 8700 km2 in NE Italy covering a plain area between Mincio and Tagliamento River from West to East. The considered parameters are related to the mean values of the last thirteen years, between 2010 to 2022. Such a first hydrogeological water balance presents a precipitation (P) of about 11090 M m3/y and a real evapotranspiration (EVT) of 5511 M m3/y, thus an effective precipitation (Pe) of 5579 M m3/y. Considering the C.I.P. the resulting Infiltration (I) is 2891 M m3/y. The rough runoff is calculated as difference between effective precipitation (Pe) and Infiltration (I), resulting in 2688 M m3/y, i.e. the 24.2% of the precipitation (P). Being the first rough water balance, it does not consider the irrigation term, which will be an important parameter of the water balance and evaluated in the continuation of research.

Unravelling the Aquifer-Scale Competition for Organic Substrate in a Polluted Aquifer by Interpreting Multivariate Statistics Through Scenario-Based Hydrogeochemical Modeling

Diego Di Curzio[1], Sergio Rusi[2], Boris M. van Breukelen[1]

[1]Delft University of Technology

[2]University "G. d'Annunzio" of Chieti-Pescara

Key Words: Chlorinated ethenes, Inhibited degradatio, Multi-scenario model, Polluted aquifer

Chlorinated solvents in groundwater degrade mainly via Reductive Dechlorination–RD, which is a microbially-mediated redox reaction . Degrading bacteria, called organohalide-respiring bacteria–OHRB, oxidize the available organic substrate (electron donors–EDs) to gain energy and reduce chlorinated solvents for respiration, instead of other inorganic Terminal Electron Acceptors–TEAs (e.g., NO3−, Mn(IV) and Fe(III) oxi-hydroxides). However, OHRB are usually less efficient in oxidizing EDs than the bacteria that use inorganic TEAs; thus, substrate-limiting conditions cause competition for organic substrate. As a consequence, chlorinated solvent degradation is inhibited when high concentrations of inorganic TEAs occur naturally or anthropogenically in groundwater.

Identifying the occurrence of the competition for organic substrate is critical to evaluate whether natural attenuation is a viable option for groundwater decontamination yet a challenging task when it comes to investigate this process at a field-scale in polluted aquifers, especially using sparse and incomplete datasets.

For this reason, we propose a scenario-based modeling approach consisting of a multi-scenario batch model, which takes advantage of mechanistic knowledge to reproduce multivariate statistical patterns (the real data Pearson correlations) and assess whether the competition for organic substrate is occurring in groundwater.

The selected site case study is a coastal silty sandy aquifer, where different cases of contamination are present: a MTBE-BTEX plume, several foundry waste dumps, and a residual plume of chlorinated ethenes.

108 scenarios with different levels of availability of inorganic TEAs, MTBE-BTEX and chlorinated ethenes were modeled both in competitive and non-competitive conditions, and Pearson coefficients were calculated on numerical results and compared with the real data correlations. The satisfactory match between the model correlations in competitive conditions and the field correlations confirms the occurrence of competition of organic substrate in groundwater. Substrate-limitating conditions as well as the presence of mostly nitrate and intermediate-to-high soluble Mn(IV) oxi-hydroxides seem to inhibit biodegradation of chlorinated ethenes.

This simplified but novel numerical approach proved to be effective in unravelling a complex hydrogeochemical process like the competition for organic substrate, by taking advantage of mechanistic process-based knowledge.

Application of Multivariate Statistical Analysis for the Delineation of Groundwater Bodies: A Case Study in Campania Region (Southern Italy)

Stefania Stevenazzi1, Konstantinos Voudouris2, Daniela Ducci1

[1]*Università degli Studi di Napoli Federico II*

[2]*Aristotle University of Thessaloniki*

Key Words: statistical analysis, water chemistry, coastal aquifers, volcanic areas

The European Guidelines for the identification and delineation of groundwater bodies require the identification of hydrogeological boundaries and the assessment of the quantitative and chemical status of groundwater. These criteria must ensure that i) a precise estimation of the water budget for each groundwater body, and ii) an accurate quantitative and qualitative description of groundwater status can be reliably assessed.

In this context, this study attempts to verify the current delineation of groundwater bodies (GWBs) through the application of multicriteria statistical analysis. The areas of interest are represented by three GWBs located in the northern part of Campania Region (Southern Italy): the Volturno Plain (P-VLTR), a coastal plain of about 1340 km² constituted of fluvial, pyroclastic and marine sediments; the Phlegrean Fields (FLE), an active volcanic area constitued of a series of monogenic volcanic edifices; and the Plain of Naples (P-NAP), an inner plain constituted of fluvial and pyroclastic sediments. The identification and delineation of GWBs in Campania Region was developed by the regional public authorities in 2007 (49 GWBs) and updated in 2021 (81 GWBs), in compliance with the European Directives.

A multivariate statistical analysis (i.e., factor analysis, FA) was performed to differentiate among the main hydrochemical processes occurring in the area. FA allowed the handling of many geochemical and physical parameters (variables) measured in groundwater samples collected at about 200 sampling points during 2013-2017. Results reveal five hydrogeochemical processes variably influencing the hydrochemical characteristics of the three GWBs: salinization, carbonate rocks dissolution, natural or anthropogenic inputs (nitrate, sulphate), redox conditions (Fe, Mn), volcanic products contribution (As). FA allows identifying the areas characterised by one or more hydrogeochemical processes, mostly reflecting known processes (water-rock interaction, chemical reaction, natural/anthropogenic phenomena), but also highlighting the influence of groundwater flowpaths on water chemistry.

The application of multivariate statistical analysis allowed to: i) evaluate the consistency and reliability of public datasets to assess groundwater quality; ii) identify the hydrogeochemical processes

characterising each GWB; iii) highlight the necessity and usefulness of large chemical database for an appropriate delineation of GWBs.

Changes in Shallow Groundwater Recharge Due to Drought Impacting the Po River Basin

Marco Rotiroti[1], Mariachiara Caschetto[1], Chiara Zanotti[1], Agnese Redaelli[1], Simone Bruno[1], Davide Sartirana[1], Elisa Sacchi[2], Carlo Riparbelli[3], Stefano Brenna[3], Letizia Fumagalli[1], Tullia Bonomi[1]

[1]University of Milano-Bicocca

[2]University of Pavia

[3]Regional Agency for Agriculture and Forestry Services – Lombardia

Key Words: climate change, return flow, isotopes, mixing model

The Po River Basin in Northern Italy is facing its worst drought in the last decades. A fundamental aspect for water resources management is the understanding of drought effects on the hydrogeological water balance, that is addressed here for the shallow Po Plain aquifers in Lombardy region.

The Po Plain alluvial aquifer system in Lombardy evolves from a mono-layer unconfined aquifer in the piedmont of the Alps (higher plain), made of sands and gravels, to a multi-layer system approaching the Po River (lower plain), where sands (confined aquifers) are intercalated with silts and clays (aquitards). The higher plain is the recharge area of the whole aquifer system. Land use is mainly agricultural. Water for irrigation is mainly provided by diversion of Alpine rivers and Subalpine lakes into an extensive network of irrigation channels. The traditional surface irrigation method is largely practiced.

Analysis of tracers of groundwater recharge, i.e., δ2H-H2O, δ18O-H2O and Cl/Br, in 44 wells tapping the unconfined aquifer in the higher plain, distributed over the entire Lombardy and sampled in March 2022, revealed that surface water, and not local precipitation, is the main recharge of the shallow aquifer, with only a few exceptions. Binary mixing models calculated using δ2H-H2O and Cl/Br indicated that the contribution of surface waters to shallow aquifer recharge is generally between 50% and 75%, the remainder being from local precipitation. Analysis of groundwater level time series detailed that surface waters mainly recharge the aquifer through irrigation return flow.

Due to drought, and surface water shortage during the growing season, two important changes are occurring: (1) the abandonment of surface-water-irrigation in favor of groundwater-fed irrigation and (2) the shifting from the inefficient surface irrigation method to more efficient sprinkler/micro/drip methods. The consequences on the hydrogeological water balance are: (1) the obliteration of the current first source of groundwater recharge and (2) the increase of groundwater abstraction, often uncontrolled, generated by the proliferation of irrigation wells. The effects are (1) the depletion of groundwater resources and (2) the drying of many typical low-land springs (fontanili).

Mitigation actions are urgently needed. The managed aquifer recharge system named "forested infiltration area", successfully experimented in Veneto region, could be a practicable strategy.

Groundwater Sustainable Development in Mountainous Aquifers for Adaptation to the Effects of Climate Change: A Case Study in the Northern Apennines

Laura Landi[1], Tommaso Casati[1], Maria Filippini[1], Stefano Segadelli[2], Alessandro Gargini[1]

[1]Alma Mater Studiorum - University of Bologna

[2]Emilia-Romagna Region: Geological Survey

Key Words: Water management, Adaptation, Climate change, Numerical modelling

The adaptation of groundwater management is essential to mitigate the issue of water scarcity and its socio-economic consequences. In fact, due to the well-known effects of climate change, drought events are becoming very common nowadays.

The discharge of springs arising from mountainous hard-rock fractured aquifers may be very sensitive to changes of recharge, especially when the reservoir feeding the spring is of limited spatial or vertical extension. At the same time, the structural complexity and heterogeneity typical of hard-rock aquifers makes their characterization particularly challenging.

In the Northern Apennines, a study has been performed to investigate the hydro-structure of two fractured arenitic aquifers that provide water supply to the local aqueducts through spring water. In the last years, cyclic recharge-discharge crisis affected the uptaken springs, inducing the necessity of integrating water supply trough tankers supplied from other sources. The aim of this study was to define an adaptation strategy to increase the local water supply in a more sustainable way.

Two numerical models were developed for two hydrogeological sectors of main interest. The models were built based on detailed field surveys, including deep borehole logging and pumping tests, and calibrated against a spring discharge monitoring performed in 2020-2022, representing an unprecedently dry period in the area.

The models were exploited to forecast the effect of new pumping wells for the integration of the local water supply with a sustainable pumping scheme. The wells were simulated in areas where the hydro-structure is likely storing groundwater which is not quickly discharging towards spring or streams. The results suggest that additional pumping can be implemented as an optimal management strategy in both hydrogeological sectors, one being significantly more productive than the other. In both cases, the pumping would provide a water supplement greater than the water volume supplied by tankers trips during the last years. Through the model simulation, the sustainability of pumping was verified in terms of impacts on the natural discharge and the environmental flow in streams. The seasonal trend of recharge-discharge crisis and the local recurrence of droughts were also considered to define a sustainable pumping schedule.

Towards Groundwater-Level Prediction Using Prophet Forecasting Method by Exploiting a High-Resolution Hydrogeological Monitoring System

Fronzi Davide[1], Alessandro Galdelli[1], Alessandro Pepi[1], Adriano Mancini[1], Alberto Tazioli[1]

[1]Università Politecnica delle Marche

Key Words: groundwater level, vadose zone, forecasting, artificial intellige

Forecasting of water availability has become of increasing interest in recent decades, especially due to growing human pressure and climate change, affecting groundwater resources towards a perceivable depletion. Hundreds of research works developed at various spatial scales have attempted to predict daily or seasonal groundwater level variations starting from measured meteorological data (i.e., precipitation and temperature) and observed groundwater levels, by exploiting data-driven approaches. Barely a few research combine the meteorological variables and groundwater level data with unsaturated zone monitored variables (i.e., soil water content, soil temperature, and bulk electric conductivity), and - in most of these - the vadose zone is monitored only at a single depth. Our approach exploits a high spatial-temporal resolution hydrogeological monitoring system developed in the Conero Mt. Regional Park, to predict groundwater level trends of a shallow aquifer exploited for drinking purposes. The field equipment consists of a thermo-pluviometric station, three water content, electric conductivity, and soil temperature probes, located in the vadose zone at 0.6, 0.9, and 1.7m respectively, and a piezometer instrumented with a permanent water-level probe. The monitored period started in January 2022 and the variables were recorded every fifteen minutes for more than one hydrologic year. Hourly and daily up-scaling data was made to calculate potential evapotranspiration by applying the Hargreaves and Samani method. The daily potential evapotranspiration was used, among others, as a variable to predict future groundwater levels. The developed model consists of three "virtual boxes" (i.e., atmosphere, unsaturated zone, and saturated zone) for which the hydrological variables characterizing each box were integrated into a time series forecasting tool based on Prophet algorithm developed in Python environment. A correlation analysis for each measured parameter was tested for its influence on groundwater level prediction and the method was fine-tuned to an acceptable prediction (20% ahead of the monitored period). This study stresses the importance of calibrating groundwater level prediction methods by exploring the hydrologic variables of the vadose zone in conjunction with those of the saturated zone and meteorological data, thus emphasizing the role of hydrologic time series forecasting as a challenging, but vital aspect to optimize groundwater management.

Groundwater Flow Modeling for the Sustainable Exploitation of the Monte Castello Aquifer

Pietro Rai[1], Luca Zini[1], Claudia Cherubini[1]

[1]Università degli Studi di Ferrara

Key Words: groundwater modeling, Modflow, fractured aquifer, reservoir

Ravedis reservoir is located in the Carnic Prealps, within the municipality of Montereale Valcellina (Friuli Venezia Giulia, North Eastern Italy). It is fed by Cellina stream, and is situated just before the outlet of Cellina Valley in the Venetian-Friulian Plain. The reservoir was designed to mitigate flood events and to store water for hydroelectric power generation and for irrigation purposes. For this reason, the lake level is raised in summer to higher levels than in the winter or wet months.

This study focuses on Monte Castello, a thin hilly system that separates the reservoir from the plain. It hosts an aquifer characterized by the presence of variously fractured dolomitic limestone.

The reservoir's creation resulted in a change in groundwater supply regime downstream of it. The presence of the lake guarantees, especially in the dry summer months, a constant source of recharge for the Monte Castello aquifer. This fact prompts evaluation of the Monte Castello aquifer's potential for use as an alternative to plain groundwater resources, which are more susceptible to overexploitation and climate change.

An extensive work of bibliographic research and analysis of piezometric data by means also of geostatistical techniques was carried out in order to characterize the study area from a hydrogeological point of view.

This study is aimed at developing a groundwater flow model of the study area with Modflow. The three main goals of the research are:

- To obtain, through inverse modeling, a reliable estimate of the distribution of the hydraulic conductivity parameter;
- To estimate the amount of water that leaks underground from Ravedis reservoir or, in other words, its losses;
- To simulate the effects of drilling a pumping well to supply water to Montereale Valcellina and surrounding villages.

The sustainable management of water bodies like Monte Castello's one, small in size but with a high potential, could represent one of the ways forward to a more resilient response to the growing demand for high-quality water resources.

Enhanced Thermal Response Test interpretation through MODFLOW-USG and PEST_HP

Sara Barbieri[1], Pietro Mazzon[1], Matteo Antelmi[1], Luca Alberti[1]

[1]Politecnico di Milano

Key Words: Geothermal energy, numerical modeling, groundwater quality, modflow-usg/pest_hp

Shallow geothermal energy exploitation has been increasing in the last few years due to the decarbonization process and technological improvement. Geothermal plants' design requires data collection and expertise that are sometimes missing, thus risking not only making the operation of the system not as efficient as possible but also generating significant thermal perturbation in groundwater. The case of closed-loop systems is the most susceptible to those needs due to the heat exchange between the heat transfer fluid circulating inside the pipe and the surrounding ground/groundwater. The presence of different lithologies along the vertical stratification of the subsoil indeed determines the coexistence of different hydrogeological property values within the probe-subsoil system.

The knowledge of these property values allows to understand the subsoil heat exchange potential thus influencing and guiding the probe design such as their length and number. The subsoil thermal properties are usually estimated through the Thermal Response Test (TRT), an in-situ experimental procedure for borehole thermal resistance and soil thermal conductivity estimation. This study aims at interpreting an ETRT (Enhanced Thermal Response Test) which is a depth-resolved TRT that allows the estimation of a depth-depending ground thermal conductivity profile. The ETRT procedure characteristics ensure a more precise estimation than a TRT thus optimizing the sizing of the installation.

The test is interpreted through a numerical model implemented with MODFLOW-USG numerical code for heat and flow transport and the PEST_HP code for assisted calibration. After a first phase of numerical model construction, it is calibrated using the temperature monitored during the ETRT as observations to evaluate the thermal properties of the subsoil.

The ETRT considered in the study are multiple and were performed under different hydrogeological conditions, thus allowing to validate the methodology adopted in different environments.

The combination of an innovative TRT such as the ETRT and effective numerical codes such as MODFLOW-USG and PEST_HP represents a step forward in numerical modeling and TRTs interpretation that would improve current methodologies for designing installations.

Impact of Drought on the Piedmont Plain (NW, Italy) Water Resources: Current Status and Predictions in the Context of Climate Change

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

[1]Earth Sciences Department, University of Turin, Italy

Key Words: Piedmont drought, groundwater level, Water temperature, climate change

In the last decade, the climate of the Mediterranean area has undergone climatic changes with a variation in weather events, a change in the rainfall regime and an accentuation of extreme events, and an increase in temperature and evapotranspiration. These changes will affect natural ecosystems, human health and water resources.

In Piedmont, 2022 was the warmest year, with an average annual temperature of around 11.4 °C, and the second least rainy year, with an average annual cumulative precipitation of 611.9 mm, of the last 64 years.

In this study, a spatiotemporal analysis of the impacts of the drought of recent years on water resources in the Piedmont plain is presented, providing some forecasting results from the application of a multiple regression model. To this scope, various statistical analyses (trends, anomalies, percentiles, multiple regression) were carried out on monitoring data of the automatic regional networks, covering the period between 2002 and 2022. More specifically, groundwater level (GWL) and temperature (GWT) were analysed in 10 piezometers; rainfall (R) and air temperature (AT) were elaborated in correspondence to 10 automatic weather stations; finally, river discharge (Q) and surface water temperature (WT) were obtained from 10 sections of the main Piedmont rivers.

The results of the analyses showed a clear link between R and GWL, R and Q, and between AT and GWT and WT. In the last 2 years, a decrease in GWL and a reduction in river Q were observed in the face of a drastic reduction in R, while AT and GWT and WT have shown increasing trends. Finally, a multiple regression model based on R data was applied to predict GWL decreases, showing that these are more pronounced and amplified when two or more consecutive drought years occur.

As predicted by the IPPC report (2022), the climate of the Mediterranean area is certainly set to change considerably in the future. Hotter and drier summers, lower annual precipitation and more extreme events are expected. In this climatic framework, we will see a progressive lowering of GWLs, which will also be amplified by withdrawals for irrigation use, induced by the scarcity of surface water. Groundwater plays a fundamental role in drought periods, and therefore, in order to reduce the lowering of groundwater tables, it will be necessary to encourage infiltration into aquifers through, for example, appropriate artificial recharge systems.

Estimation of Transit Time Along the Unsaturated Zone in the Protection of Groundwater Resources

Francesca Lobina[1], Christine Stumpp[2], Antonio Coppola[3], Andrea Vacca[1], Claudio Arras[1], Riccardo Biddau[1], Fabrizio Antonio[1], Maria Chiara[1], Salvatore Vacca[1], Stefania Da Pelo[1]

[1]University of Cagliari

[2]University of Natural Resources and Life Sciences

[3]University of Basilicata

Key Words: Unsaturated zone, Transit time, Nitrate

The growing world population coupled with the expansion of agriculture and animal husbandry has led to excessive use of organic and chemical fertilizers in soils, resulting in widespread nitrate contamination of groundwater. Despite the restrictive regulations imposed by the Nitrate Directive, no improvements in groundwater quality have been observed in many Nitrate Vulnerable Zones. In studies of vulnerability to aquifer contamination, the focus is more on the groundwater body and the unsaturated zone is often neglected. The unsaturated zone is the main factor controlling water movement and pollutant leaching, depending on the soil properties and infiltration rates. Natural attenuation processes in unsaturated zones can reduce the leaching of contaminants into groundwater. The infiltration rate determines the transit time in the vadose zone and thus the water-rock interaction time that controls the transformation, the entrapment/adsorption of the transported solutes.

This research compares two regions of Sardinia with different geological, hydrogeological and pedological features: the Arborea plain (designated as a NVZ since 2005), and the southern Campidano plain, in which nitrate concentration in groundwater frequently exceeds the limit of 50 mg/L.

The main purpose of this study is to estimate the rate of groundwater recharge using stable water isotope profiles in the vadose zone at the two sites by comparing physical properties of the soils and land use.

At each of the two study sites, soil samples were collected every 10 cm along a vertical profile and were analyzed to determine their stable water isotope ratios ($\delta 2H$ and $\delta 18O$) together with the water content, grain size distribution and physical-chemical parameters of the soils.

The peak-shift method was applied based on the assumption that seasonal effects on the isotopic composition of precipitation are traced through the soil vertical isotopic profile that were used along with the piston dis\placement method to estimate recharge rate.

The study of the transit time of water percolation along the unsaturated zone is therefore an influential factor in the assessment of the vulnerability of the aquifer and has implications in the optimization of agricultural practices and actions to protect the groundwater resource.

The Role of Carbonate Faults on Groundwater Circulation: The Case Study of Monte Marine Fault (Central Apennines, Italy)

Emma Petrella[1], Maria Rosaria Ferragonio[1], Marta Polimeno[1], Mattia Pizzati[1], Fabrizio Balsamo[1]

[1]University of Parma

Key Words: Fault zones, Carbonate aquifer, Hydrogeology, Structural geology

Springs sustain groundwater-dependent ecosystems and provide freshwater for human consumption. They often occur where faults introduce permeability heterogeneity and anisotropy.

The Monte Marine Fault (MMF) is a NW-SE-trending active extensional fault and is composed of two near-parallel and hard-linked major fault strands. It crops out almost continuously for 8 Km, bounding the eastern flank of the Aterno Valley. The Fonte Trio spring (FTs) is located near the main fault trace in the hard-linkage sector and has a discharge of a few tens of l/s.

The aim of this research is:

1) to understand the hydrogeological role of the MMF on groundwater circulation of the Aterno Plain made up of sandy-silt and alluvial deposit,

2) to identify the geological and structural features that cause the occurrence of FTs. In this context, four hydrogeological, physio-chemical and isotopic monitoring campaigns were performed in the Aterno Valley.

The results show that the main groundwater flow direction is parallel to the river (mainly NW-SE) even if some NE-SW directions of flow, coming from carbonate massif toward the alluvial plain, are found. The Aterno River has a mixed interaction with the alluvial aquifer and mainly feeds the groundwater on the left riverside.

EC and isotopic values are not homogeneous in the alluvial aquifer. Low EC values and the light isotopic signature were found in correspondence to the connection of the two partially overlapped fault strands, where a complex set of oblique-slip structures produces a wide footwall damage zone. These values are the results of a local and significant flow-throw from the carbonate aquifer. The evidence of the change in fault permeability of this zone is also supported by the presence of FTs, which occurs in the lowest elevation point at the contact between the two major fault strands and the quaternary alluvial deposits.

Thus, the MMF doen't have a unique hydrogeological behavior. It acts as an impermeable barrier along the two near-parallel fault strands, where the thickness of the damage zone is in the order of a few tens meters. Instead, a significant flow-throw is permitted in the overlap area of the two main fault strands, where the local permeability is enhanced due to the presence of 100's of meters loose fractured

materials. This peculiar structural complexity controls the occurrence of the along-fault spring and permit a significant flow-throw affecting the groundwater circulation at the basin scale.

Session 3

Emerging Challenges to Groundwater Quality and Quantity

Poster Presentations

Prioritizing Parameters Affecting Groundwater Sustainability Using the Random Forest for Groundwater Quality Indicators

Mojgan Bordbar[1], Gianluigi Busico[1]

[1]University of Campania "Luigi Vanvitelli"

Key Words: Groundwater, Random Forest, GQI, MDA

This study aims to prioritize the weights of several hydrogeological and socio-economic factors on three groundwater quality indicators (GQI) specific for irrigation (IRRI), seawater intrusion (SWI), and potability (POT) in the Campania province, Italy, using the random forest (RF) model. Each GQI has been calculated involving inorganic concentration of major ions and using different threshold limits for each index. Mean Decrease Accuracy (MDA) was applied to prioritize each factor since this method performs better for prioritizing factor, especially in situations with a clear relationship between them. The model has been implemented considering different dependent factors for GQIIRRI, GQISWI, and GQIPOT, respectively. In general, RF model results agree with the hydrogeochemical context of the study area. The MDA results identify vertical recharge as the most important factor for GQIIRRI followed by the depth to water table from the ground, the thickness of the aquifer, land cover type, distance from the agricultural wells, soil clay content, and finally hydraulic conductivity. The high weights of recharge, depth to water, land cover, and thickness are consistent with the site characteristics confirming as the vertical leaching of agricultural compounds represent the first depletion factor for groundwater quality along with the predominant role of aquifer's dilution in opposing it. Distance from the coastline is the most important factor for the GQISWI, followed by the level of groundwater above the sea, distance from rivers and lagoons, soil clay content, land cover, the thickness of the aquifer, and recharge. In particular, the high weight for distance to rivers highlight their importance as preferred highway for inland SWI for the region. Moreover, since the main recharge inflow in the area comes from the surrounding carbonate massifs which border the plain, the vertical recharge from meteoric water, has no significant influence on the SWI. Accordingly, the lower weight of recharge in explaining GQISWI is reasonable. Finally, according to MDA analysis, the most important parameter for GQIPOT is recharge followed by land cover, depth to water table from the ground, aquifer thickness, hydraulic conductivity, lithology, and soil clay content, respectively. The similar results of RF obtained for GQIIRRI and GQIPOT states the vertical nature of the leaching process, which can increase the number of pollutants in groundwater.

Identification of Major Sources Controlling Groundwater Quality Under Different Hydrogeological Regimes in Mediterranean Catchments

Maria Margarita Ntona[1], Gianluigi Busico[1], Kyriaki Kalaitzidou[2], Manassis Mitrakas[2], Nerantzis Kazakis[2], Micòl Mastroccico[1]

[1]*Campania University "Luigi Vanvitelli", Italy*
[2]*Aristotle University of Thessaloniki, Greece*

Key Words: Hydrogeochemistry, Statistical analysis, Pearson correlation, DPSIR

Multivariate statistical analysis has been widely used for the hydrochemical interpretation of groundwater data under different hydrological conditions with several techniques. This study deals with the spatial variation of hydrogeochemical characteristics of groundwater in different Mediterranean catchments and determines the natural and anthropogenic influences. The study areas are located in Greece (Anthemountas and Mouriki basins) and Italy (Upper Volturno basin). The general information about the basins was collected and evaluated by including morphological characteristics, land use, and meteorological data. The distribution of hydrochemical data in the study areas and the production of piezometric maps were performed in a GIS environment. Then, the statistical analysis of ion concentrations and calculated ionic ratios were combined to determine the hydrochemical status of the basins. The correlation between the chemical components was obtained using a Pearson's correlation matrix. Additionally, the DPSIR model was applied to highlight and compare the main pressures in the basins. According to the results, chemical fertilizers and manure are the main sources of anthropogenic pollution affecting the study areas. High concentrations of calcium and magnesium were recorded due to the presence of carbonate rocks in the Upper Volturno basin. In addition, a good correlation between calcium and magnesium and bicarbonate ($r^2=0.96$) indicates the dissolution of carbonate rocks. Strong chlorine, sodium and EC concentrations reveal seawater intrusion in the coastal part of the Anthemountas basin and the presence of geothermal fluids in the mainland. The samples in the Mouriki basin showed a positive correlation between calcium, magnesium, sulphate and nitrate due to the presence of chemical fertilizers and the decomposition of organic materials. Furthermore, agricultural activities cover more than 80% of the Greek basins while in the Italian one, it does not exceed 60%. In addition, drought and flood events have been recorded in Anthemountas and Mouriki basins, respectively. These conditions have pronounced impacts on groundwater recharge and quality. Consequently, decision-makers should take immediate action in order to protect the quantity and quality of groundwater in the studied sites.

Impact of Aggregate Mining on Groundwater in the Danube Alluvial Plain

Nóra E. Gál[1], Zoltán Püspöki[1], Julianna Mekker[1], Teodóra Szőcs[1], Éva Kun[1]

[1]SZTFH, Geology Division

Key Words: **groundwater level, aggregate mining, evapotranspiration**

Hungary facing numerous challenges on its surface and subsurface water supply, for example the effects of climate change and the increasing water demand by agriculture, industry, and household use. Our rivers are highly regulated since the 19th century, surface water retention is minimal, groundwater recharge is limited. During the last 3 decades the country goes through fast infrastructural development, mainly in Budapest and its surroundings, that puts high pressures on the nearby agglomerate reserves, among them, the excellent sand and gravel stocks of the Danube alluvial plain south to Budapest.

During the last 70 years surface mining of aggregates created mine lakes in the study area in increasing number, furthermore, mining activity escalated in the last two decades. Today, some of the abandoned lakes serve recreational purposes, for example swimming and fishing, and vivid aquatic ecosystems formed on all of them.

The significantly decreasing groundwater level of the adjoining Danube-Tisza Interfluve raised the concern that one of the causing factors is the extra evaporation of groundwater through the open water surface of the mining lakes. To determine the extent of this role of mining lakes, a complex study was launched on the area. Our aim to clarify the role of the different groundwater level decreasing factors with the help of numerical model, considering multiple climate and production scenarios. The ongoing study includes high-resolution log-facies correlation for the detailed description of hydrostratigraphy, and to reveal connections of different sedimentary sequences. Furthermore, hydrochemical and hydrogeological analysis aid to model the relationship between surface and subsurface water and the extent of changes in evapotranspiration.

A Local-Scale Numerical Model to Quantify Groundwater Infiltrations into Underground Infrastructures: The Case of Milan

Davide Sartirana[1], Chiara Zanotti[1], Marco Rotiroti[1], Mattia De Amicis[1], Mariachiara Caschetto[1], Agnese Redaelli[1], Letizia Fumagalli[1], Tullia Bonomi[1]

[1]University of Milano – Bicocca

Key Words: urban hydrogeology, 3D geodatabase, shallow aquifer, rising water levels

Urbanization, worldwide, led to progressive increase in the use of the subsurface. Therefore, interactions between groundwater and underground infrastructures (UIs) (i.e. subway lines, public and private car parks) come to attention. As a results, episodes of infiltrations and corrosion can occur for these subsurface elements. In this sense, numerical models are widely applied to manage these issues.
Infiltration episodes were documented over the years also for the city of Milan. In the framework of a further subsurface development to be achieved by 2030, the Plan of Government of the Territory has already defined the construction of new UIs. Hence, proper tools must be adopted to support stakeholders in urban planning, also considering these hydrogeologic aspects.
Thus, a steady-state numerical model, calibrated against a groundwater maximum condition, was developed for the western portion of Milan metropolitan city to simulate the UIs (i.e. subway lines and public car parks) and quantify their infiltrations. MODFLOW-USG was used, combining the Wall (HFB) and DRN packages to model the UIs. Model cells range from 100 up to 6.25 meters close to the UIs. A total of 18 layers modelled 100 – 120 meters of depth, with the UIs falling inside the first 8 layers (25 meters of depth). Different scenarios were simulated to cope with the wall conductance uncertainty of non-waterproofed subway lines, testing respectively: intact walls, a progressive saturation over time (i.e. a prolonged interaction with groundwater), and leaky walls.
Results pointed out those UIs suffering major groundwater infiltrations that were historically identified as critical in previous studies (i.e. submerged by the water table). Particularly, this occurred for the western branch of subway line M1 (i.e. Bisceglie station), and for the surroundings of Sant'Agostino (subway line M2), showing a maximum infiltration of 5.29 L/d.
The use of MODFLOW-USG was pivotal, as the HFB package was used to simulate not only the lateral walls of the UIs, but also their vertical sides (i.e. top and bottom). Hence, UIs were modelled with their real depth and volume, properly simulating both their interactions with the water table and the consequent infiltrations.
Model outputs could assist stakeholders to adopt the needed measures to avoid these UIs from being flooded in the future, also considering the already planned subsurface development of the city.

Wastewater as a Source of Cosmetic Products Contamination for Groundwater: A Case Study in Northern Italy

Laura Ducci[1], Pietro Rizzo[1], Fulvio Celico[1]

[1]University of Parma

Key Words: PCPs, semi-confined, groundwater, contamination

Due to increasing anthropic activities, novel contaminants are found in the aquatic environment with scarce information on their analysis, fate, and transport. In particular, in the last decades, the pollution of water compartments by emerging contaminants, such PPCPs (Pharmaceuticals and Personal Care Products), has increasingly attracted the attention of scientists and legislators; within the PPCPs group, pharmaceuticals are more studied in environmental matrices than personal care products (PCPs), of which little information is found in the literature. Personal care products are a group of organic chemicals added to different cosmetic products, used mainly in daily life by humans, such as lotions, body creams, and shampoo.

Within the class of personal care products, Disodium EDTA is one of the most widely used substances in cosmetics. This is a chelating agent: it reacts and forms complexes with metal ions that can affect cosmetic products' stability and/or appearance. In general, chelating agents can potentially remobilize metals from sediments and aquifers, posing a risk to groundwater and drinking water. The most significant concern, however, is that EDTA is recalcitrant and is, therefore, persistent in the environment. Moreover, previous studies showed that Disodium EDTA is also poorly biodegraded by conventional wastewater treatment plants.

Due to its recalcitrant characteristics in the environment, Disodium EDTA is a substance capable of compromising both the quality of surface and groundwater, in portions of the aquifer where the former feed the latter. Therefore, this work aimed to analyze the presence of Disodium EDTA in 18 outgoing discharges of wastewater treatment plants. Medium-composite samplings were carried out: multiple instantaneous sampling at appropriate time intervals were picked up and subsequent mixed of samples. The sampled discharges were carried out simultaneously, in a period characterized by absence of rains, to prevent wastewater's dilution. These were located in Northern Italy, in a wide area between Mantua and Parma provinces, in portions of the aquifer where surface water courses feed the aquifer, to verify the potential impact of discharges on groundwater quality.

Results demonstrated the detectable presence of EDTA in wastewaters, demonstrating the importance of developing new treatment methods capable of reducing the amount of EDTA discharged into the environment to safeguard water resources.

Spatio-Temporal Variability of Groundwater Hydrochemical Features: Examples in Different Hydrogeological Settings (Piedmont and Campania Plains, Italy)

Daniele Cocca[1], Stefania Stevenazzi[2], Daniela Ducci[2], Domenico Antonio De Luca[1], Manuela Lasagna[1]

[1]Università degli Studi di Torino
[2]Università degli Studi di Napoli Federico II

Key Words: Groundwater quality, spatial distribution, trend analysis

Groundwater chemical characteristics are influenced by natural processes and anthropogenic activities, which can change over time. The aims of this study are to identify the main ongoing processes and to compare the spatio-temporal hydrogeochemical variations in two different study areas in Italy: an alluvial plain at the foothills of the Alps relief in Piedmont Region (1840 km²) and a coastal alluvial-pyroclastic plain in Campania Region (1630 km²).

The main physico-chemical parameters from the Regional Groundwater Monitoring network databases, referred to biannual sampling, were analyzed. The average values referring to the 2015-2020 period were used for groundwater chemical characterization. Statistical methodologies (Mann-Kendall trend test) were applied to assess the evolution of parameters in the period 2000-2020.

In the Piedmont plain, groundwater is characterized by prevalent oxidizing conditions. Ca-HCO3– facies is prevalent, and a good correlation between EC-HCO3– and NO3–-Cl– is observed. All ions show low concentrations close to the Alps, which increase along the groundwater flow due to mineral/rock dissolution processes and anthropogenic impacts, with a diffuse nitrate contamination. Moreover, groundwater chemistry is more affected by natural processes than anthropogenic influences. Long-term trends reveal a significant decrease in SO42– concentration and an increase of Na+ and Cl–
.

In the Campanian plain, groundwater chemistry is influenced by volcanic edifices and related pyroclastic products and the closeness to calcareous rock formations. Ca-HCO3 facies is prevalent, with a gradual transition to alkaline type from the mountains towards the coast. Moreover, ions concentration distributions highlighted the occurrence of seawater intrusion (Na+, Cl–) and anthropogenic impact (K+, NO3–, SO42–) on groundwater quality. Long-term trends show significant increases in ion concentrations in the innermost part of the plain and decreases in the coastal areas for most of the ions (exceptions are Na+, NO3– and SO42–).

The spatial and temporal elaborations show a significant hydrochemical variability in both study areas, mainly reflecting the geological characteristics of the aquifers and surrounding rock formations, but

also influenced by land-use/land-cover and anthropogenic pressures (e.g., agricultural, urban and peri-urban areas) that differently changed over the 2000-2020 period in the study areas.

Effects of the 2016-2017 Central Italy Seismic Sequence on Groundwater Resources Within the Santa Scolastica Plain (Norcia, Sibillini Mts Range)

Lucio Martarelli[1], Rossella Maria Gafà[1], Francesco La Vigna[1], Gennaro Maria Monti[1], Angelantonio Silvi[1]

Geological Survey of Italy – ISPRA

Key Words: Hydrogeology, Groundwater resource, coseismic effects, Norcia, Italy

The Santa Scolastica Plain is located at the SW margin of the Sibillini Mts, Central Italy. In the context of a research agreement with the Sibillini Mts National Park, the ISPRA Geological Survey of Italy started hydrogeological surveys aimed to evaluate the coseismic effects of the 2016-2017 Central Italy seismic sequence on the temporal variation of groundwater resources in this area. The study, started in June 2018, was initially carried out by monthly monitoring frequency (till July 2020) and is currently still in progress with a twice-annual frequency (June-July and October; late-high- and low-water stages, respectively). Stream discharge, hydraulic head level and hydrochemical in situ measurements are carried on.

The groundwater resources of the area were affected by a sharp increase after the 2016-2017 severe seismic sequence. The intermittent Torbidone Spring was reactivated in October 2016 after many years of drought, reaching up to about 1.8 m3/s of discharge in May 2017. The Marcite resurgence yields increased from a quite constant annual mean discharge of about 0.6-0.7 m3/s before October 2016 to more than 1.3-1.6 m3/s in January-May 2018. The spring discharge of Torbidone spring suffered then a quite sudden progressive decrease and dried out at the end of the 2020 summer. The Marcite resurgences also had a decreasing stage, but with a slower rate, reaching down again about 0.6-0.7 m3/s from July 2020 to October 2022. The hydraulic heads in the selected observation wells within the plain increased from about 1 m in the down-hill NW area to about 10 m in the up-hill E sector and have as well intensely decreased with time.

The hydrogeological conceptual model suggested that the intermittent regime of the Torbidone Spring is likely due to the quite flat morphology of the impermeable layer sustaining the aquifer hosted in the Poggio Valaccone carbonatic hydrostructure. Consequently, this hydrostructure has not a high hydraulic potentiality and may yield water only when the aquifer pore pressure raises due to very high precipitations or seismic compressive strains. Finally, the piezometric field within the Santa Scolastica Plain evidenced that the riverbeds of Torbidone and Sordo streams act as preferential drainage axes for the groundwater resources.

A Coupled Experimental and Numerical Approach to Simulate the Free-Product DNAPL Migration in the Heterogeneous Alluvial Aquifer Of Parma (Northern Italy)

Riccardo Pinardi[1], Alessandra Feo[1], Andrea Artoni[1], Fulvio Celico[1]

[1]Università degli Studi di Parma – SCVSA

Key Words: DNAPL migration, Alluvial acquifer, Numerical model, Groundwater impact

Chlorinated organic compounds are widespread aquifer contaminants. They are referred to as dense non-aqueous phase liquids (DNAPLs), therefore denser than water, with a very low water solubility, capable of migrating under pressure and gravity forces through both the unsaturated and the saturated aquifer systems, until reaching a bottom aquiclude. They are usually detected at urban and industrial areas, due to their extensive application in dry cleaning, chemical production, and metal degreasing. They are persistent in the environment and are linked to toxic and sometimes carcinogenic effects. Starting from an accurate reconstruction of the geological settings, which allowed to observe a stratigraphic juxtaposition of more-permeable layers (gravel and sand) with low-permeability layers (clay and silt), the present study deals with the three-dimensional numerical model implemented to analyze the expected impact of perchloroethylene (PCE) releases in heterogenous aquifer systems. The method was introduced by previous studies and is based on the high-resolution shock-capturing flux (HRSC) conservative method to follow sharp discontinuities accurately and temporal dynamics of three-phase immiscible fluid flow in a porous medium. Several validation tests were performed in the past to verify the accuracy of the HRSC method and the CactusHydro code. The model presented here simulates the DNAPL migration with the aim of predicting (i) the free-product distribution in heterogeneous aquifers (up to several hundred meters thick), and then (ii) the distribution of possible long-term pollution sources for shallow and deep groundwaters. In addition, it simulates the free-product DNAPL pumping with the aim of designing the best hydraulic barrier system to be constructed to manage potential emergency scenarios, and minimize the negative impact on the surrounding environment. The test site is the alluvial aquifer of Parma plain (Northern Italy), where PCE were recently detected in groundwater, therefore suggesting the existence of DNAPLs sources.

Verification of snow-pillow measures through snow stratigraphy profiles for the determination of the Snow Water Equivalent in Valgrosina (northern Italy)

Corrado A. S. Camera[1], Andrea Citrini[1], Andrea Morcioni[1], Christian Casarotto[2], Giovanni P. Beretta[1]

[1]Università degli Studi di Milano

[2]Università degli Studi di Milano and MUSE Trento

Key Words: water resources, snow density, field measures, Alpine environment

Snow plays a crucial role in the Alpine environment, since many diverse human activities, directly on indirectly, deeply rely on it. Estimating the Snow Water Equivalent (SWE) is particularly important to determine water resources available through snowmelt. The overall objective of this study is to estimate the spatial-temporal evolution of the Snow Water Equivalent in Valgrosina, a tributary valley of Valtellina, which is exploited for hydropower production by A2A S.p.A. Specific objectives include: i) the verification of snow density measures at two meteorological stations equipped with snow-pillow; ii) the correlation of snow density and snow height manual, discontinuous, point measures with morphological characteristics and continuous data; iii) the development of a procedure to derive spatial maps of SWE.

During the winter season 2022-2023, four field campaigns were organized for measuring snow properties. The campaigned were carried out one per month, from December to March, to consider the evolution of the snow cover with the season. During each campaign, a snow stratigraphy profile was executed close to each of the two meteorological stations equipped with snow-pillow. Each profile was characterized in terms of snow height, temperature at 5-cm intervals, snow penetration resistance, snow density and number of layers. Each layer was described in terms of humidity, average grain size and form, and hardness (hand test). Comparisons between continuous station data and profiles were made to verify the similarity of density measures and relate possible inconsistencies to specific layer properties. Snow depth and snow density manual measures were performed at other locations in the valley, characterized by different elevation, slope and aspect in comparison to the stations and the complete profiles. An exploratory analysis was carried out to correlate continuous measures to point measures through morphometric variables.

Preliminary results show a high spatial variability of snow height and a tendency of snow-pillow to underestimate snow density and SWE (between 37% and 55%) in comparison to profiles. This underestimation is variable according to snow layer thickness and hardness. For reliable correlations, a second group of campaigns will be carried out next winter, selecting measuring points a-priori based

on morphometric characteristics. The possibility to introduce indirect spatial measures through geophysical instrumentation will be explored too.

Nationwide Groundwater Recharge Evaluation for a Sustainable Water Withdrawal Over Italy

Mauro Rossi[1], Marco Donnini[1], Giulio Beddini[2]

[1]CNR IRPI
[2]UNIPG

Key Words: groundwater recharge, sustainability, model, water balance

The quantification of the amount of groundwater recharging (GR) aquifers, is a key information for the evaluation of the sustainability of water withdrawals and for its correct management.
In an attempt to provide information and tools to achieve this objective in Italy, we applied a water balance method for estimating GR and other balance components by using gratis/libre open access data and open source software.
The model provided groundwater recharge estimates for the Italian territory within a 10-km grid-cell resolution mesh, using monthly precipitation and temperature data from 1981 to 2010 from the ISPRA SCIA database. The model was calibrated and validated with reference to literature data available for the area of Apennines (Central Italy). The comparison of GR values estimated for specific years (i.e. 1992 and 2015), along with the data of water withdrawals, highlighted the following: (i) the mineral water industry consumption was close to 0.01% of the total GR in 1992; (ii) the civil use was not negligible, being ~10% of the total GR in 2015, and correlated with the number of inhabitants; (iii) a correlation between the number of inhabitants per region and the percentage of water withdrawn for civil use, with respect to total GR, was not evident, suggesting that the sustainability of water withdrawals varied regionally.
The proposed approach may have strategic importance for developing countries, which are affected by water availability and have sustainability issues, especially in the context of climate change. Such applications would largely benefit from the findability, accessibility, interoperability, and reusability (FAIR) data.
The proposed approach provides quantitative data to evaluate different indicators identified within the Goal 6 of the 2030 Agenda for Sustainable Development of United Nations (https://sdgs.un.org) and to pursue specifically the Target 6.4 and 6.5 which aim at increasing the water-use efficiency and at ensuring the sustainable water resources management at all levels.

Characterizing the Current Italian Drought in Different Water Domains: Are Groundwater Resources More Resilient?

Paolo Colombo[1], Pietro Mazzon[1], Luca Alberti[1]

[1]Politecnico di Milano

Key Words: drought, groundwater, surface water, resilience

Drought periods are one of the most visible impacts of the changing climate we are facing. Evidence has shown that drought spells are increasing under global warming in all parts of the world. But a drought can have many faces: meteorological, hydrological, hydrogeological are some classification referring to the precipitation, surface water and groundwater domains. Since 2021, Italy has been experiencing one of its most severe meteorological and hydrological droughts ever recorded, especially in its Northern regions. Precipitation, streamflow and lakes are reaching historically low values. Groundwater levels, however, seems to respond less abruptly to meteorological drought. This study aims to assess the groundwater conditions in this extreme period and consider its responses to climate stresses in time. It applies drought indicators to historical time series of meteorological and hydro-geological variables to find differences, similarities and connections between droughts in different water domains. Satellite-observed soil moisture data is used to assess its comparability with traditional groundwater depth observations and its possibilities to be used to assess droughts at regional scales. The current drought is characterized and considered within the context of historical droughts recorded, with a focus on groundwater response and its recharge in time. Since there is still no widely accepted indicator for groundwater drought, the study analyses the applicability of the available ones to the Northern Italy case, providing a comparison between them. The results of the study are useful for drought prevention strategies, as looking to the past can prepare us for the future and will help analyse future climate change scenarios.

Modelling Plio-Pleistocene Arenaceous Aquifers in Central Italy to Evaluate Variations in Water Potentialities Due to Urbanization

Alessia Di Giovanni[1], Diego Di Curzio[2], Sergio Rusi[1]

[1]University "G. d'Annunzio" of Chieti-Pescara

[2]Delft University of Technology, Delft

Key Words: Arenaceous aquifers, Water balance, Urbanization, Numerical modelling

The constant rising demand for water caused by drought periods and the increasing of population is leading to the research and revaluation of minor springs and aquifers.

In the hilly area of the Periadriatic area in Central Italy, foredeep basin deposits (Plio-Pleistocene age) show a stratigraphic sequence with marly-clayey deposits at the bottom and arenaceous deposits and even conglomerates in the upper portion.

This stratigraphic framework combined with the geomorphological features, flat shapes and sub-vertical slopes, has allow the presence of springs at the base of the scarps, where the interface between coarse and fine deposits can be found; in this set-up, the arenaceous lithologies work as aquifer, while the marly-clayey as aquiclude.

These springs were mostly used until the middle of the last century, when they were the only water resource for every purpose; groundwater was exploited by historical complex systems of wells and drainage tunnels, nowadays abandoned, and replaced by the more complex aqueduct systems coming from the close Apennines carbonate aquifers.

Since the beginning of the last century, the urbanization of the hilly areas has spread more and more, increasing the impermeable zones and decreasing the possibility of infiltration; for these reasons the role of impermeabilization and how it has influenced the recharge of these aquifers has been considered.

In this work, to evaluate the variation in groundwater due to towns' expansion, a preliminary and simplified numerical model has been built and the water balance and the potentiometric maps have been estimated considering different urban scenarios over the last decades.

A sample area, located in the hilly zone in Central Italy, has been taken into account for the modelling; the final aim is to understand how much these variations in recharge have affected the groundwater and if the potentialities of these aquifers make them still exploitable for coping the increasing demand for water.

Hydrogeological Model of the Friulian Plain and the North Adriatic for the Sustainable Management of Water Resources

Cristina Corradin[1], Luca Zini[1], Angelo Camerlenghi[1], Aaron Micallef[2], Michela Giustiniani[1], Martina Busetti[1]

[1]University of Trieste; OGS
[2]University of Malta

Key Words: aquifer, modeling, offshore aquifers

The Venetian-Friulan Plain, located in the northeast of Italy, represents the eastern portion of the larger alluvial plain of the country. The plain was built since Pliocene by a coeval combination of marine, fluvial and glacial processes. The underground internal organization of the plain produces a complex multilayered aquifer system counting several confined aquifers that serve for agricultural, industrial, and human usage. In the last century, the non sustainable exploitation of the region's water resources resulted in a fragile equilibrium between aquifers recharge and utilization and triggered hydrogeological hazards such as salinity intrusion and subsidence. To better understand the quantitative significance of aquifers and to highlight possible strategic resources for future years, this research intends to model the complex geological assets of the region and of the north Adriatic Sea, and the genesis of the region's aquifers system. Input datasets for the modeling are borehole stratigraphic data, well logs, and seismic lines. To achieve a model that closely approximates reality, two different modeling approaches, interpolation, and geostatistics, have been performed on the same dataset. The validation process of the models and error estimation states that the best approach to model a such heterogeneous area is geostatistical analysis. Another outcome of this work is connecting for the first time the plio-quaternary glacio-eustatic fluctuations that interested the region and the Adriatic basin, as the primary depositional process responsible for the formation of the aquifer system. This latest result confirms that the North Adriatic Sea basin has a significant potential of hosting offshore freshened groundwater aquifers.

The Approach for Evaluating Tunnel Derived Impacts Against Springs and Base Flow – Improvement and Numerical Verification of Drawdown Hazard Index (DHI) Method

Ernesto Pugliese[1], Antonio Dematteis[2], Alessandro Gargini[1]

[1]Alma Mater Studiorum - University of Bologna

[2]Lombardi SA, Bellinzona-Giubiasco, Switzerland

Key Words: Hydrogeological Risk, Tunneling, Parametric Method

The excavation of a tunnel is associated to the hazard of induce unsustainable interference of groundwater flow systems, including effects against associated dependent ecosystems, in the case in which the methods of excavation and completion of the tunnel implies drainage from the rock mass. This interference can lead to a drawdown of hydraulic head and water table and to the partial or total dewatering of springs, wells or streams located at the surface. The presented research, co-financed by Italferr s.p.a., aims to make more robust and physically-based the evaluation tools and to validate parametric or statistical methods, like DHI or machine learning based tools, exploiting the huge data-base of as built tunnels projects, with emphasis on base tunnel connections through the Alps (i.e., Brenner basis tunnel, Turin-Lyon, Gotthard base tunnel). Among the parametric tools used to evaluate the risk of hydrogeological interference against springs, the DHI (Drawdown Hazard Index) method (Dematteis et al., 2001) is one of the most adopted and its first release was frequently applied as part of preliminary project phase of tunnels. Moreover, in many cases it was possible to follow the monitoring of springs and streams during the tunnel excavation, in order to verify the DHI predictions against data-sets acquired in real time and this has allowed to improve the ranking system of the DHI (Torri et al, 2007, Dematteis, et al. 2009). In recent years, the possibility of extending the assessment to surface waters (streams), wells, and Groundwater Dependent Ecosystems (GDEs) is being analysed. Streams can also be significantly interfered with during tunnelling, with consequent impacts on surface water ecosystems. To this end, elements of the DHI correlation matrix are being added and modified, and the different weights of the matrix elements updated. The intrinsic process of the evaluation is being revised from the binary interaction matrix (BIM) to the global interaction matrix (GIM), showing all partially-coupled interaction matrices (PCIMs), making explicit the equations of the calculation for each cell of the matrix (Jiao, 1995). The implemented method was tested on as-built recent projects. The Potential Inflow (PI) produced by the matrix, as a proxy of tunnel drainage, was compared to the actual water inflows.

Statistical Analyses of Springs Discharges Fed by Karstified and Fractured Limestone Aquifers (Central Italy)

Mina Yazdani[1], Mauro Rossi[1], Costanza Cambi[2], Lucio Di Matteo[2], Daniela Valigi[2]

[1]CNR-IRPI di Perugia

[2]Dip. di Fisica e Geologia - Università di Perugia

Key Words: Spring discharge, Limestone aquifer, Cross-correlation, Central Italy

The investigation of spring discharge response to meteorological variables is a preliminary but fundamental step towards the understanding of aquifer dynamics and improving their predictability over time. We designed a comprehensive statistical analytical workflow to analyse and predict spring discharges and their dependence on changing meteorological and climatic conditions at different temporal scales. This was applied to four springs monitored at a daily scale for at least 30 years (Bagnara, Capo d'Acqua di Nocera Umbra, Alzabove, and Lupa), which have been affected by prolonged drought periods in the last decades. The studied springs are fed by limestone aquifers characterised by different degrees of karstification and fracturing, mainly exploited for domestic water use. They are located along the Umbria-Marche Apennine (Central Italy) chain in areas with low anthropic pressure (i.e., the spring discharge only depends on the recharge). The proposed workflow first aims to characterise the completeness and inconsistencies of discharge and meteo-climatic time series through univariate statistical tests (e.g., Pettitt, Re-Cusum) at the annual scale. As a second step, the correlation of discharge with reference climate change indices is investigated and quantified at annual time scales, using statistical univariate (i.e., autocorrelation functions) and bivariate metrics (i.e., correlograms, cross-correlation functions). In addition, spring discharge dependence on meteorological variables (precipitation and temperature) is analysed at a daily scale, using bivariate metrics (i.e., correlograms and cross-correlation functions). The response and sensitivity of spring discharges to aggregated meteorological variables over sub-yearly periods are also quantified using cross-correlation function analyses. Finally, springs' recession curves are analysed to check the different behaviour during no-recharge periods.

A Direct Application of PEST Code to Highlight Structural Defects in Groundwater Model. A Case Study From Milan, Santa Giulia, Italy

Mara Dal Santo[1], Mustafa Ramadan[2]

[1]Stantec Inc Italia, Palazzo Canova, Segrate, Milan

[2]Nablus, West Bank, Palestinian Territories

Key Words: Groundwater Model, Data assimilation, PEST, Contaminated site

This study demonstrates how data assimilation is vital in exposing structural defects of a model. Such a goal has been met by applying the numerically-enhanced conceptual modeling approach (NECoM) on a contaminated site in Milan. The site is located in the Po Plain where 4 main aquifers were identified into alluvial deposits. To verify the effectiveness of a hydraulic barrier, a model for the topmost unconfined aquifer has been carried out. Model Muse version 5.1.1 has been used based on MODFLOW6 code. The model domain covers an area of 20 km2. Two General Head Boundaries has been assigned. Lambro has been represented by a RIVER condition and a WELL package has been set for wells with known pumping rates. Hydraulic conductivity was initially assigned based on geological and hydrogeological data. The recharge has been calculated using climatic data and the coefficients of potential infiltration.

The simulation has been performed within the School of Hydrogeological Modelling of SYMPLE, under a steady-state regime, using the piezometric levels of September 2019. Inverse modelling was carried out to estimate the hydraulic conductivity (K) distribution through PEST code. The highly parametrized inversion scheme consists of 126 pilot points. Tikhonov regularization and singular value decomposition were used to include prior information in the calibration dataset. Relevant prior information has been extracted from pumping tests results and boreholes stratigraphic interpretation. A sensitivity analysis has been carried out along the data assimilation process.

The obtained hydraulic conductivity field identified an anomalous zone of K. Two hypotheses have been put forward: a physical heterogeneity of K exists, but was not detected by the site investigation, or the K parameter assumed a surrogate role in compensating important structural defects of the model, i.e. a wrong assignation of the RIVER boundary condition. Stratigraphic logs exist in the area and are quite similar to those of other zones despite having a different calibration value. The second hypothesis seems to be more likely. In addition, the head distribution near the river does not show the deflection of a gaining stream. Therefore, it is recommended to modify the model structure. This kind of numerical insights enquiring model defects are only achievable through the highly parametrized approach through the use of model-partner software such as PEST.

Groundwater Recharge Assessment Using a Daily Soil Water Balance Model. The Case Study of the Strategic Karst Aquifer of Avella Mts. (Southern Italy)

Paola Petrone1[1], Pantaleone De Vita[1], Vincenzo Allocca[1]

[1]DiSTAR - Università degli Studi di Napoli

Key Words: groundwater recharge, karst aquifer, soil water balance, southern Italy

Karst aquifers are a strategic resource for many regions of the world. They are used mainly for drinking purposes and play an important role for the economic development and conservation of groundwater dependent ecosystems. Currently, the increase water consumption and the climate variability threaten the natural balance of aquifers, therefore an accurate groundwater recharge assessment is fundamental to manage correctly and preserve them.

The southern Apennines include many of these aquifers among which Avella karst aquifer that is a strategic groundwater resource for Campania region, as it supplies drinking water to 76 municipalities for a total of about 1,500,000 inhabitants.

The Soil Water Balance code (SWB, version 1.2) has been applied to simulate the spatial and temporal variations of groundwater recharge of Avella aquifer for the time span from 2010 to 2021 and with a spatial resolution of 20 meter.

The SWB code uses a modified Thornthwaite-Mather approach, daily precipitation and air temperature and cartographic data that include DEM, hydrologic soil groups, soil available water, land use and other data about soil type such as interceptions rather than roots and maximum recharge depth.

Results show how, at the basin scale, the groundwater recharge varies over time. At the annual scale, groundwater recharge ranging from a minimum of 35.6 mm (2016) to a maximum of 2,530 mm (2010), with an average value of 660.5 mm. At the monthly scale, a minimum, average and maximum value of 0 mm (August), 56.32 mm and 280.31 mm (November) respectively was estimated. Finally, an average daily groundwater recharge of 1.8 mm/day was quantified, with a maximum value (2nd December) of 22.99 mm/day.

This new approach allowed a deeper understanding of space and time scale variability of water balance components and offers a practical tool for a more aware management of karst aquifers of the southern Apennines which are severely impacted by strong climatic variability.

More than 10 Years of Experiences in Airborne Em Applied to Hydrogeology: State-of-the-Art and Next Steps

Antonio Menghini[1], Arianna Rapiti[1]

[1]EMERGO SRL

Key Words: HYDROGEOPHYSICS, AIRBORNE EM, WATER CRISIS, MODELLING

Airborne Electromagnetics (AEM) is become a mature technology that gained ever more the capability in supporting the hydrogeological community to face the increasing water demand. Considering the severe water crisis that is affecting Europe, and in particular North Italy, Spain and France, the possibility to get a detailed hydrogeological framework in a fast way, it is certainly a strategic tool for the public authorities that wish to plan new production wells, to protect strategic aquifers from pollution and to manage in the more appropriate way any future exploitation of the groundwater resources. The constant improvements in instrumental performances, thanks to the increase of the energizing moment and to the recovery of the very early response of the subsurface, allowed in the last years to achieve greater depth of exploration and, at the same time, better shallow resolution. Right now, most of the available AEM instruments are able to explore with great detail a depth ranging from 4 to 400-500 meters. Morover, it is possible to achieve high vertical and lateral resolution, unimaginable with the standard geophysical methods and, even worse, with direct approaches, e.g. sparse boreholes. The most relevant case-studies, collected all over the World and in very different geological scenarios, will be presented: from the detection of freshwater aquifer, both in fractured and granular aquifers, to the seawater intrusion along coastal aquifers. The growing interest in AEM application for Hydrogeology is testified by some projects we are currently carrying out with Italian and German institutions (private and public ones) which realized that only by means of an accurate modelling, it is possible to take quick and useful decisions. The state-of-the-art (with pros and cons) of the AEM technology is reported, with a look at the future steps (integration with ground geophysics and ancillary data, use of drones, advancements in inversion codes, etc.).

Dealing with the Conservation of Rural Landscape Cultural Heritage and Sustainable Water Quality

Luigi Alessandrino[1], Monica Pantaloni[2], Gianluigi Busico[1], Jonathan Domizi[2], Francesco Botticini[2], Nicolò Colombani[2], Alberto Tazioli[2], Giovanni Marinelli[2]

[1]Università della Campania "Luigi Vanvitelli"
[2]Università Politecnica delle Marche

Key Words: Water quality, Nitrate pollution, DOC pollution, cutural heritage

The aim of this study was to assess the surface waters quality in rural landscapes typical of the Marche region, in order to understand the potential impact that scattered residential areas could have on surface water quality respect to large settlements. The study area is part of Aspio watershed (Province of Ancona) historically affected by diffuse nitrate pollution, namely the subwatershed of Scaricalasino, which includes the hystorical towns of Osimo and Offagna and the recent development areas of San Biagio and Scaricalasino village. Among these settlements, the rural isolated farmhouses are an integral part of this landscape and represent a cultural heritage milestone to be preserved. The parameters used to assess the surface water quality were electrical conductivity, temperature, pH, nitrate, labile and recalcitrant dissolved organic carbon (DOC), which were used as indicators to discriminate from agricultural or sewage pollution. The sampling plan was divided into two seasonal campaigns, one in November 2022 after a prolonged period of drought (45 samples) and one in February 2023 during the groundwater recharge seasons (46 samples). In the sampling campaign of November 2022, none of the analysed samples exceeded the WHO limit of 50 mg/l for nitrate with an average concentration of 33.1±8.5 mg/l and relatively high DOC 13.4±9.2 mg/l with peaks near the large settlement of Osimo. In the sampling campaign of February 2023, nitrate concentrations detected were higher (44.7±11.6 mg/l) with a few samples exceeding the WHO limit and lower DOC concentrations (3.3±0.7 mg/l). In drought conditions the low nitrate concentrations and high DOC were due to prevailing baseflow conditions fed by leaking sewers from Osimo and S. Biagio settlements, while Offagna newly complemented with a grey water infrastructure did not contribute significantly to nitrate and DOC export except. The rural farmhouses did not increase nutrient leaching in baseflow conditions. During recharge season the highest nitrate concentrations were found in small streams directly draining agricultural fields and near Osimo, while the low DOC was due to dilution by runoff. This case study showed that the rural isolated farmhouses were a minor component in nutrient export compared with concentrated settlements, while their surrounding agricultural fields produce nitrate pulse during the wet season that need to be mitigated, e.g. increasing riparian vegetation to achieve sustainability.

Not only Surface Water Reservoirs or Impoundments Could Mitigate Water Shortage Effects in Mountainous Settings: The Potential Yield of the Pantano Arenitic Aquifer in Northern Apennines

Alessandro Gargini, Maria Filippini, Stefano Segadelli

[1]*BiGeA, Alma Mater Studiorum University of Bologna*
[2]*Geological Service - Emilia-Romagna Region*

Key Words: Northern Apennines, Arenite, Groundwater, Groundwater budget

The recurring drought events in Northern Italy, as those in years 2017, 2021 and 2022, have induced a severe shortage of surface water resources for agriculture and energy production. The chance to cross the Po river by foot from one bank to the other is becoming customary and not only during the summer season. In the public debate on water planning and policies, strong pressures are directed towards the design and build-up of small reservoirs in the mountains or of impoundments in the plain in order to sustain the water demand during the main droughts. The enhanced exploitation of groundwater resources, even in the spirit of an ephemeral and emergency approach, is poorly taken into account although the resilience to the driver of climate of some aquifer reservoir, along with the better water quality, is certain. This is the case, for example, of a Miocenic arenitic aquifer, pertaining to the Pantano formation (PAT) of the Epi-Ligurian series. PAT outcrops extensively in the Northern Apennines throughout the watersheds of Secchia, Panaro and Reno rivers, forming plates of almost pure sandstones of 200-300 m thickness above a permeability threshold represented by shaly and argillaceous Ligurian units. Locally, due to concurrent geological, sedimentological, geomorphological, and geochemical factors, strategic groundwater reservoirs have been developed storing a huge volume of permanent reserve with a high renewal time of the whole stock. This research is based upon data collected in the hydrological year 2021-2022 from 32 springs and 4 boreholes, including: spring discharge measures on a monthly basis, pumping and borehole dilution tests, hydrochemical and isotopic analysis on a seasonal basis. Groundwater budgeting of distinct sectors of the arenitic aquifer provided a coefficient of effective infiltration value in the range 0,53-0,27 and a positive correlation with the proximity to the shore line of the original depositional setting. The potential incremental yield through pumping during the critical dry season was estimated in the range 3-6 L/s in the most productive sectors. The conceptual model linking the depositional setting of the arenite to the potential yield could be extended in the future to other sectors of PAT in Emilia-Romagna region for the evaluation and development of a strategic integrative water resource for adaptation to the effects of Climate Change.

Modeling Reductive Dechlorination through Enzyme-Based Kinetics: Implications for Reactive Transport Models Simulating Biodegradation of Chloroethenes

Diego Di Curzio[1], Michele Laureni[1], Mette Martina Broholm[2], David Weissbrodt[3], Boris M. van Breukelen[1]

[1]Delft University of Technology
[2]Technical University of Denmark
[3]Norwegian University of Science and Technology

Key Words: Biodegradation, Enzyme-based kinetic, Reactive transport modeling, Polluted aquifers

In polluted aquifers, chloroethenes often degrade through a microbially-catalyzed redox reaction called Reductive Dechlorination (RD), recently referred to as Organohalide Respiration. Obligate and versatile organohalide-respiring bacteria (OHRB) use chlorinated solvents as electron acceptors to gain energy by producing reductive dehalogenases enzymes (RDases).

In reactive transport modeling, time-dependent RD is generally modeled through kinetic equations. Even though some try to incorporate information about bacterial metabolism (e.g., Michaelis-Menten equation or Monod terms for bacterial growth), they often provide a simplified description of metabolic regulation dynamics behind RD. In addition, in recent years, the use of microbial data and biomarkers is becoming widespread in polluted site investigation, along with the rapid development of high-throughput technologies to measure them. Thus, more sophisticated numerical solutions are needed.

For this reason, we developed gene-centric enzyme-based kinetics that can explicitly mimic RD via production of RDases via transcription of functional genes into mRNA and its translation to proteins (metabolic regulation). Data from microcosm experiments gained from literature (i.e., concentrations of chloroethenes and chloride, and abundances of Dehalococcoides spp. and functional genes mRNA transcripts) were used for parameter calibration through batch models. The same calibrated kinetics were then used in elementary 1D reactive transport models (e.g., continuous or pulse injection) to assess the spatiotemporal evolution of RD along a flowline.

Both the batch and 1D models show that as long as chlorinated ethenes are available – and biodegrade –, the OHRB, mRNA transcripts and RDases behaviors are correlated: bacteria grow by degrading chloroethenes and to this end produce RDases via metabolic regulation. When chloroethenes are completely degraded, transcripts decay and RDases deactivate rapidly, whereas bacteria abundance

remains high. This evidence suggests that OHRB remain longer in groundwater, even though they are no longer active, and biodegradation is not taking place.

Integrating the proposed enzyme-based kinetics in reactive transport models proved to allow reproducing observed spatiotemporal patterns of pollutants and biomarkers and unravel the biogeochemical mechanisms underlying the biodegradation of highly toxic and carcinogenic chemicals like chloroethenes that contaminate groundwater resource.

Baseflow quantification effectiveness by digital recursive filters

Antonia Longobardi[1], Leisan Khasanova[1], Maria Francesca Palmiero[1]

[1]University of Salerno

Key Words: hydrograph filtering, baseflow, digital filters, mass balance

Over the past 30 years, groundwater (GW) age derivation has attracted attention in researchers and professionals to overcome quality-related challenges in the management of aquifer systems. GW ages can be determined following either hydraulic-based techniques or isotope-based approaches. By the term age modelling, instead, reference is made to developed methods that qualitatively couple hydrodynamics with isotope-based ages in order to reduce the uncertainties involved.

Here we present an age modelling application to the shallow alluvial aquifer in the Po River Basin. We used the 3H/3Hetri method to assess the aquifer renewability in a portion of the plain where the extremely variable recharge contributions and the intrinsic variability in aquifer geometry, make sometimes water management arduous.

Results from 44 wells showed 3H activities ranging from 0.52 to 5.02 T.U.. To use 3He for age computations, the fraction produced by 3H decay (3Hetri) must be separated by other sources: dissolved He in solubility equilibrium with the atmosphere (Heeq), excess air trapped at the vadose zone (Heea) or 3He produced from 6Li (3Herad). The 3He/4He ratios normalized to that of the atmosphere range from 0.30 to 3.25 revealing the dominant presence of 3Hetri with a minor contribution of Herad.

The slight Herad contribution to the Hetot identifies older GWs, reaching values of 60±20yr, detected near the piedmont and in the higher plain. The downstream middle plain, instead, revealed younger ages of about 24±2yr. Chronometers also unraveled mixing processes, detailing older GWs in the higher plain as the result of a young component containing 3H and another older than 70 years mostly 3H-free. In the middle plain, oppositely, mixing counts at least two components where the youngest portraits shorter flowpaths able to lower background aquifer age values, particularly where return flow due to intensive irrigation occurs, thus acting as a young recharge component to the aquifer.

The age modelling approach turned to be effective in deepening the knowledge related to the hydrogeological functioning of the alluvial aquifer in the Po River Basin, by elucidating the relations between residence time and flow patterns. GW ages interpretation along with information from wells' lithologs, screens locations and intervals, vadose zone behaviors and recharge patterns allows the identification of reliable conceptual models and sustains efficient management strategies of GW resources.

Groundwater Age Modelling to Refine Knowledge on the Hydrogeological Functioning of the Shallow Alluvial Aquifer in the Po River Basin

Mariachiara Caschetto[1], Chiara Zanotti[1], Daniele Pinti[2], Elisa Sacchi[3], D Sartirana[3], A Redaelli3, S Bruno[3], L Fumagalli[3], T Bonomi[3], C Riparbelli[4], S Brenna[4], M Rotiroti[3]

[1]DISAT, University of Milano-Bicocca

[2]GEOTOP and Université du Quebec à Montreal

[3]Dept. of Earth and Environmental Sciences, University of Pavia

[4]Regional Agency for Agriculture and Forests of Lombardy, ERSAF, Milan, Italy

Key Words: Groundwater, Hydrogeochemistry, Age Modelling, Water Quality

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Emerging Challenges in Groundwater Flow Modeling in Folded and Faulted Areas, a Case Study in the Apennine

Cristina Di Salvo[1], Randall J. Hunt[2], Max W. Newcomer[2], Daniel T. Feinstein[2], Elisabetta Preziosi[3]

[1]CNR-IGAG

[2]U.S. Geological Survey

[3]CNR-IRSA

Key Words: numerical models, folded aquifers, MODFLOW-NWT, NWTOPT

The development of numerical models is a fundamental step for the adoption of water management plans aiming to preserve groundwater resources. 3D numerical modeling in folded and faulted terrains can be challenging; reproducing such complex geometry of model layers can result in different layer thicknesses of saturated portions, which can result in drying and rewetting of cells during model iterations, leading to numerical instabilities, preventing convergence, or increasing numerical error. Otherwise, an excessive system simplification used to attain stability may lead to unsatisfactory predictive capability of the model. Recent advances have targeted such issues, including development of solvers that facilitate achieving convergence and/or reduce computational errors (Niswonger et al., 2011; Hunt and Feinstein, 2012). The aim of this research was to develop and test a procedure for groundwater flow modeling in a karst, folded, multilayer aquifer. Seeking parsimony, the complexity of the conceptual model was reproduced by progressively adding layers and hydraulic conductivity zones, from a 2D to a quasi-3D and a fully-3D model. During this process the model response was evaluated through manual trial-and-error history matching of a steady state solution. An equivalent porous media approach was used; however, modeling identified a discrete groundwater circulation pattern, successfully simulated by adding a high permeability longitudinal strip. The fully-3D model matches the observed flow at the different reaches along the river, with reliable flow paths and recharge partitioning into layers. The Newton-Raphson formulation of MODFLOW-2005 (MODFLOW-NWT) was required to achieve convergence and reduce model error. The steady state numerical modeling demonstrated the major impact of geological structure on controlling flow direction, water heads, and spatial distribution of river and springs outflows. A preliminary transient simulation was then performed using monthly stress periods and variable pumping simulated by MODFLOW's WEL package to test effects of withdrawals for water supply on the aquifer. Initial runs showed a very high mass balance error and runtime. To reduce both mass balance error and runtime, the USGS software for the optimization of the MODFLOW-NWT solver inputs, NWTOPT (Newcomer and Hunt, 2022), was

used. NWTOPT identified improved solver inputs, which gave a superior tradeoff between acceptable mass balance error and much reduced runtime.

Multidisciplinary Investigations for the Geological and Hydrogeological Reconstruction of the Krapinske Toplice Thermal Field (Croatia)

Marco Pola[1], Staša Borović[1], Maja Briški[1], Ivan Kosović[1], Mirja Pavić[1], Kosta Urumović[1], Tihomir Frangen[1], Bojan Matoš[2], Ivica Pavičić[2]

[1]Croatian Geological Survey

[2]University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering

Key Words: thermal water, monitoring, structural control, Croatia

Hrvatsko zagorje region (NW Croatia) is characterized by several thermal and subthermal springs that are used for recreational and spa tourism. The occurrence of thermal water is connected to concurrent favorable geological, hydrogeological, and thermal conditions. Mesozoic carbonate complex extensively crops out in Hrvatsko zagorje representing a preferential recharge area for small- to intermediate-scale hydrothermal systems. The infiltration of meteoric water and the groundwater flow are favored by the bedrock fracturing that is connected to Cenozoic tectonic activity. This activity is affected by ongoing tectonics between the structural domains of the Southern Alps, the Dinarides, and the Pannonian basin. The groundwater heating is enhanced by the increased heat flow characteristic for the Pannonian basin.

The Krapinske Toplice thermal field has been investigated as it represents a typical thermal system in Hrvatsko zagorje. Hydrochemical monitoring was conducted from 2021 to 2023 to monitor the physico-chemical characteristics of the thermal water. Geological and geophysical investigations were used to reconstruct the geometry of the aquifer, and data from pumping tests were reinterpreted for its hydrogeological parametrization.

The main characteristics of the monitored water are: i) a temperature of 42.5 °C, ii) a neutral pH of 6.9 - 7.1, iii) EC of approximately 500 µS/cm, iv) a Ca-HCO3 hydrochemical facies, and v) meteoric origin determined by O and H isotope ratios plotting on the local meteoric water line. The monitored parameters were constant during the observation period suggesting a negligible effect of pumping. SiO2 geothermometers pointed to a reservoir equilibrium temperature of 67°C.

Geological investigations highlighted the occurrence of folded structures in the study area, i.e. an overturned anticline with tight limbs, that lifts the Triassic dolomite to a depth of 240 m. The fracture systems in the fold hinge zone favor the rising of the thermal water up to shallow depths. The reinterpretation of pumping tests conducted in two deep wells (approximately 1km) reaching the carbonate aquifer is ongoing.

The integration of the results will permit to propose a comprehensive conceptual model for the Krapinske Toplice thermal system that could be used as a "template" for similar systems in the Hrvatsko zagorje region.

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A Multidisciplinary Study of the Groundwater of Somma-Vesuvius Coastal Volcanic Aquifer, Italy

Pasquale Allocca[1], Rosario Avino[2], Stefano Caliro[2], Nicola Castello[1], Silvio Coda[1], Emilio Cuoco[2], Pantaleone De Vita[1], Sara Saviano[3], Bari Vincenzo Allocca[1]

[1]DiSTAR - University of Naples Federico ll
[2]INGV - Osservatorio Vesuviano
[3]CNR IRPI

Key Words: Hydrogeology, Hydrogeochemistry, Isotope, Volcanic Aquifer

The groundwater of volcanic aquifers are vital sources in many areas of the world, widely used for human consumption and for optimizing monitoring protocols for volcanic surveillance.
In this paper, a GIS-based multidisciplinary study of Somma-Vesuvius aquifer system has been undertaken, employing a hydrogeological, hydrochemical and isotopic dataset available in literature referred to the period 1978-2010 and new field data collected in the period September 2021-March 2022 from 60 wells and thermo-mineral springs.
The results show some hydrogeological changes and novel hydrochemical evidences from basin to local scale. A general rise of piezometric levels of Somma basin up to maximum values of 12 m has been observed, due to the deactivation of drinking-water well fields. Conversely, for the Vesuvius basin a piezometric lowering up to 8 m has been observed, due to the strong groundwater withdrawals as confirmed by a local deficit of water balance. A predominant Ca-Mg-HCO3 facies for the groundwater of Somma basin and a prevailing Na-HCO3 facies for Vesuvius basin has been observed. At the local scale, Na-Cl-SO4 water type has been detected for the first time in the Somma aquifer, within wells located near deep normal faults. The average groundwater temperature is equal to 15.9 °C for the Somma aquifer, whereas it raises to 18.2 for the Vesuvius one, with peaks up to 23.9 and 24.7 °C observed in wells located in the vicinity of deep faults. The average electrical conductivity values are equal to 2,045 and 3,250 µS/cm for the Somma and Vesuvius aquifer, with peaks up to 16,930 µS/cm registered in wells located near deep normal faults and not far from the sea.
The isotopic data of δ18O, δD and δ13C and the concentration of some gases (CO2, He, Ar and N2), together with hydrochemical data, confirm a multiple mixing between shallow volcanic groundwater, highly mineralized and hot deep magmatic fluids, and deep karst groundwater rising along deep normal faults. The continuous monitoring of groundwater highlights that during pumping water from wells these shallow groundwater-deep hot fluids interactions undergo acceleration and increase.

The results allowed to deepen the hydrogeological and hydrochemical knowledge of the Somma-Vesuvius aquifer, highlighting a potential use of groundwater as a new proxy for volcanic surveillance and monitoring.

Groundwater Temperature Variations in the Turin Metropolitan Area (Piedmont, NW Italy): Building a Flow and Heat Transport Model for the Assessment of Future Climate Change Scenarios

Egidio Elena[1], Molson John[2], De Luca Antonio Domenico[1], Lasagna Manuela[1]

[1]University of Torino, Earth Sciences Department

[2]Département de géologie et de génie géologique, Université Laval, Québec (QC) Canada

Key Words: Groundwater, Climate Change, Groundwater temperatures, Groundwater modelling

This study represents the first investigation into the dependency of shallow groundwater temperature (GWT) on climate variability and anthropogenic activities in the Turin metropolitan area (Piedmont, NW Italy).

First, a study of GWT and air temperature (AT) data on a regional scale was carried out in order to understand the relationship between the two temperatures. It was possible to observe that, in the time period 2010-2019, GWT shows a general increase throughout the Piedmont Po plain, with a mean increase of 0.85 °C/10 years while AT has a mean increase of 1.69 °C/10years.

Given these results over a 10-year time interval, a 3D groundwater flow and heat transport model for the Turin city area was developed using the Smoker/Heatflow numerical code. The objective of the modelling is to better understand flow and heat transport dynamics in the shallow aquifer; moreover, a further aim was to analyse how climate change and anthropogenic activities influence GWT, also from a forecasting perspective. Following calibration of the model with the available data, future predictions will be made using AT data from different IPCC scenarios for the city of Turin. Initially, data from the RCP 4.5 (medium) and RCP 8.5 (very high) scenarios will be included.

The development and application of this model will make it possible to simulate variations in GWT on a local and city-scale in order to better understand how urban groundwater temperatures at Turin will respond to the different climate and anthropogenic impact scenarios in the perspective of better future management of the resource.

Session 4

Groundwater Dependent Ecosystems

Oral Presentations

Novel Experimental Approaches in Ecohydrodynamics of Real Vegetated Rivers

Giuseppe Francesco Cesare Lama

University of Naples Federico II

Key Words: Ecohydrodyanmics, Vegetated rivers, Field Experiments, Ecohydraulics

The rigorous analysis and the prediction of the effects of the hydrodynamic interaction between flow and riparian vegetation in natural and manmade vegetated water bodies are the main objectives of Ecohydromechanics. Riparian vegetation has a paramount impact on both flow resistance and water quality in vegetated open channels. Defining the most appropriate management practice of riparian vegetation inside both natural and manmade water bodies is crucial for assuring a balance between a satisfactory level of hydraulic conveyance and a high environmental value of water. The presence of riparian vegetation significantly affects both mean and turbulent flow fields, with important implications on oxygen production and transport of nutrients within vegetated open channels.

Experimental analysis and modeling were performed in this work, to provide additional understanding of the hydrodynamic interaction between riparian vegetation and flow at field scale in an abandoned reclamation channel colonized by rigid and emergent plants of Phragmites australis (Cav.) Trin. ex Steud., also known as Common reed. Different riparian vegetation management scenarios were evaluated: undisturbed conditions, partial riparian vegetation cover and total riparian vegetation removal. Field hydraulic tests were carried out for investigating the experimental cross-sectional distributions of streamwise velocity and main turbulence features (Reynolds stresses and Turbulent Kinetic Energy).

The outcomes of the experimental activities were employed for modeling the flow resistance of the examined vegetated reclamation channel by employing both 1D numerical simulations and literature models, which accuracies were assessed by comparing experimental and modeled vegetative global flow resistance coefficients. In the case of partial riparian vegetation cover, a methodology based on the detailed analysis of the experimental cross sectional streamwise velocity distribution was proposed. This methodology provides estimates of global flow resistance with prediction errors smaller than the direct application of the examined models.

The methods and applications discussed in this study represent an extremely useful scientific starting point for further research in the field of biomass monitoring and management identified across vegetated water systems worldwide.

Hydrogeological Assessment and Modelling for the Authorisation of Water Recharge in the Bereg Marshes

Éva Kun [1], György Tóth[1], Teodóra Szőcs[1], Nóra E. Gál[1], Andrea Szűcs Jordánné[1], Julianna Mekker[1], Zoltán Püspöki[1]

[1]SZTFH

Key Words: protected wetlands, groundwater, evapotranspiration, numerical modelling

An analysis under the Water Framework Directive should be carried out for all plans and interventions affecting water. Our focus area (contracted by the Hortobágy National Park Directorate) is the Bereg Plain. Bereg was an administrative county, its territory is now mostly in western Ukraine and a smaller part in north-eastern Hungary. The surface of the Bereg Plain is cut by the abandoned beds of the ancient rivers of the Quaternary period. The remains of the former bed of the river Tisza can also be seen in many places in the area, where the Bereg marshes have survived from the end of the Ice Age to the present day. Their survival is due to the cold microclimate with high humidity created by the forests and the acidic pH of the cation-poor groundwater near the surface. They are unique in terms of their biogeography, being the most southerly occurrences in Europe in lowland conditions. The aim is to ensure the long-term preservation of protected wetlands of high priority, typically formed in backwater. In this case, the abstraction of groundwater for the purpose of supplying and controlling stagnant water and backwater is in fact a groundwater-dependent ecosystem protection and as such can be considered an exceptional case. A finite difference modelling complemented with sequence stratigraphical and hydro-geochemical study was prepared to evaluate the effects of modified groundwater recharge in the Bereg marshes, and water management conclusions were drawn. The impact of cross-border (Ukraine) extraction and other water level reductions could only be accounted for in the model study, due to the lack of more detailed information, by an estimated reduction of the surface water levels, which increased the area of influence of the planned production increases but did not change the low value of the calculated water level reduction. The extent of groundwater evapotranspiration in the forests with higher trees and deeper roots in the Bereg area is well demonstrated. The effect of groundwater evaporation is also reflected in the groundwater level time series, indicating its important role in such ecosystems. The ecosystems here are also partly dependent on groundwater, and the effect of changes in infiltration on groundwater levels is relatively significant, with the effect of this being evident in the recent declines in water levels. Our investigations could continue with the Ukrainian region if our planned project is successful in the Danube Region Programme.

Hydrogeochemical and multi-isotope constraints on the geochemistry of the Bagno dell'Acqua alkaline lake, Pantelleria Island (Southern Italy)

Marino Domenico Barberio[1], Francesca Gori[1], Maurizio Barbieri[1], Tiziano Boschetti[1], Francesco Latino Chiocci[1], Marco Petitta[1]

[1]Sapienza University of Rome, Italy

Key Words: Alkaline lakes, Hydrogeochemistry, Isotopes, Monitoring

Alkaline lakes are among the aquatic environments on the Earth's surface with the most extreme conditions. Apart from the hydrogeological and hydrogeochemical interest in their peculiar saline features, their relevance lies in the understanding of such extreme ecosystems in relation to the origin of life. However, the temporal and spatial hydrogeochemical evolution of this kind of surface aquatic system is poorly understood due to the lack of suitable data. In order to take a step forward in the comprehension of this complex natural framework, since May 2021 to February 2023 we carried out continuous and discrete hydrogeochemical monitoring of the alkaline lake Bagno dell'Acqua (Pantelleria Island, Southern Italy), and of surrounding thermal and hypothermal springs and wells. This endorheic volcanic lake is located within a caldera depression and formed through the upwelling of the water table. The lake is constantly fed by thermal springs situated on its shores and occasionally by rainfall events. We continuously measured chemical-physical parameters of the lake by using two multiparametric probes. In addition, three hydrogeochemical screening surveys for the determination of the chemical content, including one for multi-isotopic measurements, were performed on approximately 10 sampling points including springs and lake. The continuous recorded data shed light on the substantial homogeneity of the water column, and on the dependence of chemical-physical properties on meteorological conditions. Results of major and trace elements analysis confirm the link between the lake and thermal springs. The efficient removal of Ca and Sr elements from lake water by mineral precipitation is also verified. New data from isotope analysis, including ∂18O, ∂2H, and ∂3H (H2O), ∂34S and ∂18O (SO4), 87Sr/86Sr ratio, and ∂11B, revealed the geochemical dynamic of springs and lake water. The main processes that regulate the geochemical composition of Bagno dell'Acqua can be summarized as follows: i) mixing between infiltered meteoric, and sea waters, ii) enrichment in alkaline elements due to intense water-rock interactions enhanced by deep thermal fluids (i.e., CO2), iii) salinization due to the high evaporation rate, and iv) precipitation of carbonate mineral phases. Our study provides a contribution to a wider study for the conservation of the biodiversity of the lake, and new insights for the evaluation of the environmental impact associated with climate changes.

Climate Change and Irrigation Practices Dissociate Reduction of N Fertilizers from the Improvement of Water Chemistry in Groundwater Dependent Rivers

Edoardo Severini[1], Monia Magri[1], Elisa Soana[1], Marco Bartoli[1], Fulvio Celico[1]

[1]University of Parma

Key Words: GDE, Irrigation, Nitrate, Climate change

In the last decades the intensification of agricultural practices has deeply altered nitrogen (N) and water cycles. Climate change is expected to further modify the hydrological cycle, in particular in southern Europe, also producing indirect effects on N cycling through the adaptive strategies that farmers will put in action.

The effects of climate change on biogeochemical cycles, especially within agroecosystems, are scanty in the literature.

Here we show how the Chiese River watershed (northern Italy) can serve as an interesting opportunity to analyse the effects of climate change on water use in agriculture and its implication on N contamination. In summer, the Chiese River is dried out for irrigation purposes. Nevertheless, most of the irrigation is sustained by the wells drilled in the phreatic alluvial aquifer. Wells-based irrigation over permeable and fertilised soils and percolation of NO3- from the vadose zone to groundwater result in accumulation of NO3- along the groundwater flowpath and limited losses via denitrification due to dominant oxic conditions. The climate change-related larger use of wells for irrigation maintains elevated nitrate concentrations in the groundwater and contrasts other measures targeting the reduction of N excess over arable land. In the Chiese watershed the Soil System Budget revealed a decrease of N surplus (by 44% from 2000 to 2018) and today accounts for 132 Kg N ha-1 y-1. Nevertheless, in two monitored wells the nitrate (NO3-) concentration remained high and stable, with an average of 65.3 mg NO3- L-1 and up to 98 mg NO3- L-1. The dried-out Chiese river gains part of the groundwater used for irrigation and NO3- concentration at the river mouth approaches 20 mg NO3- L-1 during the irrigation period.

Our results demonstrate how, from the 2000's, the overabundant fertilization and flooding irrigation via groundwater abstraction increase the N concentration in the river and groundwater, leading to the violation of both Nitrate and Water Framework directives. In February 2023, the European Commission sent a reasoned opinion to Italy for failure to fully comply with the Nitrates Directive. We anticipate our assay to be a starting point for the conversion of the northern Po Plain to more efficient irrigation and fertilization practices to contrast climate change effects, which will otherwise lead to the inevitable deterioration of surface and groundwater quality.

Karst Lakes Fragile Environments to be Known and Protected

Luca Zini[1], Chiara Calligaris[1], Christian Leone[1], Pietro Rai[1], Philippe Turpaud[1]

[1]Università degli Studi di Trieste

Key Words: Karst, Polje, Tracer test, Karst Lake

The westernmost part of the Classical Karst Region, a cretaceous carbonate aquifer shared between Italy and Slovenia, is characterised by the presence of four lakes in an area of only 25 km2 (Mucille, Doberdò, Pietrarossa and Sablici). These lakes, in a context of mature karst, are subject to ephemeral inundation due to the water table fluctuation. Consequently, these unique wet environments host a luxuriant vegetation and an extremely rich biodiversity. This area is a fragile territory endangered by invasive anthropic activities (dams, land reclamation works, …) and climate change (prolonged heat waves, droughts and flash floods). Despite the small size of the area, the hydrogeological links between the different structures are quite difficult to decipher. Several experiments are still ongoing to better constrain the hydrogeology and to preserve and restore the naturalness of the area. Few years ago, several dye-trace experiments were performed from the Doberdò lake, topographically the higher one of the area. In 2020 a dam field experiment was realized in this lake to verify the best practice to avoid its gradual burial. During 2017 and 2020, the polje of Mucille was deeply investigated to define the mechanisms of the increase of the flood frequency. No later than March 2023, a dye-tracer experiment took place in the area of Sablici emphasizing the complexity of a very small but extremely important place. Indeed, this lake is close to a freshwater tapping point of the Trieste water supply system and in the vicinity of heavily trafficked infrastructures such as state road, motorway and railway, which have been in the past source of pollution. The results obtained during these studies allow to better clarify the connections between the different areas and to highlight that karst environments are challenging systems to comprehend. These researches also highlight how the influence of the anthropic activities jointly with climate changes had a strong impact on the lakes area hydrogeology and consequently on the whole system. Furthermore, these results might provide insights for comprehensive proposals of protection protocols. Indeed, biodiversity, drinking-water quality and aquifer reserves quantity must be considered in the recommendation to help the system to maintain its resiliency.

The Contribution of Occult Precipitation to Karst Aquifers Recharge in Semi-Arid Zones

Laura Sanna[1]

[1]***CNR – IGAG***

Key Words: Stable isotope, Groundwater recharge, Karst hydrogeology, Global change

Decreasing rainfall and increasing evapotranspiration due to climate change are among the main pressures that affect the availability of groundwater resources, especially in karst areas. Around 25% of the global population receives drinking water from karst aquifers. In many semi-arid regions, karst springs are often the only accessible freshwater source and their karst groundwater are particularly sensitive to hydrological changes related to modification of rainfall patterns, particularly during droughts. It is evident how critical is It is evident how critical is to improve knowledge of karst aquifers recharge for managing and preserving their resources of karst aquifers recharge for managing and preserving their resources.

In a framework of rising temperatures and change in the rainfall regime, occult precipitation represent a further atmospheric moisture sources available as support to the local hydrological budget at regional scale. This process occurs naturally in different environments around the World when air humidity is high and its condensation forms water droplets. Although this precipitation are not detected by standard rain gauges, it is considered an additional water input relevant for groundwater dependent ecosystems.

In this study, the contribution of the occult precipitation to the hydrogeological balance of the gypsum karst of Sorbas (a semi-arid zone in Southern Spain) has been investigated analysing water stable isotope signature of rain, springs, cave drippings and condensation of atmospheric vapour within karst systems coupled with cave meteorological data.

The results show that favourable conditions for occult precipitation occur seasonally, starting from summer and continuing until December. In this period, the ephemeral water input to the karst aquifer recharge has been estimated to be a significant proportion of groundwater, sustaining the hydrological baseflow during the hot and dry season.

Session 4

Groundwater Dependent Ecosystems

Poster Presentations

Groundwater Recharge Area Assessment Using Stable Isotopes Tracers: Examples in the Alpine (Italy) and Andean (Ecuador) Regions

Luis Miguel Santillan Quiroga[1], Daniele Cocca[1], Manuela Lasagna[1], Chiara Marchina[1], Domenico Antonio De Luca[1]

[1]University of Turin

Key Words: Alps, Andes, groundwater recharge, stable isotopes

The stable isotopes of oxygen and hydrogen are commonly used as tracers to determine the recharge area of groundwater resources.

In the Chibunga river basin (Chimborazo province, Ecuador, volcanic area), 3 sampling campaigns were carried out from December 2020 to March 2022, in an area of 522 km2, to determine the recharge altitude of the aquifer used for drinking water purposes by the city of Riobamba. Water was sampled in 13 springs, 1 lake, 7 rainwater collectors, 3 rivers, and 11 wells, at altitudes ranging from 2750 to 4790 m asl. The geological setting of the basin shows stratified lavas and pyroclastic deposits. Based on isotope concentrations, the average height of the groundwater recharge area is 3750 m asl, corresponding to the base of the volcano (δ18O: -18.2/-10.8‰, δ2H: -126.4/-80.8‰(min/max)).

In the Mont Avic Park (Alpine sector, NW Italy, metamorphic rocks, and glacial deposits), the Chalamy river basin was analysed. 5 sampling campaigns were carried out from May 2021 to September 2022 in an area of 32 km2, covering 11 lakes, 5 rainwater collectors, 2 rivers and the "Perrot" spring. They are located at altitudes between 1200 and 2600 m asl. The valley, characterised by steep slopes and rocky outcrops, shows a plateau with many glacial lakes. Based on isotope concentrations, the average recharge altitude of the spring used for drinking water purposes is 2050 m asl (δ18O: -13.41/-7.10‰, δ2H: -96.01/-40.34‰(min/max)).

In the Maggiore Valley (Po plain sector, NW Italy, incoherent permeable deposits) a well field of regional importance is present. The recharge areas of deep exploited aquifers were studied. 2 sampling campaigns were carried out in 2021 with 50 samples regarding shallow and deep aquifers and rivers, at an altitude below 400 m a.s.l. The study identified the recharge areas mainly in Alps reliefs, with an average recharge elevation of about 1100 m a.s.l. A minor contribution resulted from the shallow aquifers in the plain sectors; moreover, an important groundwater mixing between shallow and deep aquifers in the Po riverside plain was identified (δ18O: -12.5/-8‰, δ2H: -79.2/-48.7‰(min/max)).

The recharge areas and main existing processes were highlighted with stable isotopes, confirming the usefulness of their use in different contexts.

Drivers of Taxonomic and Functional Diversity of a Volcanic-Sedimentary Porous Water Table Aquifer

Tiziana Di Lorenzo[1], Stefano Amalfitano[2], Stefano Ghergo[2], Daniele Parrone[2], David Rossi[2], Annamaria Zoppini[2], Diana Maria Paola Galassi[3], Agostina Tabilio Di Camillo[3], Elisabetta Preziosi[2]

[1]CNR-IRET and NBCF

[2]CNR-IRSA

[3]UNIVAQ

Key Words: groundwater, microbial communitie, crustaceans, biogeochemistry

Groundwater hosts a high diversity of invertebrates, which show morphological, physiological, and behavioral adaptations to thrive in the energy-limited, oxygen-depleted, and thermally stable subterranean environment. Groundwater invertebrate diversity patterns are influenced by both long- and short-term environmental conditions, such as geochemistry, lithology and anthropogenic contaminants. However, the role of the local hydrogeochemical settings and key environmental variables in influencing the distribution of groundwater species is still little explored. In the present study, we investigated the taxonomic and functional diversity of the groundwater invertebrate assemblage of a volcanic-sedimentary porous water table aquifer near Rome (Sabatini Mountains, Italy). We predicted that the biogeochemical characteristics and lithology of different aquifer areas would be reflected in the taxonomic and functional composition of the invertebrate assemblage. To this end, we collected groundwater samples from private wells and springs from alluvial, volcanic, and fractured volcanic settings from March 2012 to December 2014. Overall, we collected 424 crustacean specimens belonging to 9 taxa, of which 7 are obligate groundwater dwellers (stygobites). We emphasize the collection of the Tertiary relict of ancient marine origin, the stygobitic harpacticoid Pseudectinosoma reductum (Crustacea, Copepoda). Overall, the taxonomic and functional structure of the biological assemblage was intimately associated with the geochemistry of groundwater, suggesting that the abundance of invertebrates is linked with the circulation of deep geothermal groundwater through fractures. This finding suggests that the role of long-term factors overcomes that of more contemporary drivers in shaping the assemblage structure.

Figure 1- Valletta, Old railway train station

Figure 2-Valleta, Siege Bell War Memorial

Figure 3-Marsamxett Harbour

Figure 4- Sliema, Sea water distilling monument.

Figure 5- Marsamxett Harbour

Figure 6- Corinthia Hotel - Flowpath Conference

List of participants

1. Matthew Agius
2. Luca Alberti
3. Luigi Alessandrino
4. Pasquale Allocca
5. Claudio Arras
6. Sara Barbieri
7. Angela Barolo
8. Rebecca Bartolo Cutajar
9. Alessandro Berta
10. Julia Bonello
11. Mojgan Bordbar
12. Staša Borović
13. Gianluigi Busico
14. Ella Busuttil
15. Charles Buttigieg
16. Raisa Cachia
17. Chiara Calligaris
18. Costanza Cambi
19. Corrado Camera
20. Davide Cappellari
21. Maria Clementina Caputo
22. Alfred Caruana
23. Mary Caruana
24. Tommaso Casati
25. Mariachiara Caschetto
26. Maria Elena Cavallini
27. Claudia Cherubini
28. Andrea Citrini
29. Daniele Cocca
30. Silvio Coda
31. Nicolò Colombani
32. Paolo Colombo
33. Stefania Da Pelo
34. Mara Dal Santo
35. Adriana Damato
36. Lorenzo De Carlo

37. Francesco Maria De Filippi
38. Henry Debattista
39. Justin Demanuele
40. Francesco Demichele
41. Diego Di Curzio
42. Alessia Di Giovanni
43. Tiziana Di Lorenzo
44. Lucio Di Matteo
45. Marco Donnini
46. Walter Dragoni
47. Daniela Ducci
48. Laura Ducci
49. Egidio Elena
50. Eriberto Eulisse
51. Daniel Farrugia
52. Luke Farrugia
53. Maria Rosaria Ferragonio
54. Maria Filippini
55. Giovanni Forte
56. Stefania Franchini
57. Fronzi Davide
58. Ondine Gaerty
59. Rossella Maria Gafà
60. Mattia Gaiolini
61. Nóra E. Gál
62. Charles Galea
63. Luke Galea
64. Pauline Galea
65. Alessandro Gargini
66. Nadia Gatt Gafa
67. Gilbert Gauci
68. Giasi Concetta
69. Martina Gizzi
70. Francesca Gori
71. Dunstan Hamilton
72. Joanna Incorvaja
73. Angela Ingenio
74. Ata Joodavi

75. Éva Kun
76. Francesco La Vigna
77. Laura Landi
78. Manuela Lasagna
79. Luca Laudi
80. Francesca Lobina
81. Antonia Longobardi
82. Valeria Lorenzi
83. Francesca Lotti
84. Alice Lucchelli
85. David Macdonald
86. Julian Mamo
87. Susanna Mancini
88. Alex Manucci
89. Massimo Marchesi
90. Pier Andrea Marras
91. Lucio Martarelli
92. Dario Masante
93. Marco Masetti
94. Micol Mastrocicco
95. Mazzon Pietro
96. Melillo Massimo
97. Marzio Melis
98. Antonio Menghini
99. Mercieca Claude
100. Dejan Mizzi
101. Veronica Mizzi
102. Alice Murgia
103. Marco Saulo Nannucci
104. Maria Margarita Ntona
105. Jimenez Isaac Ojea
106. Giuseppe Onorati
107. Matteo Paoletti
108. Paolucci Vittorio
109. Dongkyu Park
110. Nicola Pastore Nicola
111. Marco Petitta
112. Emma Petrella

113. Paola Petrone
114. Riccardo Pinardi
115. Pisani Christa
116. Fabrizio Antonio Piscedda
117. Vincenzo Piscopo
118. Marco Pola
119. Marta Polimeno
120. Porru Maria Chiara
121. Elisabetta Preziosi
122. Ernesto Pugliese
123. Michelle Radovanovic
124. Pietro Rai
125. Agnese Redaelli
126. Cinthya Ribero
127. Rachelle Riolo
128. Stefan Riolo
129. Pietro Rizzo
130. Mauro Rossi
131. Marco Rotiroti
132. Sergio Rusi
133. David Sacco
134. Umair Sajjad
135. Spiteri James Saliba
136. Laura Sanna
137. Luis Miguel Santillan Quiroga
138. Manuel Sapiano
139. Davide Sartirana
140. Chiara Sbarbati
141. Saviour Scerri
142. Michael Schembri
143. Dylan Schembri
144. Christoph Schuth
145. Antonio Maria Sessini
146. Edoardo Severini
147. Stefania Stevenazzi
148. Surian Benedetta
149. Glenda Taddia
150. Alberto Tazioli

151. Ariel Thomas
152. Roberto Tonucci
153. Andrea Vacca
154. Daniela Valigi
155. Vanessa Vella
156. Hiba Wazaz
157. Kim Yongcheol
158. Chiara Zanotti
159. Luca Zini

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