MINISTRY FOR THE ENVIRONMENT, ENERGY AND ENTERPRISE
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WATER BE THE CHANGE

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Flowpath 2023

National Meeting on Hydrogeology

Conference Day 2

Thursday 15th June 2023

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1. Executive Summary

The National Meeting on Hydrogeology Day 2 Conference took place on Thursday 15th June 2023. The conference provided an opportunity to discuss the hydrological characteristics of Malta and enhanced opportunities for increased cooperation between the Italian and Maltese hydrological communities.

The conference was held at 5-Star superior Corinthia Hotel in St Julian's.

Participants were able to sign up for the workshop through the link https://water.org.mt/join-the-drops/6th-edition-flowpath/, where they could fill in a form, or by calling +356 2777 2777, or by sending an email to info@emcs.com.mt to register.

The ample parking spaces and Corinthia's perfect location facilitated the attendance of the participants. A seated lunch was organised for all attendees as well as two coffee breaks where networking was possible.

In total, 130 people attended this conference. The attendees were made up of private and public individuals, PhD students, and different ministerial representatives. All attendees registered their attendance at the registration desk. The conference was open to all, and walk-ins were also accepted on the day.

The conference lasted till early in the evening and was hosted by Mr Keith Demicoli, a well-known TV presenter and moderator. The workshop consisted of 28 presentations delivered by different experts in the sector. Throughout the report, one can find the presentations that were used by the various speakers, as well as the key points of each speech.

Exhibition stands were set up next to the coffee facilities. In the seated area, a notepad and pencil were provided for each participant. Various Water Be the Change campaign related merchandise items including pencils, pens, notebooks and sticky notes were also available at the exhibition stands.

2. Conference Agenda

Date: June 15th, 2023

Venue: Corinthia Hotel, St Julian's, Malta

Time	
08:30	**Registration**
09:00	**Part 1** Keynote Speech 1: The Potential Contribution of Ancient Water Cultures to Groundwater Management in Achieving the SDGs | Dr Eriberto Eulisse Keynote Speech 2: Water management in times of climate change – do we have a water problem in Germany? The case of the Hessian Ried | Prof. Christoph Schuth
09:30	**Part 2** Session 3: Emerging Challenges to Groundwater Quantity and Quality | Conveners: Dr Claudio Arras & Dr Julian Mamo Stochastic Simulation for Defining NO3 and F Background Levels in Different Groundwater Bodies of the Campania Region | Dr Gianluigi Busico Radar Precipitation Data as Functional Input for Deriving the Potential Volume of Water Available for Infiltration: The Pilot Case of Lombardy Region | Mr Andrea Citrini The Sustainable Yield of a Well in Low-Permeability Fractured Aquifers: New Insights from Pumping Tests Interpretation | Ms Chiara Sbarbati Multidisciplinary Investigation of Groundwater Flow in Unsaturated Slopes Susceptible to Shallow Flow Slides | Dr Giovanni Forte
11:00	**Coffee Break & Poster Session**
11:30	**Part 3** New Insights on Groundwater Flow of The Tavo Tapped Karst Springs (Gran Sasso Aquifer, Central Apennines) Using Tracer Tests | Dr Valeria Lorenzi. Modelling Transient Groundwater Flow Dynamics in The Tabriz Unconfined Aquifer Near Urmia Lake (Iran) | Ing Mattia Gaiolini. Climate Change Resilience in The Poor Hydrogeological Setting of The Northern Apennines: The Case of The Nadìa Spring | Dr Maria Filippini First Hydrogeological Water Balance in The High and Middle Venetian Plain Between Mincio and Tagliamento Rivers (NE, Italy) | Dr Davide Cappellari Unravelling The Aquifer-Scale Competition for Organic Substrate in A Polluted Aquifer by Interpreting Multivariate Statistics Through Scenario-Based Hydrogeochemical Modelling | Dr Diego Di Curzio. Application Of Multivariate Statistical Analysis for The Delineation Of Groundwater Bodies: A Case Study In Campania Region (Southern Italy) | Dr Stefania Stevenazzi.
13:00	**Lunch & Poster Session**

14:00	**Part 4**
	Changes In Shallow Groundwater Recharge Due to Drought Impacting the Po River Basin | Prof Marco Rotiroti Groundwater Sustainable Development in Mountainous Aquifers for Adaptation to The Effects of Climate Change: A Case Study in The Northern Apennines | Ms Laura Landi Groundwater Flow Modeling for The Sustainable Exploitation of The Monte Castello Aquifer | Dr Pietro Rai Enhanced Thermal Response Test Interpretation Through MODFLOW-USG And PEST_HP | Ms Sara Barbieri Impact Of Drought on The Piedmont Plain (NW, Italy) Water Resources: Current Status and Predictions in The Context of Climate Change | Dr Susanna Mancini Estimation Of Transit Time Along the Unsaturated Zone in The Protection of Groundwater Resources | Ms Francesca Lobina The Role of Carbonate Faults on Groundwater Circulation: The Case Study of Monte Marine Fault (Central Apennines, Italy) | Ms Emma Petrella Towards groundwater-level prediction using Prophet forecasting method by exploiting a high-resolution hydrogeological monitoring system | Dr Davide Fronzi Impact Of Climate Change on Water Resources: Considerations Regarding the Uncertain Future of Water Resources in The Central Apennines (Italy) | Prof Walter Dragoni
16:15	**Coffee Break & Poster Session**
16:45	**Part 5**
	Session 4: Groundwater Dependent Ecosystems | Convener: Dr Maria Filippini Keynote Speech 4: Diversity, Traits, Services, Vulnerability and Conservation of Groundwater Ecosystems | Dr Tiziana Di Lorenzo Hydrogeological Assessment and Modelling for The Authorisation of Water Recharge In The Bereg Marshes | Ms Eva Kun Hydrogeochemical And Multi-Isotope Constraints on The Geochemistry of The Bagno Dell'acqua Alkaline Lake, Pantelleria Island (Southern Italy) | Dr Francesca Gori Climate Change and Irrigation Practices Dissociate Reduction of N Fertilizers from The Improvement of Water Chemistry in Groundwater Dependent Rivers | Dr Edoardo Severini Karst Lakes Fragile Environments to Be Known and Protected | Mr Luca Zini The Contribution of Occult Precipitation to Karst Aquifers Recharge in Semi-Arid Zones | Dr Laura Sanna Towards EuroKarst 2024 (Presentation)
18:50	**Concluding Session**

3. Detailed report of conference proceedings

3.1 Part 1

DR ERIBERTO EULISSE, CEO, GLOBAL NETWORK OF WATER MUSEUMS

KEYNOTE SPEECH 1: THE POTENTIAL CONTRIBUTION OF ANCIENT WATER CULTURES TO GROUNDWATER MANAGEMENT IN ACHIEVING THE SDGS

Dr Eulisse stated that the contribution of water museums and ancient hydro-technologies is crucial in achieving the goals of sustainability in groundwater management. He emphasized the importance of making the invisible visible and highlighted the role of water museums in supporting science communication and policy makers in targeting sustainability in managing groundwater. According to Dr Eulisse, museums are considered reliable sources of information in the common opinion. He elaborated that they have the ability to address and explain complex problems in simple ways, making them effective communicators with the public. Additionally, the speaker posited that museums serve as safe learning platforms for both adults and children, offering experiential learning opportunities and promoting awe and wonder. Dr Eulisse discussed the evolving functions of museums, noting new trends in popup exhibits for community engagement. Museums, for Dr Eulisse, have shifted from the concept of "collections" and classified objects to promoting heritage awareness and communicating global challenges in the Anthropocene. He elaborated that Science museums, Eco-museums, and "extended museums" now focus on connecting with local communities and seeking greater involvement of locals.

In order to effectively communicate groundwater challenges, Dr Eulisse emphasized that science alone is not sufficient; a bridge between science and society must be created to address the challenges of the Anthropocene. He put forth that museums, with their ability to engage the general public, serve as cornerstones of this bridge, as they act as agents of change and provide platforms for networking and exchange. Dr Eulisse highlighted the UNESCO-IHP Resolution N.5-XXIII (2018), which established the Global Network of Water Museums (WAMU-NET) as a flagship initiative of UNESCO-IHP. He mentioned the "Agua Para Siempre!" museum in Puebla, Mexico, which was created by local communities in a semi-arid area. The speaker explained that the museum showcases the local people's attachment to their identity and culture in relation to water, contrasting with the state's approach. WAMU-NET, as stated by Dr Eulisse, is committed to building a new culture of water and reinstating a new relationship between humanity and water that encompasses scientific, technical, social, cultural, artistic, and spiritual dimensions.

Dr Eulisse referred to Phase 9 of the IHP Strategic Plan (2022-2029) and discussed its five priorities. He also recognized WAMU-NET as a key institution involved in promoting water sustainability education. Priority 2 of IHP Phase 9, as stated by the speaker, emphasised the importance of broad water education to encourage a change in behaviours towards greater eco-social awareness. He informed that UNESCO-designated sites and the Global Network of Water Museums are mobilized to raise awareness and improve the water culture of citizens through interdisciplinary materials and leading practices in water education for mass media.

In conclusion, Dr Eulisse highlighted the significant contribution of water museums and ancient hydro-technologies in achieving sustainability in groundwater management. He reiterated that these museums serve as powerful tools for science communication, policy making, and promoting a new culture of water that values ecosystem sustainability, as well as facilitating the necessary bridge between science and society, fostering greater awareness and understanding of groundwater challenges.

Question: How can the scientific community become more involved in water?

Dr Eulisse stated that there are different ways of operating together. He acknowledged that in Italy one of the main goals is to develop a shared practice related to ancestral knowledge. Dr Eulisse noted that this topic is currently missing within UNESCO and IHP, and thus, are seeking cooperation to address this gap. The speaker informed that there are 9 UNESCO chairs, mostly from Europe, that form a group of scientists dedicated to furthering this cause. Recently, Dr Eulisse explained that efforts have been made to incorporate an environmental approach. Over the past 2 years, the speaker elaborated that a series of webinars have been organized, with the aim of involving artists in conveying new messages to larger audiences. He affirmed that this initiative plays a vital role in raising awareness about key topics and facilitating cooperation among interested parties.

PROF. CHRISTOPH SCHÜTH, TECHNICAL UNIVERSITY OF DARMSTAD

KEYNOTE 2: WATER MANAGEMENT IN TIMES OF CLIMATE CHANGE – DO WE HAVE A WATER PROBLEM IN GERMANY? THE CASE OF THE HESSIAN RIED

Prof. Schüth stated that climate change is indeed a reality in Germany, although its severity may not be as pronounced as in southern regions. He emphasized that while precipitation itself may not be a significant problem, the combination of reduced precipitation and higher temperatures poses challenges for water management. The Hessian Ried region, which Prof. Schüth informed is located in the upper Rhine valley between the Main, Rhine, and Neckar rivers, and the Odenwald mountains, is of particular interest in this discussion. He elaborated that it is characterized by a thick sedimentary fill of the graben structure, making it a vast aquifer with abundant water resources. However, the speaker acknowledged that this area also faces significant water demands, especially due to its intensive agricultural activities, occupying approximately 33% of the region.

Prof. Schüth highlighted the historical background of the Hessian Ried, explaining that before the 19th century, the Rhine River meandered through the valley, resulting in a swamp-like landscape and causing health issues such as malaria among the population. According to Prof. Schüth, in order to address these challenges, the engineer Johann Gottfried Tulla initiated a project to straighten the Rhine, which was completed in 1876. The speaker noted that the groundwater in the Hessian Ried is highly dynamic, characterized by fluctuating water tables. He also informed that wet years could lead to flooding, while dry years with organic-rich layers can cause subsidence and damage to buildings. Moreover, the speaker noted that groundwater resources in the region face competing demands for agriculture (particularly irrigation) and public water supply, such as the city of Frankfurt and southern Hesse, as well as the preservation of ecosystem services like forests.

In the 1960s and 1970s, the Hessian Ried experienced a sharp decline in groundwater tables. Prof. Schüth attributed this decline to urbanization, stating that large cities like Frankfurt require significant water resources, often imported from distant locations. according to Prof. Schüth, the increasing urbanization in the region, has disrupted water cycles, resulting in large surface areas being sealed, reduced evapotranspiration and infiltration, and the generation of substantial quantities of wastewater. As a consequence, the speaker noted that the reliance on local water resources has decreased due to quality issues, necessitating the importation of water. To address these challenges, the Water Association Hessian Ried was established in 1979. Its duties, as outlined in Prof. Schüth's presentation, include providing water for agricultural irrigation, groundwater infiltration, ensuring a safe and reliable public water supply, and improving the ecological situation in the area. Additionally, Prof. Schüth stated that the association is guided by the "Groundwater-Management-Plan," which aims to maintain groundwater levels within specified upper and lower thresholds through the adjustment of infiltration and extraction rates. One crucial element of water management in the region, as explained by Prof. Schüth, is the Biebesheim Waterworks, which treats Rhine water to drinking water quality. The treated water has been used for irrigation and infiltration purposes since the 1990s.

Prof. Schüth affirmed that various infiltration systems have been implemented in the Hessian Ried; these include artificial trenches, large-diameter wells, and former drainage trenches repurposed for infiltration. Prof. Schüth emphasized the importance of resilience through infrastructure in water management and distribution in southern Hesse. While concerns were initially raised about small local water providers being marginalized with the integration of supply networks, Prof. Schüth assured that these providers continue to operate. He underscored the significance of utilizing local resources to enhance the overall resilience of the water management system, noting that the interconnected systems offer backup solutions during supply difficulties in specific areas. Prof. Schüth stressed that this does not render local water providers redundant; on the contrary, their presence and utilization of local resources are vital in strengthening the system's ability to withstand challenges. Turning our attention to the water supply in Frankfurt Rhein-Main, Prof. Schüth revealed that approximately 50% of the water in the southern part of Frankfurt is sourced from native groundwater, while the remaining 50% is obtained from treated and infiltrated Rhine water. He discussed how this combination of water sources reflects the region's reliance on both local resources and external water supplies to meet the demands of a growing population.

Prof. Schüth concluded that it is crucial to continue monitoring and adapting water management strategies in response to climate change. By prioritizing sustainability, efficient resource allocation, and the protection of ecosystems, he posited that a reliable and resilient water supply can be ensured for both present and future generations in the Hessian Ried and beyond.

Question: What are the options for water management? And who will be responsible if groundwater rises up too much?

Prof. Schüth stated that there are two main options for water management in the area: infiltration, where they can predict and prepare for incoming rainwater and also increase pumping if necessary, and pumping from a nearby water source that supplies the water system. He acknowledged that managing infiltration is easier as it is close to the pumping station, allowing for targeted pumping in specific areas with higher groundwater levels. However, he also agreed that if there is a consistent increase in rainfall over the years, it could lead to similar problems as in the past. Regarding responsibility and financial matters related to potential damages to houses or infrastructure, Prof. Schüth did not have specific information. Nevertheless, he mentioned that such issues have not occurred in recent years. Nevertheless, he highlighted the current concern about lower rainfall and rising temperatures, which could pose future challenges in the region.

Question: With regard to infiltration in the groundwater; how do you go about clogging issues and overall maintenance? Is the water inside reacting to gravity?

Prof. Schüth stated that the water treatment system employs gravity in long ditches filled with a sand and gravel mixture. According to the speaker, one significant benefit of this setup is that the water originates directly from the treatment process, minimizing the risk of clogging. Moreover, he noted that the sediments beneath the ditches exhibit excellent hydraulic conductivity.

3.2 Part 2

DR GIANLUIGI BUSICO, UNIVERSITY OF CAMPANIA LUIGI VANVITELLI

TITLE: STOCHASTIC SIMULATION FOR DEFINING NO3 AND F BACKGROUND LEVELS IN DIFFERENT GROUNDWATER BODIES OF THE CAMPANIA REGION

Dr Busico stated that the aim of the United Nations Sustainable Development is to ensure the availability and sustainable management of water and sanitation for all. Specifically, he informed that the aim is to address two key targets: achieving universal and equitable access to safe and affordable drinking water and access to adequate and equitable sanitation and hygiene by 2030. Dr Busico highlighted the current status of water and sanitation worldwide, emphasising that while there has been an increase in drinking water use from 70% to 74% between 2015 and 2020, there are still 2 billion people excluded from this essential service. Similarly, the speaker elaborated that sanitation coverage has improved from 47% to 54%, but approximately 3.6 billion people lack access. He also emphasised that hand washing with soap and water, a critical hygiene practice, has increased from 67% to 71%, but 2.3 billion people are still excluded.

To address these challenges, Dr Busico introduced several key datasets in his presentation. The MERIT (Map of global terrain elevations) dataset provides a high-accuracy digital elevation model, which is crucial for understanding the topography of the region. The Global Water Table depth (WTD) map offers insights into the depth to water globally. The World Soil Information Service (WoSIS) dataset provides valuable information on soil properties such as water retention, bulk density, electrical conductivity, organic carbon, and nutrient content. The BIGBANG Database offers monthly data on precipitation, snow cover, evapotranspiration, and recharge for the Italian Peninsula. Lastly, the Corine Land Cover dataset offers information on the spatial distribution of land use classes.

Dr Busico discussed stochastic simulation techniques to define the background levels of nitrate (NO3) and fluoride (F) in various groundwater bodies in the Campania Region. He noted that the goal is to contribute to the sustainable management of water resources and ensure the safety and quality of drinking water through means of analysis.

MR ANDREA CITRINI

TITLE: RADAR PRECIPITATION DATA AS FUNCTIONAL INPUT FOR DERIVING THE POTENTIAL VOLUME OF WATER AVAILABLE FOR INFILTRATION: THE PILOT CASE OF LOMBARDY REGION

Mr Citrini stated that the pilot case study aimed to understand the water availability and its distribution in the study area with the utmost accuracy. He noted that the study had several specific objectives. The speaker explained that firstly, it aimed to correct the radar signal in the study area by utilising data recorded from rain gauges, ensuring that the radar estimates were more reliable and suitable for hydrological applications. Another objective of the study, as outlined by Mr Citrini, was to define the mean annual Potential

Groundwater Recharge (PGWR) in the study area for the period of 2011-2020. He informed that by integrating data from rain gauges of the Italian network, the mean annual cumulative precipitation was successfully corrected. The speaker assured that the use of rain gauge data improved the accuracy of the estimates, as indicated by the increase in Kling-Gupta Efficiency (KGE) values.

Mr Citrini noted that in comparison of the study's results with the findings of ISPRA's national project “BIGBANG”, demonstrated a good agreement in terms of precipitation and PGWR magnitudes. Despite using different computational methods, he maintained that the research outcomes aligned well, validating the reliability of the pilot case study. The study also revealed that potentially more water is available for infiltration in the mountainous areas compared to the lowlands. However, Mr Citrini emphasised that a more comprehensive understanding of the phenomenon would require a more complex water balance equation and the inclusion of other geomorphological variables, such as slope.

Mr Citrini discussed the pilot case study in the Lombardy Region, which highlighted the practical application of radar technology and its significance in water resource management. Mr Citrini emphasised the need for further actions to operationalise this methodology. He informed that a Master's thesis study conducted by Matilde Di Nardo is currently exploring multiple approaches to enhance the research project. The speaker listed such enhancements as follows: moving from the annual scale to the event scale, expanding the weather station database to include rain gauges from neighbouring regions like Switzerland, testing additional interpolation techniques (both deterministic and geostatistical), and applying a more sophisticated water balance equation to obtain more accurate results considering the complexity of the phenomenon. Mr Citrini concluded that the study demonstrated the successful utilisation of radar precipitation data in deriving the potential volume of water available for infiltration. He underscored that the findings show the importance of radar technology in water resource management and provide a foundation for further advancements in this field.

Ms Chiara Sbarbati, Department of Ecological and Biological Sciences, Tuscia University

Title: The sustainable yield of a well in low-permeability fractured aquifers: new insights from pumping tests interpretation

Ms Sbarbati stated that she would be presenting new insights on the sustainable yield of wells in low-permeability fractured aquifers. Groundwater sustainability, defined as the development and use of groundwater without causing unacceptable environmental, economic, or social consequences (Alley et al., 1999), was the focal point of her speech.

Regarding the sustainable pumping flow rate of a well, Ms Sbarbati discussed two important factors. The first factor was the reliable yield of the well, which takes into account the supply constraints and potential yield based on the characteristics of the well and aquifer. The second factor was the sustainable yield of the well, referring to the discharge rate that would not cause the water level in the well to drop below a prescribed limit. The aims of the study presented by Ms Sbarbati were as follows:

- To analyse pumping tests conducted in low-diffusivity heterogeneous fractured aquifers.
- To assess the dependence of the sustainable yield of a well on the drawdown trend over time.
- To define a cost-effective procedure for planning the initial operation of a well in terms of flow rate and pumping time.

Ms Sbarbati explained that the study focused on two test sites located in Western Turkey. To conduct the investigation, according to the speaker, six constant long-term pumping tests were performed. She noted that pre-processing techniques were applied to the water level data to reduce acquisition noise and drawdown data versus time were analysed using semi-log plots. Ms Sbarbati assured that aquifer parameters such as transmissivity (T) and storativity (S) were also determined, and the most critical cases for long-term well productivity were selected. Pumping scenarios were implemented based on the observed drawdown trends.

Ms Sbarbati discussed the several observations she made with regard to the response of the aquifer and well to pumping. She outlined the following observations as such:

- The andesitic and metamorphic aquifers had strong heterogeneity.
- The variation in T and S values covered three orders of magnitude.
- The drawdown-time trend often differed between the pumping well and observation wells.
- In some cases, there was no correlation between drawdown and distance from the well.
- Pseudo-steady state and transient flow regimes were identified among the pumping tests.
- The well-specific capacity reflected the observed variability in T, ranging across three orders of magnitude.

Ms Sbarbati noted that the importance of test duration in these heterogeneous fractured aquifers was emphasized by all the conducted tests.

The results of the pumping tests, as reiterated by Ms Sharbati, provided valuable insights into the response of fractured aquifers to pumping and offered guidance on the sustainable yield of wells. Ms Sbarbati concluded that the drawdown trend over time, measured in the pumping well, appeared to be the key factor in determining the sustainable yield of the well, surpassing the influence of hydraulic parameters. She also recommended conducting pumping tests at constant flow rates for significant durations.

Dr Giovanni Forte, University of Naples Federico II

Title: Multidisciplinary investigation of groundwater flow in unsaturated slopes susceptible to shallow flowslides

In his presentation, Dr Forte focused on the multidisciplinary investigation of groundwater flow in unsaturated slopes susceptible to shallow flow slides. He highlighted the main features of flow slides, including the triggering factors such as rainwater infiltration and the predisposing factors related to the local geomorphological, topographical, and stratigraphic setting. Dr Forte stated that the primary aim of his study is to characterize the hydrogeological behaviour of pyroclastic slopes, which involves studying the role of variability in different soil horizons in terms of their continuity and thickness. Additionally, Dr Forte investigated the dynamics at the stratigraphic contact between the soil cover and bedrock.

To achieve comprehensive characterization and monitoring, Dr Forte employed a range of equipment, such as a weather station with instruments such as pluviometers, air thermoigro-meters, radiometers, anemometers, and gonio-anemometers. He informed that manual and automatic soil monitoring equipment such as tensiometers, TDR (Time Domain Reflectometry), triaxial accelerometers, digital thermometers, watermark sensors, and Decagon sensors were also utilized. Furthermore, Dr Forte noted that geological and geotechnical characterization was conducted through the drilling of 25 boreholes, excavation of 6 trenches, implementation of 9 ERT (Electrical Resistivity Tomography) surveys in different seasons, and the creation of stratigraphic cross-sections. Grain-size and physical properties assessments, along with laboratory tests, complement the research efforts. Dr Forte presented a numerical model that solves the water continuity equation in 2D, treating the soil as a continuous medium with a rigid solid skeleton. He maintained that this Finite Element Method (FEM) model incorporates key factors such as mesh geometry, boundary conditions, permeability and retention curves, and net infiltration resulting from rainfall.

Based on his research findings, Dr Forte drew several conclusions. He highlighted the significant role of soil horizon variability in terms of continuity and thickness. For instance, the presence of the pumice layer B facilitates downward water drainage, resulting in reduced volumetric water content (VWC) in the upper layers and increased VWC in the lower layers. Dr Forte observed that a thicker pumice layer leads to lower VWC in the upper layers. Additionally, he noted that the lack of continuity in the pumice layer can lead to the formation of suspended water lenses along the slope. The aquitard layer C2, according to Dr Forte was found to contribute to the formation of a suspended groundwater table, consequently increasing the VWC. Furthermore, Dr Forte emphasized the importance of studying the interactions at the stratigraphic contact between the soil cover and bedrock. Moreover, he explained that the distribution of groundwater is influenced by the buried paleo-morphology of the bedrock. Through a multidisciplinary approach and the integration of various monitoring techniques and numerical modeling, Dr Forte's work contributed to a comprehensive understanding of these complex processes. He posited that the findings could inform the development of effective mitigation strategies for such geohazard-prone areas.

Questions: Have you used any strategies to optimise the definition of the variability model?

Dr Busico stated that unfortunately, biases were found in the results and data manipulation. He maintained that the goal now is to overcome these issues by implementing a completely new strategy. He informed that the study area will be divided into specific conditions, and each issue will be addressed separately to prevent any data clustering that might affect the results. Although some differences are still visible, Dr Busico elaborated that there is not a significant contrast between the Wall approach and the Systematic approach. The challenge, according to the speaker, lies in justifying the use of machine learning algorithms to present more equitable results. Therefore, he acknowledged that the focus is shifting towards an approach that enhances result stratification. He noted that this project is still a work in progress since it recently began, however, the positive aspect is that the results obtained so far are consistent.

3.3 Part 3

DR VALERIA LORENZI, SAPIENZA UNIVERSITY OF ROME

TITLE: NEW INSIGHTS ON GROUNDWATER FLOW OF THE TAVO TAPPED KARST SPRINGS (GRAN SASSO AQUIFER, CENTRAL APENNINES) USING TRACER TESTS

Dr Lorenzi began her presentation by describing the hydrogeological setting of the Gran Sasso Aquifer in Central Italy. She stated that the Gran Sasso aquifer in Central Italy encompasses a vast calcareous-karstic ridge. Its springs display consistent discharge levels throughout the year, with groundwater being supplied by the fracture network and buried karst system. Main faults divide the groundwater flowpaths, and the Campo Imperatore basin acts as a key recharge area. It is important to note that the aquifer is located within a National Park and is traversed by a highway tunnel, which affects its hydrological dynamics.

She went on to explain that in April 2022, a tracer test was conducted in the northeastern section of the Gran Sasso aquifer, focusing on two prominent springs: the Vitella d'Oro spring (GS5) and the Mortaio d'Angri spring (GS6). The Vitella d'Oro spring receives water from two different sources. Part of its flow is derived from the basic carbonate aquifer, while the remainder originates from direct infiltration into the Rigopiano Conglomerates. The latter leads to the activation of the karst network in the Rigopiano ditch, which is often accompanied by increased turbidity. This combination of water sources results in multiple vulnerabilities within the spring system. The discharge rate of the Vitella d'Oro spring is approximately 303 litres per second. On the other hand, the Mortaio d'Angri spring serves as an outlet for the regional aquifer. It receives groundwater inflows from the Campo Imperatore, with a discharge rate of around 250 liters per second.

During the tracer test, two safe and environmentally friendly tracers, uranine and naphtionate, were used. The injection point was located in the Rigopiano ditch. The test measured the dispersion of the tracers over distances of 1.2 km to the I Fluorometer (Vitella d'Oro spring catchment area, 748 m asl) and 1.4 km to the II Fluorometer (Tavo River, 610 m asl). The tracers were injected with a one-hour interval, using 20g of uranine and 100g of naphthionate.

As part of the tracer test, the Albillia FL30 Fluorometer probe was installed to monitor the dispersion of tracers. The field fluorometer recorded data every 5 minutes. Continuous monitoring and traditional sampling using amber glass bottles were conducted. Charcoal bags were also deployed near the monitoring and injection points to capture any residual traces of the tracers. After the test concluded, the used charcoal bags were replaced with fresh ones at the same locations, considering the potential for tracer movement through activated karst conduits even after the test had ended. During the tracer test, the discharge rates at various points within the aquifer were measured. The Tavo River exhibited a discharge of 439 l/s, while the Vitella d'Oro spring had a discharge of 378 l/s. At the injection point, the discharge was recorded at 32 l/s.

The water samples collected during the tracer test were analysed at the University of Karlsruhe Institute of Technology (KIT) laboratory in Germany using the Perkin Elmer LS-55 laboratory fluorometer. This fluorescence spectrophotometer utilizes a pulsed xenon lamp as the excitation source. The presence of the tracers in the samples was detected by observing the appearance of their respective peaks in the sample spectrum. Uranine exhibited an absorption maximum at 490 nm, while Naphthionate had an absorption maximum at 320 nm.

During the overview of the results, Dr Lorenzi reported that the Vitella d'Oro spring showed tracer arrival approximately 11 hours after the injection of the tracers at the Rigopiano ditch. In contrast, the Tavo River exhibited tracer arrival at approximately 9.45 hours after the injection of the tracers at the same location. The quantitative tracing analysis produced tracer breakthrough curves, which serve as valuable tools for understanding the aquifer system and assessing the percentage of tracer recovery. It was observed that the Tavo River exhibited a higher percentage of recovery compared to the Vitella d'Oro spring.

Dr Lorenzi discussed that out of the eight monitoring points, Uranine tracer was detected in six of them. Additionally, the presence of Uranine was also identified in the charcoal bags installed after the test. This finding indicates the existence of two distinct groundwater circuits within the aquifer, each exhibiting different response times.

Dr Lorenzi concluded her presentation with the following remarks:

- The Mortaio d'Angri spring is only recharged by the regional-scale aquifer, fed by the base flow;
- The Vitella d'Oro spring is characterised by a relatively complex groundwater basin. The presence of karst networks and karst conduits determines a rapid response to meteoric events;
- The tracer reaches the tunnel of the Vitella d'Oro spring with a longer response time than the Tavo River. Tracer does not flow freely on the surface water but infiltrates into the ground, reaching the aquifer under the Rigopiano ditch, and then re-emerges in the confluence area between the Rigopiano ditch and the Tavo River;
- The water coming from the Rigopiano ditch arrives with reduced percentages at the Vitella d'Oro spring and Tavo River (recovery rate around 20%) and the other 80% of spring discharge would coming from the regional base flow;
- The presence of a longer and more complex pathway into the karst system, feeding both the Vitella d'Oro spring and the Tavo River, with delayed response times, is also demonstrated by the presence of tracer in the charcoal bags in the period following the test;
- These results show how the Vitella d'Oro spring is particularly sensitive to both basin-scale variations and extremely local recharge conditions, thus considering the spring vulnerable to discharge reduction/exhaustion in a potential climate change scenario.

ING MATTIA GAIOLINI, MARCHE POLYTECHNIC UNIVERSITY

TITLE: MODELLING TRANSIENT GROUNDWATER FLOW DYNAMICS IN THE TABRIZ UNCONFINED AQUIFER NEAR URMIA LAKE (IRAN)

Ing Gaiolini started his delivery by giving the audience a brief explanation of the reseach questions. He explained that the general question is to estimate climate changes impacts on groundwater resources at the aquifer scale, whilst the specific questions include remotely sensed evapotranspiration rates to accurately simulate this component, and to quantify groundwater exploitation impact on groundwater balance.

The speaker went on to discuss the study area of this research, the Urmia Lake basin in northwestern Iran, which spans an area of approximately 52,000 km^2. Human activities such as agriculture and water consumption have contributed to the drying of the lake, resulting in a decrease in groundwater quantity and quality. In order to develop the model, data from national and global databases were utilized. The PM11 method and MODFLOW-2005 NWT code were employed for flow simulation, with a model domain consisting of 110 rows, 155 columns, and 1 layer of varying width and thickness. The study incorporated 68 stress periods representing different seasons. The SRTM Digital Terrain Model, featuring a resolution of 20x20 m cells, was used, and average hydraulic conductivity values were determined for different geological formations.

In addition, the steady-state simulation was calibrated using PEST (Doherty, 2010) by comparing the simulated heads to observed heads for the year 2000. The validation process utilized a comprehensive network of monitoring wells that measured hydraulic heads throughout the simulation period. The model not only offers precise estimation of the water balance but also enables a detailed examination of individual water budget components. In addition, two different scenarios were presented: EVT (Evapotranspiration) and RCH (Rich). It was observed that the RCH-Mean scenario resulted in a significant overestimation, reaching up to 7 m^3/s during wet periods and averaging 2 m^3/s overall. Moreover, the study examined the impact of various scenarios (Validated Model, d-Mean, d-Median, EVT-ETS1, RCH-Mean) on the parameters.

Finally, in order to assess the impact of water exploitation on the water budget, a scenario without human water use was tested, and the results were compared with the baseline scenarios. In this scenario, no water extraction from wells was considered. Additionally, a new two-dimensional matrix was created to account for changes in both land use and soil texture.

In his concluding remarks, Ing Gaiolini addressed both the general and specific research questions. Regarding the general question, he emphasized that long-term groundwater decline is primarily influenced by climate changes, with human stressors playing a minor but still significant role, accounting for approximately 5% of the overall decline. Furthermore, he provided the following answers to the specific research questions:

- The evapotranspiration turned out to be one of the major causes of the groundwater decline during dry periods, playing a major contribution in the groundwater budget.
- High resolution spatialization of the extinction depth over the domain did not lead to significative better results in terms of model performance, thus at the aquifer scale such resolution resulted redundant.
- The scenario without human stressor did not produce significative groundwater budget changes, while groundwater heads increased just near pumping wells.

DR MARIA FILIPPINI, UNIVERSITY OF BOLOGNA

TITLE: CLIMATE CHANGE RESILIENCE IN THE POR HYDROGEOLOGICAL SETTING OF THE NORTHERN APENNINES: THE CASE OF THE NADIA SPRING

In her presentation, Dr Filippini commenced by presenting a visual representation showcasing the regional distribution of tapped springs. Additionally, she presented a comprehensive analysis of rainfall and air temperature trends over the past two decades in a few selected states. Notably, the data revealed a recurring pattern where every five years witnessed a significant downturn in rainfall levels followed by a subsequent upswing in temperature.

She went on to mention a list of field investigations conducted in the surroundings of the springs in 2022. The investigations included:

- Structural and geomorphological surveys to verify/integrate the existing geological maps;
- Continuous coring of the aquifer down to 80 m b.g.s. (7 km southward from the Nadìa spring - same geological formation);
- Continuous monitoring of the spring discharge;
- Spring water sampling for major ion and water isotope analyses;
- Tracer test from “cave” to spring.

Dr Filippini claimed that during the field investigations, significant observations regarding the geomorphology, coring, and structual styles were made. The hydrograph of the spring in 2022 revealed a distinct pattern with a pronounced recharge season followed by a recession season. However, in the drought years of 2021 and 2022, the recharge peak was nearly absent.

Furthermore, the speaker mentioned that a tracer test was conducted on January 10th, 2023, by injecting sodium chloride and uranine (50g) approximately 340m upgradient from the Nadia spring. The current discharge monitoring data has been compared with historical records from 1915-1918 on a monthly scale. The analysis reveals a clear decrease in both the annual discharge amount and the average annual flow rate compared to the past. Moreover, the findings indicated an inverse relationship between the recession coefficients of the isographs and the discharge at the beginning of the recession, which suggests that as the discharge decreases, the recession coefficients tend to increase.

The speaker closed off by emphasising the following key points:

- Nadìa is the base spring of a large reservoir hosting homogenized groundwater;
- The aquifer permeability is locally increased due to geomorphological, structural, and karst phenomena;
- These two elements provide high resilience to recharge decrease in the short term (single drought years);
- The reservoir of the spring is characterized by multiple drainage systems and the "lamination capacity" increases with decreasing flow rate;
- This suggests higher resilience to recharge decrease in the future centuries compared to the past.

DR DAVIDE CAPPELLARI, UNIVERSITY OF PADOVA

TITLE: FIRST HYDROGEOLOGICAL WATER BALANCE IN THE HIGH AND MIDDLE VENETIAN PLAIN BETWEEN MINCIO AND TAGLIAMENTO RIVERS (NE, ITALY)

Dr Davide Cappellari explained that during his presentation he would be discussing a study conducted as part of the AMARONE project, a collaboration between the University of Padova and the Eastern Alps Water Authority. The project aims to examine the water resources in the high and middle Venetian Plain.

The speaker described that the study was conducted in a wide area spanning 8648km^2. The study area extends from the Mincio River in the West to the Tagliamento River in the East. The northern boundary is determined by the mountain basins that drain into the Venetian plain, while the southern boundary is defined by measuring stations for outflows.

Dr Cappellari explained the water budget formula which is made up of storage, precipitation, river flow, groundwater flow, artificial flow, and evapotranspiration. The hydrogeological balance was made considering the average year from 2010 to 2022. The work flow included the data collection from the weather stations, which was then used to compute the precipitation, evapotranspiration, infiltration and the surface runoff.

He highlighted that a total of 229 weather stations were scattered throughout Lombardy. The study considered the variability of precipitation, temperature, solar radiation, and wind speed. To ensure the representativeness of the data, only stations with a minimum of 6 years of data from the study period were selected, while others were excluded.

Furthermore, it was mentioned that the collected data was specialized using Natural Neighbour Interpolation with a cell size of 100 x 100m. The hydrogeological balance was then performed for each cell. To calculate Evapotranspiration, the FAO Penman-Montheit equation was employed. The equation required mean speed, temperature, and solar radiation as input parameters, while other necessary parameters could be derived easily.

Dr Cappellari presented the concept of effective precipitation as the amount of precipitation that reaches the soil. It was calculated by subtracting evapotranspiration from total precipitation. The average annual value of effective precipitation was found to be 3.76 BCM/year, with notably lower values observed during the summer months. Further analysis revealed that the effective precipitation is divided into infiltration and surface runoff, which depend on the permeability of the soil.

The speaker explained that the dominant lithology varies across different regions. In the Lessini mountains, the dominant lithology consists of Volcanites and Limestones. In the Prealps, Limestones prevail as the dominant lithology. Montello is characterized by Conglomerate, while Garda Lake exhibits Morainic lithology. The High Plain predominantly consists of Gravel and Sand, whereas the Low Plain is characterized by Sand, Silt, and Clay as the dominant lithology.

In addition, he went on to discuss the results of the calculation. It was determined that the infiltration rate was measured at 1.94 BCM/year, while the runoff, representing the difference between precipitation and infiltration, was approximately 1.82 BCM/year.

At the end of the presentation, the following key points were highlighted:

- Able to estimate the magnitude and distribution of the quantity involved on the hydrogeological balance.
- High percentage of evapotranspiration
- From March to September the groundwater recharge was low
- From October to February the groundwater recharge was high.

Dr Diego Di Curzio, Delft University of Technology

Title: Unravelling the aquifer-scale competition for organic substrate in a polluted aquifer by interpreting multivariate statistics through scenario-based hydrogeochemical modelling

In his presentation, Dr Diego Di Curzio began by posing the question, "What is competition for substrate?" He explained that it refers to the biochemical mechanisms involved when different types of bacteria consume various electron acceptors, such as well-known inorganic ones like oxygen and nitrogen, or through reductive dechlorination.

He also addressed the challenges associated with sparse datasets, which include a lack of spatiotemporal consistency and incomplete parameter sets. These issues, when combined with multivariate statistics and reactive transport modelling, can result in biased inference and less reliable results. To overcome this limitation, the approach involves starting with a sparse dataset and conducting factor analysis. Based on this dataset, multiple scenarios are defined, each with different hydrogeochemical boundary conditions. Multi-scenario batch modelling is then performed, resulting in a statistical distribution of numerical Pearson coefficient.

The speaker explained that the selected case study focuses on a residential area located near the Adriatic Sea. Key characteristics of the site include:

- Presence of known foundry waste burials, with the possibility of additional unidentified burials
- A fuel spill resulting in a floating fuel pool, leading to the formation of an MTBE and BTEX (MBTEX) plume
- Existence of a chlorinated ethene plume of unknown origin
- Potential interaction between the different contamination sources
- The coastal aquifer in the area is composed of sandy-silty sediments, with a thickness of 10 to 15 meters and containing sedimentary organic matter
- The aquifer is recharged primarily by direct infiltration of rainfall
- The hydraulic gradient is low, decreasing towards the shoreline, which results in a decrease in groundwater flow rate downstream
- The groundwater table is shallow, suggesting that the foundry wastes and/or the sewage system may intermittently be in the saturated zone.

Dr Di Curzio discussed discussed the groundwater quality in the study area and highlighted the following points:

- The presence of an MBTEX plume, with higher concentrations of contaminants (C) in the core of the plume (order of thousands of ug/L) and lower concentrations in the external part (order of a few ug/L).
- A chlorinated ethene (CEs) plume was identified in a limited area, with abundant daughter products
- Both manganese (Mn) and iron (Fe) were found to be highly abundant within the plume, with peak concentrations observed immediately downstream of the foundry waste dump.
- Nitrate and sulfate concentrations were found to be the lowest within the plume

- Nitrate exhibited concentrated areas of high concentrations, referred to as "hotspots".

The speaker presented the initial findings from the multivariate statistical analysis and discussed the implementation of a scenario-based batch model. The modelling results were explained, revealing the statistical distribution of Pearson coefficients derived from 108 scenario models, which were then compared with the experimental data.

He went on to discuss the impact of MBTEX availability and its correlation with numerical and experimental results. At low MBTEX concentrations, a strong correlation was observed between the numerical and experimental data. The speaker emphasized that substrate limitation plays a crucial role, leading to competition between inorganic Terminal Electron Accepting Processes and reductive dechlorination. Interestingly, the amount of chlorinated ethenes was found to have a limited influence on their relationship with inorganic TEAs. The speaker highlighted that competition for substrate can occur at both high and low concentrations of chlorinated ethenes. Additionally, the effect of inorganic TEAs availability was explained, shedding light on their significance in the system. Furthermore, the speaker discussed the competition for substrate within the MBTEX plume.

In his concluding remarks, Dr Di Curzio highlighted the following key points:

- The novel scenario-based numerical approach was able to identify and investigate the competition for organic substrate;

- The competition for substrate is favored in conditions of substrate limitations and/or in the presence of mostly nitrate and, to a lesser extent, intermediate-to-high soluble Mn(IV) oxi-hydroxides, which act as competing inorganic TEAs;

- The amount of chlorinated ethenes as well as the solubility of Fe(III) oxi-hydroxides seem to play an unclear, minor, or negligible role in the competition process;

- This approach took advantage of mechanistic process-based knowledge to overcome the issue of spatio-temporally sparse datasets, which often lead to incorrect and biased interpretations of the processes occurring in a polluted aquifer.

DR STEFANIA STEVENAZZI, UNIVERSITY OF NAPLES FEDERICO II

TITLE: APPLICATION OF MULTIVARIATE STATISTICAL ANALYSIS FOR THE DELINEATION OF GROUNDWATER BODIES: A CASE STUDY IN CAMPANIA REGION (SOUTHERN ITALY)

Dr Stefania Stevenazzi started her delivery by informing the audience that groundwater quality in areas characterised by different geological formations, diversified ecosystems, highly developed by human activities and located along the coastline may result in heterogeneous hydrochemical facies distribution. However, when dealing with large datasets, classical graphical methods such as Stiff, Piper, and Schoeller have some inherent limitations. This study aims to achieve two specific objectives. Firstly to identify the hydrogeochemical processes, and secondly, to verify the current delineation of four groundwater bodies in Campania Region. These objectives will be accomplished through the application of hydrogeochemical methods, including classical and colour-coded Piper diagram, as well as multivariate statistical analyses using R-mode Factor Analysis.

The study area includes three groundwater bodies: the Volturno Plain characterized by fluvial, pyroclastic, and marine sediments, the Plain of Naples comprising fluvial and pyroclastic sediments, and the Phlegrean Fields, an active volcanic region with monogenic volcanic formations. In these plains, two main porous aquifers exist: a shallow phreatic aquifer and a deeper semi-confined (or confined) aquifer, separated by a variable thickness tuff layer.

The speaker explained that this study utilized multiple datasets for hydrochemical analysis. The Campania Trasparente 2018 dataset contributed information from 172 sampling points, with samples collected between 2016 and 2017. The ECOREMED Life Project 2012-2017 dataset provided data from 27 sampling points, collected in 2013. The Regione Campania-DICEA project 2016 dataset included 33 sampling points, collected in 2016. The Regional Environmental Agency - ARPAC dataset encompassed 31 sampling points, with the most recent samples collected between 2014 and 2017. In addition, data from Ebrahimi et al. (2022) published in the Journal of Geochemical Exploration were utilized, consisting of 42 sampling points with samples collected in 2019. The parameters considered in the analysis included electrical conductivity (EC), pH, major ions (Ca, Mg, Na, K, HCO3, Cl, SO4, NO3), and minor elements (As, Fe, Mn, V, B).

Dr Stevenazzi went on to discuss that graphical methods like Piper, Schoeller, and Stiff diagrams are used to visualize aqueous geochemical data, providing insights into the spatio-temporal evolution and mixing of water in hydrogeologic systems. To effectively utilize these methods, several steps are followed. Firstly, the dataset(s) are prepared, ensuring an error of $\leq \pm 10\%$ in the ionic balance. Then, suitable software like WQChartPy is chosen to generate the geochemical diagrams. A color-coded Piper Diagram is one specific technique employed, utilizing a background colour scheme to fill the trilinear Piper plot. Each water sample is assigned unique RGB values based on its position in the Piper diagram. Interpolation through Inverse Distance Weighting helps map the spatial distribution of RGB values. Finally, a comparison is made with previous studies and groundwater body delineations.

Multivariate statistical analysis enables the grouping of water samples based on similarities among numerous geochemical and physical parameters. This analysis helps in understanding the main processes that influence the spatial distribution of hydrochemical parameters. The steps involved in this analysis include dataset preparation, grouping of similar parameters from chemical analysis, mapping the geographical distribution of resulting factors, and comparison with previous studies and groundwater body delineations.

She also went over the findings, explaining that after applying varimax rotation to the factor loadings, the analysis for Dataset E produced three factors, with Factor 1 being "seawater intrusion/hydrothermal fluids," Factor 2 being "carbonate dissolution," and Factor 3 being "Anthropogenic input."

In her closing statements, Dr Stevenazzi emphasised the following important takeaways:

- Evaluate the consistency and reliability of public available datasets (i.e., source; sampling date; XYZ data; complete information on sampling points, e.g., well screen depth);
- Highlight the necessity and usefulness of large chemical database to assess multivariate statistical analysis;
- Identify the hydrogeochemical processes, mostly reflecting known processes (salinization, carbonate rocks dissolution, natural or anthropogenic inputs, redox conditions, volcanic products contribution), but also highlighting the influence of groundwater flowpaths on water chemistry; some processes are peculiar of one GWB, but others are in common between two or more GWBs;
- Open issues: evaluation of the hydrogeochemical processes differences during wet or dry periods (seasonality); evaluation of the long-term trend evolution of hydrogeochemical processes; improvement of the performance of the interpolation techniques.

Question 1: Dr Maria Filippini was questioned about the utilization of a statistical approach to determine the trend in precipitation. The inquiry arose due to the lack of clarity regarding the observed decrease in the total amount of precipitation as depicted in the graph presented at the beginning of her presentation.

She clarified that for this specific task, they did not conduct a statistical analysis to evaluate the trend in precipitation. The purpose of the graph presented was to illustrate local data points showing periodic peaks and valleys in temperature over a span of 20 years, rather than focusing on a decreasing trend in rainfall. It was noted that during years with low rainfall, springs with rapid recharge and discharge experience difficulties. While long-term trend analysis is being pursued in other research, it was not the focus of this particular study.

Question 2: Ing Mattia Gaiolini was asked whether a water balance anaylsis was conducted prior to the modelling process.

Ing Gaiolini stated that they did not perform a separate water balance analysis prior to the modelling. Instead, they directly reproduced the water balance by utilizing a non-budget routine within the model.

3.4 Part 4

PROF MARCO ROTIROTI, UNIVERSITY OF MILANO-BICOCCA

TITLE: CHANGES IN SHALLOW GROUNDWATER RECHARGE DUE TO DROUGHT IMPACTING THE PO RIVER BASIN

Prof Marco Rotiroti explained that during his presentation he would try to answer this question: 'Which are the effects of drought on the hydrogeological water balance of shallow Po Plain aquifers in Lombardy region?' by discussing the main features of Po Plain aquifers, then the current main sources of recharge of Po Plain aquifers, and finally how recharge is likely to change (is changing) due to drought.

The speaker discussed the hydrogeology of Po Plain Aquifers in the Lombardy region. He explained that groundwater flows from North to South, leading to the distinction of two areas: the Higher Plain and the Lower Plain. The Higher Plain consists of a single-layer unconfined aquifer composed of sands and gravels, while the Lower Plain is a multi-layer system with alternating confined sandy aquifers and silty-clay aquitards containing peat. The speaker highlighted how the lithological and hydrological features impact groundwater simulation. For instance, the lower permeability layers in the Lower Plain prevent surface infiltration, causing groundwater in this area to originate from the Higher Plain and undergo a lengthy subsurface journey. Consequently, groundwater in the Lower Plain has long residence times, spanning hundreds or thousands of years, whereas groundwater in the Higher Plain has shorter residence times, averaging around 30 years. The speaker emphasized that the shorter circulation of groundwater in the higher plain renders it more vulnerable to drought and climate change impacts.

He further explained that the predominant land use in the southern part of the plain area is agriculture, with almost all agricultural fields being irrigated, except for a few exceptions. The notable exception is an area in the northwestern part that remains unirrigated. Surface water serves as the primary source for irrigation, facilitated through water diversions from Subalpine lakes and Alpine rivers to irrigation channel networks. These channels transport water close to the fields, where various irrigation techniques are employed. The traditional surface irrigation technique is the most commonly used method in the Lombardy region.

To determine the main source of recharge in the higher plain, the speaker along with his colleagues employed tracers such as isotopes and chemical tracers, specifically Chlorine and Bromine. A total of 44 wells located on 15 transects along groundwater flowpaths were sampled across the entire higher plain. The objective was to trace groundwater recharge and ascertain whether the return flow from irrigation was the primary source of recharge in the higher plain or not.

When looking at the results, it was revealed that surface irrigation, which relies on surface water bodies, is the primary source of recharge (50-75%) in the irrigated areas of the higher plain. Despite being an inefficient method with substantial water loss to the subsurface (approximately 50%), it significantly contributes to recharge. Additionally, unlined irrigation channels play a significant role in recharging the aquifer, in addition to the return flow within the fields.

As a result of drought and the related surface water shortage during the growing season (summer), the following changes are expected:

- Transition from surface-water irrigation to groundwater-fed irrigation through the use of irrigation wells, leading to increased groundwater output;
- Shift from inefficient surface irrigation methods to more efficient alternatives such as sprinkler, micro, and drip irrigation;
- Transition from water-intensive crops like corn to less water-intensive crops like sorghum, resulting in decreased groundwater input.

Prof Rotiroti also highlighted that all these actions imply some consequences also for the ground water balance, which include the depletion of groundwater resources and the drying of many typical low-land springs (fontanili). To address the challenges mentioned, implementing managed aquifer recharge systems such as infiltration ponds and forested infiltration areas can serve as potential solutions. These measures are particularly suitable for the Lombardy region and are urgently needed to mitigate the depletion of groundwater resources.

The speaker's main takeaway was that the surface irrigation in the higher plain, which is fueled by Alpine surface water bodies, can be regarded as Italy's largest "unintentional" MAR system because it allows Alpine rain and snowmelt to seep into the aquifers beneath the Po Plain. This accidental MAR system is being erased by adaptation to climate change, thus urgent new activities are required to stop the anticipated groundwater depletion.

Ms Laura Landi, Alma Mater Studiorum, Università di Bologna

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

In the beginning of her presentation, Ms Laura Landi emphasized the significance of water scarcity as a prominent issue in contemporary times. Consequently, the need to adapt water management practices becomes crucial, with groundwater assuming a vital role in this endeavour. Scientific studies have been conducted in vulnerable regions, particularly mountainous aquifers, to explore sustainable approaches for the exploitation of groundwater resources.

The Northern Apennines in Italy face significant vulnerability, particularly with regards to their aqueduct systems, which heavily rely on the affected springs. Droughts have been increasingly prevalent since last year due to the impacts of climate change. The aquifers in the northern Apennines predominantly consist of various formations, with the Pantano

Formation standing out for its hydrogeological properties that makes it one of the most productive formations in the area.

Furthermore, Ms Landi discussed the study area with an aquifer comprising various members of the Pantano Formation, displaying a gradient from northwest to southwest. She highlighted the impact of increasing drought occurrences, happening roughly every 25 years, on the local springs within the aqueducts. During summer, these springs struggle to meet water demands, necessitating immediate action. To tackle this challenge, the study suggests utilizing two specific aquifer sectors known for their favourable structure. These sectors provide a sustainable water supplement, offering a viable solution to address water scarcity issues.

The Arpolli sector in the southwest corner boasts a significant thickness of confined aquifers and houses major springs within the northern region. The Tole sector comprises less permeable members of the Pantano Formation, but its bowl-shaped aquifers hold potential for exploitation. Numerical models were developed for both sectors to optimize groundwater utilisation. The proposed solution is viewed as an emergency adaptation strategy wherein the necessary water supplement will be provided solely during the summer season. The rest of the time, the system can revert to its original conditions, ensuring sustainable operations.

In conclusion she stated that the Arpolli sector received 1,999 m^3 of water supply through tanker trips in 2022, while the Tolè sector received 6,870 m^3. However, with the proposed solutions in place, the potential water supply significantly increases. The Arpolli sector can potentially receive over 40,000 m3 of water, while the Tolè sector can receive more than 19,000 m3. The significant increase in potential water supply provided by the proposed solutions implies the availability of emergency water supply that can be harnessed during critical periods.

In addition, the developed models have enabled the definition of an optimal pumping schedule as a management strategy, taking into consideration various factors. These factors include the hydrogeological setting of the area, the potential impact on spring discharge, and the preservation of environmental flow. Moreover, the models also ensure the sustainability of groundwater extraction, even during challenging climatic conditions. The favourable hydrogeological properties and hydro-structures observed in the study area highlight the need for site-specific investigations to establish sustainable management strategies. This is particularly crucial for vulnerable regions like mountainous aquifers, as they face future climatic crises.

DR PIETRO RAI, UNIVERSITY OF TRIESTE

TITLE: GROUNDWATER FLOW MODELING FOR THE SUSTAINABLE EXPLOITATION OF THE MONTE CASTELLO AQUIFER

Dr Pietro Rai began by highlighting the issue of overexploitation of lowland water resources and frequent droughts, causing a decline in hydro chemical properties. To address this, the proposed solution is to utilize alternative sources and responsibly manage foothill resources to alleviate pressure on the plain.

Dr Rai outlined the objectives of the Monte Castello Aquifer project. The primary focus is to investigate the hydrogeological properties of the Monte Castello site, with a specific emphasis on its interactions with the Ravedis reservoir. Furthermore, the project aims to create a hydrogeological flow model to assess the leakage of the reservoir and evaluate the potential consequences of drilling a pumping well.

The speaker also addressed the Piezometric Monitoring System, which involved the implementation of a groundwater flow model. Data collection began in 2014, using both automated and manual systems. The collected dataset was properly validated to ensure reliable inputs for the modelling process.

Dr Rai then presented the modelling results, which included the estimation of the volumetric budget to determine the reservoir's leakages. It was found that the reservoir's leakages during winter conditions amount to 2240m^3/day, while during summer conditions, they increase to 2932m^3/day.

As he wrapped up his presentation, Dr Rai highlighted the following remarks:

- Hydrogeological characterization of the area showed a close link between Ravedis reservoir and Monte Castello aquifer;
- Modeling of the aquifer is greatly affected by the lack of information on hydrogeological parameterization;
- The previous point influenced in particular the attempt to evaluate the effects of the construction of a pumping well;
- The model created allowed to obtain a preliminary estimate of the reservoir’s leakages.

Question 1: Prof Marco Rotiroti was asked whether he had conducted an estimation of the new water balance, taking into account the potential reduction in water irrigation demand resulting from the implementation of more efficient techniques and the transition to less water-intensive crops.

Prof Rotiroti explained that they have not yet conducted a specific estimation of the new water balance considering the decrease in water irrigation demand due to more efficient techniques and the switch to less water demanding crops. However, they have observed quantitatively the effects of groundwater depletion in certain locations, where the groundwater level has dropped up to 10 meters. This serves as an indication of the crisis and the decline in water availability. To gain a better understanding, they are currently collaborating with other universities to develop a comprehensive basin-wide groundwater model. This modelling effort aims to provide a general balance of the groundwater resources. Marco expressed hope that within the next two years, they will be able to provide a quantified assessment of the water balance.

Question 2: In the context of water management in the Po Plain, Prof Marco Rotiroti was queried regarding a feasible solution to effectively tackle the water challenges faced by the region.

Prof Rotiroti proposed that one of the best solutions is to utilize a system of channels to redirect water from the river during the rainy season, because the winter period is becoming dry. This system would ensure that the water is accessible and can be used to fill the irrigation channels, ultimately irrigating the fields.

Question 3: Dr Rai was questioned on the causes behind the increased leaking throughout the summer. He explained that it is related to the purpose of the reservoir which is to maintain its water level at minimum approximately from September to May, ensuring its functionality in mitigating fluid-related issues. Conversely, during the summer season, the reservoir's level is adjusted to maximise water storage capacity and facilitate water production.

MS SARA BARBIERI, POLYTECHNIC UNIVERSITY OF MILAN

TITLE: ENHANCED THERMAL RESPONSE TEST INTERPRETATION THROUGH MODFLOW-USG AND PEST_HP

Ms Sara Barbieri began her presentation by defining shallow closed loop systems, where such systems are used to to couple energy to the ground through closed-loop vertical/horizontal U-shaped pipes. Specifically, the situation in Milan Municipality will be discussed, focusing on the geothermal plants in the area. The municipality currently has a significant number of open loop systems, including 791 pumping wells and 653 reinjection wells. In addition, there are 605 closed-loop systems utilizing borehole heat exchangers. However, the main issue at hand is the high risk of mutual interference, which poses a threat to the efficiency of the geo-exchange systems. Furthermore, there is concern about potential interference with other underground infrastructures, such as drinking wells and subways.

She explained that when designing closed-loop systems, two crucial aspects to consider are legislation and system efficiency. In Italy, specific legislation was enacted on September 30th, 2022, which outlines the requirements for closed-loop systems. According to the legislation, underground thermal parameters must be estimated from literature for installations below 50 kW, while installations with thermal power exceeding 50 kW require a thermal response test. Additionally, the selection of materials, adherence to environmental requirements, and proper installation procedures must comply with the UNI technical standard.

Efficiency in underground heat exchange is a key factor to consider. It aids in estimating the underground thermal and hydrogeological properties. It is essential to take into account the presence of other geothermal plants or adjacent underground utilities to avoid potential interference and optimize overall system performance.

The speaker also went through the importance of thermal properties along the depth. She stated that these data help identify layers with higher thermal conductivity and thermal borehole resistance, which are essential for designing efficient probes. Furthermore, interpreting the data using 3D numerical models allows for the estimation of water table velocity, if present. Having knowledge of soil and aquifer properties vertically aids in designing a system that maximizes efficiency and mitigates potential interference with other underground structures.

Ms Barbieri also discussed the Thermal Response Test and Enhanced Thermal Response Test numerical solutions. She highlighted that the research group has simulated these tests using the MODFLOW numerical code. It was mentioned that the CLN-DRT packages have been validated for Thermal Response Tests, while preliminary validation has been conducted for Enhanced Thermal Response Tests.

In addition, she cited two case studies, one with a negligible flow and the other with a not negligible flow, and she described the input information, attributes, and outcomes for each.

Ms Sara Barbieri underlined the following comments as she concluded her presentation:

- Relevance of vertical distributed thermal and hydrogeological properties;
- Importance of training for technicians/engineers to consider the presence of any underground structures in the surrounding area ;
- Strongly recommended numerical modeling for groundwater flow velocity estimation;
- To avoid the waste of the geothermal resource, a strong regulation that aims to avoid interference between installations and implementation of a public database of existing plants are needed.

DR SUSANNA MANCINI, DEPARTMENT OF EARTH SCIENCES, UNIVERSITY OF TURIN

TITLE: IMPACT OF DROUGHT ON THE PIEDMONT PLAIN (NW, ITALY) WATER RESOURCES: CURRENT STATUS AND PREDICTIONS IN THE CONTEXT OF CLIMATE CHANGE

Dr Susanna Mancini stated at the outset of her presentation that over the previous ten years, the climate of the Mediterranean region had seen climatic changes that included variations in weather events, a shift in the pattern of rainfall, an accentuation of extreme events, and an increase in temperature and evapotranspiration. She indicated that the report presents a spatiotemporal analysis of the effects of the recent drought years (2021-2022) on water resources in the Piedmont Plain. The study incorporates meteorological data, river data, and groundwater data.

She emphasised that the subject of the study was the shallow unconfined aquifer. The Piedmont Plain, which makes up 27% of the region's land area and is the Po Plain's westernmost portion, is the area's largest and most significant GW reservoir. For this study, a selection of monitoring wells was utilized, consisting of 10 wells for groundwater level and groundwater temperature measurements. Additionally, data from 20 weather stations were incorporated, with 10 stations providing rainfall data and 10 stations offering air temperature readings. Moreover, information from 20 river stations was included, with 10 stations supplying discharge data and 10 stations providing water temperature data.

The speaker also highlighted that extensive statistical analyses were conducted on the monitoring data obtained from automatic regional networks. The period of analysis spanned from 2002 to 2022, considering annual and monthly average data. Various statistical methods, including trend analysis, anomalies, box plots, and comparisons, were applied to the data. The results revealed that while no statistical trend was observed in rainfall over the analysed period, both 2021 and 2022 experienced significant decreases in rainfall compared to the long-term average. Annual rainfall deficits ranged from -19% to -60% in 2021 and from -45% to -71% in 2022. The year 2021 was characterized as a dry year, while 2022 was identified as one of the driest years recorded in the past 65 years.

She went on to discuss that recent years have seen a consistent rise in air temperatures, leading to the formation of severe drought conditions in Europe and Italy. These meteorological factors have created the most devastating drought in the region in the past 500 years. Consequences of changing water resources include rising groundwater and water temperatures. Groundwater proves more resilient to climate change compared to air and surface water.

Although there is no statistical trend in river discharges, critical deficits were observed in 2021 and 2022 due to insufficient rainfall. In 2022, the deficit in river discharges ranged from -55% to -100%. Approximately 80% of groundwater levels exhibit a decreasing trend over time. In 2022, the groundwater level reached its lowest point in the entire study period.

Dr Mancini emphasised thta in 2022, the majority of monitoring wells recorded a negative annual anomaly in groundwater levels. Anomaly analysis revealed significant deviations, reaching up to -3m for yearly data and exceeding -6m for monthly data compared to reference values. This analysis identified Cuneo and Alessandria plains in Piedmont Plain as the most critical areas for groundwater in 2022.

The speaker also discussed the negative effects, which include:

- Some shallow wells became dry;
- Alterations in the discharge of fontanili (plain springs, typical of Po Plain, an oasis of biodivesity and an important resource for the area;
- Depletion of springs discharge in alpine areas.

A forecast for 2023 is possible by considering three precipitation scenarios using a multiple regression model between rainfall and groundwater level. The first scenario assumes similar precipitation to 2022, resulting in a projected decrease of approximately 1m in groundwater level. The second scenario assumes average precipitation for 2023, resulting in a relatively constant groundwater level compared to 2022. The third scenario considers an increase in precipitation up to 1200mm/year, leading to an estimated 0.5m increase in groundwater level.

In her closing remarks, Dr Susanna Mancini highlighted the following points:

- GW temperatures and levels have been highly impacted by the 21-22 drought. However, GW showed to be onre resilient than air and surface water;
- The impacts on surface water are clearly visible;
- GW impacts are not directly observable, only the analyses of continuous monitoring data allow us to detect variation on quantity and quality of GW;
- Challenges : to work with stakeholders and agencies to implement GW monitoring network not only for shallow aquifers but also for confined and semiconfined aquifers (the most important for drinking).

Ms Francesca Lobina, University of Cagliari

Title: Estimation of Transit Time along the Unsaturated Zone in the Protection of Groundwater Resources Susanna Mancini

As she opened her presentation, Ms Francesca Lobina stated that nitrogen pollution in groundwater is primarily caused by agricultural activities, excessive fertilizer use, and nitrate contamination. The European community implemented the nitrate directive and water framework directive to address this issue, but improvements have been insufficient. The unsaturated zone, despite being a crucial factor in water movement and pollutant leaching, is often overlooked. Natural attenuation processes in the unsaturated zone can mitigate contaminant leaching into groundwater. The infiltration rate plays a significant role in determining transit time in the vadose zone and influences water-rock interaction time.

She claimed that this research aims to estimate the rate and timing of groundwater recharge at two sites using stable water isotope profiles in the vadose zone. The study involves comparing the physical properties of the soils to gain insights into the recharge process. The study focuses on two main areas: the Arborea Plane, known for its high agricultural and animal husbandry productivity, and the Campidano Area, characterized by intensive agricultural activities

The speaker followed up by displaying distribution maps of nitrate concentrations in groundwater in the Arborea and Southern Campidano Sites. She went on to discuss that manure application is the main source of nitrate at the Arborea facility. The aquifer in Arborea is shallow, while the Campidano region has a multilayer aquifer. Currently, we are in the process of developing a hydrogeological model specifically for the Campidano area. It is important to note that rainfall serves as the primary source of recharge for both areas.

She described the study's approach, pointing out that it uses the piston flow method to calculate groundwater recharge. It acknowledges that water infiltration in the unsaturated zone often exhibits piston flow behaviour. The 'peak-shift' method is employed to estimate groundwater flow velocity. Monthly analysis of rainwater isotopes (δ18O and δ2H) is conducted. Soil samples are collected at 10cm intervals along a vertical profile using a hand auger or core drill machine. Soil physical properties such as water content, grain size distribution, and volumetric water content are determined. The collected soil samples are then sent to the Institute for Soil Physical and Rural Water Management in Vienna for analysis of stable water isotopes.

The results from the Arborea Site show a seasonal variation in the isotopic composition of rainfall in Sardinia, with heavier compositions observed during winter and lower values in May. March stood out as a dry month. Assuming that the -3.34% value represents the spring peak (around April/May 2022), it indicates a decrease of -35cm in just 9 months, reaching January 2023. This corresponds to an average water flow velocity of 0.12cm/day or 0.0012m/day. The calculations indicate that out of the total 673mm of rainfall, only 12% (80mm) contributes to aquifer recharge over the 9-month period.

Ms Francesca Lobina then provided an explanation of the outcomes for the Campidano Site: In the first few centimetres, the evaporation front is visible, and it then appears that there may be several seasonal cycles. There is a clay-like texture, a slower flow, and it appears that irrigation has had an impact.

To finish her presentation, Ms Lobina made the following comments:

- The pronounced seasonal differences observed in the isotopic signatures of rainwater makes possible to apply the "peak-shift" method;
- Estimation of recharge rate is in the expected order of magnitude; however, discrepancies can be related to irrigation;
- Further analyses in both the study areas are required to better interpret the collected data; they include:
    - Definition of soil water retention curve (to determine the precise value of θr);
    - Evaluation of soil hydraulic conductivity values;
    - Isotope analysis of irrigation water at different time.
- A site-specific estimation of nitrate leaching can be obtained by measuring nitrate concentrations in soil water below the root zone with suction cups (it is an ongoing work).

Question 1: Dr Susanna Mancini was asked to provide her perspective on determining an optimal time frame to observe and assess the impact on groundwater. She emphasized the significance of continuous data collection for monitoring groundwater levels and understanding its response to various factors such as weather patterns, climatic conditions, and human activities.

Question 2: Dr Mancini was further questioned regarding the suitability of monthly data resolution for monitoring groundwater. She expressed her opinion on the preference for working with monthly data, stating that it offers several advantages, including the ability to observe oscillations and fluctuations in groundwater levels. However, she highlighted that the suitability of monthly data depends on the specific objectives of the study or analysis.

Question 3: Ms Sara Barbieri was inquired about the current status and future plans regarding the measurement of temperatures and groundwater, considering the potential hydraulic impacts of temperature changes of 1 or 2 degrees on temporary ecosystems. Ms Barbieri provided insights regarding the case of Milan, where she highlighted the absence of monitoring aquifer temperature. She mentioned that another university is conducting a study aiming to analyse temperature data at various depths and establish multiple monitoring points. However, Ms Barbieri expressed concern about the limited focus of authorities on monitoring groundwater levels without considering the thermal perception of aquifers, which presents a significant challenge. She suggested the need for engagement with the authorities and raising awareness about the importance of monitoring aquifer temperatures. Ms Barbieri acknowledged that occasional monitoring campaigns are conducted, but due to limited resources, they face constraints in conducting frequent monitoring activities.

MS EMMA PETRELLA,

TITLE: THE ROLE OF FAULTS ON GROUNDWATER CIRCULATION: THE CASE STUDY OF MONTE MARINE FAULT (CENTRAL APENNINES, ITALY)

In the beginning of her presentation, Ms Emma Petrella stated that many of the urban settlements in Central Italy are situated near active faults in intermontane basins. Deformation along faults causes the media's permeability to be heterogeneous and anisotropic. An obstruction to flow, a conduit for flow, or a complex conduit/barrier are all possible outcomes of fault zones.

She claimed that the aim of the study is to investigate the hydrogeological behaviour of a complex fault zone. The study aims to address questions such as whether these complex faults function as barriers, drains, or conduit-barriers for groundwater flow, and whether their role remains consistent throughout their entire length. Furthermore, she indicated that the study focuses on a complex fault zone situated in the Central Apennines, specifically in the western part of the Gran Sasso carbonate aquifer. Known as the Monte Marine Fault, this fault exhibits a northwest to southeast orientation and is characterized by active extensional movement. The fault zone is located within partially dolomitized carbonate rocks. The structural configuration of the fault zone displays significant variations along its length. It consists of two nearly parallel major fault strands, featuring a master fault surface with normal kinematics. Additionally, a hard-linked step-over zone is present, characterized by east-west trending faults that give rise to distinctive bad-land morphologies due to the presence of fragmented rocks.

Ms Petrella also outlined the monitoring plan that concentrated on the Aterno Valley basin, a tectonic depression aligned in the northwest to southeast direction (half graben). The basin comprises approximately 200m of Quaternary alluvial deposits. The plan included various hydrogeological investigations, such as groundwater level monitoring and river discharge measurements. Additionally, geochemical and isotopic investigations were conducted, involving the analysis of physicochemical parameters and isotopic compositions. The monitoring activities were carried out every three months, beginning in May 2021 and concluding in May 2022.

The speaker then brought up the study's results, which revealed several important findings. Firstly, a dominant groundwater flow direction parallel to the river was observed, indicating a strong hydraulic connection between the two. Additionally, secondary underground drainage axes in a northeast-southwest orientation were identified, originating from carbonate massifs and extending towards the alluvial plain. The overall groundwater flow scheme remained consistent over time, with fluctuations occurring primarily in groundwater levels. The Aterno River exhibited a mixed interaction with the alluvial plain, both in temporal and spatial aspects, but predominantly contributing to groundwater recharge on the left riverside. Analyzing the groundwater flow scheme raises the question of whether this high potential area is generated by the flow-through from the carbonate aquifer along the fault length, local infiltration, or a combination of both processes.

To answer the question regarding groundwater flow, an assessment of electrical conductivity and stable isotoped was conducted which revealed non-uniform patterns in the Aterno Plain. Low electrical conductivity values were found along the Monte Marine Fault and in the central part of the plain, indicating a flow-through mechanism from the carbonate aquifer. Stable isotopes confirmed this finding, showing lighter isotopic signatures in the step-over zone, suggesting a local and significant flow-through from the carbonate aquifer.

Geological investigations revealed that the main fault strands act as barriers due to the presence of a thick, low-permeability fault core. In contrast, the step-over zone exhibited a thinner fault core with high permeability in the transition and damage zones. These findings demonstrate significant differences between the two areas in terms of permeability and fault characteristics.

The following remarks were delivered by Ms Emma Petrella to conclude her presentation:

- The MMF does not have a unique hydrogeological behavior;

- It is an impermeable barrier where the thickness of the damage zone is in the order of a few tens of meters;
- A significant flow-through is permitted in the step-over area, where the local permeability is enhanced due to the presence of 100's of meters of loose fractured materials (breccias);
- This peculiar structural complexity controls the occurrence of the along-fault spring and permits a significant flow-through from carbonate aquifer toward the alluvial plain.

DR DAVIDE FRONZI, MARCHE POLYTECHNIC UNIVERSITY

TITLE: TOWARDS GROUNDWATER-LEVEL PREDICTION USING PROPHET FORECASTING METHOD BY EXPLOITING A HIGH-RESOLUTION HYDROGEOLOGICAL MONITORING SYSTEM

In his introduction, Dr Davide Fronzi spoke about climate change and hydrological drought. He emphasized the global recognition of the effects, particularly groundwater depletion. The Mediterranean region was identified as a significant "hotspot" for climate change impacts. Italy and its institutions have been actively addressing these issues through initiatives like Decreto Siccita. This decree establishes a committee to monitor and manage droughts, with Article 11 specifying the production of forecast scenarios by the Permanent Observatory.

In the discussion on groundwater prediction and artificial intelligence, the speaker emphasized several key points. Firstly, there has been a rapid increase in the collection of sensor data for groundwater management. Additionally, more than a hundred articles have highlighted the challenge of dealing with nonlinear relationships in groundwater time series and have suggested the adoption of intelligent models to improve prediction accuracy. Popular techniques such as Auto Regressive Integrated Moving Average, Long Short-Term Memory, and Artificial Neural Networks have gained recognition in this domain. However, among the AI-based methods, Prophet stands out as a promising option for modeling groundwater time series. Its capabilities include capturing various periodicities, including seasonal patterns associated with special events, and effectively incorporating non-periodic abrupt changes such as earthquakes.

Dr Fronzi then defined Prophet, and described it as a machine learning-based forecasting model that produces accurate predictions. Trend, seasonality, and holidays make up the three key model components of a decomposable time series model. The input dataset is usually entered into the hydraulic, and with the help of model optimisation and fitting, the model is able to create a forecasting window for the near future.

He continued by saying that the lack of meteoric recharging for the years 2020 and 2021 was determined to be the primary cause of the water table decline due to a combination of the declining precipitation trend and an increase in storm rainfall occurrences. As a result, it was decided to apply this model in this area, and monitoring of the Vadose zone started in 2022.

The speaker also described the development of a simplified model comprising three components: Box 1 representing the atmosphere, where precipitation and air temperature are recorded; Box 2 representing the Vadose Zone of the aquifer, where variables are monitored at depths of 0.6m, 0.9m, and 1.7m; and Box 3 representing the saturated zone.

In the first test, an attempt was made to predict groundwater levels by utilizing variables from Box 1 (atmosphere). Subsequently, the focus shifted to forecasting groundwater levels in the near future. During the validation phase, covering the last 45 days of data, the results of the prediction were observed. When utilizing atmospheric data to predict groundwater levels, a considerable correlation was observed, although the error metrics remained high. However, upon removing temperature as a regressor, the prediction accuracy improved. The most promising results were obtained by incorporating data from the Vadose Zone, specifically at a depth of 1.7m below ground level. This approach yielded a correlation of over 95% and a notable reduction in error metrics.

Dr Davide Fronzi concluded his speech with the following remarks:

- The Prophet is proven to be a good and easy instrument to predict near future groundwater level;
- The vadose zone hydrologic variables have been demonstrated to be much "powerful" than the meteoric variables to predict groundwater level (the actual infiltration process is considered) only if temperature is excluded or the noise is naturally reduced;
- Implement the model by using the effective rainfall as regressor by calculating the evapotranspiration and compare the prediction with the ones depicted from the vadose zone (on going);
- Continue the monitoring during the years to "catch" and strengthen the seasonal effect;
- Predict the groundwater level for specific periods potentially related to an increase in water demand.

PROF WALTER DRAGONI, PERUGIA UNIVERSITY

TITLE: IMPACT OF CLIMATE CHANGE ON WATER RESOURCES: COSIDERATIONS REGARDING THE UNCERTAIN FUTURE OF WATER RESOURCES IN THE CENTRAL APENNINES (ITALY)

In his opening remarks, Prof Walter Dragoni Walter mentioned that the current presentation serves as an update to a previous talk he gave a few years ago. He expressed concern that based on the forthcoming results he will present, further updates may be necessary in the coming years

He claimed that the aim is to look into how current climate change is affecting the springs in Italy's Central Apennines. Bagnara Spring (111 l/s) was selected as the sample case; at present, groundwater recharge for the limestone area in the Umbria region is approximately 450 mm/year (45 m^3/s).

The speaker continued by going over the Bagnara Spring's hydrogeological structure. Its recharge area is only 7.5 km^2 and its average elevation is 1150 m. The spring elevation is 630 m asl. Monthly temperature and rainfall are measured at NOCERA UMBRA station, which is located at 535 m asl. Missing data is calculated from GUBBIO station, which is located 36 km from the spring.

Prof Dragoni went on to describe the structure of the SPRING model, which follows a lumped approach on a monthly basis. It utilizes semi-empirical formulas to simulate rainfall transformation into evaporation, runoff, and aquifer recharge. Groundwater flow is represented using the Darcy equation, with a focus on Darcian flow and exclusion of non-Darcian flow due to satisfactory results and complexity considerations. The model performs a monthly water balance analysis for individual components and the overall system, employing the least squares method for optimisation.

In addition, Prof Walter Dragoni discussed potential future scenarios during his presentation. He mentioned that they simulated these scenarios using three circulation models commonly employed by the European Commission's Bologna Centre for Climate Change. Downscaling was performed based on user requirements. The simulation involved two projections of the Intergovernmental Panel on Climate Change (IPCC) related to future socio-economic pathways: SSP2-4.5 (mild) and SSP5-8.5 (severe).

In total, nine simulations were conducted, consisting of six simulation datasets representing future scenarios and three simulations using real data with the three models. The latter served as a validation to assess how well the models simulated the actual reality.

Furthermore, Prof Dragoni discussed the outcomes of the three calibrated models on a yearly basis. The average rainfall obtained from the models showed negligible differences. Additionally, the temperature simulated by the models closely matched the observed data. However, a challenge arose when the circulation models produced contrasting results, with one suggesting less rainfall, another indicating more rainfall, and another showing similar outcomes. In light of this, the question was raised regarding the next steps to be taken with these models considering the varying results from the circulation models.

He suggested he might end by warning people to use caution and not to believe what the models portray. Moreover, a histogram was presented comparing the measured data (red bar) from the observatory with the model calibrations (blue bars), which showed reasonably good agreement. Additional graphs showcased the distribution of different rainfall frequencies on a monthly basis, representing the probability distribution of rainfall for each month. Furthermore, the presenter displayed graphs for each model, illustrating the monthly rainfall from 1984 to 2016 and highlighting the differences between measured and simulated rainfall. It was acknowledged that the models exhibited limitations in accurately predicting rainfall on a monthly basis, leading to uncertainty that impacts the annual average in the models.

Prof Dragoni made the following comments to wrap off his presentation:

- This work confirms that, at present, global climate models provide conflicting rainfall scenarios in the area considered here.;
- Uncertainty affects both the annual averages and the variability of the series;
- For consecutive periods of several months, the models amplify rainfall variability, with a tendency for high rainfall events to increase. This should be considered a bias, since amplification also affects the simulation of measured data;
- The characteristics of the simulated rainfall series impact the flow rates generated by the SPRING model, which are more variable than the measured ones, also in terms of periods with very high rainfalls;
- In these areas, it is impossible to confidently plan drastic actions to minimize not clearly defined impacts. At present, the goal to be pursued should be "not-regret actions," i.e., actions that in any case are not negative, neither from the points of view of water resources nor of the environment and economy: For instance, simply not polluting and not wasting water. And, of course, monitoring the evolution of the climate and of the yield of springs.

Question 1: Prof Walter Dragoni was asked about the predictability of modelling future scenarios, with a consideration for time intervals up to 100,000 years. The current scenario projections typically span up to 200 years. The question posed was whether it is feasible to rely on a 100-year model or if shorter time intervals, such as 10 to 20 years, should be utilized. He responded by stating that focusing on short time intervals, such as 1 or 2 years, would be devoid of meaningful implications, as it would serve primarily for publishing papers. Conversely, projecting scenarios all the way to 2100 would also lack significance due to the inherent complexities involved. Prof Dragoni highlighted that forecasting the occurrence of wars in the next 100 years is challenging, as it involves both the intricate nature of modelling complex systems and the uncertainties surrounding human actions.

Question 2: Ms Emma Petrella was asked a question regarding the identification of fault nature and potential barriers using geological maps or other means, instead of conducting highly detailed investigations. He specifically mentioned instances where water was observed permeating through certain points within the fault. The query aimed to determine whether it is possible to discern such information solely by examining geological maps or if more extensive investigations would be necessary. Ms Petrella responded by stating that geological structure investigations are conducted to address such inquiries.

Question 3: An attendee raised a question to Prof Dragoni, expressing agreement with the challenges associated with forecasting rainfall and climate patterns in the next 20 to 30 years. He acknowledged that their research focus does not involve evaluating the accuracy of these models. However, he highlighted the importance of considering groundwater and groundwater discharge, citing data availability in Italy over the past century. He noted that continuous monitoring exists in certain cases, while in others, information is more scattered. He also emphasized that there has been a decrease in groundwater discharge and snowmelt, accompanied by rising temperatures, indicating the impact of climate change on groundwater systems. He acknowledged the difficulty in fully understanding and predicting future changes but suggested that forecasts could be based on existing discharge monitoring data.

Prof Dragoni emphasized the importance of consulting the latest models to understand future scenarios. According to various models, a 50% decrease in rainfall is expected over the next 30 years. The existing barriers may not be sufficient for long-term safety, prompting the need to reevaluate the management of springs. Although there is currently no clear evidence of decreased rainfall in the area, slight increases of 1 to 2mm have been observed. Prof Dragoni cautioned against relying solely on the forecast of one model and suggested considering multiple perspectives. The question of building many dams as a solution requires careful consideration.

Question 4: The comment directed towards Prof Dragoni expressed the opinion that certain models may be insufficient, as their usefulness extends beyond mere forecasting. The commenter emphasized the significance of utilizing models that incorporate present and past data. They argued for the necessity of comprehensive models that provide a historical perspective on springs, including factors such as the presence of pumping wells in the vicinity and the potential effects on individual springs. The commenter regarded this as an important consideration in understanding and managing springs effectively. Prof Dragoni expressed agreement with this comment.

Question 5: Dr Davide Cappellari was asked whether he believes it is feasible to consider these variables in addition to the typical seasonal recharge distribution. Dr Cappellari responded by emphasising the importance of understanding the system thoroughly and strategically placing sensors to collect data. He suggested incorporating regressors to enhance predictions based on our knowledge of the system. Additionally, Dr Cappellari highlighted the significance of utilizing artificial intelligence to further advance our understanding and modelling capabilities.

Question 6: Prof Dragoni responded to Dr Cappellari, acknowledging the effectiveness of his simulation but noting the presence of errors in all models. He expressed curiosity about the underlying mechanism that allows a system to produce a flawless simulation without any prior knowledge or data cleaning. In his opinion, this highlights a gap in our understanding. Prof Dragoni expressed a desire to learn more about the development of these models and gain insights into how such occurrences can take place.

Dr Cappellari responded by explaining that the prediction accuracy is attributed to the extensive dataset used in the model. The incorporation of a substantial amount of data, potentially exceeding 20% of the available data, contributes to the reliability of the predictions. He further mentioned that the model can provide forecasts beyond the typical two-month timeframe, enabling water system management for several months in advance.

3.5 Part 5

DR TIZIANA DI LORENZO, RESEARCH INSTITUTE ON TERRESTRIAL ECOSYSTEMS (IRET) NATIONAL RESEARCH COUNCIL (CNR)

KEYNOTE 4: DIVERSITY, TRAITS, SERVICES, VULNERABILITY AND CONSERVATION OF GROUNDWATER ECOSYSTEMS

Dr Di Lorenzo stated that groundwater serves as the world's largest freshwater ecosystems. She informed that within the upper part of the continental crust, groundwater is predominantly fresh. Dr Di Lorenzo highlighted a phenomenon known as Darkness Syndrome, where organisms inhabiting groundwater have evolved behavioural adaptations to survive in extreme environments. These adaptations encompass various morphological, physiological, and behavioural traits. Morphologically, the speaker elaborated that these organisms often display depigmentation, anophtamly/microphthalmy (reduced eye size or absence of eyes), and elongation of sensory organs. Physiologically, she explained that they have adapted to cope with food scarcity, exhibiting low metabolism, low acclimation ability, low fertility, and enhanced longevity. Furthermore, Dr Di Lorenzo these organisms have developed a tolerance for stable temperatures, with a narrow thermal niche. Their behavioural traits include wandering, thigmotaxis (tendency to stay close to surfaces), and slow locomotion, which aid in adapting to limited food resources.

Dr Di Lorenzo emphasized the risks posed by anthropic pressures on groundwater ecosystems. These pressures include habitat reduction or depletion, contamination, and the impacts of climate change. Dr Di Lorenzo explained that groundwater animals, due to their low metabolism, are significantly more sensitive to these pressures compared to surface water animals, rendering them ten times more susceptible to harm. Unfortunately, she acknowledged that the new groundwater directive fails to account for this vulnerability, representing a critical concern that needs to be addressed. Dr Di Lorenzo underscored that groundwater animals play a vital role in maintaining ecosystem health as they possess the ability to feed on viruses and pathogens, making valuable contributions to water quality and human health. However, the speaker maintained that the global decline in species diversity poses a significant threat to these groundwater animals. The speaker stated that the reduction in their numbers jeopardizes the crucial ecosystem services they provide, such as the purification of brown water, as well as their role as environmental engineers.

Dr Di Lorenzo concluded that the study of groundwater ecosystems reveals the intricate interplay between diversity, traits, services, vulnerability, and the need for conservation efforts. Her research shed light on the adaptations of groundwater organisms to extreme environments and highlighted the risks they face from anthropic pressures. Dr Di Lorenzo reiterated that recognizing the importance of groundwater animals and their valuable ecosystem services is crucial to safeguarding these fragile ecosystems for future generations.

Question: What other considerations need to be accounted for with regard to groundwater organisms?

Dr Di Lorenzo stated that the lowering of the water table due to drought is a cause for concern. In comparison to recharging groundwater, the process of lowering the water table poses more significant dangers. To ensure the safety of the recharged water, she emphasized the importance of carefully assessing its quality, utilizing adequate thresholds in accordance with guidelines and advised adopting a conservative approach. This cautious approach is particularly crucial due to the organisms' long lifespans, as even minimal exposure to pollutants over extended periods can prove hazardous to them. Additionally, Dr Di Lorenzo warned against recharging hot water, as it could have adverse effects on the ecosystem. Altering the water temperature might activate organisms, leading to increased metabolic activity, and a subsequent rise in oxygen consumption. Given that oxygen concentrations in groundwater are already low, such changes could prove fatal to these organisms, leading to their demise. Therefore, Dr Di Lorenzo posited that careful consideration and adherence to safety measures are essential when undertaking groundwater recharge to avoid unintended consequences.

Question: In order to convince many people that these organisms are important, not only for people that are fond of them, one could argue their usefulness to society. Thus, can we prove that they are also useful for decontamination of groundwater?

Dr Di Lorenzo stated that at the moment, there is no definitive answer, but there is a belief that these organisms could prove to be highly valuable for denitrification purposes. The speaker explained that the denitrification process requires low oxygen concentration and an abundance of organic substances, conditions which groundwater organisms are adept at handling. Their ability to thrive in low oxygen environments and feed on microbes makes it a reasonable assumption to explore. However, she posited that the real challenge lies in testing this hypothesis, as reproducing the precise conditions in a laboratory setting is exceedingly difficult.

Question: Groundwater ecology has yet to make its mark and I believe that it is the next frontier in groundwater management. We need to put more spotlight on groundwater management as well as groundwater pollution.

Dr Di Lorenzo agreed that there is a need to understand one another and work collaboratively. She concluded that this conference has been a great opportunity.

MS EVA KUN, SZABÁLYOZOTT TEVÉKENYSÉGEK FELÜGYELETI HATÓSÁGA (SZTFH)

TITLE: HYDROGEOLOGICAL ASSESSMENT AND MODELLING FOR THE AUTHORISATION OF WATER RECHARGE IN THE BEREG MARSHES

Ms Kun stated that she would like to begin by introducing the audience to the Bereg marshes, providing some background information about the research area. The Bereg marshes, according to Ms Kun, are a significant ecological feature located in the Hortobágy National Park. However, the speaker informed that over time, the number of wetlands in the area has drastically reduced, and the ecological condition of the remaining ones has deteriorated, primarily due to the decreasing groundwater levels. She highlighted the importance of the Water Framework Directive (WFD) in protecting and achieving sustainable use of the EU's water environment. Ms Kun explained that under Article 4.7 of the WFD, Member States have the opportunity to grant exemptions or derogations from the requirements of the directive under specific circumstances. In the case of the Bereg marshes, an exemption under Article 4.7 was sought to upgrade the water recharge systems of the bogs and marshlands in the Bereg and Nyírség areas.

Ms Kun then discussed the possible causes of the decrease in groundwater levels in the Bereg marshes. She emphasized three key factors: climate change, riverbed erosion of the Tisza River, and increased groundwater production. These factors, as asserted by Ms Kun, have contributed to the decline in groundwater levels, impacting the wetland ecosystems and their overall ecological condition. To address these challenges, Ms Kun explained that hydrogeological modelling was conducted. She outlined the modelling process which involved both horizontal and vertical divisions. In terms of horizontal division, Ms Kun indicated the model extended across national borders in the north and east, encompassing the most significant regional water abstraction districts. She affirmed that the number of model cells was limited to ensure the model's efficiency. Regarding the vertical division, Ms Kun mentioned that the model consisted of seven layers. She elaborated that the first layer represented the groundwater aquifer, while the subsequent layers represented different geological complexes, including the upper and middle Pleistocene complexes, the lower Pleistocene complex, and the upper, middle, and lower parts of the Upper Pannonian complex.

Based on the modelling results, Ms Kun drew several conclusions. She emphasized the importance of maintaining good groundwater status in harmony with the objectives of the Water Framework Directive to preserve the good environmental status of groundwater-dependent ecosystems. She also highlighted the significance of managing the quantitative demand on groundwater to ensure the preservation of wetlands. In terms of suggested activities, Ms Kun proposed the implementation of complex groundwater level observation, possibly with high-frequency measurements within a day using transmitters. This would enable timely intervention and monitoring of groundwater levels. Additionally, she stressed the need to coordinate water management goals with other water uses to mitigate the adverse effects of climate change. Furthermore, she emphasized the importance of considering cross-border information, particularly regarding wetlands and water production, to ensure effective and collaborative management strategies.

Ms Kun reiterated the importance of hydrogeological assessment and modelling in the authorization of water recharge in the Bereg marshes. She highlighted the need for continued monitoring and management efforts to maintain the good environmental status of groundwater-dependent ecosystems and emphasized the significance of collaboration and coordination in achieving water management goals.

DR FRANCESCA GORI, SAPIENZA UNIVERSITY OF ROME

TITLE: HYDROGEOCHEMICAL AND MULTI-ISOTOPE CONSTRAINTS ON THE GEOCHEMISTRY OF THE BAGNO DELL'ACQUA ALKALINE LAKE, PANTELLERIA ISLAND (SOUTHERN ITALY)

Dr Gori stated that the main goals of the study were to contribute to a wide multidisciplinary study for the conservation of the biodiversity of the Bagno dell'Acqua lake and to gain new insights into the evaluation of the environmental impact associated with climate changes. According to the speaker, the study aimed to expand understanding of this extreme aquatic environment, specifically an alkaline lake, by investigating the origin and mixing of lake water, groundwater, and ascending deep thermal fluids. Dr Gori informed that Pantelleria Island is the emerged summit of a large submarine volcano located in the Sicily Channel Rift Zone. She went on to elaborate that the island is characterized by volcanic products, including effusive basalts and explosive trachytes to peralkaline rhyolites. The volcanic system of Pantelleria is still active, with current volcanic activity limited to low temperature fumarolic emissions and thermal springs. The speaker maintained that the only surface water on the island is represented by Bagno dell'Acqua Lake.

Bagno dell'Acqua Lake is an endorheic alkaline lake situated inside the Cinque Denti caldera depression. The lake's surface area, as informed by Dr Gori, is strongly influenced by water input from rainfall, runoff, and a contribution from the thermal aquifer. The southwest shoreline of the lake is affected by hydrothermal activity, primarily releasing CO_2. Dr Gori highlighted the main findings of the study, which included the delineation of the conceptual model of groundwater flow through hydrogeological and hydrogeochemical monitoring. The geochemical composition of Bagno dell'Acqua was found to be regulated by several processes, as explained by Dr Gori. She elaborated that these processes include mixing between infiltered meteoric and sea waters, enrichment in alkaline elements due to intense water-rock interactions facilitated by deep thermal fluids (specifically CO_2), salinization caused by high evaporation rates, and the efficient removal of Ca and Sr elements from the lake water through mineral precipitation, influenced by pH and biological activity. Furthermore, Dr Gori emphasized that the mixing of infiltered meteoric and sea waters plays a significant role in shaping the geochemical composition of Bagno dell'Acqua Lake. She maintained that this mixing process contributes to the overall water chemistry and influences the presence of various elements in the lake.

Another important factor highlighted by Dr Gori is the enrichment of alkaline elements in the lake due to intense water-rock interactions, which are enhanced by the presence of deep thermal fluids, particularly CO_2. These interactions result in the release of alkaline elements into the lake water, further influencing its chemical composition. The study also found that the high evaporation rate in the lake leads to salinization. As water evaporates, Dr Gori explained that the concentration of dissolved salts increases, leading to higher salinity levels. This salinization process affects the overall chemistry of the lake and contributes to its alkaline nature. Dr Gori pointed out that the lake water exhibits efficient removal of calcium (Ca) and strontium (Sr) elements through mineral precipitation. This removal, according to Dr Gori, is attributed to the lake's pH levels and the influence of biological activity. The precipitation of minerals effectively removes these elements from the lake water, leading to their reduced presence in the system.

In conclusion, Dr Gori's study on the Bagno dell'Acqua alkaline lake in Pantelleria Island provided valuable insights into the hydrogeochemical and multi-isotope constraints that shape the lake's geochemistry. The study shed light on the origin and mixing of lake water, groundwater, and deep thermal fluids, while also contributing to the wider effort of conserving biodiversity in the lake. The findings highlighted the importance of various processes, such as mixing of different water sources, water-rock interactions, evaporation, and mineral precipitation, in shaping the unique chemistry of the lake.

DR EDOARDO SEVERINI, UNIVERSITY OF PARMA

TITLE: CLIMATE CHANGE AND IRRIGATION PRACTICES DISSOCIATE REDUCTION OF N FERTILIZERS FROM THE IMPROVEMENT OF WATER CHEMISTRY IN GROUNDWATER DEPENDENT RIVERS

Dr Severini presented his research on the topic of climate change and its implications for nitrogen fertilizers and water chemistry in groundwater dependent rivers. He highlighted the observed effects of climate change in Southern Europe, including severe droughts and low discharge in the summer, as well as flash floods in other seasons, which have significant consequences for water resources and agricultural practices. The focus of Dr Severini's study was the River Chiese and its watershed, an area characterized by intensive agriculture and animal farming within Nitrate Vulnerable Zones (NVZs). The primary agricultural practices in this region, as informed by Dr Severini, involved excessive nitrogen fertilization and flood irrigation over highly permeable soil and aquifers. He assured that to investigate the issue, sampling points were established in wells and the river, with the collaboration of the regional environmental agency (ARPA), to conduct a comprehensive assessment.

The speaker mentioned one working hypothesis which considered the potential positive feedback loop that could contribute to nitrogen contamination. Dr Severini observed the rapid percolation and solubilization of excess nitrogen from the soil, the maintenance of oxidized microbial nitrogen pathways, the accumulation of nitrate in groundwater, and the subsequent mobilization of nitrate-polluted groundwater to the surface drainage system. He reiterated that these processes contribute to the contamination of both surface water and groundwater. In his presentation, Dr Severini demonstrated that despite a reduction in nitrogen inputs over a period of 20 years, the contamination levels did not decrease proportionally. He noted that groundwater nitrate concentrations remained above the European thresholds, and the River Chiese exhibited a sharp increase in downstream nitrate concentrations, classifying it as lower quality under the Water Framework Directive. A significant factor exacerbating this issue, concluded Dr Severini, is the excessive use of irrigation, primarily supported by wells. He informed that in order to meet the high irrigation demands, which can be four times the river discharge during the irrigation period, the river can be completely dried out. This reliance on wells for irrigation leads to elevated nitrate concentrations in the river, surpassing the thresholds set by the Water Framework Directive. During the irrigation period, the river transforms into a Groundwater Dependent Ecosystem, rendering it particularly susceptible to groundwater nitrate contamination.

Dr Severini also investigated why similar rivers in the Po Plain region did not exhibit the same level of contamination. He stated that the excessive use of wells for irrigation was found to lower the groundwater table due to increased evapotranspiration. This, in turn, promotes the accumulation of nitrate and creates high oxygen concentrations, which impede denitrification processes. Dr Severini's research emphasized the significant impact of traditional agricultural practices on surface and groundwater contamination, particularly when combined with the effects of climate change. The drying out of the river and the overexploitation of groundwater for irrigation purposes, driven by prolonged droughts, create a detrimental feedback loop that exacerbates nitrogen contamination. This phenomenon, known as the "irrigation loop," poses substantial challenges for water resource management and necessitates the adoption of sustainable agricultural practices to minimize nitrogen pollution.

MR LUCA ZINI, UNIVERSITY OF TRIESTE

TITLE: KARST LAKES FRAGILE ENVIRONMENTS TO BE KNOWN AND PROTECTED

Mr Zini stated that in a mature karst area, ephemeral lakes represent a unique but extremely fragile environment for naturality and biodiversity. He acknowledged that these lakes are intricately connected to the presence and permanence of water, and any changes, whether natural or man-made, have a rapid impact. Therefore, understanding the hydrodynamics of these lakes is essential in order to comprehend their ability to adapt to changes and, more importantly, to protect and preserve them.

Mr Zini assured that in order to achieve this, hydrogeological studies have been conducted. He assured that a geological and geomorphological survey has been carried out to assess the geological formations and landforms surrounding these lakes. Additionally, speleological surveys have provided insights into the cave systems and underground water flow, as explained by Mr Zini. The speaker noted that continuous monitoring using CTD (Conductivity, Temperature, and Depth) measurements has been implemented to track the hydrological parameters over time. Tracer tests have also been conducted, as elaborated by Mr Zini, to trace the movement of water and understand its flow paths. Furthermore, an evaluation of the impact of possible remediation measures has been undertaken.

In the past three decades, a significant change has been observed in the hydrogeological regime of the karst lakes. Mr Zini emphasized that these changes are primarily attributed to reclamation works and the increasing frequency of intense rainfall and drought periods. According to Mr Zini, it is crucial to act swiftly in order to preserve these delicate ecosystems. Only through a comprehensive understanding of the entire hydrodynamics, the speaker asserted, intervention could be executed effectively, thereby preventing further damages.

In conclusion, the fragility of karst lakes necessitates urgent action for their preservation. Mr Zini's research underscores the importance of comprehending their hydrodynamics to protect these unique environments. By conducting hydrogeological studies, assessing impacts, and implementing appropriate measures, we can ensure the conservation of these valuable ecosystems for future generations.

Dr Laura Sanna, National Research Council of Italy

Title: The contribution of occult precipitation to karst aquifers recharge in semi-arid zones

Dr Sanna stated that the focus of her research is on the contribution of occult precipitation to the recharge of karst aquifers in semi-arid zones. She began by introducing the study area, the gypsum karst of Sorbas, which is located in the district of Sorbas in South-East Spain. This protected natural area spans only 12 km2 but hosts over 1,000 caves, some of which extend for more than 1,000 meters. The speaker noted that the climate in Sorbas is characterized as semi-arid and the majority of the rainfall is distributed in just 3-4 days throughout the year. She informed that there are approximately 30 rainy days annually, with the minimum mean rainfall occurring in July and the maximum in November. The region, as explained by Dr Sanna, experiences high evapotranspiration rates of 1100 mm per year, leaving less than 25% of the total rainfall as useful water, amounting to approximately 60 mm per year.

Dr Sanna highlighted the geomorphology of the study area, describing it as a topographically elevated landscape at around 400 meters above sea level, featuring a northeast-elongated platform with steep edges overlooking dry valleys. The epikarst in this region consists of dolines, various forms of karren, and fields of tumuli. Additionally, the characteristic cave morphologies are triangular interbedded galleries. The speaker informed that the Sorbas area is situated in the Tabernas-Sorbas Basin, which is an intramontane Neogene depression in the Betic Belt that underwent Messinian evaporite deposition. She acknowledged that the structure in this area is poorly deformed and exhibits tabular stratification with a slight inclination, with the lithology in the region shows strong contrasts, particularly at the gypsum-marls boundary. There are six permanent springs in the area.

Dr Sanna emphasized that while the volume of occult precipitation in the study area may seem negligible compared to the annual rainfall received, it is important to consider certain factors. The estimated condensation rate value is likely a low estimate due to evaporation effects on the instrument's surface and the container used to collect the water, which have not yet been quantified. However, in deeper galleries, the evaporation effect could be significantly reduced, potentially leading to increased "useful condensation." Therefore, Dr Sanna concluded that further investigation is needed to better understand the contribution of occult precipitation to karst aquifer recharge in semi-arid zones.

Question: Did you take into consideration groundwater levels with regard to irrigation?

Dr Severini stated that there was a noticeable increase in groundwater levels within just one month after initiating irrigation. However, he emphasized that the complete impact and significance of this irrigation practice can be fully appreciated over a more extended period, spanning at least one year.

PROF. MARCO PETITTA, EARTH SCIENCES DEPARTMENT, SAPIENZA UNIVERSITY OF ROME

TITLE: TOWARDS EUROKARST 2024

In the realm of hydrogeology, the prospect of organizing another conference in Italy on the subject brought forth a notable development. Prof. Pettita communicated the encouraging news that EuroKarst 2024 would convene in the historic city of Rome. This forthcoming event instilled a sense of enthusiasm among the scientific community. However, Prof. Pettita emphasized the necessity of financial preparation, cautioning that the conference would not be free to attend. Funding considerations would play a crucial role in ensuring the successful execution of the event. To participate in the conference, the speaker stipulated that each delegate must contribute pertinent insights into the realm of Karst aquifers. For those not well-versed in the subject, conducting research on Karst areas in their respective regions was suggested to furnish valuable knowledge for the exchange of ideas during the conference.

The Health Science Department of Sapienza University, situated within its main campus, was designated as the host venue for the conference, as informed by Prof. Pettita. He noted that the organizing committee comprised three esteemed Italian universities: the University of Siena, the University of Bari, and Sapienza University of Rome. The collective involvement of these prominent institutions indicated a profound academic impact for the event. To bolster the conference, efforts were underway to secure influential sponsors to support its objectives.

As part of the conference timeline, Prof. Pettita announced that the event would open in September, with the submission of research papers scheduled until mid-November. The process of accepting and declining papers would be concluded by December. Adhering to the customary practices of EuroKarst meetings, the speaker assured that meticulous preparations would be made, culminating in the publication of the conference proceedings.

Francesco revealed that the journal will feature papers from the ongoing conference. As part of this process, a survey will be sent out to all the contributors to gauge their interest in publishing their contributions in the journal. He hoped that many of them will be interested, and the first issue, which he envisions as the start of a series, is scheduled to be released in March.

Prof. Serigussi announced that the next national congress will be held in Torino.

4. Presentations

WATER
BE THE CHANGE

flowpath

Malta 2023

14th – 16th June
National Meeting on Hydrogeology

JUNE 14-16, 2023

WATER.ORG.MT

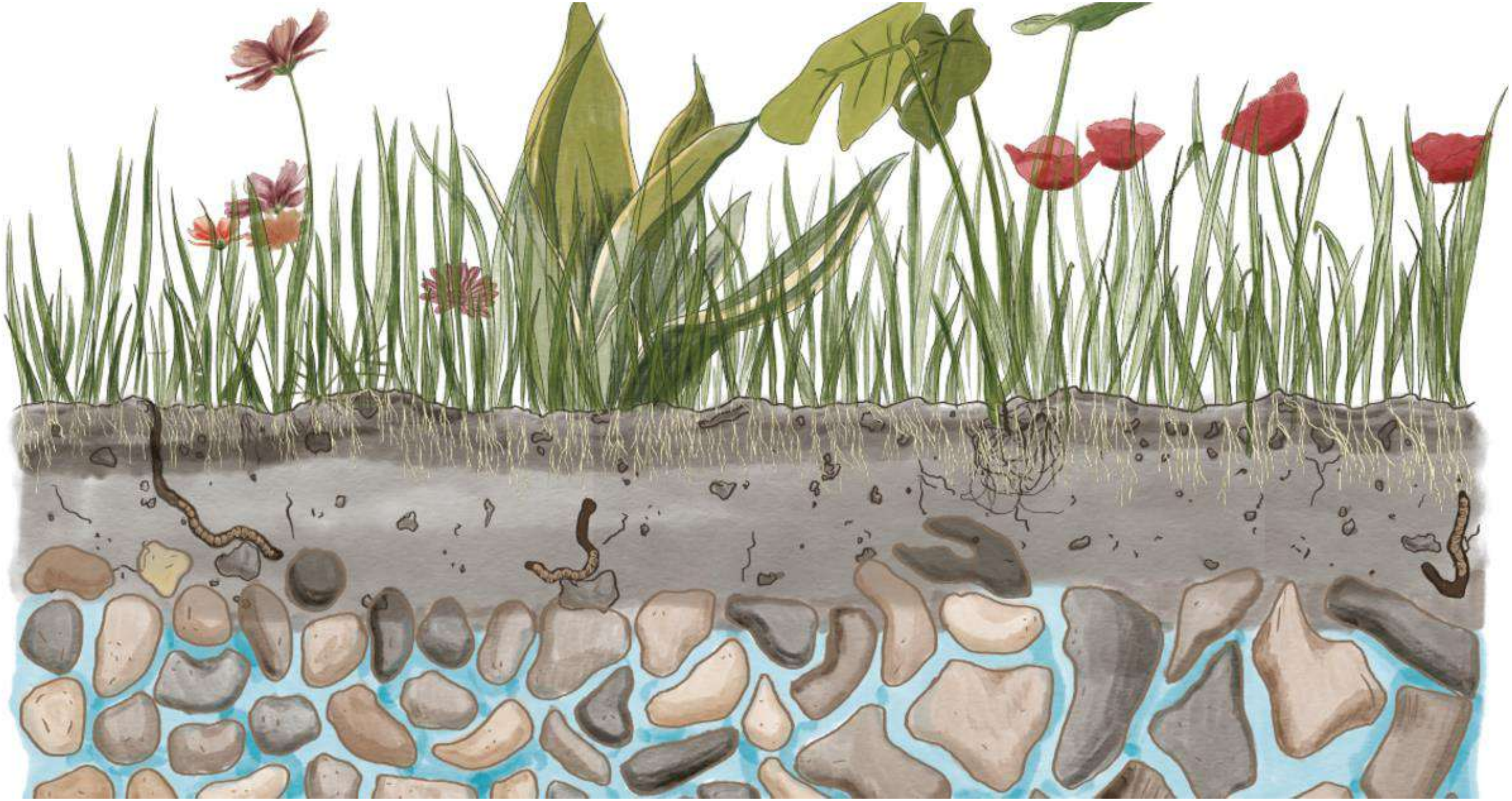
The contribution of water museums and ancient hydro-technologies to achieve the goals of sustainability in groundwater management

Eriberto Eulisse – CEO, Global Network of Water Museums
www.watermuseums.net

- How can we improve sustainable groundwater management?
- Why people should care about it?
- How can museums and interpretive centres support science to target SDGs?

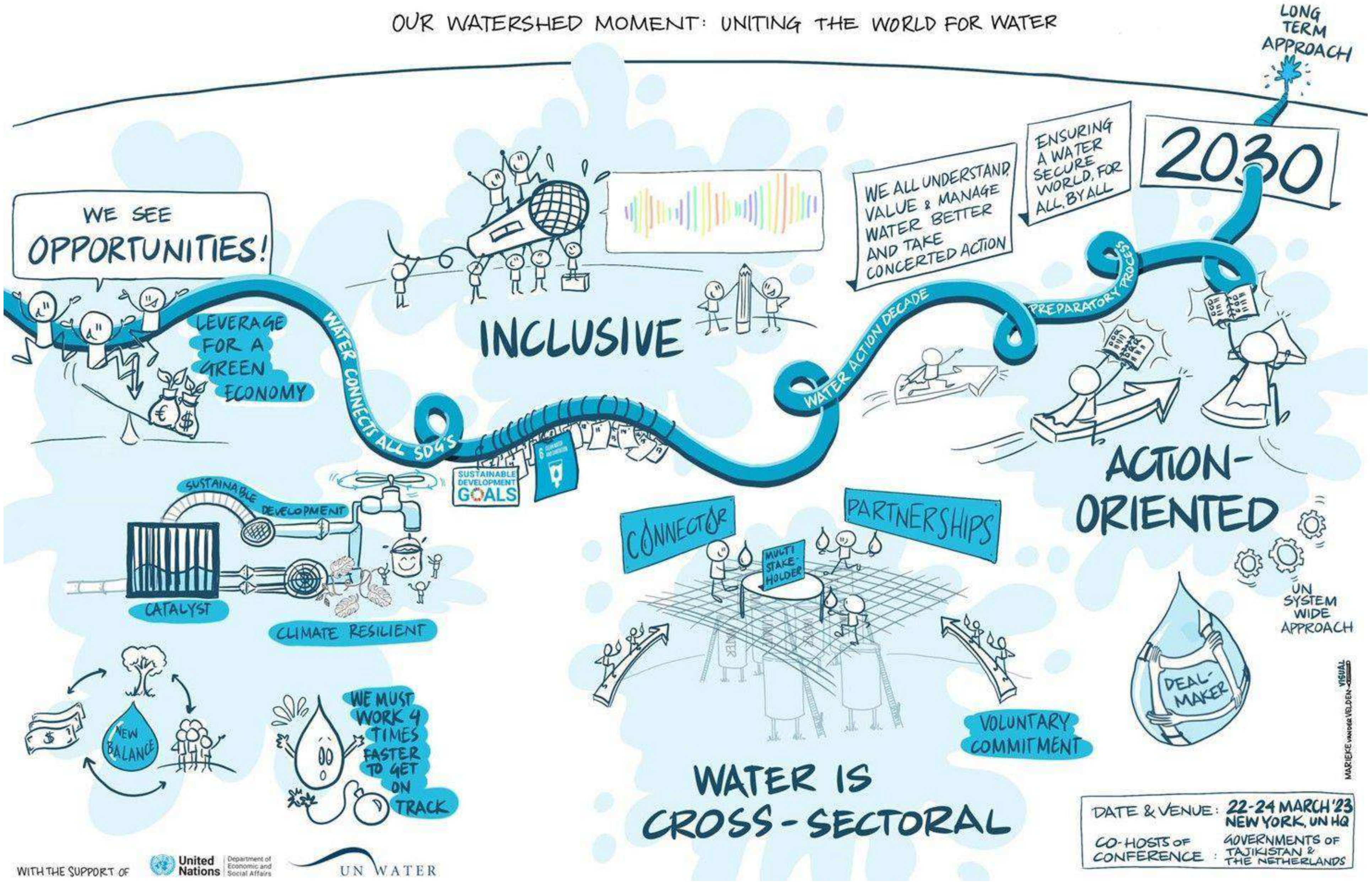
UN WATER SUMMIT, PARIS 2022

Groundwater: making the invisible visible



VISION STATEMENT UN 2023 WATER CONFERENCE

OUR WATERSHED MOMENT: UNITING THE WORLD FOR WATER



WATER ACTION AGENDA & IHP 9

The role of water museums and ancient hydro-technologies to make the invisible visible, supporting science communication and policy makers to target sustainability in managing (ground)waters

WHY MUSEUMS?

In common opinion, museums are considered as a ***reliable source of information***

Museums address & explain complex problems in simple ways : they know how to ***communicate with the public***

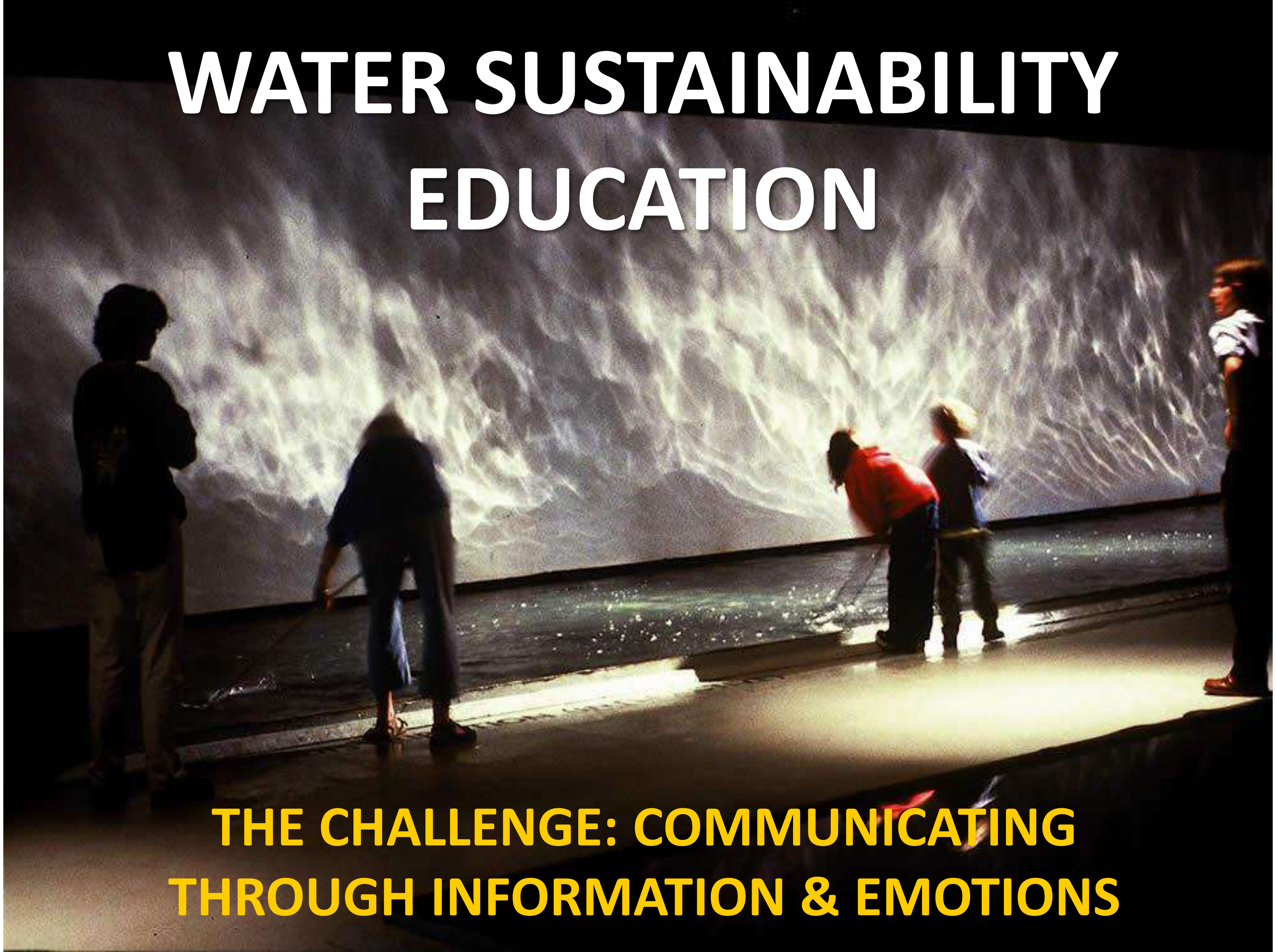
Museums are safe learning platforms for both ***adults & children***

WHY MUSEUMS?

Many people learn science topics not so much from the media or classrooms, but from ***personal interactions in informal settings***, such as museums

Museums are ***fun & creative***, promote ***awe & wonder***

Museums offer today ***experiential learning opportunities*** as they transmit key concepts to face global challenges


WATER SUSTAINABILITY
EDUCATION
THE CHALLENGE: COMMUNICATING
THROUGH INFORMATION & EMOTIONS

EVOLUTION OF MUSEUMS' FUNCTIONS

New trends in popup exhibits for community's engagement

From the concept of "collections" and classified objects to heritage awareness promotion and communication of global challenges in the Anthropocene

Science museums, ecomuseums and "extended museums" focus on connecting with their local communities: they are more interested to people's opinions and look for greater involvement of locals

How to communicate groundwater challenges?

Science is the necessary condition, but it’s not sufficient to successfully communicate with people & communities

The creation of a new bridge between Science & Society must be sought to face the Anthropocene challenges

Museums are the cornerstone of this bridge: they know how to engage the general public

Museums and exhibitions are agents of change and platforms for networking and exchange

UNESCO-IHP RESOLUTION N.5-XXIII (2018)

The Global Network of Water Museums (WAMU-NET)

is a 'flagship initiative' of UNESCO-IHP

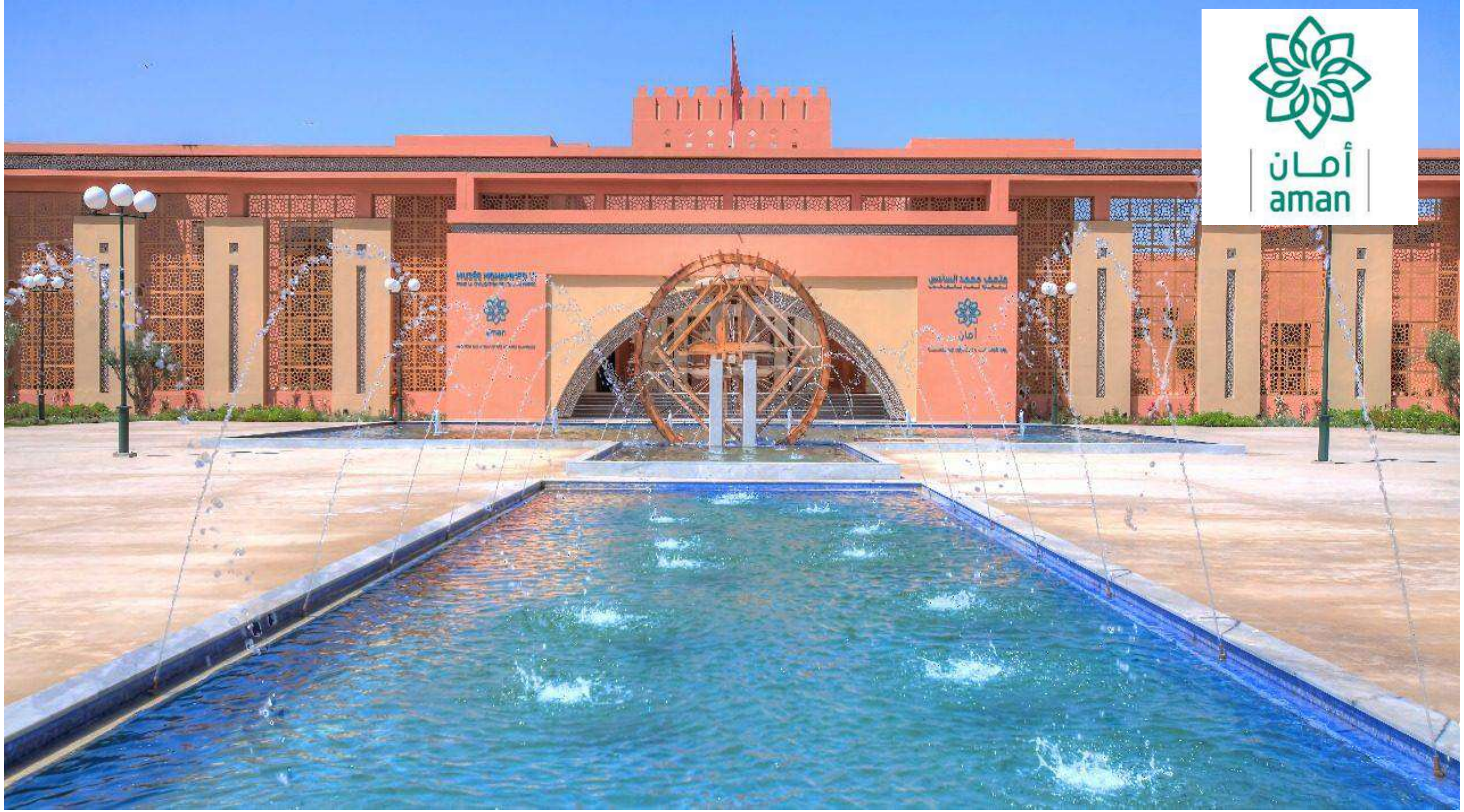
(Intergovernmental Hydrological Programme)

90+ MEMBERS IN 40 COUNTRIES

Yazd Regional Water Authority

YAZD WATER MUSEUM

YAZD, IRAN



MUSEE POUR LA CIVILIZATION DE L'EAU
MARRAKECH, MOROCCO

MUSEUM 'AGUA PARA SIEMPRE!'

PUEBLA, MEXICO

HYDRIA MEDITERRANEAN WATER NETWORK

MIO-ECSDE, GREECE

GHAJN: NATIONAL WATER CONSERVATION AND AWARENESS CENTRE. RABAT, MALTA

WATER MUSEUMS GLOBAL NETWORK

unesco
Intergovernmental Hydrological Programme

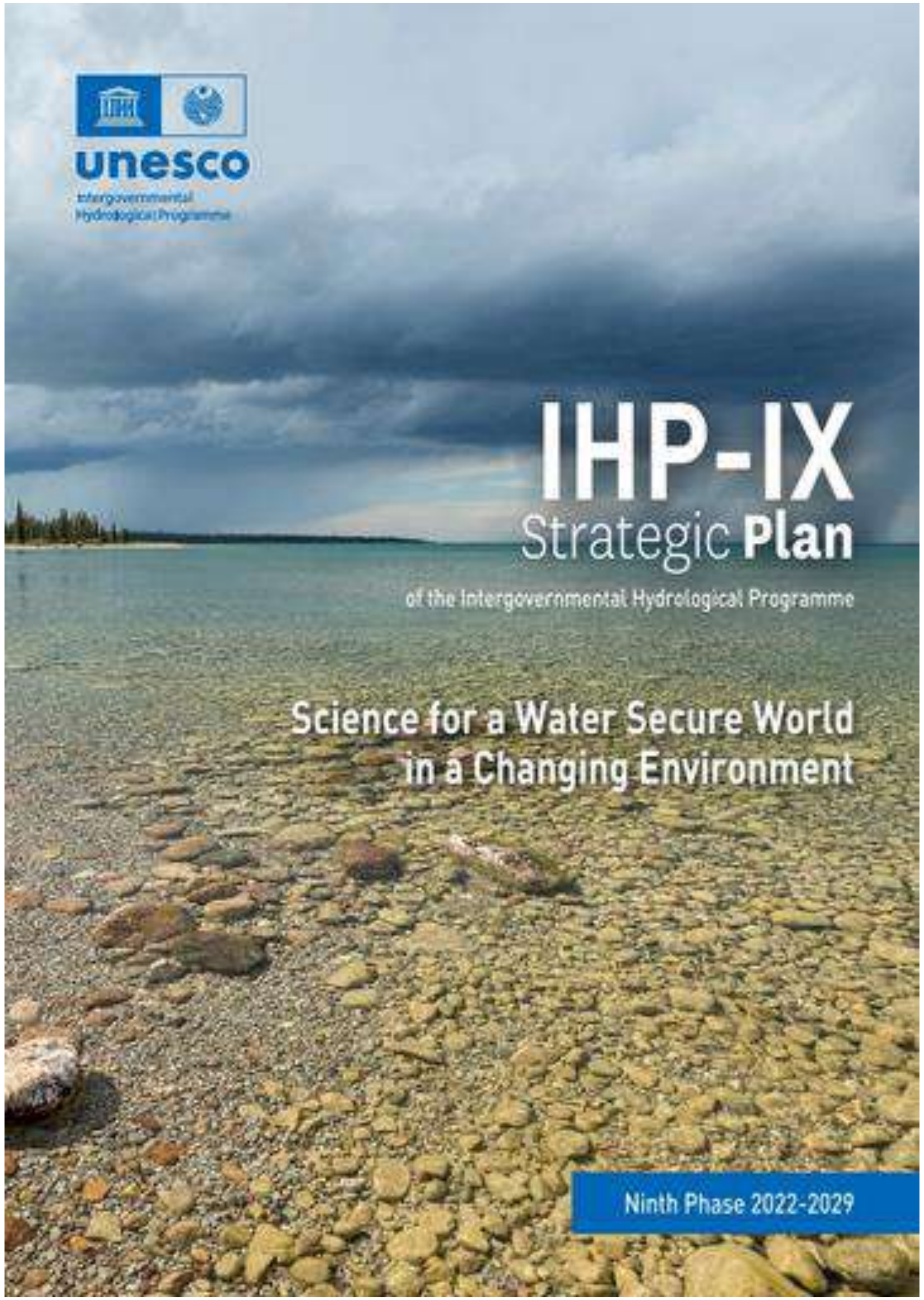
WAMU-NET'S COMMITTMENT TO BUILD A «NEW CULTURE OF WATER»

We must "reinstate a new relationship
between humanity and water:
a new 'sense of civilization' which
can help to reconnect people and water
in all its dimensions - including scientific,
technical, social, cultural, artistic and spiritual"

«Manifesto" or founding ethical charter, 2017

PROMOTING PARADIGM SHIFT

From the prevalent cultural paradigm of ‘domination over Nature’ to one of ‘ecosystem sustainability’



Phase 9 of IHP Strategic Plan (2022-2029)

Five priorities:

- Research
- Education
- .....

WAMU-NET is included among the key institutions that must be involved to promote «water sustainability education»

PRIORITY 2 OF IHP PHASE 9:
«WATER SUSTAINABILITY EDUCATION»

"IHP-IX encourages a broad conception of water education …. to favor a change in behaviors towards a society with greater eco-social awareness […] supporting the development of interdisciplinary materials such as guidelines, briefing papers, and case studies on leading practices in water education for mass media contributing raising awareness of public at large.

***UNESCO-designated sites and the Global Network of Water Museums will be mobilized in raising awareness and improving water culture of citizens."* (§ 119, p.25)**

https://unesdoc.unesco.org/ark:/48223/pf0000381318

INTERNATIONAL CONFERENCES

4th Conference (2022): Marrakech, Morocco

Water Museums and Groundwater : Making the Invisible Visible

WATER MUSEUMS GLOBAL NETWORK

unesco Intergovernmental Hydrological Programme

KINGDOM OF MOROCCO
MINISTRY OF RELIGIOUS ENDOWMENTS
AND ISLAMIC AFFAIRS

aman MUSÉE MOHAMMED VI
POUR LA CIVILISATION DE L'EAU AU MAROC
MINISTERE DES HABOUS ET DES AFFAIRES ISLAMIQUES

OUR CONTRIBUTION TO THE UN-WATER SUMMIT ON GROUNDWATER (2022)

VALUING ANCIENT WATER CULTURES

Ancestral Knowledge and Hydro-Technologies
as an Inspiring Source of Innovation

Monumental well of San Patrizio, Orvieto, Italy and Qanat underground galleries, Iran

The *Aflaj* Water Supply System in Oman: Sustainable Water Management through Millennia

THE *FALAJ*: ANCIENT KNOWLEDGE SYSTEM AND PEOPLE'S AWARENESS OF SUSTAINABLE WATER

The *falaj* (plural: *aflaj*) is a gently sloping subterranean tunnel that drains out groundwater and valley runoffs and brings it to farmlands in rural Oman. As such, the *falaj* is an extended hydraulic system that may stretch several kilometers, spanning different areas with various geological and botanical conditions that require specific knowledge and know-how for its management.

Relying on such hydraulic models, over the centuries local communities came across different issues in terms of water quality, ownership, and social management of a scarce resource.
Such challenges have been solved thanks to empirical and technical know-how rooted in thorough environmental knowledge.
(**Figs. 1 and 2**)

This traditional water mining system has proved to be the most crucial water source in many parts of Oman over the past millennia. It's most likely that the *falaj* system came into existence as a collective social response to climate change in the late Bronze Age when Oman experienced a dramatic decline in precipitations.
Many communities shifted accordingly their water management practices from disappearing surface streams to groundwater. In this period, the emergence of the cut-and-cover tunnels bears witness to an overall decrease in water resources, which led the local communities adopting such a technique to tap water at lower levels. Around 2,450 BC, when the region's precipitation had a downward trend, the first tunnels of this kind came into existence.

What marks out the *falaj* as a unique heritage is not only its role for sustainable water supply in a desertic region, but also its contribution to the social and cultural fabric of Oman. Centuries of local people's endeavor to find solutions to a variety of problems faced while digging and maintaining their *aflaj*, enabled them to better adapt to drier and harsher environments. Indeed, the construction and maintenance of these tunnels demand a high level of knowledge that has been shaped over the centuries and handed down from generation to generation.

This know-how paved the way for local communities to develop a special awareness towards their natural environment and heritage of water. (**Fig. 3**)

The *aflaj* system highlights a high level of social consensus and convergence which are manifest in every aspect of people's life in traditional communities. For this reason, the potential loss of the *falaj* systems also undermines social cohesion and may cause potential massive migration from rural to urban areas. (**Fig. 4**)

The *aflaj* irrigation system of Oman is a World Heritage site since 2006, composed of five individual *falaj* in the north of Oman: *falaj* Al Jeela, *falaj* Muyasser, *falaj* Daris, *falaj* Malki and *falaj* Khatmein.

MORE:

Fig. 1. Canal-bridge to allow water overtaking a depression in a valley (*wadi bani kharous*). © University of Nizwra.

Fig. 2. The Al-Khutmain in Birkat al-Mouz *falaj* is connected to a historical tank built for charity goals and to quench thirsty travelers. © University of Nizwra.

Fig. 3. Maintenance of the mother-well of the Daris *falaj* in Nizwa (World Heritage list of UNESCO). © University of Nizwra.

Fig. 4. Proper management of *aflaj* allows Omani rural communities to survive in arid environments. © University of Nizwra.

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Re-adapting the Circular Irrigation System of Oases in the M'zab Valley, Algeria

THE OASIS: A PARADIGMATIC MODEL FOR SUSTAINABLE IRRIGATION AND AGRICULTURE

The emergence and sustainability of life in the desert oases, which have undergone many changes over time, have always been closely associated with careful management of water resources. In this respect, the M'zab valley represents an exceptional case - as it was inscribed on the UNESCO List of World Heritage in 1982.

The pioneers of the Ibadite faith, one of the currents of Islam practiced by a minority of Muslims, gradually settled in the wadi of the M'zab Valley in the 11th century. Here they built five fortified cities (*ksour*) along the M'zab *wadi*. To make the best use of scarce water resources, they conceived and built an ingenious water recharge system aimed to capture surface water from the hydrological cycle (up to 3 annual flash floods) and divert it in local loops.

The circularity of such an ingenious practice is materialized by a set of hydraulic structures for transport (canals and tunnels), sharing (distributors, dikes, water intakes), and storage of surface water in the aquifer (dams and catchment wells). However, the circularity of the oasis system is not only limited to water. It also permeates the organization of other activities such as agricultural production, waste and energy management. (**Figs. 1 and 2**)

On the outskirts of the ancient oases, from the 1980s new agricultural lands were created by the state to favor an entrepreneurial agriculture inspired by the agro-industrial model, groundwater exploitation and use of chemicals. These practices are developed by investors not originating from the region and whose main interest is economic profit.

The native farmers, being aware that the new agriculture is incompatible with the traditional agro-systems, have been forced to develop a different farming model. They are now combining a variety of practices, inspired both by the ancient know-how and most recent technological innovations. For instance, they applied the concepts of permaculture and agro-ecology and have also introduced water-saving irrigation techniques, such as drip irrigation and exogenous crops with low water consumption. Like their ancestors, today's oases farmers try to respect the fragile balance between human needs and nature. (**Fig. 3**)

The development of new agro-industrial practices created a competition over water. The main challenge for the future is the sharing of water between upstream farmers (the modern extensions) and downstream (the ancient oasis). At first glance, this is an unequal battle. Upstream farmers have the priority in access to water, while the ancient palm groves have suffered from urbanization, land fragmentation, and social disruption.

And yet, the system based on the ancestral water culture highlights a good practice that should be promoted further to foster a more farsighted development paradigm and face desertification and climate change. (**Fig. 4**)

MORE:

Fig. 1. The ancestral dyke built downstream of the Ben Isguen palm grove is functional to stop flood waters and recharge the aquifer. (photo by Farah Hamamouche).

Fig. 2. The surface and groundwater irrigation network. The channel width is proportional to the water flow. (photo by Farah Hamamouche).

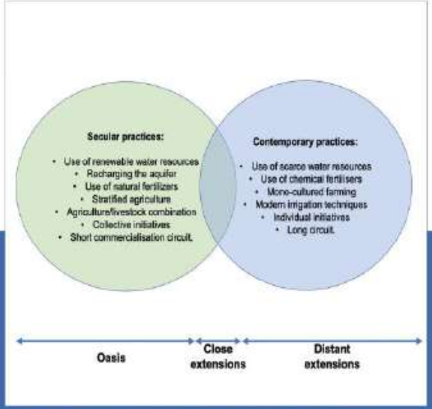

Fig. 3. Differences in agricultural and irrigation practices between modern extensions and ancient oases that apply the principle of circularity. (source: Saidani et al., 2022).

Fig. 4. Re-adaptation of dykes in the new agricultural lands aims at recharging groundwater and recovering sediments as organic fertilizer. (photo by Farah Hamamouche).

Indigenous Hydro-Technology and the *Tecuates* of the Tehuacan Valley, Mexico

ANCIENT TECHNOLOGY SOLUTIONS FOR FARSIGHTED GROUNDWATER MANAGEMENT IN ARID AREAS

The famous Tehuacan-Cuicatlan Valley of Mesoamerica is an invaluable heritage of humanity located in an arid and semi-arid zone of striking biodiversity. The struggle for water is the predominant theme throughout regional history and several hydraulic artefacts bear evidence of the innovative capacity and constant adaptation of humans to adverse natural conditions. Indigenous communities domesticated teosinte and created modern corn around 5,800 BC. Early development of crops allowed for the emergence of agricultural settlements. From the 2nd millennium BC, rainwater harvesting was also developed through a system of small dams and canals. Over the centuries, local communities built complex canal networks to convey spring water to the terraced agricultural plots by raising, leveling, and compacting the soil. Terraced farmlands also facilitated the recharge of the groundwater table.

With the continuous water flow in the canals, the mineral component of the liquid element encrusted the irrigation ditches and created an impressive, fossilized structure called *tecuates* - a name derived from the Nahuatl *'te-coatl'* (i.e. stone-snake), which refers to indigenous cosmovision linking water to life. The evocative archaeological remains of these canals are still visible today. However, the indigenous water culture of *tecuates* was progressively disrupted by the Spanish colonist, who introduced another hydraulic technology: that of *galerias filtrantes* (seeping galleries) of Arab origins. Still today, local communities use the *galerias* brought by the Spaniards.

The various hydraulic waterworks introduced in each period generated complex socio-technological systems that sometimes still coexist. Unlike other parts of the world, today the *galerias filtrantes* of Tehuacan are kept operational thanks to the hard work of farmers' water societies. Some 225 registered galleries are managed by well-structured water and canal societies and provide 170 million cubic metres of water for irrigation each year. (**Fig. 1**)

In 1980, with the belief that villagers had to cooperate more to solve their water needs - instead of waiting for government support - a civil association launched the program called *Agua para Siempre!* ('Water Forever!'). Since then, over 11,600 agroecological waterworks have been accomplished. In 1999, it was decided to also create the water museum *Agua para Siempre!* to promote indigenous water education and preserve the traditional knowledge of using natural resources. Today the museum is actively engaged in protecting groundwater by considering three basic principles: the empirical knowledge of agro-ecology; the regional socio-cultural organizational patterns; and the use of appropriate local technology for each tributary watershed. (**Figs. 2 and 3**)

The entire water heritage of the Tehuacan Valley clearly illustrates the continuum paradigm of managing water over millennia through a combination of different hydro-technologies. Such a rich heritage of ancestral techniques and know-how illustrates well a key contribution to sustainable water management targeted by the SDGs. (**Fig. 4**)

MORE:

Fig. 1. Hand-dug '*galeria filtrantes*' (seeping tunnel) collects water for irrigation. © Raúl Hernández Garciadiego.

Fig. 2. Traditional rock dams filter water and simultaneously allow infiltration. © Raúl Hernández Garciadiego.

Fig. 3. A small rural dyke delivers water for nature, agriculture and the households. © Pablo Herrerías Guerra.

Fig. 4. Water spring linked to a system of well and seeping galleries (*galerias filtrantes*). © Raúl Hernández Garciadiego.

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The System of *Socavones* in the Oasis of Pica-Matilla, Atacama Desert, Chile

THE GROUNDWATER HERITAGE OF ARID AREAS: A SUSTAINABLE BUT FORGOTTEN LOW-COST WATER SUPPLY SYSTEM

Pica-Matilla is an oasis located in the hyper-arid Atacama Desert, at the foothill of the Andean Cordillera, in the North of Chile. It is one of the most arid areas on Earth. The filtration galleries of Pica (called *socavones*; singular, *socavón*) are the most southern known of the Latin American continent. Their origin goes back to the middle of the 17th century. They were built to irrigate the vineyards and boost the vine industry, influenced by the proximity to the mines of Potosí. Indeed, the word *socavón* refers to an artificial underground gallery used for mining. (**Fig. 1**)

Filtration galleries are the traditional water management systems used to provide a reliable supply of water in arid and semi-arid climates. They consist of an underground and almost horizontal tunnel with vertical shaft wells, which tap and drain groundwater from the earth surface. Groundwater seeps into the wells and tunnels in the saturated part of the aquifer and flows downward by gravity, up to the exit point that supplies water for domestic purpose and irrigate downslope lands. (**Figs. 2 and 3**)

The origin of the filtration galleries dates back to the 1st millenium BC in ancient Persia, now Iran. It then spread to other cultures, China to the east and North Africa to the west. When the Muslims conquered the Iberian Peninsula in the 8th century AD, they implemented these hydraulic works in all the peninsula. Later, the Spanish would take this technique to the Americas during the conquest, between the 16th and 17th centuries.

The system of *socavones* rely entirely on passive tapping of the available water by gravity. As such, the natural supply of water in a filtration gallery can never exceed the groundwater recharge. For this reason, *socavones* represent a truly sustainable and low-cost water supply system. Unfortunately, despite the high value of such an ancient groundwater heritage to combat desertification, the *socavones* are neither protected nor valorized.

The owners of land with *socavones*, who used to enter in the galleries for their maintenance, nowadays do not dare to enter any more. They are falling into decay and slowly vanishing, both from memories and people's perceptions. Most are abandoned while groundwater extraction through deeper wells leads to aquifer salinization. (**Fig. 4**)

Today, only two out of more than twenty *socavones* of Pica and Matilla are still managed by farmers' collective associations. Water is distributed through a network of canals and according to strict regulations. But most of *socavones* are abandoned while groundwater extraction through shallow and deep wells increases, leading to aquifer drawdown and salinization. As it happens today in many other countries, unfortunately filtration galleries are abandoned and replaced by wasteful pumped wells and boreholes.

MORE:

Fig. 1. Water and life emerge out of a *socavón* in one of the driest deserts on Earth. Cones correspond to ventilation wells. © Fundación Carpe Science.

Fig. 2. Ventilation well (*lumbrera*). In Pica-Matilla, the *lumbreras* are not vertically aligned with the main gallery. © Fundación Carpe Science.

Fig. 3. The narrow gallery of San Isidro still with flowing water. However, due to the lowering of the aquifer level, today water does not reach the land surface. © Fundación Carpe Science.

Fig. 4. Exit point of Santa Rosita. Despite being abandoned, sometimes water continues to flow out of the *socavones* and feeds vegetation in the desert. © Fundación Carpe Science.

Steps to Water: The Forgotten Stepwells of India

NEGOTIATING SPACE AND DESIGNING WATER: EMERGENCE AND DECLINE OF THE HISTORICAL ARCHITECTURE OF INDIAN STEPWELLS

There are more than 3,000 stepwells built between the 7th and 19th centuries which dot the semi-arid landscape of Gujarat and Rajasthan, in western India. They all extend along the trade routes that carry into Central Asia. These elaborate architectural wonders, usually from three to nine levels deep (20 to 25 metres), mark the invisible landscape of underground water, providing cool shade, life and sustenance to villagers, communities, and weary travellers (**Fig. 1**)

The gift of water in India is considered a pious act. Consequently, many stepwells were funded by women and men of wealth - kings, queens and merchants - often to honour a deceased relative or a deity (typically, a female goddess). Indeed, water is largely associated with the feminine in India. Stepwells were special spaces for women - to fetch water, meet friends and spend time away from home and domestic work. (**Fig. 2**)

Stepwells draw water from an underground aquifer. They are filled through a process of seepage wherein rainwater, caught in a depression, percolates and is filtered through fine silt. With its deep vertical shape, the stepwell protects people from sun and hot winds, maintaining water at a constant temperature of approximately 13° Celsius.

Over the last century, the development of piped water systems and notions of public health have led to the disregard of these ancient structures. Yet, there are small signs of redemption. In the old city of Jodhpur, the recently restored *Toorji ka Jhalra* lies at the centre of the aptly named Stepwell Square - a popular meeting place with cafes, galleries and shops. Restoration work excavated to a depth of 60 metres and discovered intricate carvings, waterspouts and even the remnants of an old Persian hydraulic wheel. Built by a queen from the Marwar region in 1740, this stepwell is a clear example of the role of women in hydro-philanthropy. (**Fig. 3**)

Samerth, the NGO based in Gujarat, in 2018-19 revived four small stepwells with community participation in the semi-arid region of Kutch, providing water for domestic and livelihood purposes to 400 rural families. The wells are maintained by local youth groups and water committees, also involving women. Despite many obstacles, today a growing number of female water leaders are ensuring that their voices are heard in community water governance.

Recognising the importance of ancient water management systems, the Indian Ministry of Water Resources has also made recent investments to recharge aquifers. However, successful restoration of stepwells is a complex process which requires a trans-disciplinary approach involving engineers, conservation architects, hydrologists, and also local associations and the civil society. (**Fig. 4**)

MORE:

Fig. 1. The octagonal structure of Bai Hari ni Vav, a stepwell commissioned in 1485 by the homonymous woman. Ahmedabad, Gujarat. © Somya Parkh, 2019 - Living Waters Museum.

Fig. 2. The Mata Bhavani stepwell with ritual decorations and flowers. 11th century, Ahmedabad, Gujarat. © Arnav Das, 2018 - Living Waters Museum.

Fig. 3. The 18th century stepwell of Toorji ka Jhalra, Jodhpur, Rajasthan. © Bhawani Singh, 2021 - Mehrangarh Museum Trust.

Fig. 4. The freshwater basin of Tapi Bhavadi, a less-known stepwell in the old city of Jodhpur, Rajasthan. © Bhawani Singh, 2021 - Mehrangarh Museum Trust.

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unesco Intergovernmental Hydrological Programme

Valuing Ancient Water Cultures

An Inspiring Source of Innovations for Sustainable Groundwater Management

Learning from past practices and knowledge to make the invisible visible: from Indian stepwells to Omani *aflaj*, Moroccan *khettaras*, Algerian oases, Chilean *socavones*, Mexican *tecuates*, and Mediterranean cisterns and wells

www.watermuseums.net/campaigns/valuing-ancient-water-cultures/

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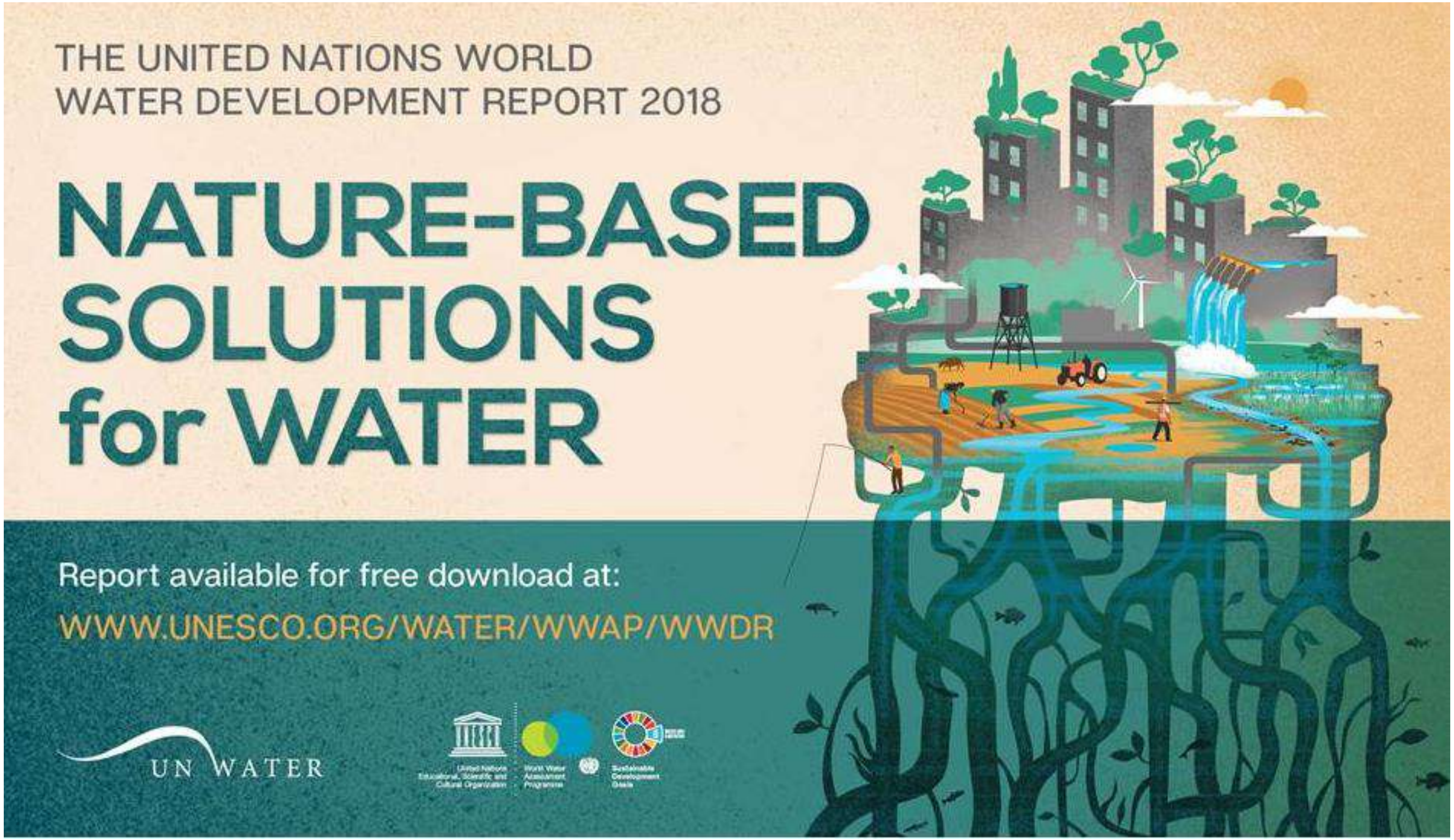
igrac International Groundwater Resources Assessment Centre

VILLE DE PARIS

MUSÉE DES ÉGOUTS DE PARIS

Report 2018 - WWAP



INTERNATIONAL CONFERENCE

Ancestral Hydrotechnologies as a Response to Climate, Health and Food Emergencies

1st Conference (2023): Barcelona, Spain

UPC
UNIVERSITAT POLITÈCNICA
DE CATALUNYA
BARCELONATECH
UNESCO Chair on Sustainability

unesco
Chair

> Creation of a CoP (Community of Practice) with other UNESCO Chairs to investigate AHTs as NBSs

IHP Resolution n.7-XXIV (2021)

TOWARDS A "WORLD INVENTORY" OF WATER MUSEUMS, INTERPRETIVE AND VISITORS' CENTRES

The Intergovernmental Council of IHP invites:
"the IHP Secretariat to compile an inventory of the different water museums (…) across the world, and encourages Member States to support the Secretariat in this effort by communicating information on existing water museums"

CENSUS OF NATURAL & CULTURAL HERITAGE
TANGIBLE AND INTANGIBLE ASSETTS




TAXONOMY FOR THE WORLD INVENTORY (1)

Six categories (grouped in three main types) are used to make systematic classification of existing water museums, interpretive centres etc - but also to enable identification of potential new ones :

a) TYPE 1: EXHISTING INSTITUTIONS

1.1 MUCD - Museums, Collections and Documentation Centers

1.2 IDEM – Interpretive and Visitors' Centres, Digital Museums, Eco-Museums, Community-based Museums, Extended Museums

TAXONOMY FOR THE WORLD INVENTORY (2)

B) TYPE 2: POTENTIAL / FUTURE MUSEUMS AND INTERPRETATION CENTRES

2.1 WASH - Waterscapes (Cultural Landscapes), Sites, and water-related Heritage Assets

2.2 ANTE - **Ancestral Hydro-Technologies, Community-based practices,** and Citizens Observatories

2.3 INTL - Intangible Heritage and the Heritage of 'Living Waters'

C) TYPE 3: GOOD PRACTICES TO ACHIEVE THE SDGS

3.1 GOOD – Solutions that can potentially contribute to climate adaptation and good practices to manage resilience and scarce water resources

TWO PILOT CASE STUDIES :
ITALY AND THE NETHERLANDS

The toolkit provides 2 case studies implemented at regional level on the Po Delta (IT) and the Rhin Delta (NL)

https://www.watermuseums.net/activities/world-inventory/

BENEFITS AND COOPERATION OPPORTUNITIES

- Promoting further scientific data, archival images related to groundwater management at your institution
- Organising exhibitions in cooperation with local museums (and WAMU-NET) to better engage the public
- Strenghtening education & communication activities
- Targeting the SDGs contributing to Phase 9 of IHP also in cooperation with WAMU-NET
- Fostering new holistic approaches and community's engagement in resilience planning

World Water Assessment Programme

JRC EUROPEAN COMMISSION

WATER MUSEUMS GLOBAL NETWORK

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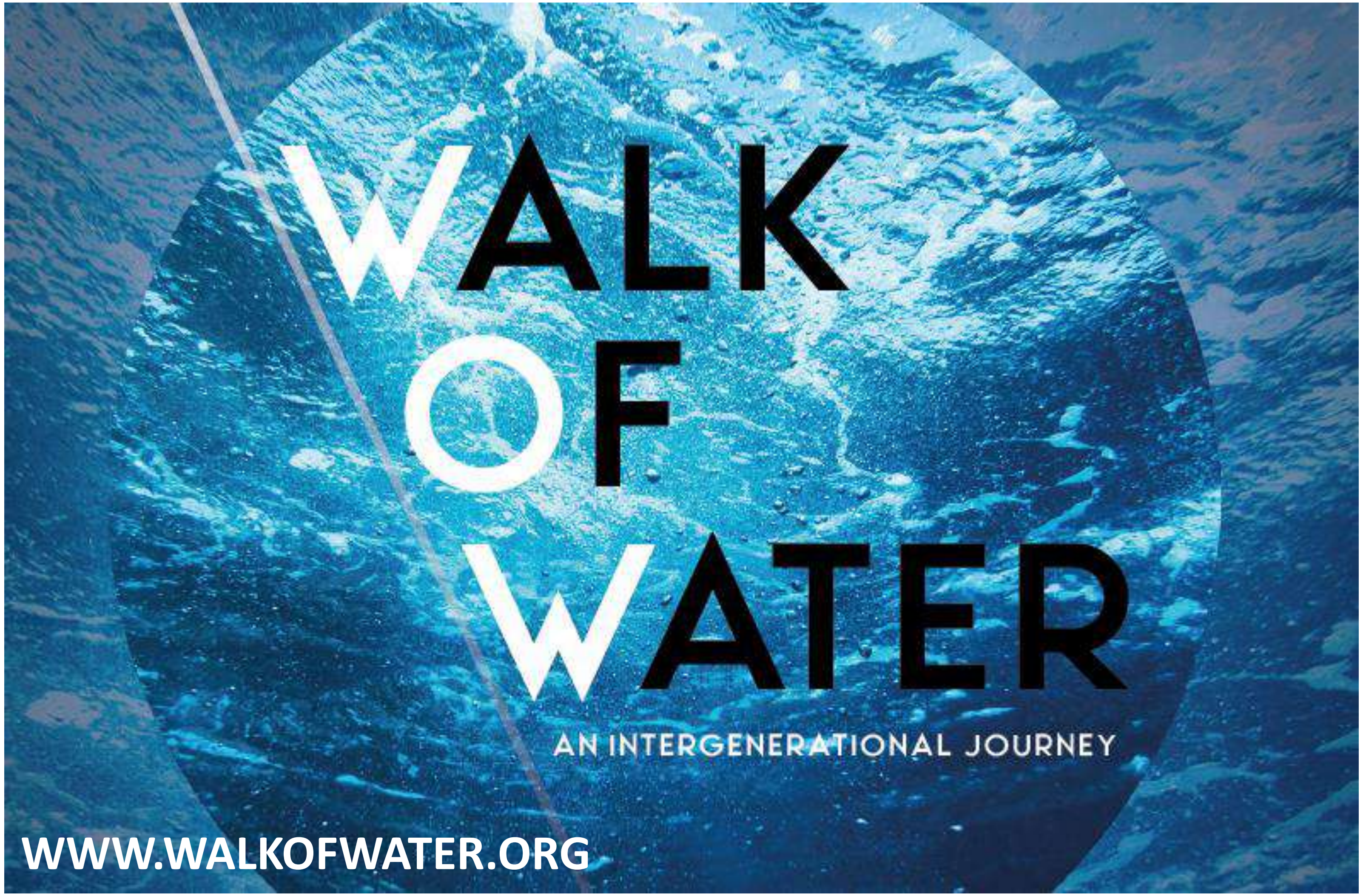

LAUNCH IN NY ON MARCH 22nd @ 2023 UN WATER CONFERENCE

WATER SUSTAINABILITY EDUCATION

YOUTH CONTEST AND AWARD

THE WATER WE WANT

4th Edition 2023

https://thewaterwewant.watermuseums.net

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NETHERLANDS NATIONAL IHP-HWRP COMMITTEE

Resolution n. XXIV-7 of the Intergovernmental Council of UNESCO-IHP titled "UNESCO-IHP in support of developing the Global Network of Water Museums (WAMU-NET)"

DOWNLOAD THE TOOLKIT FOR THE TWO-STEP IMPLEMENTATION @

https://www.watermuseums.net/world-inventory/

WATER MUSEUMS GLOBAL NETWORK

THANK YOU FOR YOUR ATTENTION

WWW.WATERMUSEUMS.NET

INFO@WATERMUSEUMS.NET

GOVERNMENT OF MALTA

WATER
BE THE CHANGE

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Associazione ACQUE SOTTERRANEE

SOCIETÀ GEOLOGICA ITALIANA 1881 MENTE ET MALLEO

IGAG
Istituto di Geologia Ambientale e Geoingegneria

unesco
Intergovernmental Hydrological Programme

AIGA ASSOCIAZIONE ITALIANA GEOLOGIA APPLICATA E AMBIENTALE

ENGEOL IAEG AIGI

IRSA CNR

ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale

Sistema Nazionale per la Protezione dell'Ambiente

EUROPEAN UNION
European Regional Development Fund

VisitMalta

water services corporation

iah aih Italian Chapter

THE ENERGY & WATER AGENCY

WATER
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flowpath

Malta 2023

14th – 16th June
National Meeting on Hydrogeology

JUNE 14-16, 2023

WATER.ORG.MT

Water management in times of climate change – do we have a water problem in Germany ?

The case of the Hessian Ried

Christoph Schüth
Technical University Darmstadt

TECHNISCHE UNIVERSITÄT DARMSTADT

WATER
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Climate and climate change in Germany…

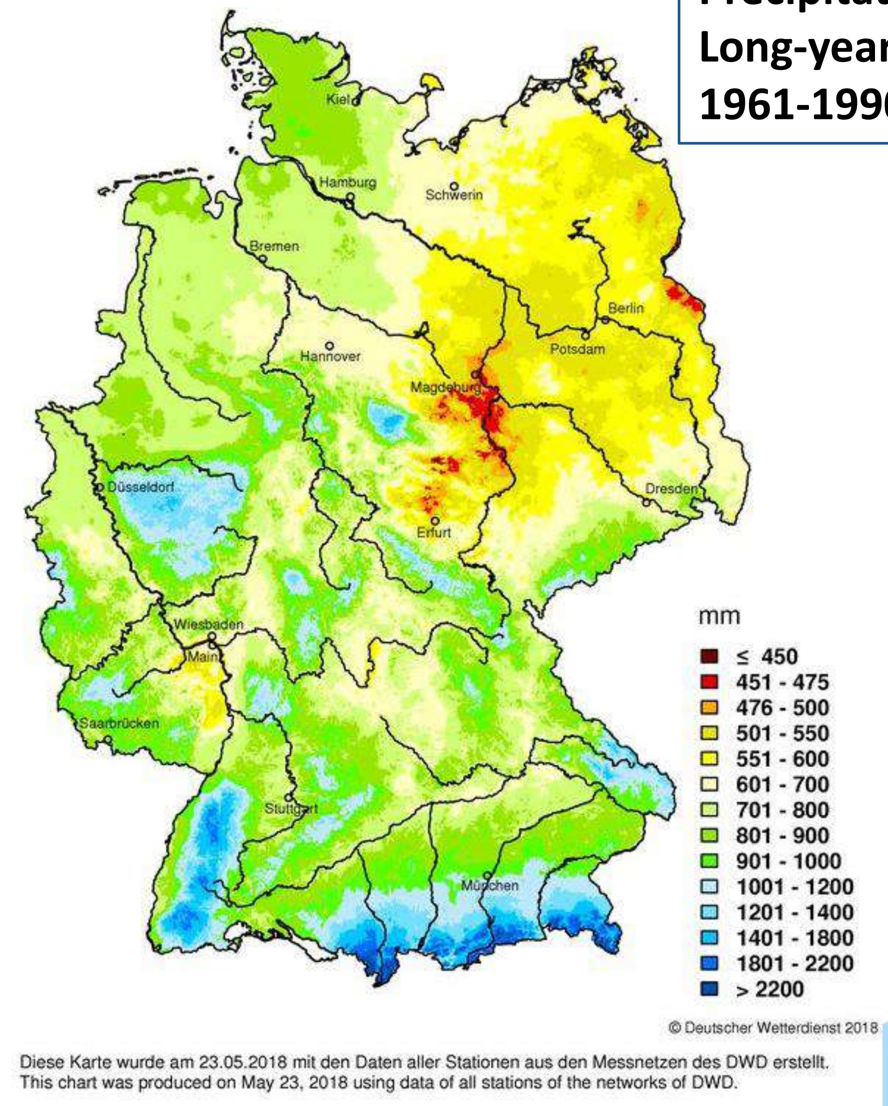
Ahr-valley, 2021

Forest in Franconia, 2019

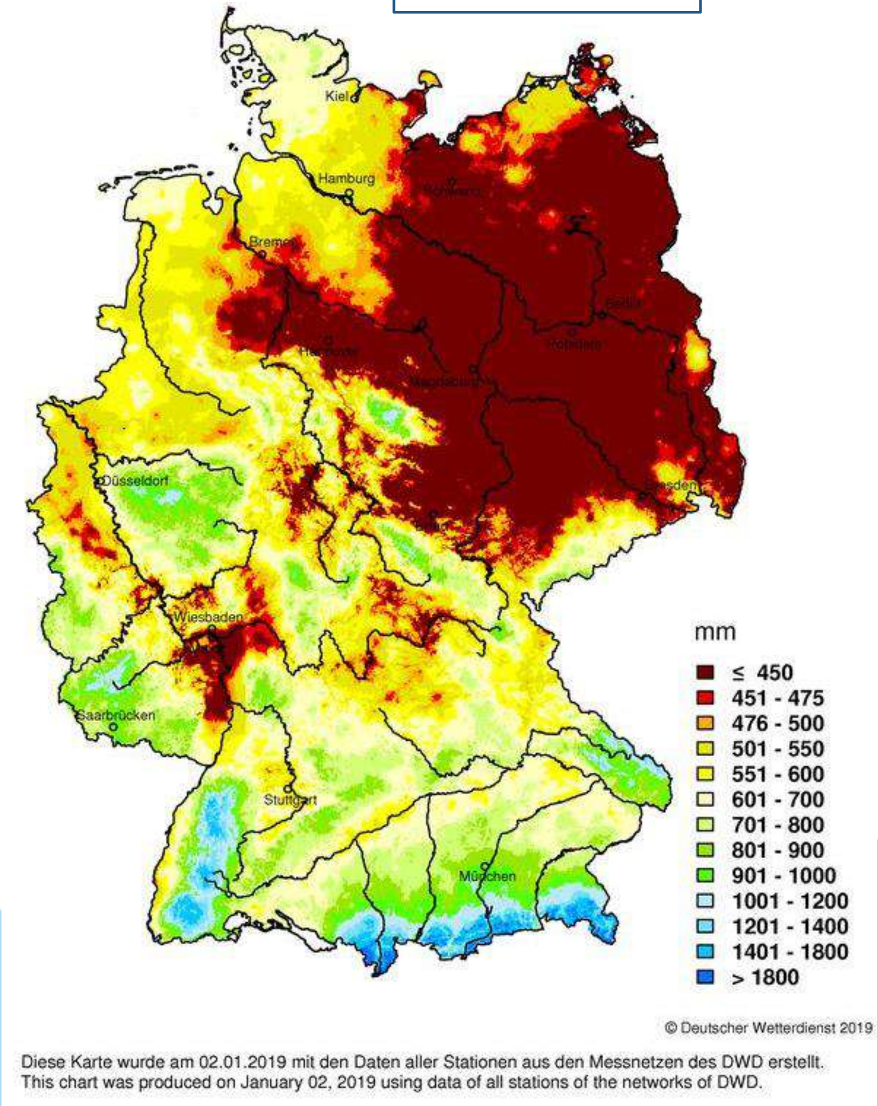
WATER
BE THE CHANGE

Spatial and temporal variations in precipitation…

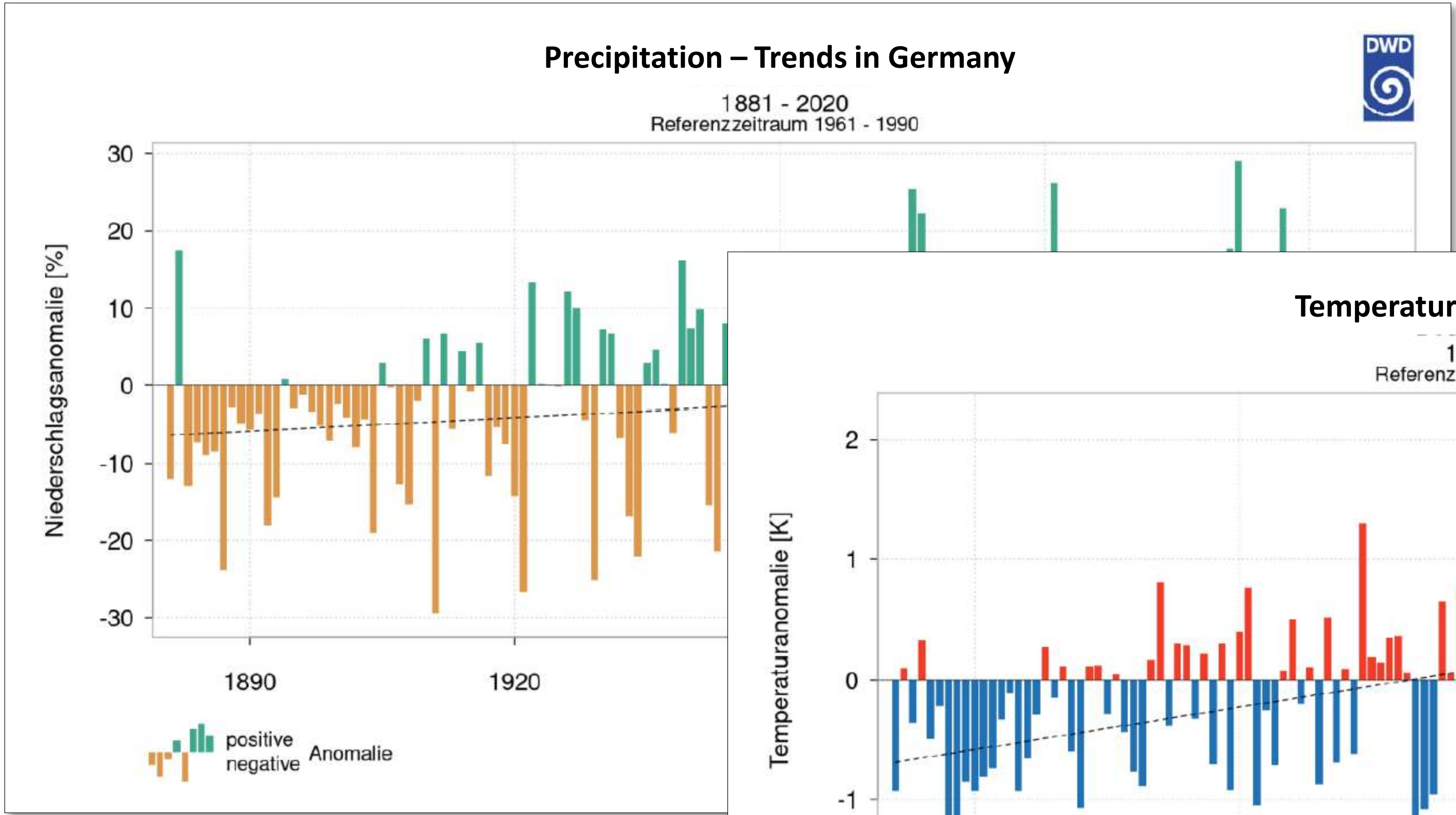
Precipitation
Long-year average
1961-1990

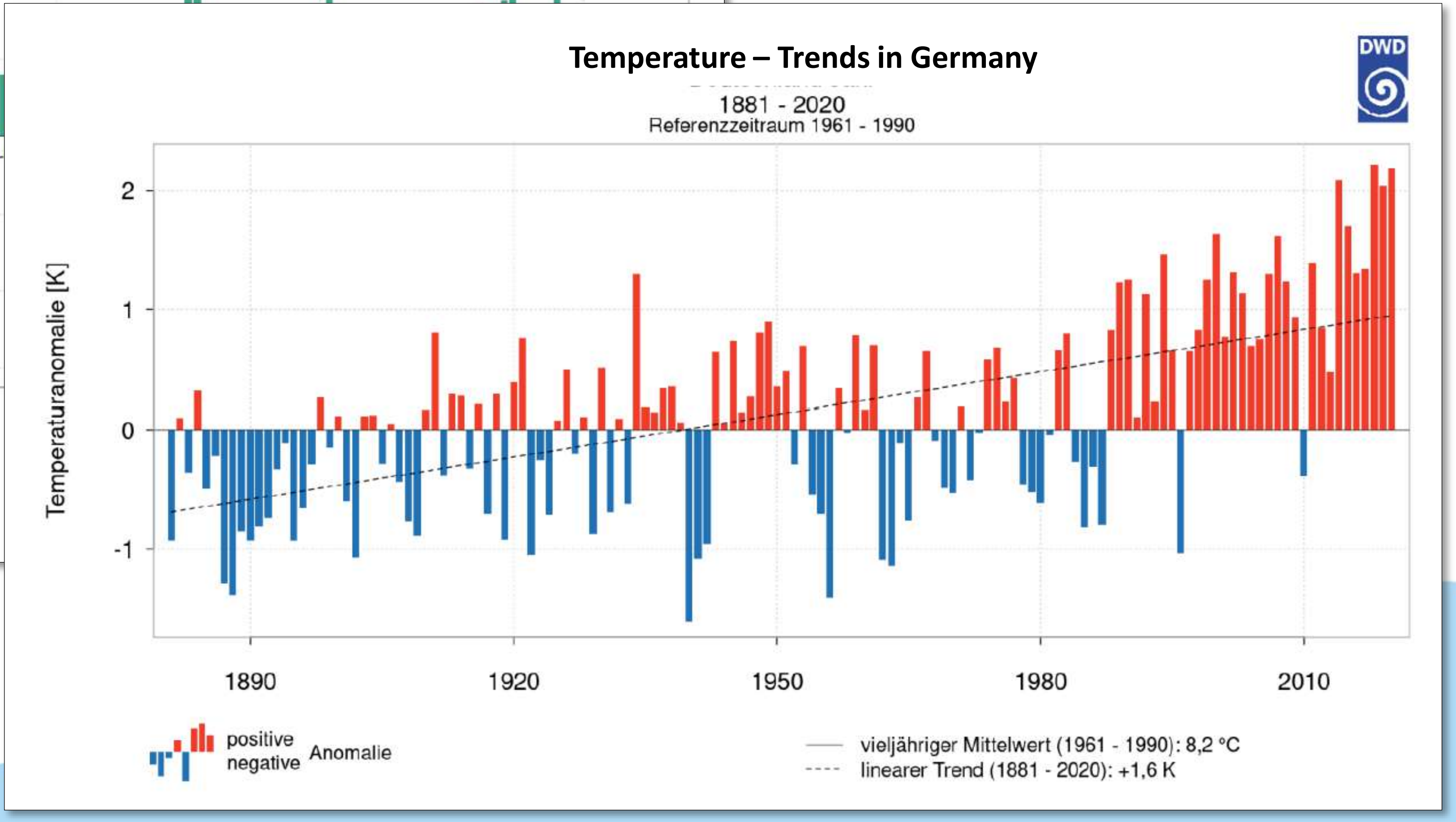


Precipitation
2018



Temporal variations in precipitation and temperature…

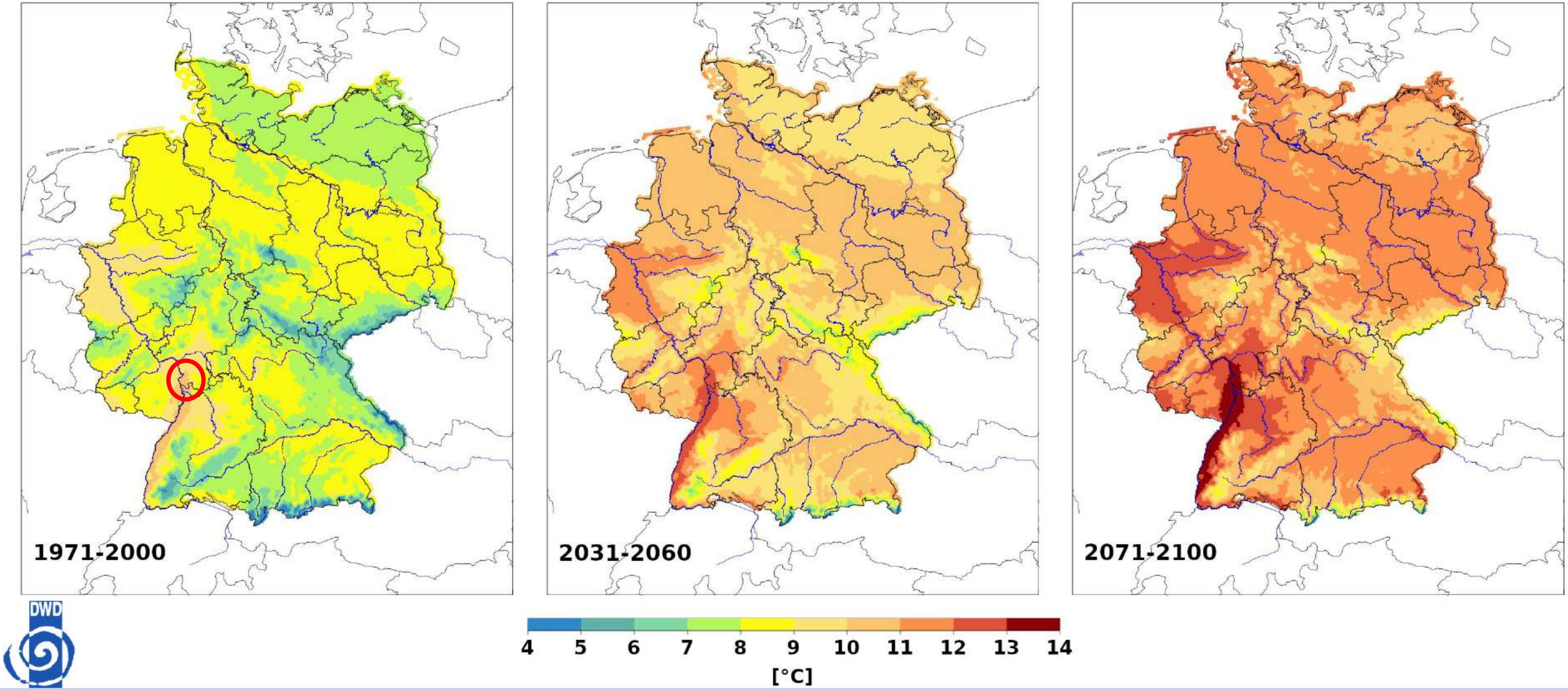




WATER
BE THE CHANGE

Climate Change… Germany - Temperature

30-year average temperature (2m) from COSMO-CLM climate simulations with 3 km grid spacing for the historical period (1971-2000, left), the near future (2031-2060, center), and the far future (2071-2100, right). The projections for the near and far future were calculated with the RCP8.5 scenario.



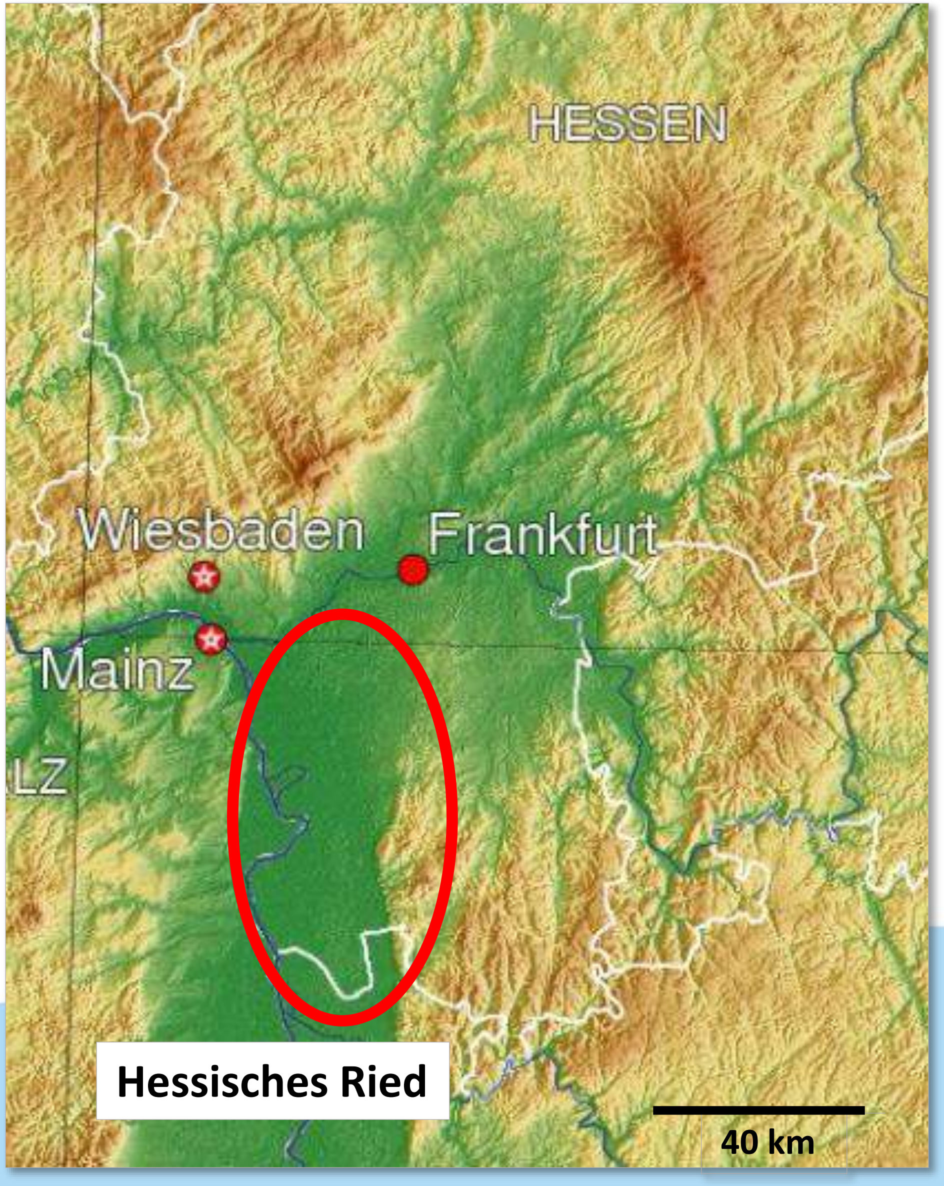
The Hessian Ried

Alluvial plain in the upper Rhine valley between the rivers Main (north), Rhine (west), Neckar (south), and the Odenwald mountains (east).

Thick sedimentary fill of the graben structure → great aquifer.

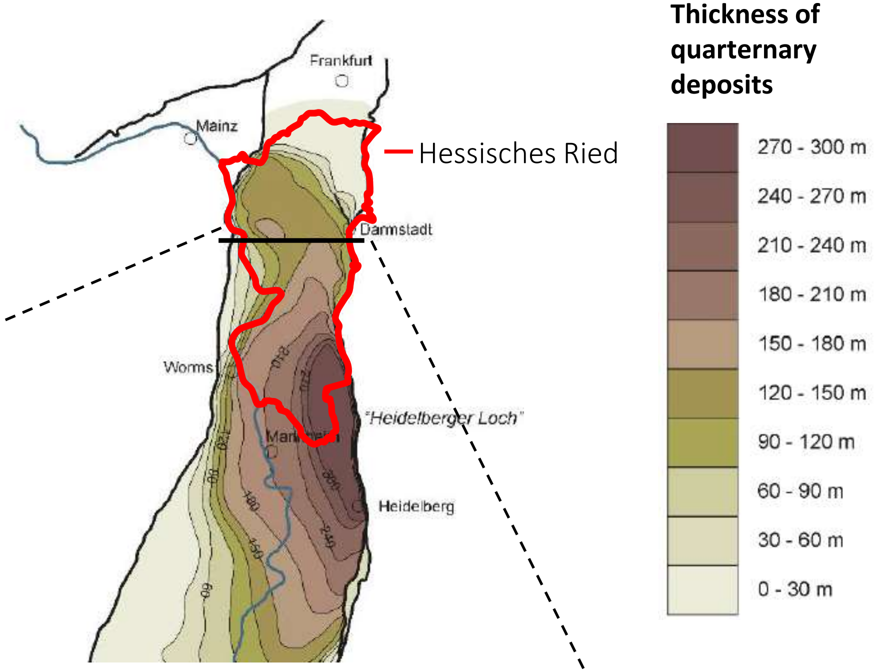
Covers an area of approx. 1200 km^2.

33% of the area are intensively used for agriculture.

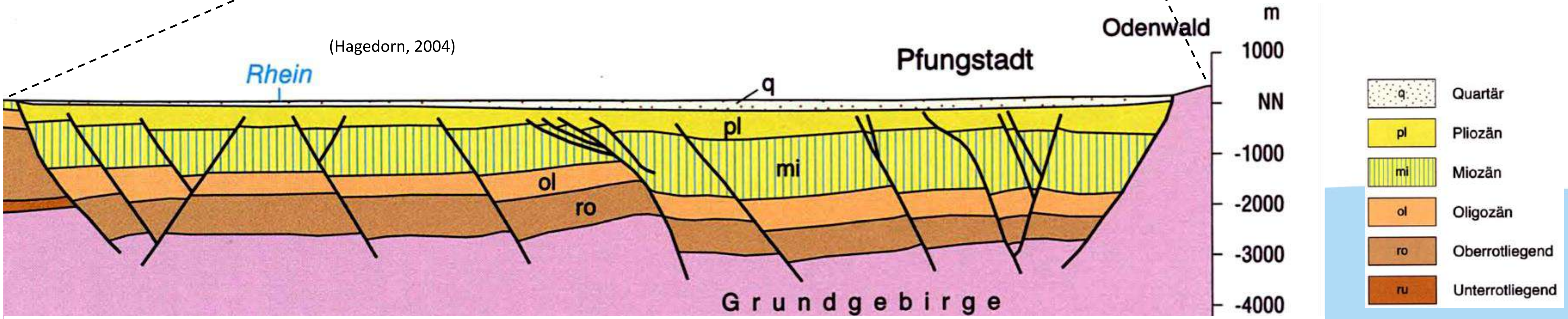


The Hessian Ried – Geological background

Part of the northern Upper Rhine Graben with well permeable quaternary sediments (aquifer heavily used for water extraction)



(Hagedorn, 2004)



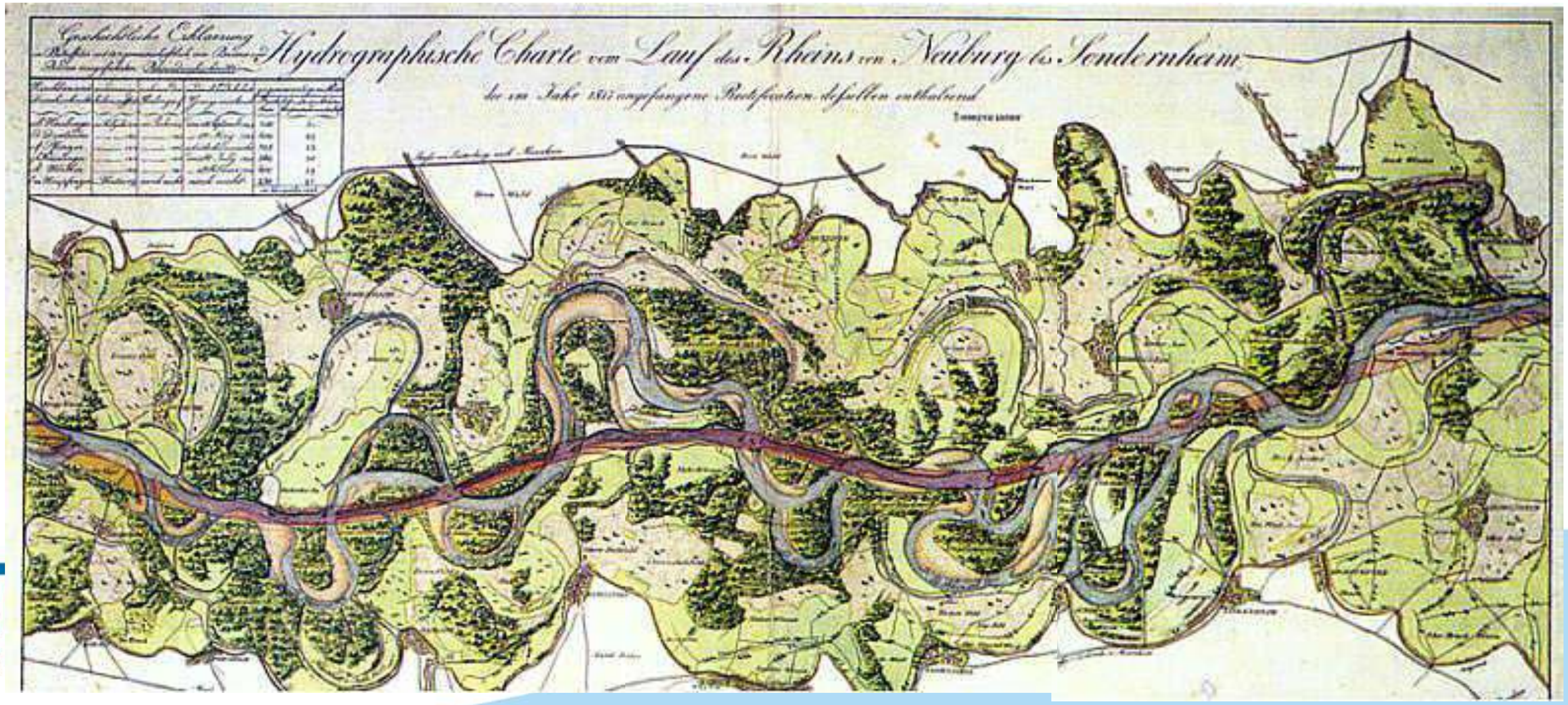
Geologische Übersichtskarte 1:200.000, CC 6310 Frankfurt a.M.-West, BfG – Hannover 2001

The Hessian Ried – History

Before the 19th century, the Rhine was maeandering in the Rhine valley, leading to a swamp-like landscape with Malaria cases in the population living there.

The engineer Johann Gottfried Tulla (1770 - 1828) initiated a program to straighten river Rhine that started 1817 and was completed in 1876.

Straightening of river Rhine



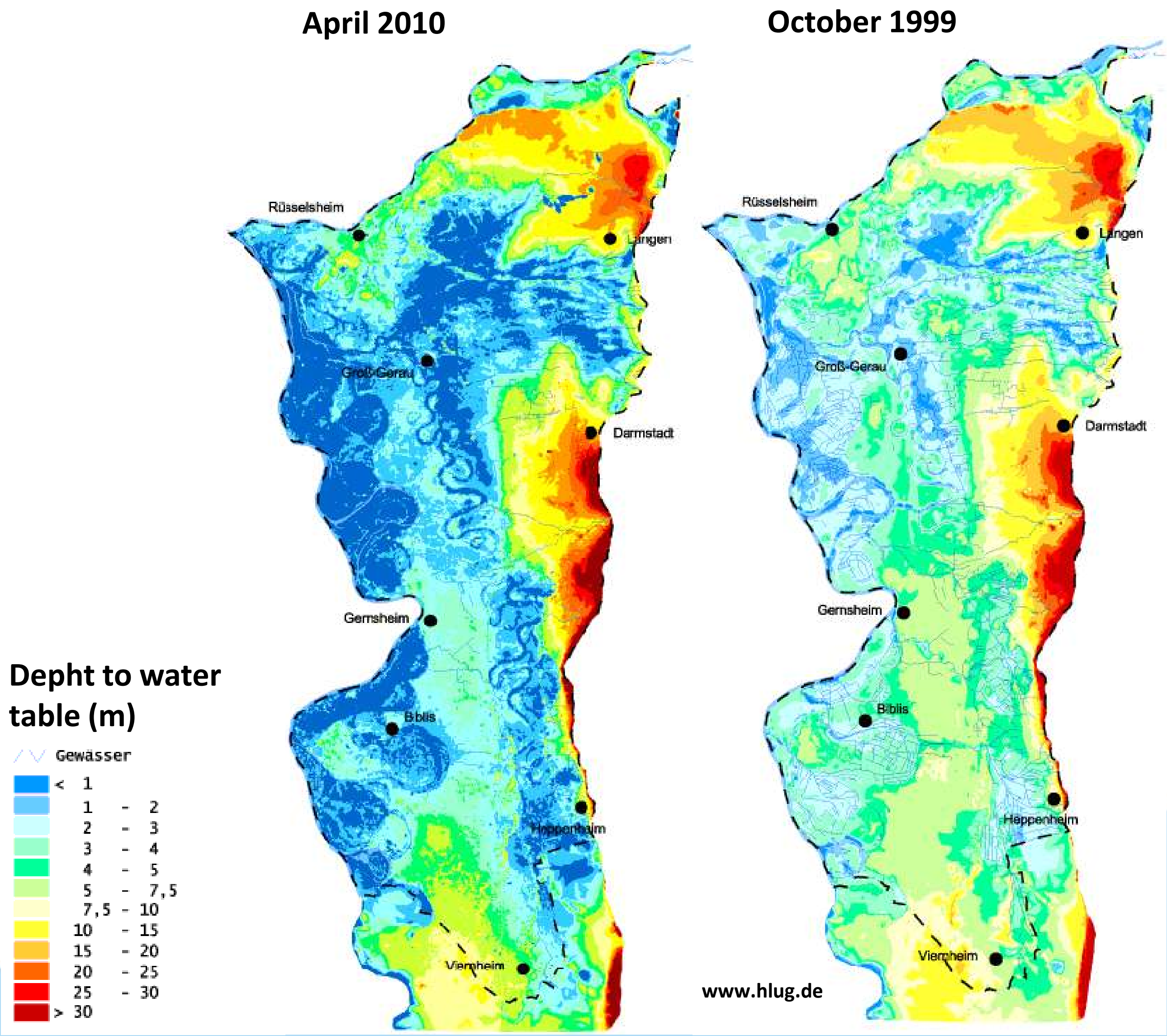
The Hessian Ried – groundwater dynamics

Highly dynamic water table – flooding in wet years, subsidence and damage to buildings in dry years due to organic rich layers.

Competing uses of groundwater resources for agriculture (irrigation) and public water supply (Frankfurt and south Hesse), as well as 'Ecosystem Services' (e.g. forests).

Dry period 1971 - 1976

Wet period 1979 - 1981



The Hessian Ried – groundwater dynamics

Dry period 1971 - 1976


Im Ried droht die Versteppung
Einst gab es Wasser im Überfluß / Landwirte sind vor allem über die Wasserwerke verärgert
Ried von Katastrophe bedroht
Grundwasserspiegel sinkt weiter / Lösung: Puffer-Speicher
Stehen im Ried eines Tages Kakteen?
Hermann Heckmann: Ökologisches Gleichgewicht im Ried kann wieder hergestellt werden
Zukunft für das Ried: eine Sandwüste?
Und die Landesregierung fordert immer mehr Wasser, obwohl die Wälder schon verdörren
Sogar das Löschwasser fehlt
Sofortmaßnahmen gegen die Grundwasser-Absenkung im Ried begrüßt
Ueber hundert Gebäudeschä
Das RP in Darmstadt antwortet dem Bergsträßer Landt
Grundwasser fast sechs Meter tief
Ein Forsthydrologe will künstlich aus dem Rhein bewässern
Rheinwasse
Großbauprojekt zur Grundw
Grundwasserabsenkung hinterläßt deutliche Spuren:
Klaffende Risse in De
Mehrere Häuser kaur
Betroffene halten aus Furcht vor der Baupol
Totale Versteppung . . .
Resolution der Groß-Rohrheimer Bürgerversammlung

Wet period 1979 - 1981

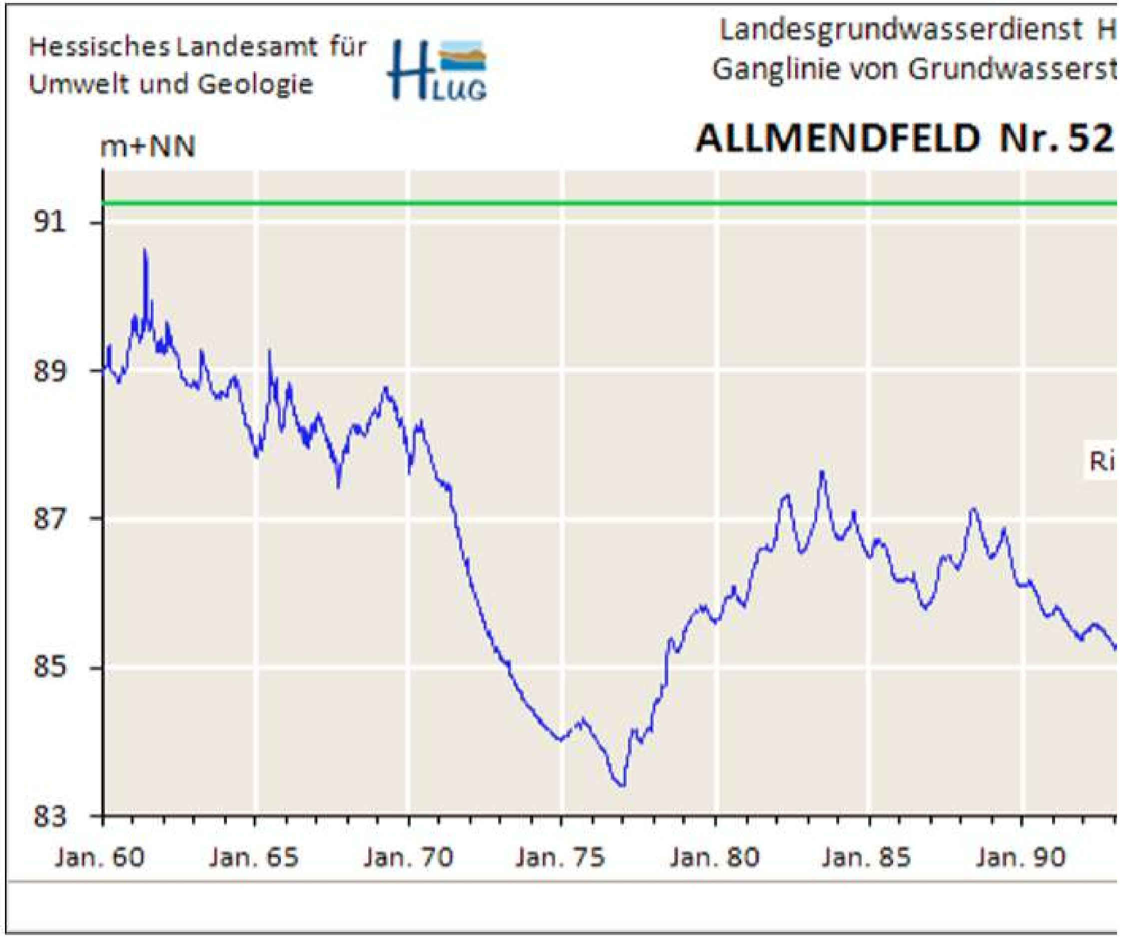

Hüttenfelder Bürgern steht das „Wasser bis zum Hals"
Öffentlicher Brief der Bürgerinitiative / Grundwasserschäden an Gebäuden
Grundwassergeschädigte Bürger gründen einen Kreisverband
Auch von Absenkung Betroffene sollen sich anschließen
Nur Regenwasser in den nassen Kellern
Aus der Stadtverordnetenversammlung – Regierungspräsident entlastet Hartnagel
Rodauer Keller seit Monaten unter Wasser
Hausbesitzer wollen Feuchtigkeit nicht länger hinnehmen
Grundwasserspiegel soll gesenkt werden
Wer in Trockenjahren gebaut hat, steht im Grundwa
Umweltminister Schneider und SPD-Landtagsfraktion auf Informationsfahrt im hessischen Ried
Mehr Was
Warum steigt das Grundwasser an?
GUD will Daten sammeln und Ursachen feststellen lassen

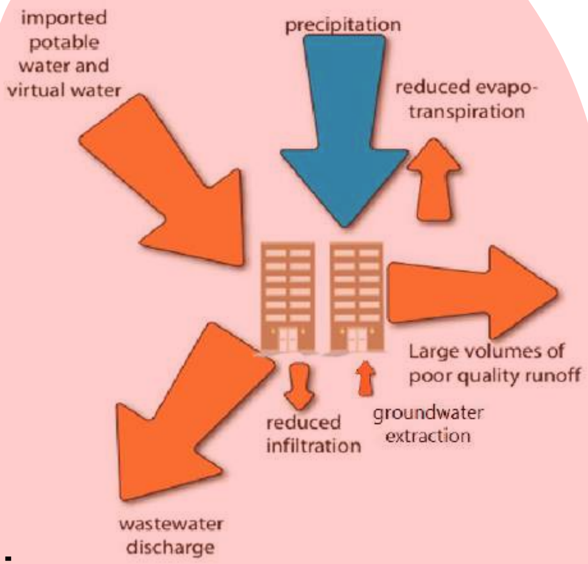
Dry period 1989 - 1994


Ried droht zu versteppen
Naturschützer sind besorgt über Grundwasserabsenkung
Risse an vierzig Häusern
Könnte Infiltration das Grundwasser stabilisieren?
In Eschollbrücken stieg der Pegel um einen Meter
Risse im Ried
Erneut Schäden an über 300 Häusern – Der Grundwasserspiegel ist dramatisch gesunken
durch Torfschicht?
Absenkungen auf der K 67 festgestellt
Topf für Hilfsfonds ist erst halb voll
Umweltministerium appelliert an Wasserentnehmer, Setzrißgeschädigte zu unterstützen
Schäden an 55 Gebäuden
Grundwasserabsenkung: Stadt wendet sich an Petitionsausschuß
„Das bißchen Regen hilft nichts"
Grundwasserabsenkung zeitigt Risse an Häusern
Feudtner kritisiert den Umweltminister
Ried-Grundwasser sinkt katastrophal
Die Werte von 1976 sind bald erreicht – Gespräch mit Umweltminister Fischer

Falling groundwater tables in the Hessian Ried in the ’60s and ’70s

Overextraction in the Hessian Ried, mainly to supply Frankfurt with water

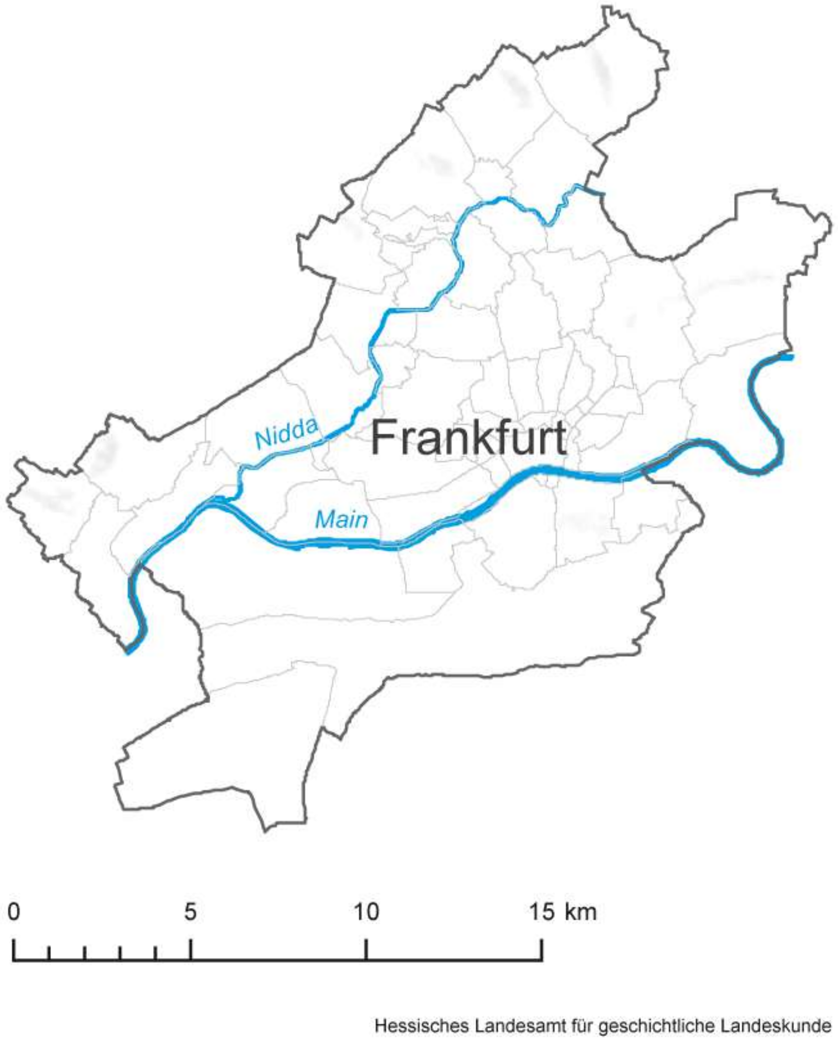




Current Urbanization

Significantly altered water cycles, large surface areas sealed, reduced evapotranspiration/infiltration, large quantities of wastewater, reduced use of local water resoures due to quality problems, **large quantities of water are imported**

Example Frankfurt Rhein-Main



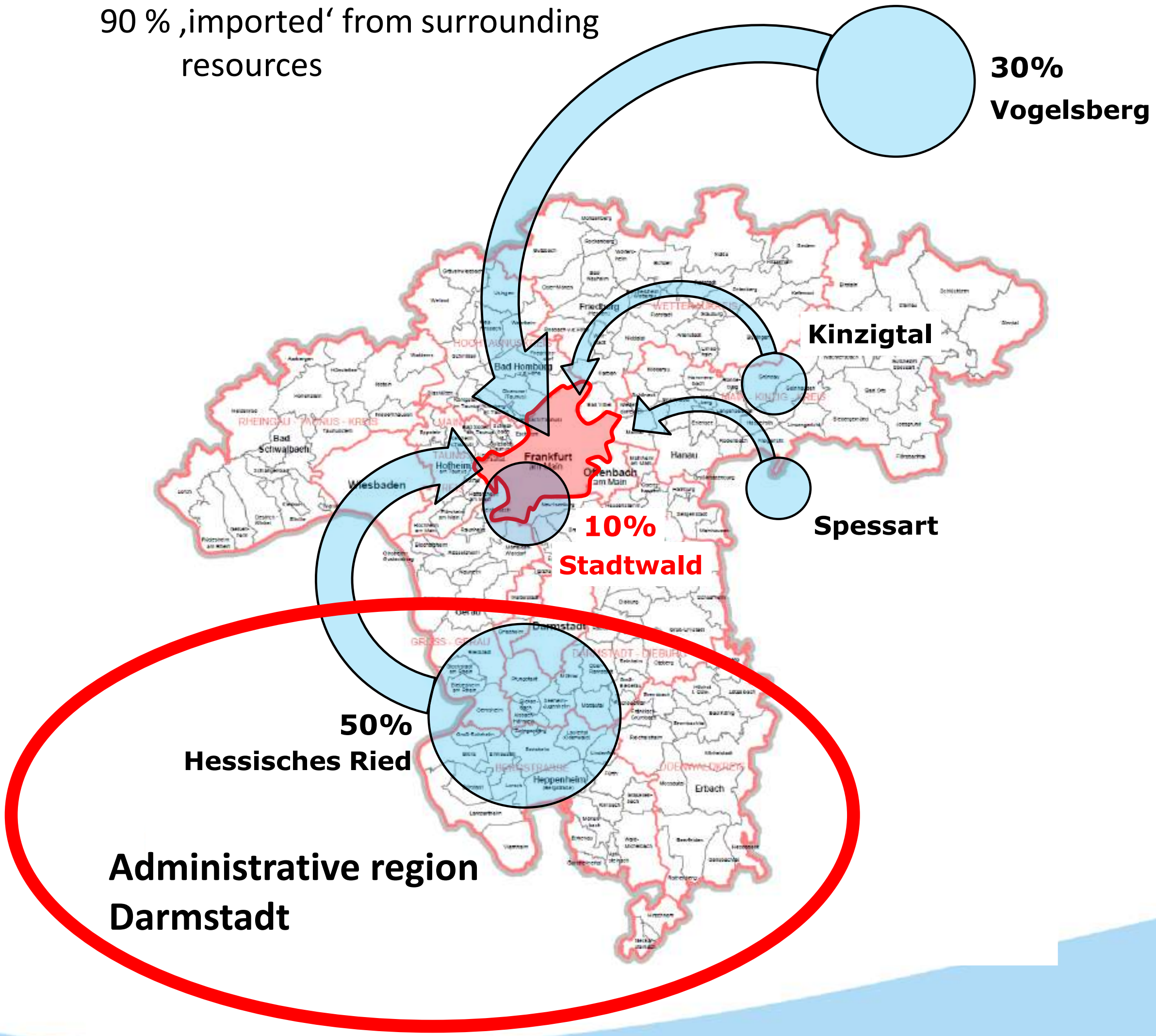
750.000 residents
350.000 daily commuters

Water demand ~ 60 Mio m³/a

Example Frankfurt Rhein-Main

Water demand ~ 60.000.000 m³/a

90 % ‚imported‘ from surrounding resources



Point discharge of about 100.000.000 m³/a treated waste water into river Main

In addition 20.000.000 m³/a treated waste water from industry

Water Association Hessian Ried

founded in 1979

- **Duties according to the articles of association**

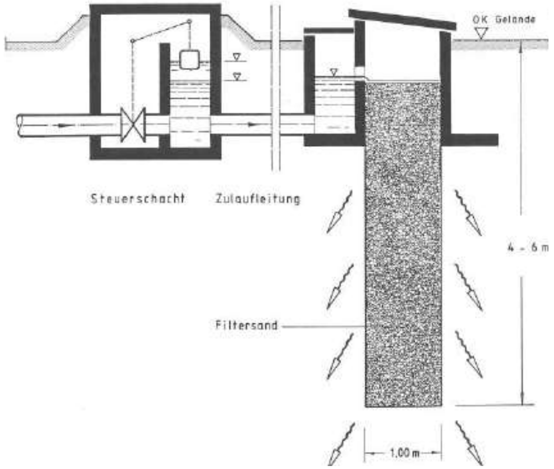
  - provide water for agricultural irrigation
  - provide water for groundwater infiltration
  - ensure a safe & reliable Public Water Supply
  - improve the ecological situation in the area concerned
  - further duties according to the „Groundwater-Management-Plan“, i.e.
    maintain groundwater levels between an upper and lower threshold by adjusting infiltration and extraction rates

Waterworks Biebesheim – Treatment of Rhine Water

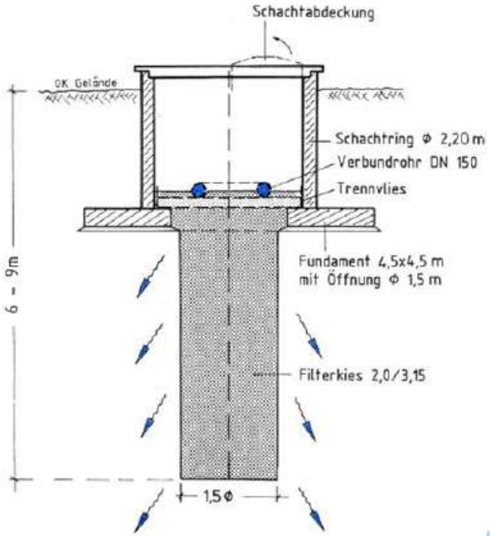
Max. 5,400 m³/h directly out of the river Rhine (0,1% of avg. Rhine discharge). Full treatment to drinking water quality.

Water is provided for irrigation and infiltration → since the 90‘s !

Infiltration Systems



Infiltration through artificial trenches



Infiltration through large diameter wells

Former drainage trenches, now used for infiltration

Wasserverband Hessisches Ried

http://www.wasserverband-hessisches-ried.de/html/index.html

Water management installations

Capacity Biebesheim treatment plant

43 Mio m³/y

Capacity infiltration

38 Mio m³/y

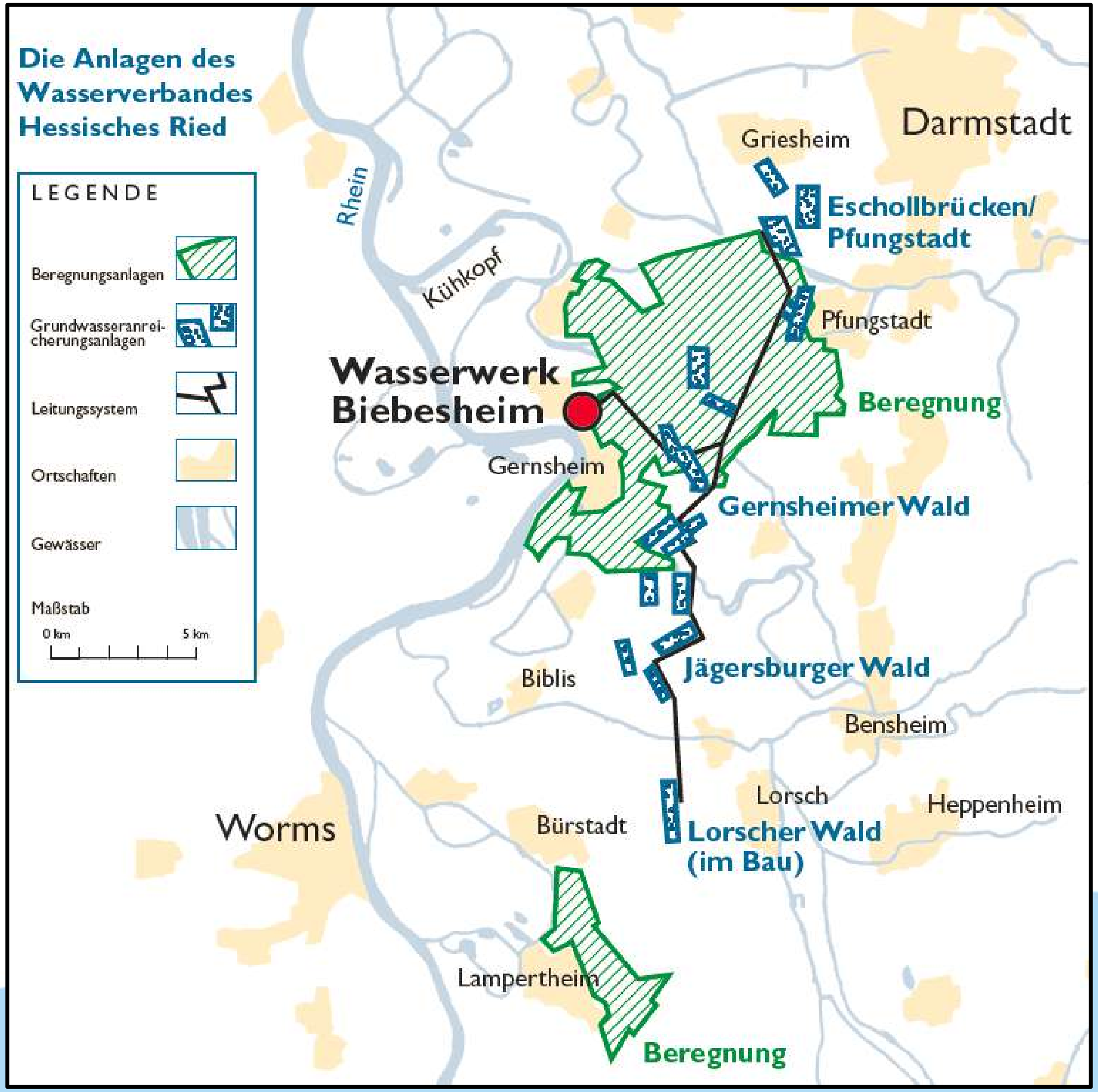
Capacity of the three water works for public water supply

52 Mio m³/y

Irrigation

2,5 – 8,5 Mio m³/y

(up to 4.5 Mio m³/y from Biebesheim + groundwater)



http://www.wasserverband-hessisches-ried.de/html/24.html

Water management installations

EXTRACTION

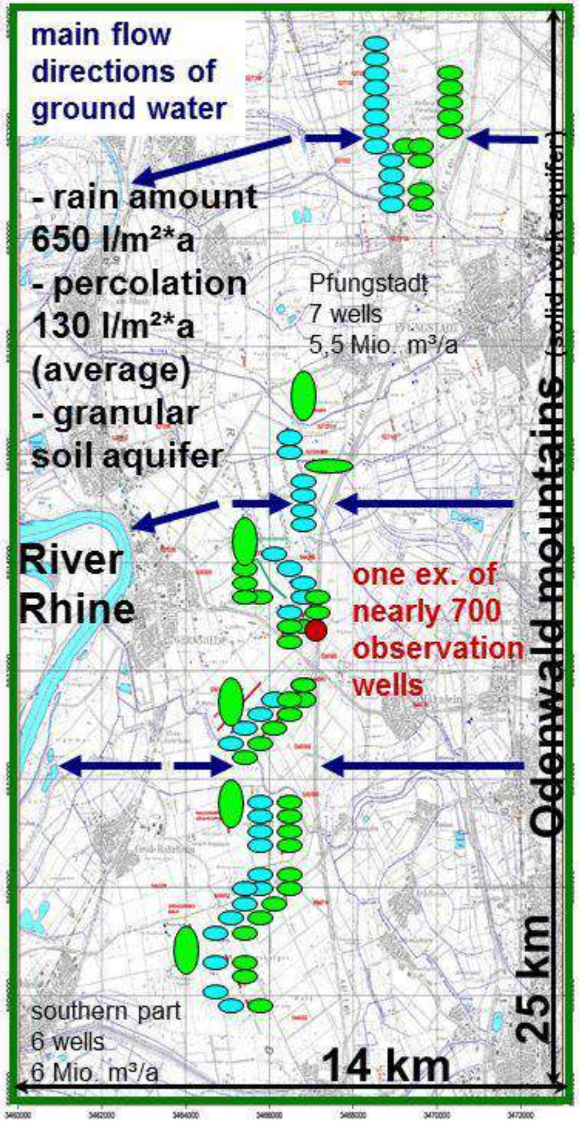
major water works

19 wells
12,5 - 20 Mio. m³/a

15 wells
12,5 - 17,5 Mio. m³/a

(northern part)
13 wells
10 – 15 Mio. m³/a

together:
Today 40 of 52 Mio. m³/a
planning 52 of 64 Mio. m³/a
+12 Mio. m³/a



INFILTRATION

infiltration complexes

11 trenches
1 single well
2 basins
2,5 – 12,7 Mio. m³/a

5 trenches
17 groups with
7 wells (177 wells)
8 – 12,7 Mio. m³/a

2 trenches
12 groups with
5 wells (62 wells)
1 single well
5,5 – 12,7 Mio. m³/a

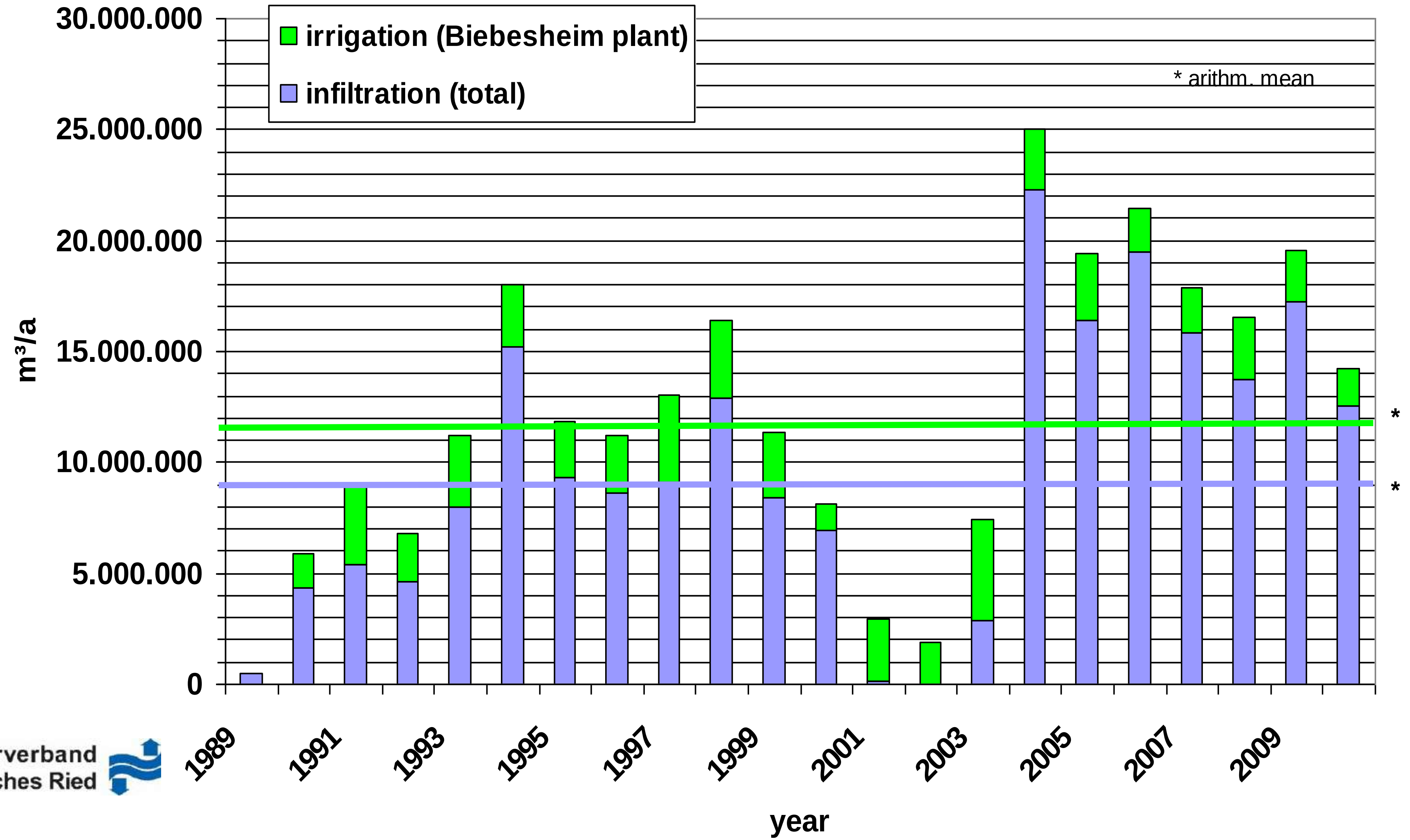
Wasserverband Hessisches Ried

REGULATION

MONITORING

Irrigation and infiltration variations

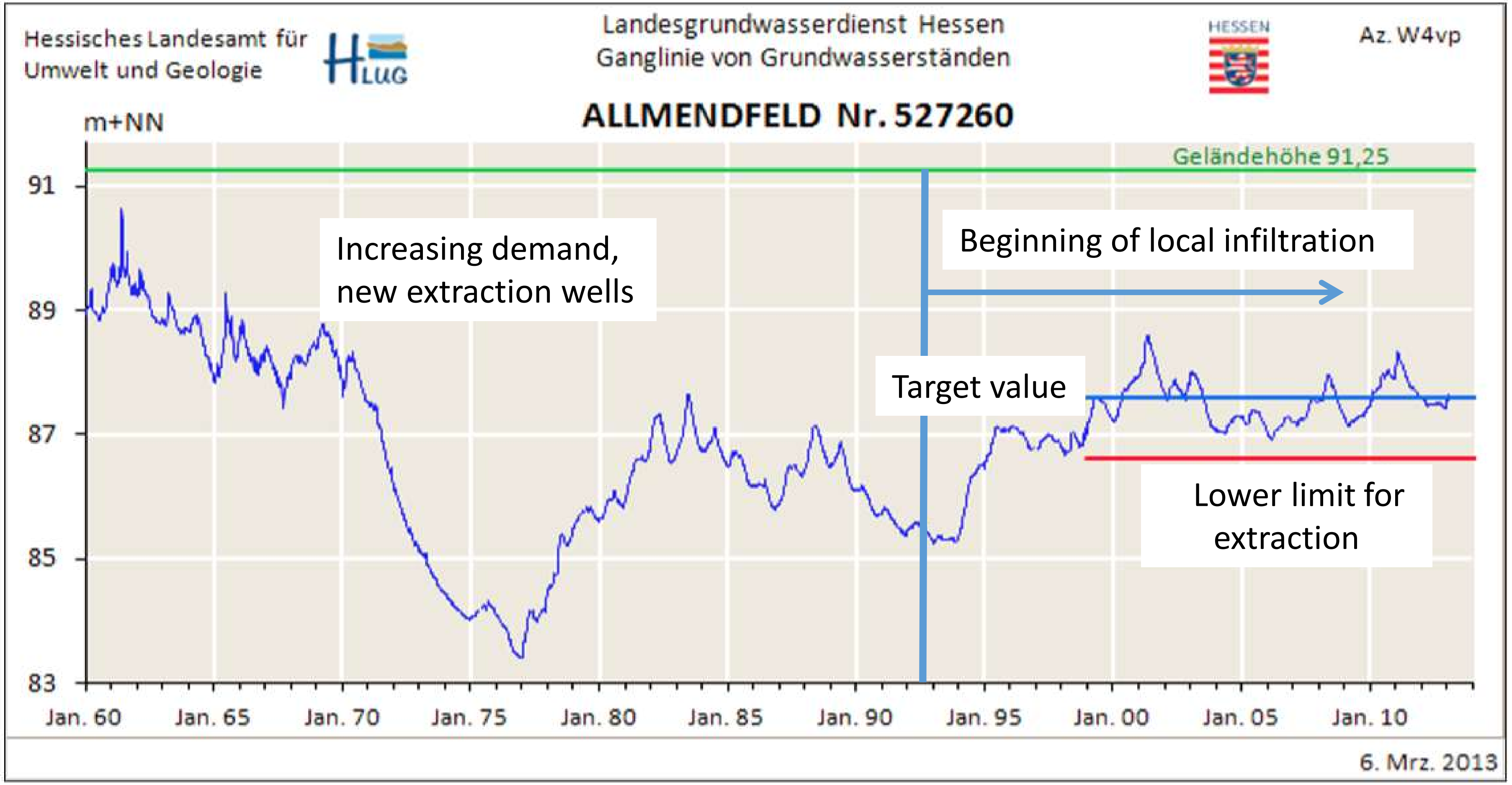
*



Wasserverband Hessisches Ried

Regulation and Monitoring

At 46 piezometers in the Hessian Ried target values for groundwater levels are defined, especially also lower limits for groundwater levels → **Groundwater Management Plan of the Hessian Ried**.



BE THE

Resilience through infrastructure…

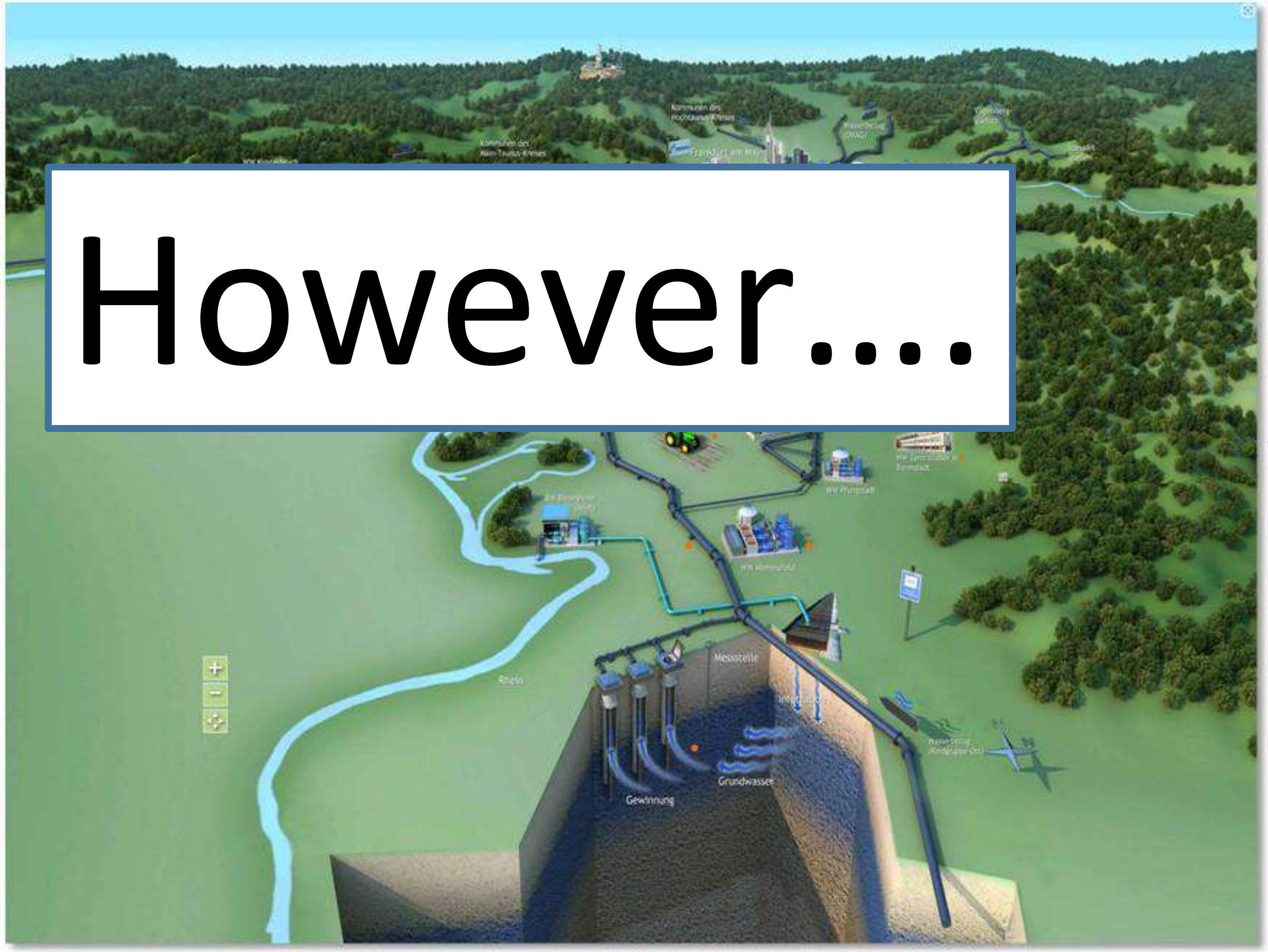
hessenwasser

Water management and distribution in the south of Hesse

Supply networks offer back-up solutions when certain areas have supply difficulties

This in no way means that local water providers are redundant, quite the contrary.

Local resources should be used to increase the overall resilience of the system.

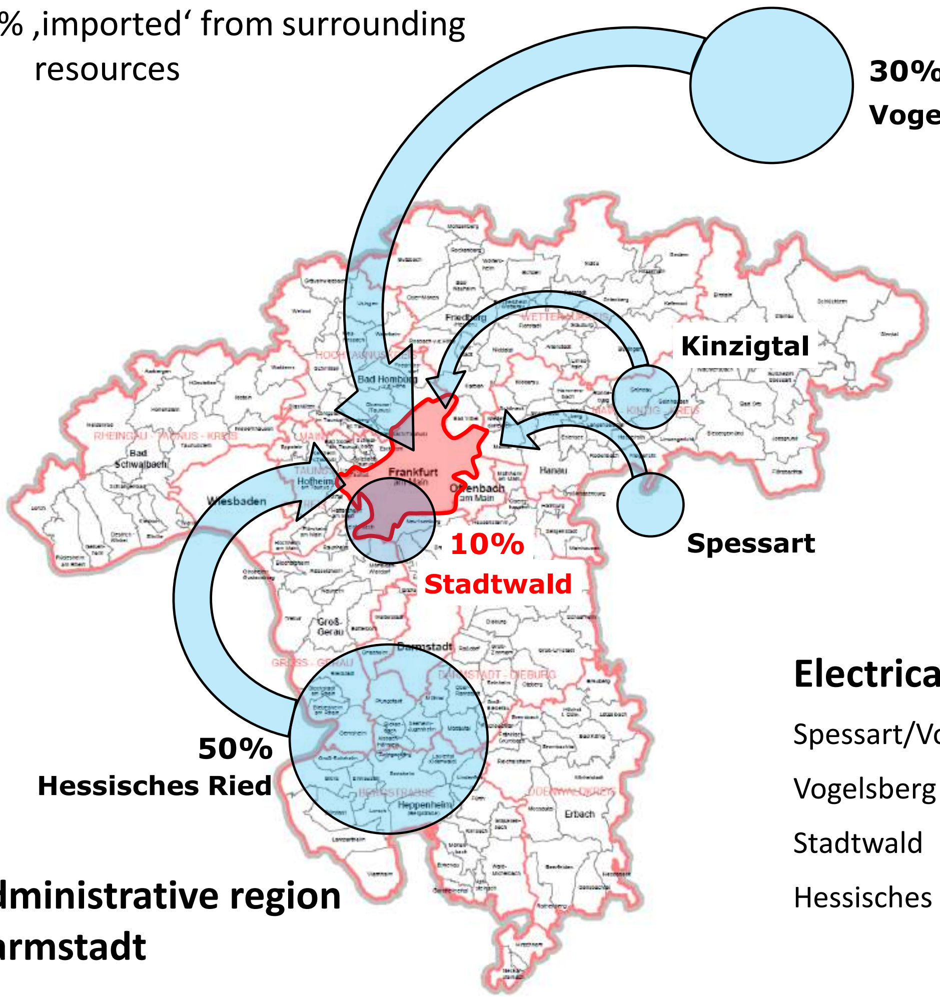


However….

Water supply Frankfurt Rhein-Main

Water demand ~ 60.000.000 m³/a

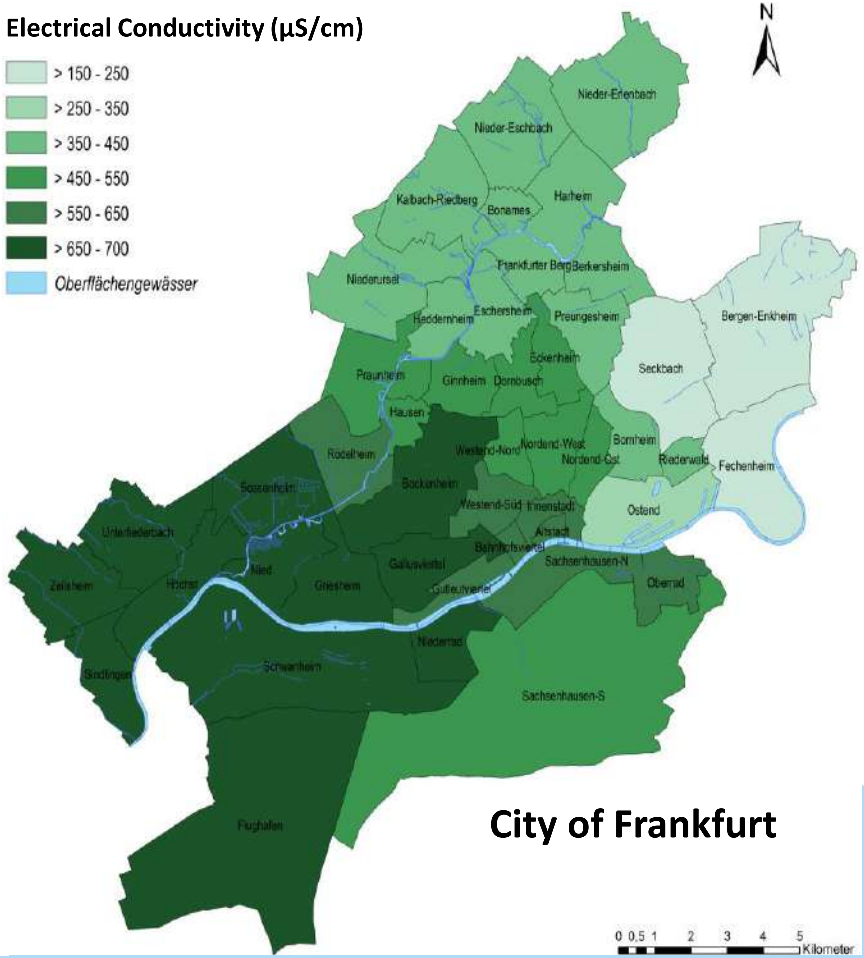
90 % ‚imported‘ from surrounding resources



Administrative region Darmstadt

El. Cond. tap water Frankfurt

Water source clearly defined



Electrical Conductivity (µS/cm)

Spessart/Vogelsberg	170 – 230
Vogelsberg	390 – 430
Stadtwald	570 – 720
Hessisches Ried	710 – 740

Hessenwasser, 2012

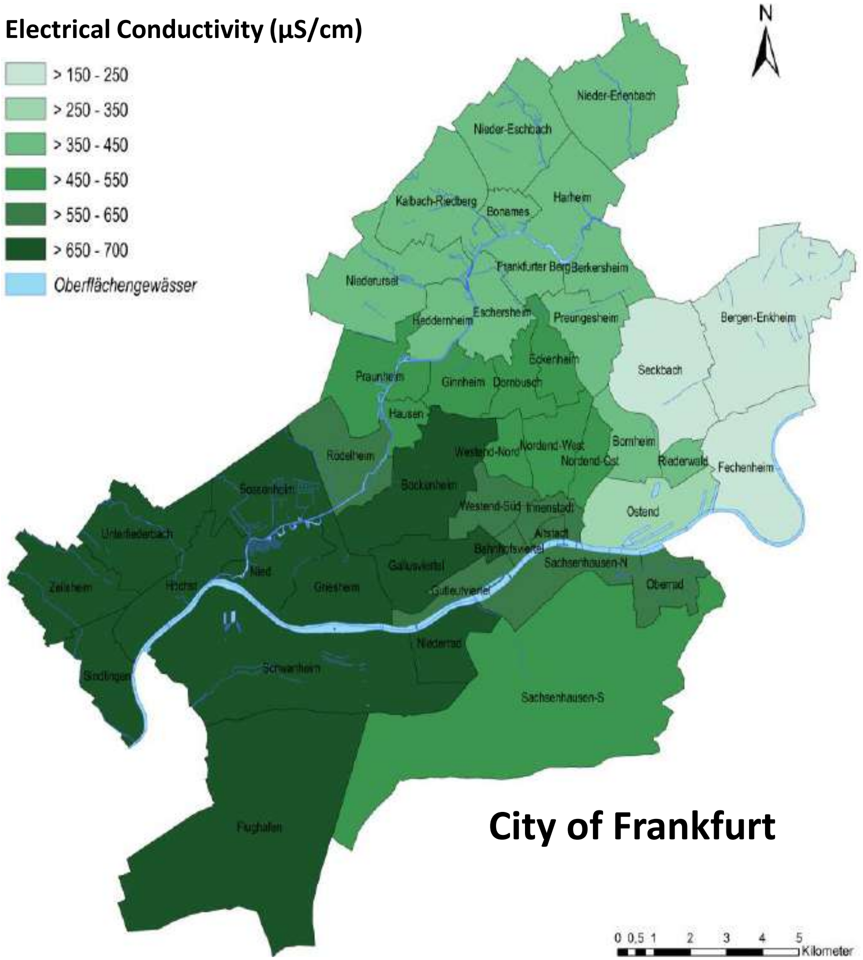
Data from Püttmann et al., Uni Frankfurt

Frankfurt vs. Vogelsberg

The fight for water…

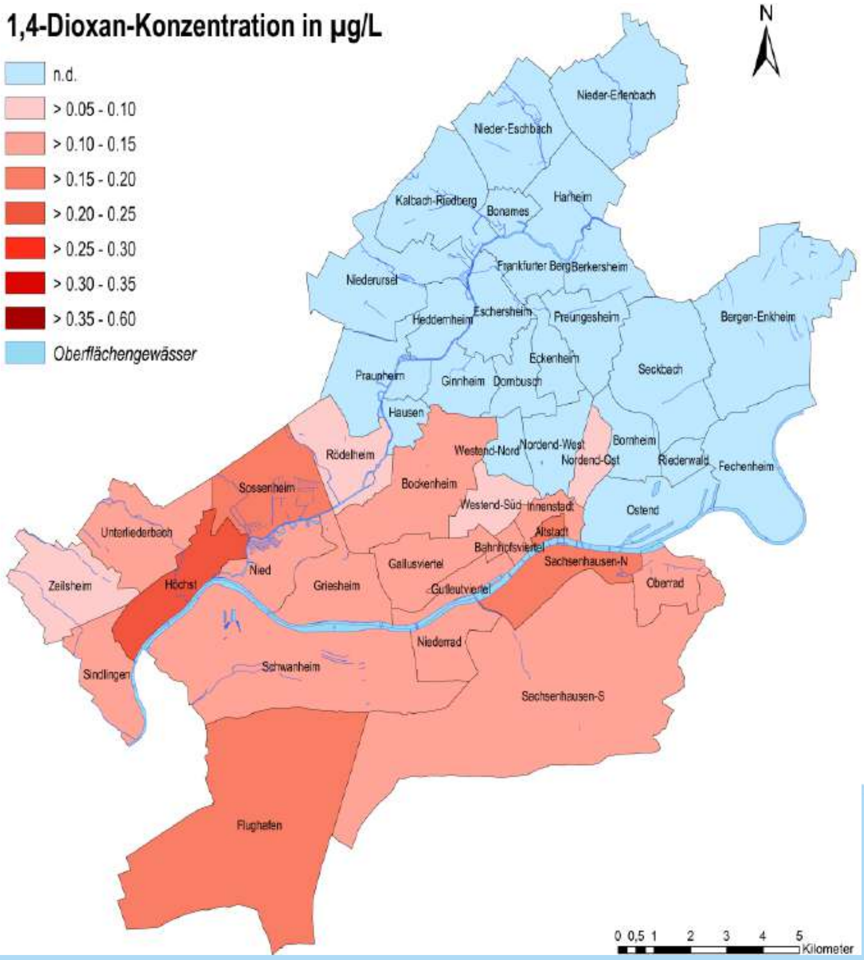
Water supply Frankfurt Rhein-Main

El. Cond. tap water Frankfurt
Water source clearly defined



City of Frankfurt

1,4-Dioxane tap water Frankfurt
Contamination source clearly defined



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Spessart/Vogelsberg	170 – 230
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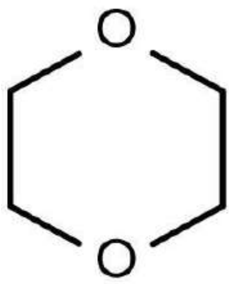
Hessisches Ried	710 – 740

Hessenwasser, 2012

Data from Püttmann et al., Uni Frankfurt

1,4-Dioxane - Concentrations and mass fluxes in Oder, Rhein, Main



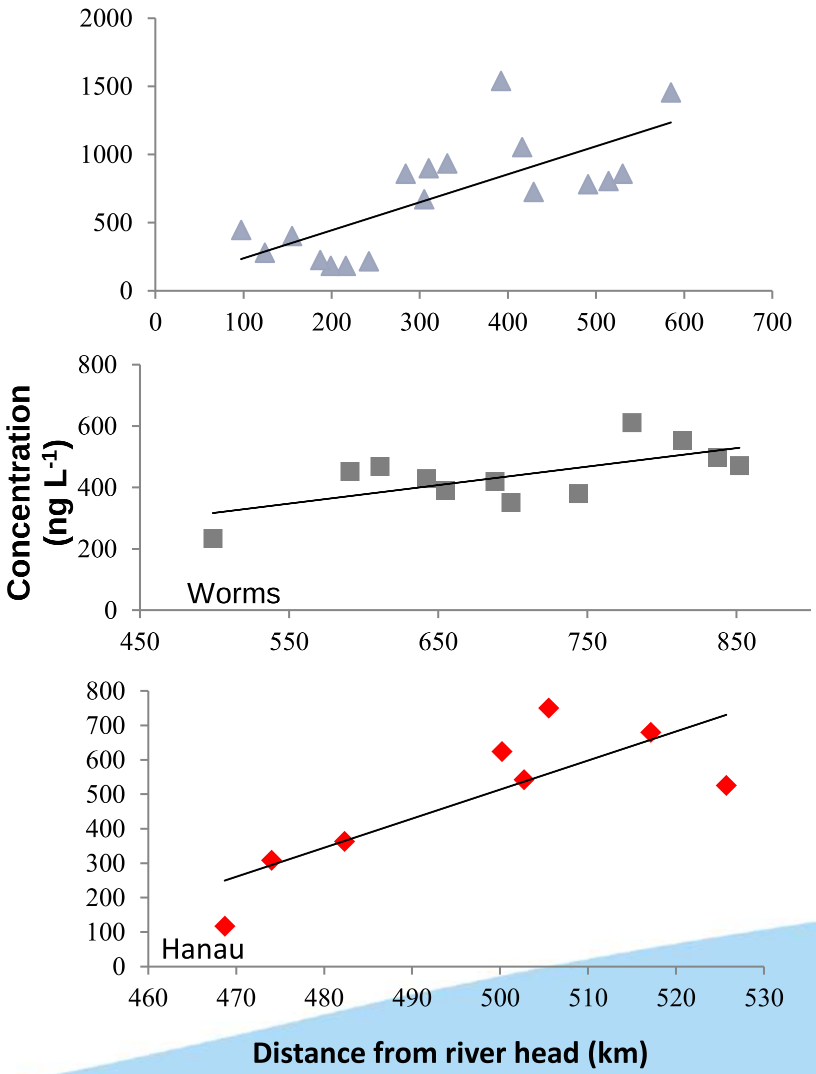
Production > 1000 t per year in the EU (ECSIS, 2103)

Industrial solvent (pharmaceuticals, colours, glues etc.)

By-product in surfactant production (polyethoxylates) and polyester

Octanol-Water partition coefficient:
Log K_{ow} = -0,27

Water solubility:
miscible



Oder
Average Concentration: 700 ng/L
Average Flux: 7 kg/d

Rhein
Average Concentration: 440 ng/L
Average Flux: 135 kg/d

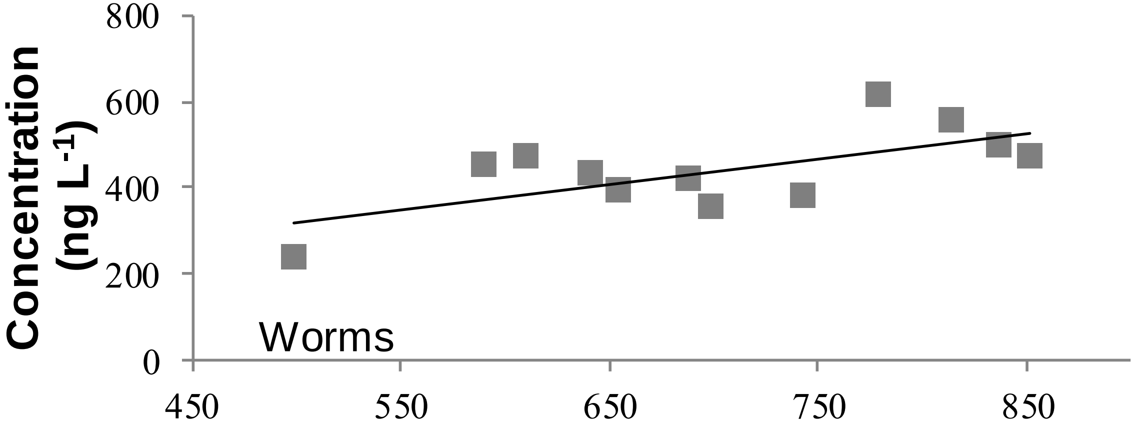
Main
Average Concentration: 490 ng/L
Average Flux: 6.5 kg/d

Stepien et al. (2014):
Water Res. 48, 406-419

Data from Püttmann et al., Uni Frankfurt

Water supply Frankfurt Rhein-Main

Average Concentration: 440 ng/L
Average Flux: 135 kg/d

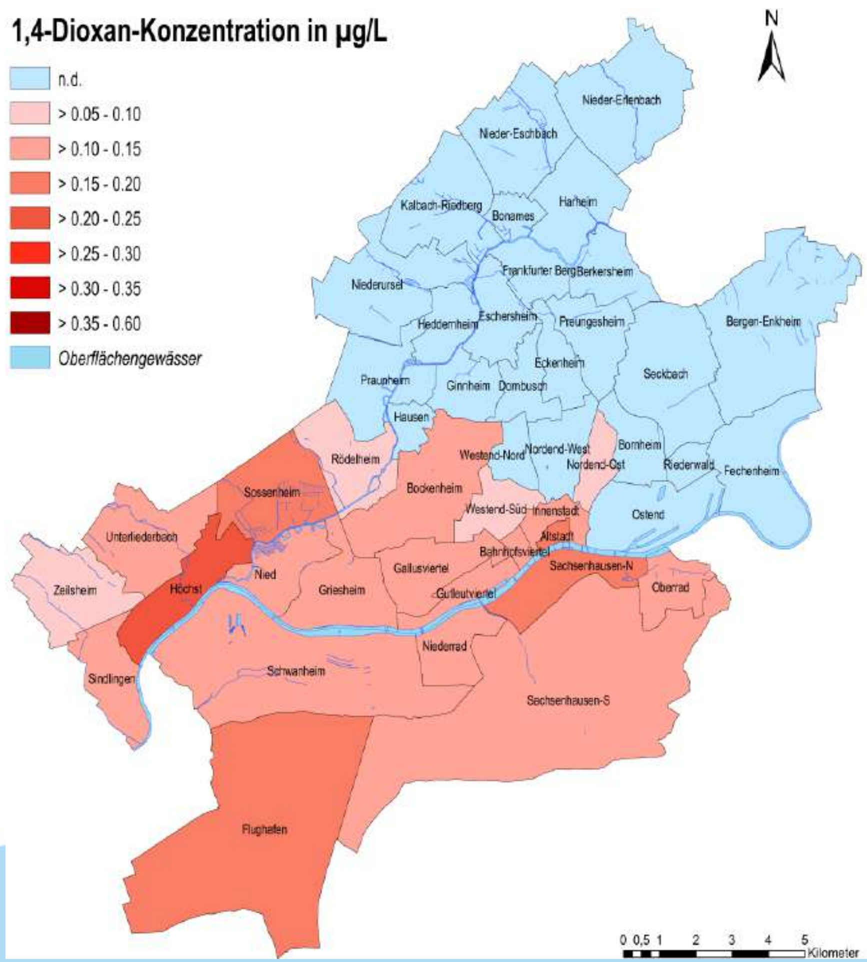


Rhein

About 50% of the water in the south of Frankfurt is native groundwater, and 50% trated and infiltrated Rhine water

1,4-Dioxane tap water Frankfurt

Contamination source clearly defined



Resilience through infrastructure…

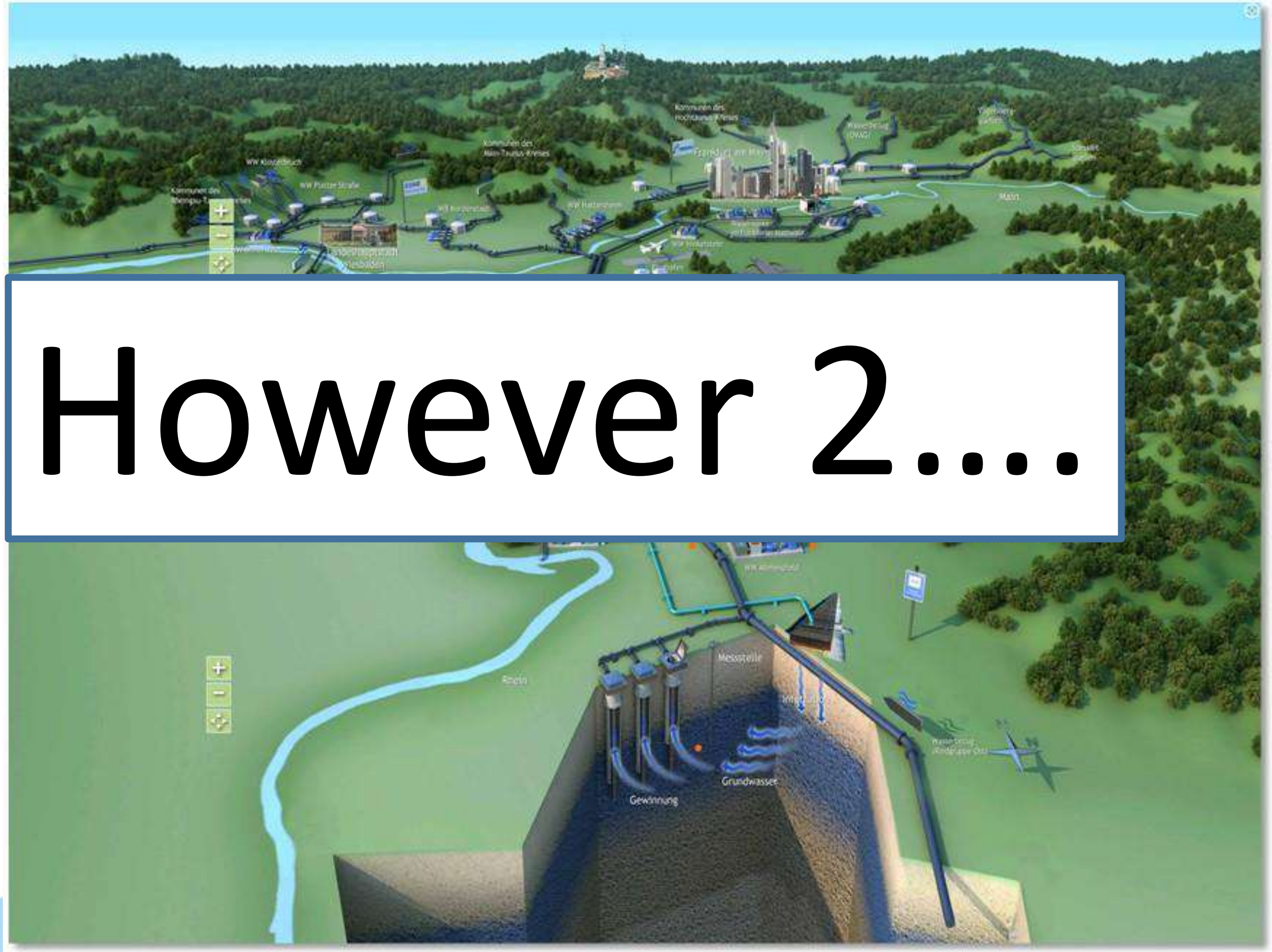
hessenwasser

Water management and distribution in the south of Hesse

Supply networks offer back-up solutions when certain areas have supply difficulties

This in no way means that local water providers are redundant, quite the contrary.

Local resources should be used to increase the overall resilience of the system.



However 2....

In 2016, Germany is sued by the EU Commission due to high nitrate….


European Commission - Press relea

ARD Home Nachrichten Sport Börse Ratgeber Wissen Kultur Kinder Die ARD Fernsehen Radio ARD Medi

tagesschau.de

Startseite Videos & Audios Inland Ausland Wirtschaft Wahlen Wetter Ihre Meinung Mehr

Startseite › Inland › EuGH verurteilt Deutschland wegen Nitratbelastung

Entscheidung des EuGH

Deutschland wegen Nitratbelastung verurteilt

Stand: 21.06.2018 11:49 Uhr

Der Europäische Gerichtshof in Luxemburg hat Deutschland wegen Verletzung von EU-Recht verurteilt, weil die Bundesregierung zu wenig gegen Nitrate im Grundwasser unternommen hat. Geklagt hatte die EU-Kommission.

Deutschland hat nicht genug gegen die zu hohe Nitratbelastung in seinen Gewässern unternommen. Der Europäische Gerichtshof (EuGH) in Luxemburg urteilte, die Bundesrepublik habe damit gegen die

GERMANY

EU sues

nitrate fe

The European Com

nitrate fertilizer in

millions of euros in

the Cou

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litrates are

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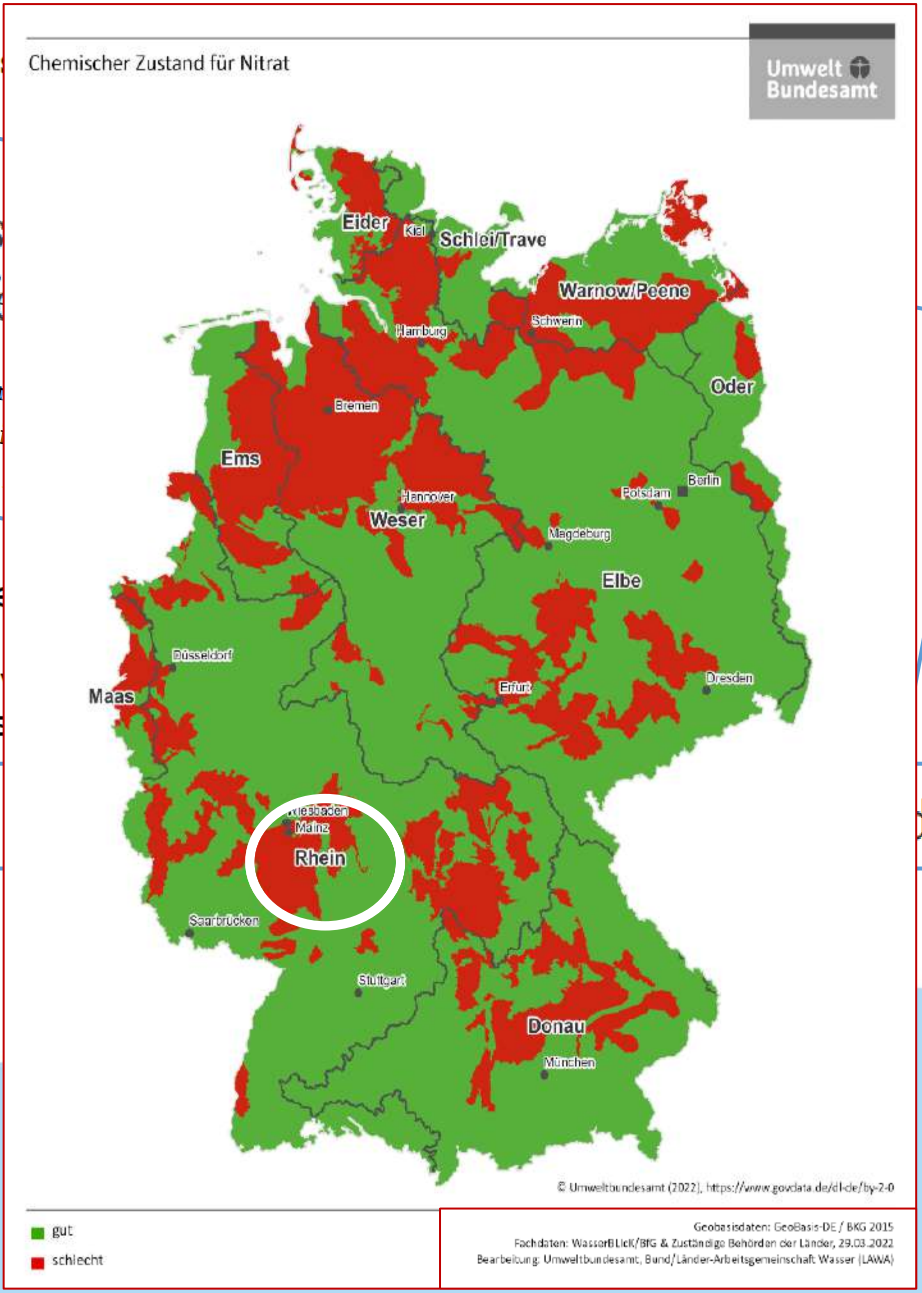
EU sues

ds



Would take 2 more hours…..
We better stop here

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Sistema Nazionale per la Protezione dell'Ambiente

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Malta 2023

14th – 16th June
National Meeting on Hydrogeology

JUNE 14-16, 2023

WATER.ORG.MT

STOCHASTIC SIMULATION FOR DEFINING NO_3^- AND F^- BACKGROUND LEVELS IN DIFFERENT GROUNDWATER BODIES OF THE CAMPANIA REGION.

Gianluigi Busico, Mojgan Bordbar, Dario Tedesco, Micòl Mastrocicco*

Session 3: Emerging Challenges to Groundwater Quantity and Quality

WATER
BE THE CHANGE

Università
degli Studi
della Campania
Luigi Vanvitelli
Dipartimento di Scienze e Tecnologie Ambientali Biologiche e Farmaceutiche

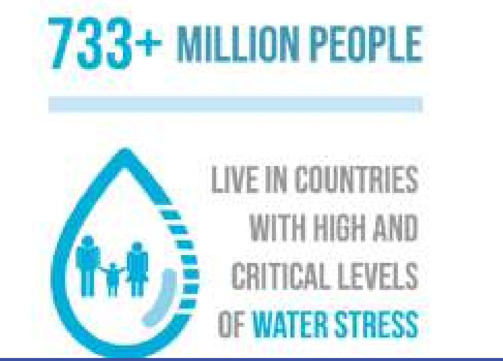
Objective 6. Ensure availability and sustainable management of water and sanitation for all

I "It should be noted that the chronic and consistent lack of data on almost all SDG indicators related to water, especially underground resources, is a serious obstacle to an accurate assessment of progress at national and global levels."

6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all

6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations

From 2015 to 2020, drinking water use increased from 70 to 74%, but 2 billion people remain excluded; sanitation from 47 to 54% but 3.6 billion excluded; hand washing with soap and water from 67 to 71% but 2.3 billion excluded.



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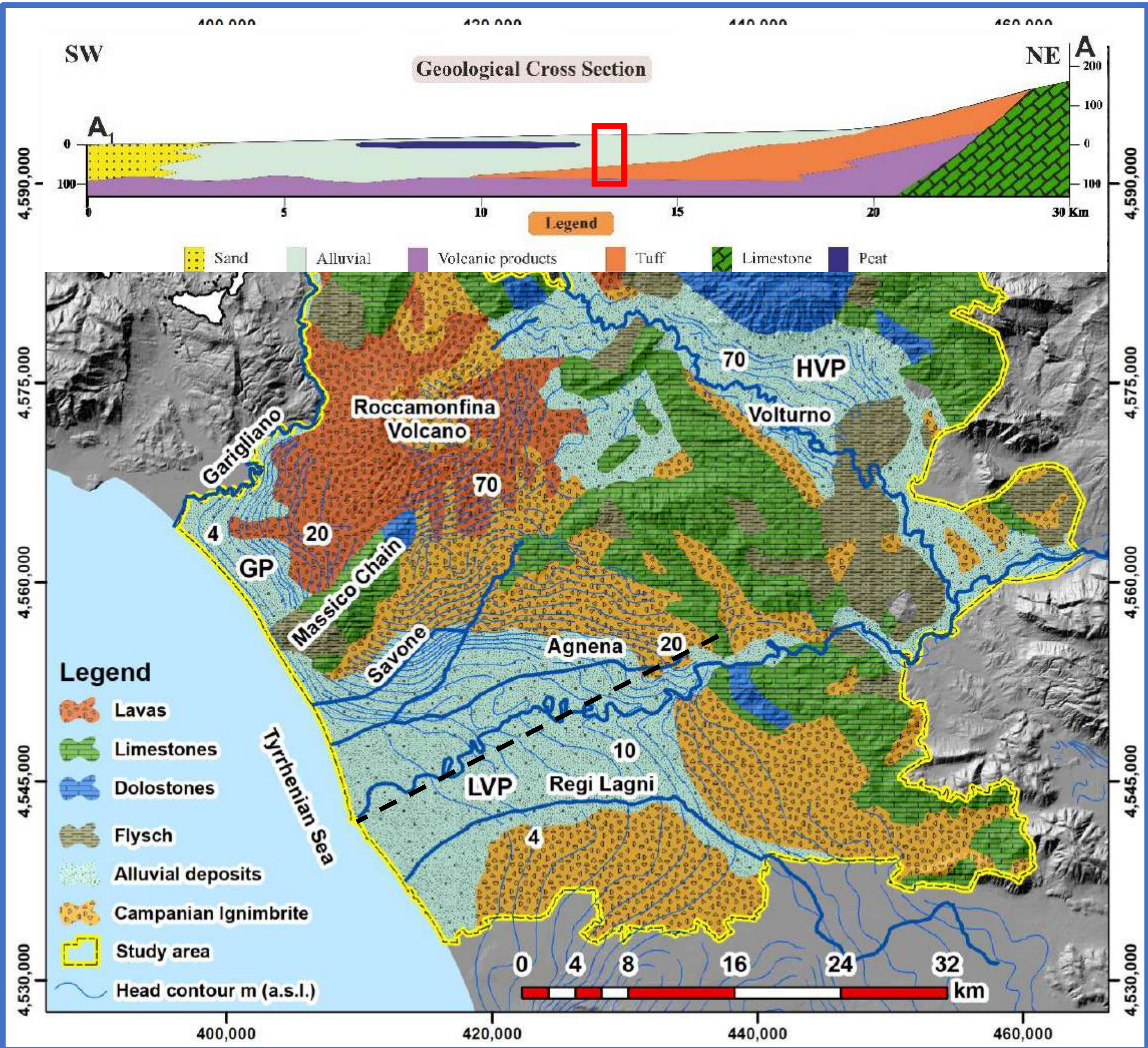
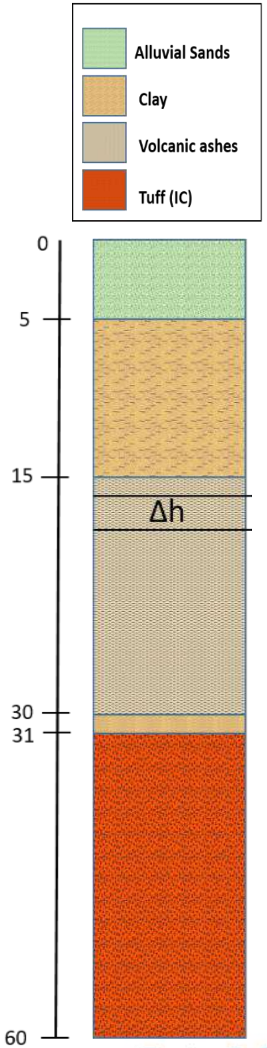
CHANGE





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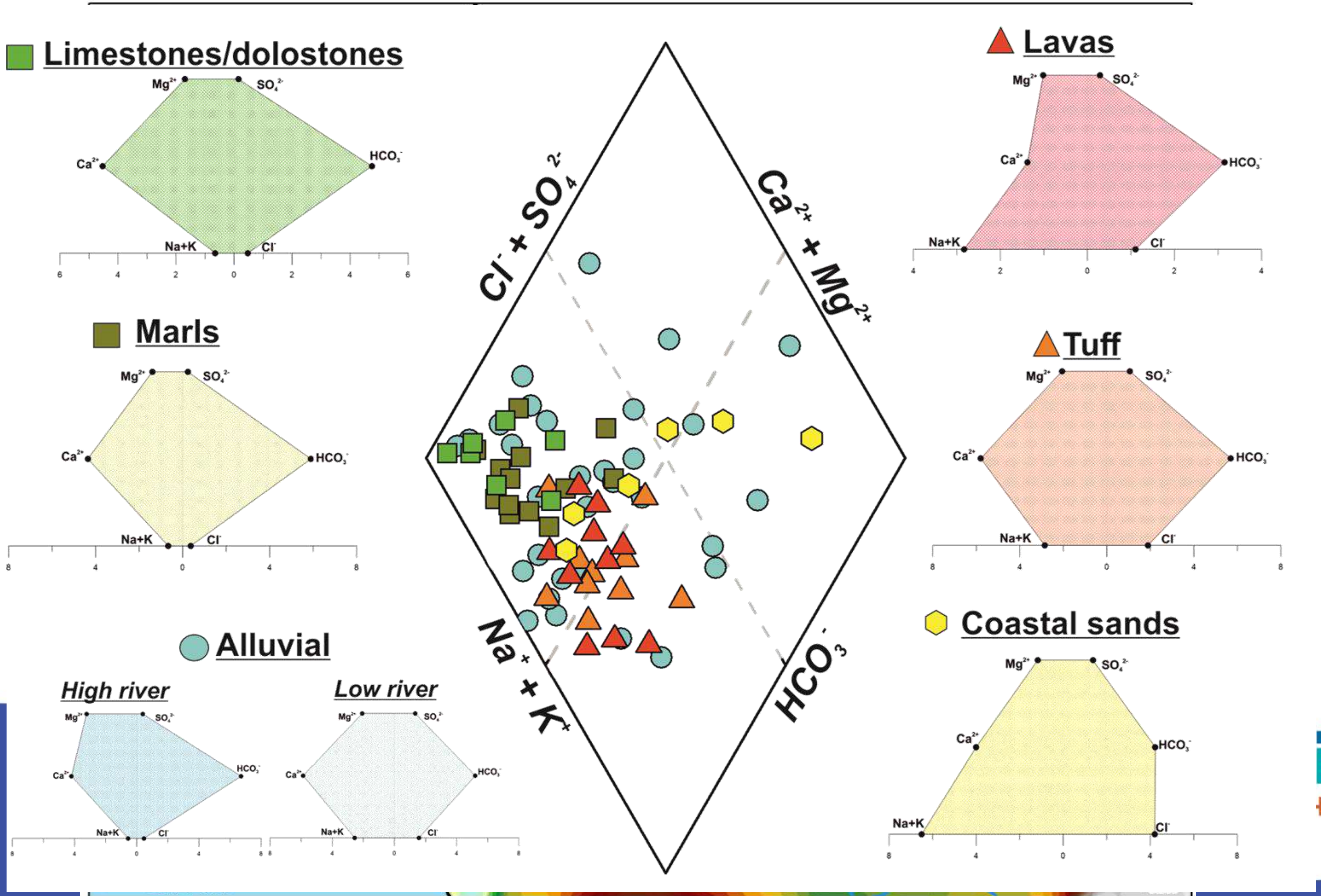
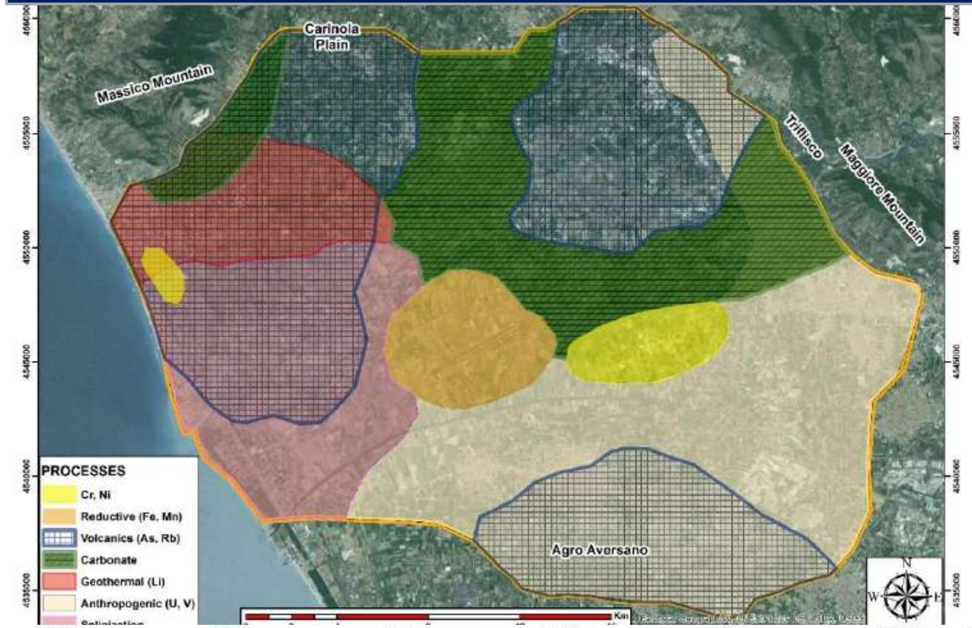
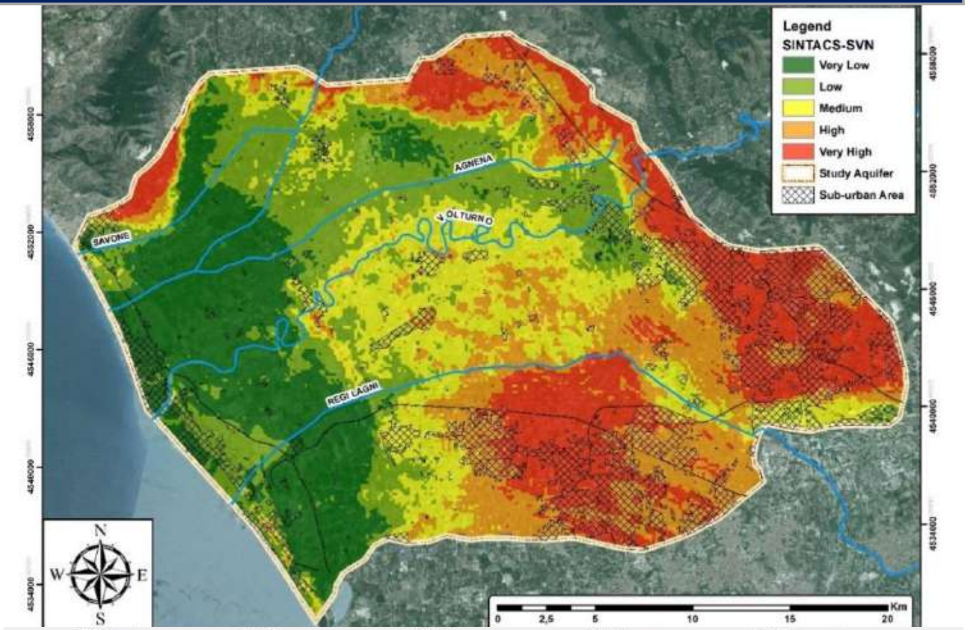
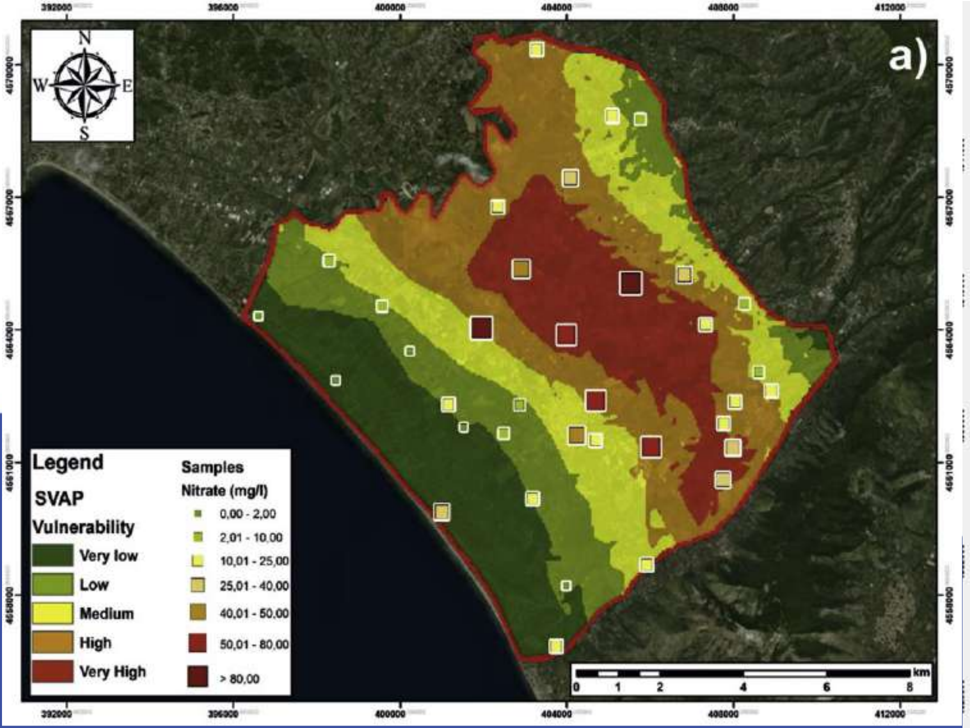
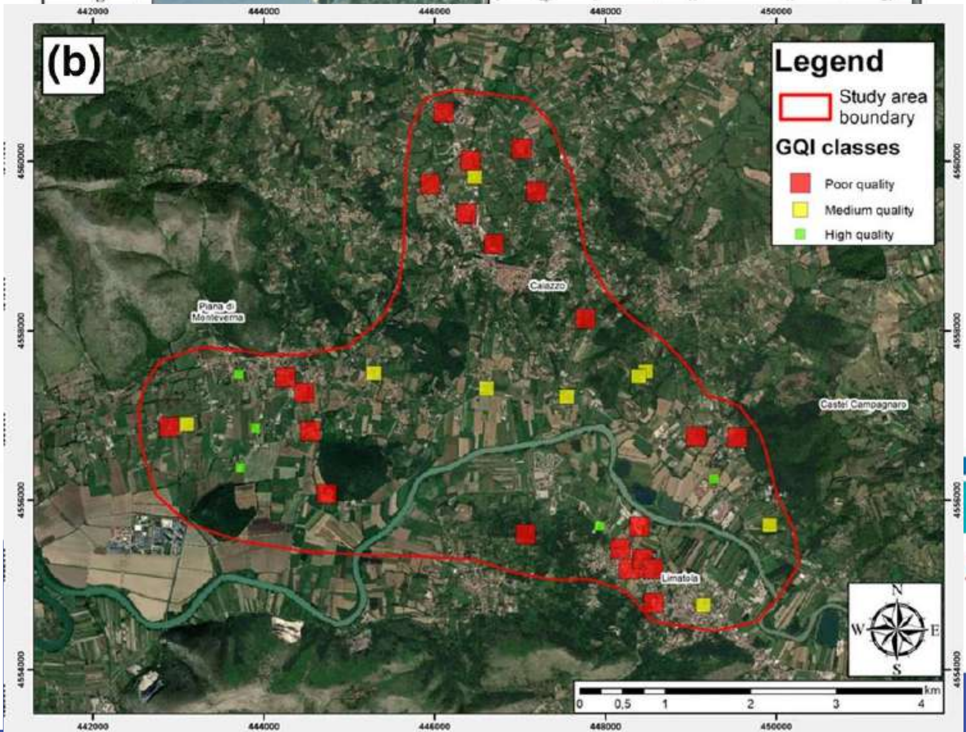

Limestones/dolostones
Marls
Alluvial
High river
Low river
Lavas
Tuff
Coastal sands
Cl⁻ + SO₄²⁻
Ca²⁺ + Mg²⁺
Na⁺ + K⁺
HCO₃⁻
Mg²⁺
SO₄²⁻
Ca²⁺
HCO₃⁻
Na+K
Cl⁻

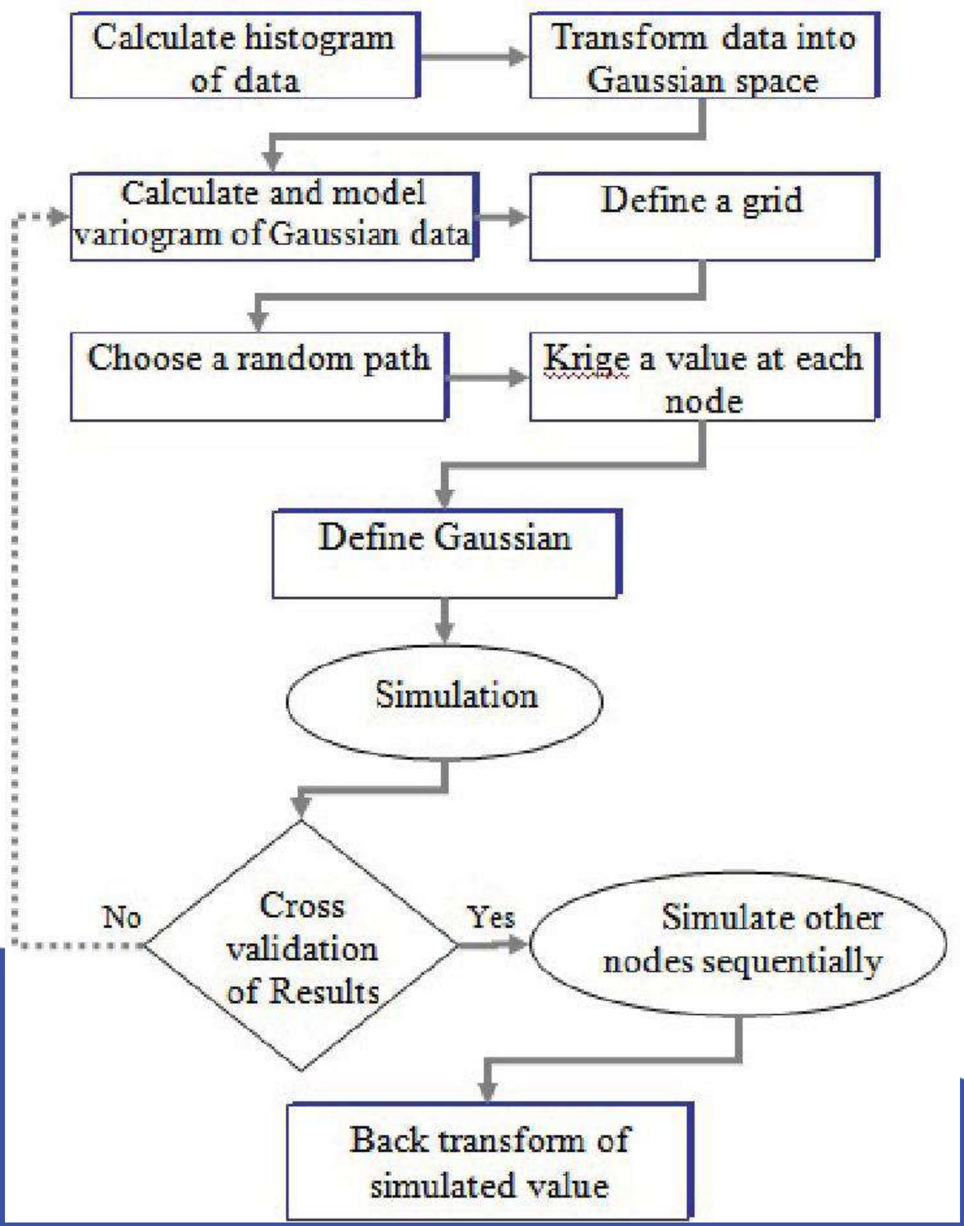

Carinola Plain
Massico Mountain
Trifilisco
Maggiore Mountain
Agro Aversano
PROCESSES
Cr, Ni
Reductive (Fe, Mn)
Volcanics (As, Rb)
Carbonate
Geothermal (Li)
Anthropogenic (U, V)

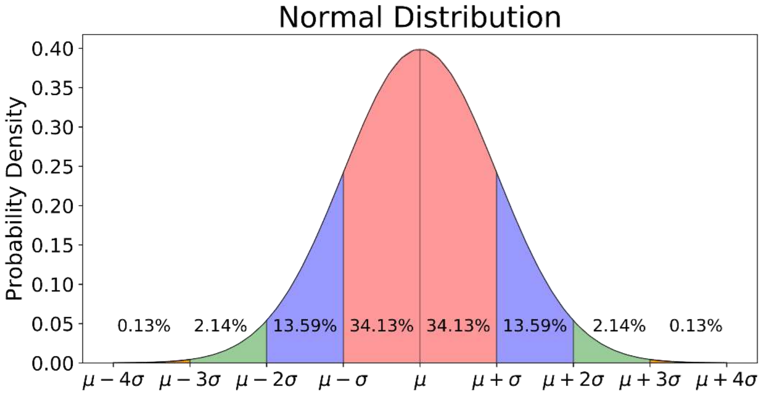

Legend
SINTACS-SVN
Very Low
Low
Medium
High
Very High
Study Aquifer
Sub-urban Area
AGNENA
V. OLTURNO
SAVONE
REGI LAGNI


a)
Legend
SVAP
Vulnerability
Very low
Low
Medium
High
Very High
Samples
Nitrate (mg/l)
0,00 - 2,00
2,01 - 10,00
10,01 - 25,00
25,01 - 40,00
40,01 - 50,00
50,01 - 80,00
> 80,00


(b)
Legend
Study area boundary
GQI classes
Poor quality
Medium quality
High quality
Caiazzo
Limatola
Castel Campagnaro

GAUSSIAN GEOSTATISTICAL SIMULATION



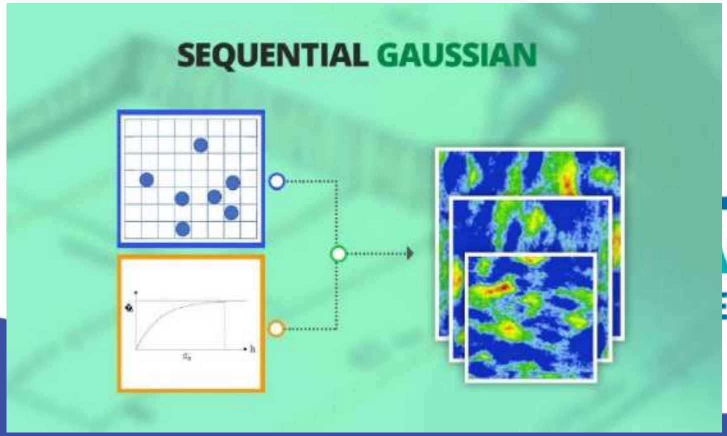


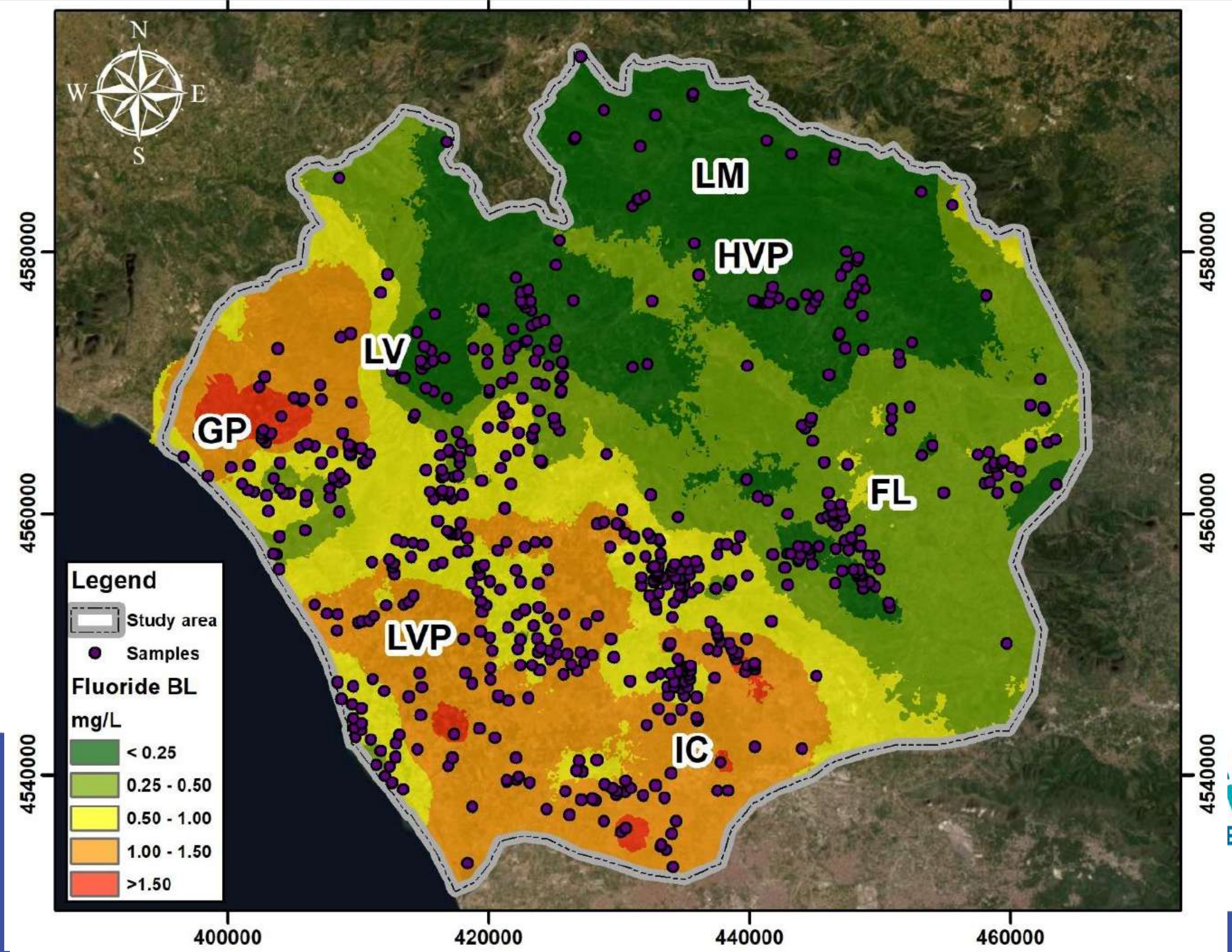
Variogram models of normal scores data have been computed and fitted with a standardized spherical model described by the following equations

$$\gamma = c_0 + c\left[1.5\left(\frac{h}{a}\right) - 0.5\left(\frac{h}{a}\right)^3\right], h < a$$

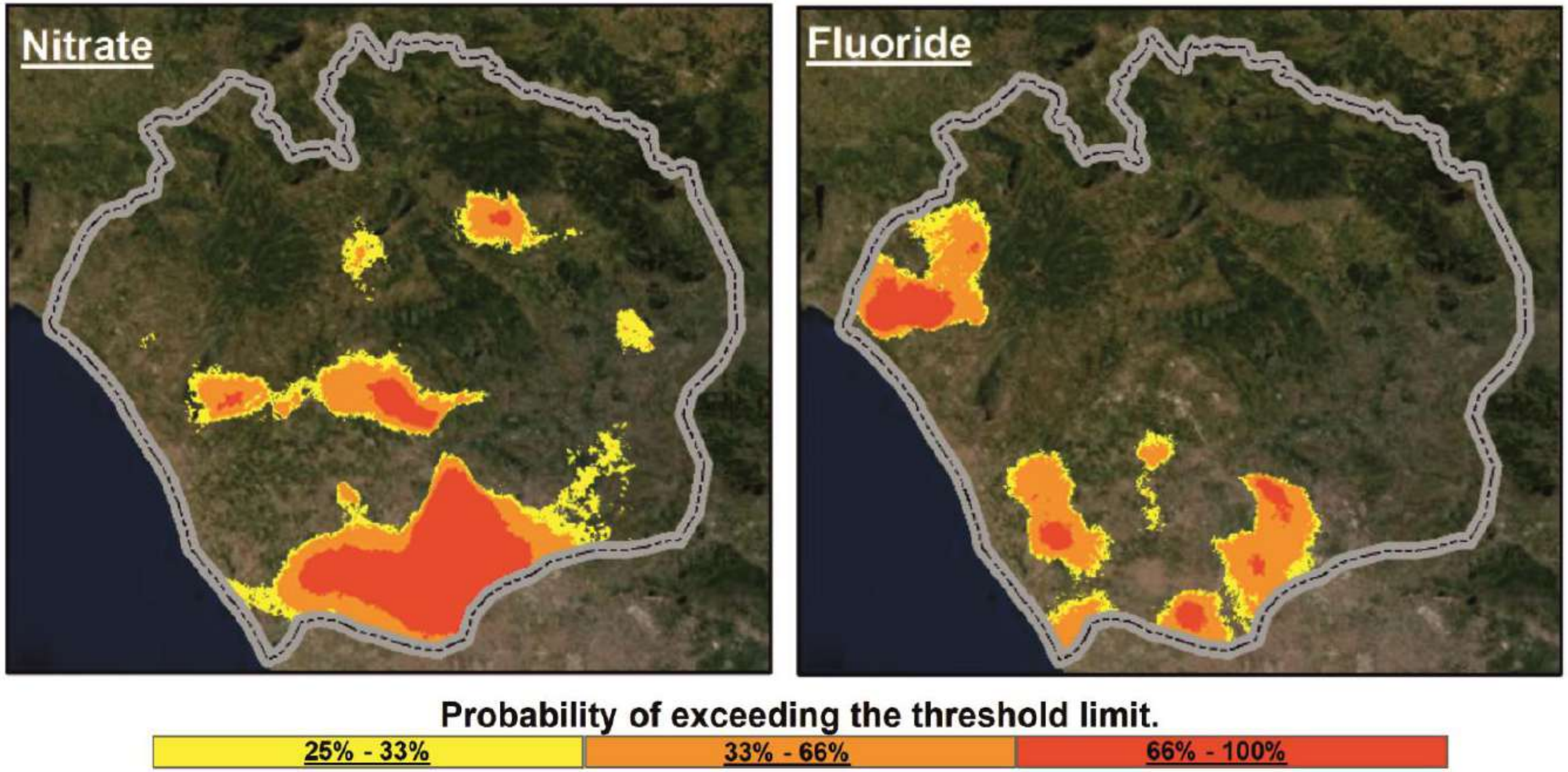
$$\gamma = 1, \ h > a$$

Where $c_{0,}$ c, and a represent the nugget effect, the sill, and the range, respectively. Simulations have been then post-processed To draw (i) the median maps and (ii) the probability maps.

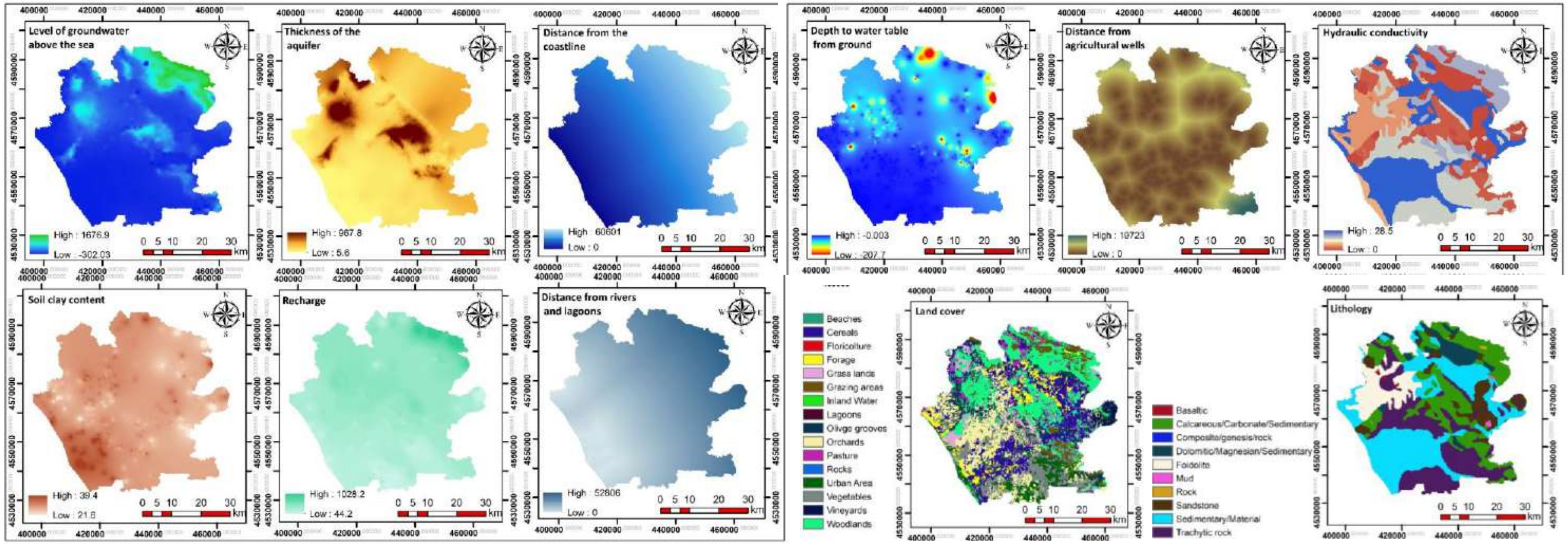



N
S
W
E
LM
HVP
LV
GP
FL
LVP
IC
Legend
Study area
Samples
Fluoride BL
mg/L
< 0.25
0.25 - 0.50
0.50 - 1.00
1.00 - 1.50
>1.50
4580000
4560000
4540000
400000
420000
440000
460000

LOCATION AND GEOLOGY	NITRATE		FLUORIDE	
	ABL	MAX MED	NBL	MAX MED
High Volturno Plain	23.74	37.91	2.93	3.6
Low Volturno Plain	14.4	26.21	3.93	5.5
Garigliano Plain	16.09	23.4	4.41	5.28
Limestones	14.96	25.34	2.91	3.6
Campanian Ignimbrite	46.73	71.71	3.38	4.4
Lavas	10.63	16.9	4.64	5.81
Flysch	13.68	20.1	2.58	3.28

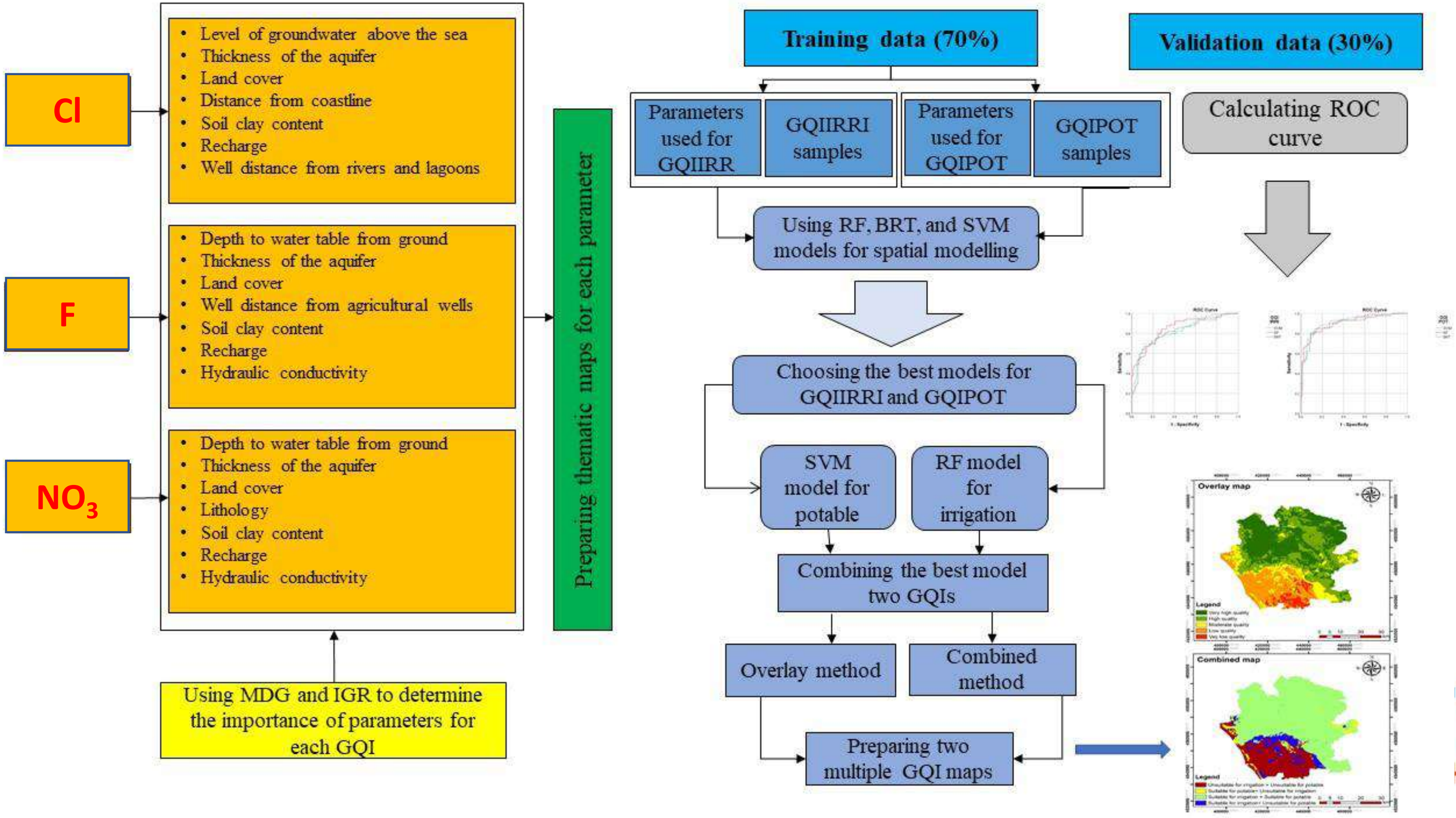


Wath is next?



Database Name	Description	Format	Citation
MERIT - Map of global terrain elevations	High accuracy DEM developed by removing multiple error components (absolute bias, stripe noise, speckle noise, and tree height bias) from existing spaceborne DEMs (SRTM3 v2.1 and AW3D-30m v1).	Raster (~90m resolution)	Yamazaki et al. 2017; 2019
Global Water Table depth (WTD)	Global map of depth to water [m]	Raster (~1km resolution)	Fan et al. 2013
World Soil Information Service (WoSIS)	Soil water retention, bulk density, electrical conductivity, organic carbon, total nitrogen, content of sand, clay, and silt	Vector (PT)/Geodatabase	Batjes et al. 2017
BIGBANG Database	Monthly value of precipitation, snow cover, evapotranspiration, and recharge for the Italian Peninsula.	Raster (~1km resolution)	Braga et al. 2021
CORINE LAND COVER	Spatial distribution of land use classes	Vector (PT)/Geodatabase	European Union, Copernicus Land Monitoring Service

Machine learning application on Gaussian results



THANKS FOR THE ATTENTION

CITATION AND USEFULL LINKS

- Busico, G., Cuoco, E., et al. (2018). Multivariate statistical analysis to characterize/discriminate between anthropogenic and geogenic trace elements occurrence in the Campania plain, southern Italy. *Environmental Pollution, 234*, 260-269. doi:10.1016/j.envpol.2017.11.053
- Busico, G., Kazakis, N., et al.(2017). A modified SINTACS method for groundwater vulnerability and pollution risk assessment in highly anthropized regions based on NO_3^- and SO_4^{2-} concentrations. *Science of the Total Environment, 609*, 1512-1523. doi:10.1016/j.scitotenv.2017.07.257
- Rufino, F., Busico, G., Cuoco, E., Darrah, T. H., & Tedesco, D. (2019). Evaluating the suitability of urban groundwater resources for drinking water and irrigation purposes: An integrated approach in the agro-aversano area of southern italy. Environmental Monitoring and Assessment, 191(12) doi:10.1007/s10661-019-7978-y

The present study is supported and financed by the project "NAtural and anThropogenic groUndwateR bAckground Level (NATURAL)" founded by University of Campania Luigi Vanvitelly PI: Dr. Gianluigi Busico

Università degli Studi della Campania *Luigi Vanvitelli*
Dipartimento di Scienze e Tecnologie Ambientali Biologiche e Farmaceutiche

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Malta 2023

14th – 16th June
National Meeting on Hydrogeology

JUNE 14-16, 2023

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Radar precipitation data as functional input for deriving the potential volume of water available for infiltration: the pilot case of Lombardy Region.

flowpath Malta 2023

14th – 16th June
National Meeting on Hydrogeology

Andrea Citrini[1], Giovanni Pietro Beretta[1], and Corrado Camera[1]

[1]Dipartimento di Scienze della Terra "Ardito Desio",
Università degli Studi di Milano, Milan, Italy

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UNIVERSITÀ DEGLI STUDI
DI MILANO

DIPARTIMENTO DI SCIENZE
DELLA TERRA "ARDITO DESIO"

Aims and research goals

The study aims to understand the **water availability** and **its distribution** in the study area as accurately as possible.

- To **correct the radar signal** in the study area using data recorded from **rain gauges**.
- To **define** the **mean annual** Potential GroundWater Recharge (**PGWR**) in the study area in the **2011-2020 period**.
- To **prove that** the use of **radar** in combination with data retrieved from rain gauges could be **a useful tool** to estimate the water resource entering the system.

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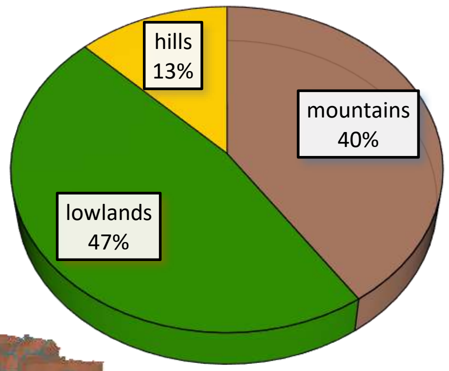
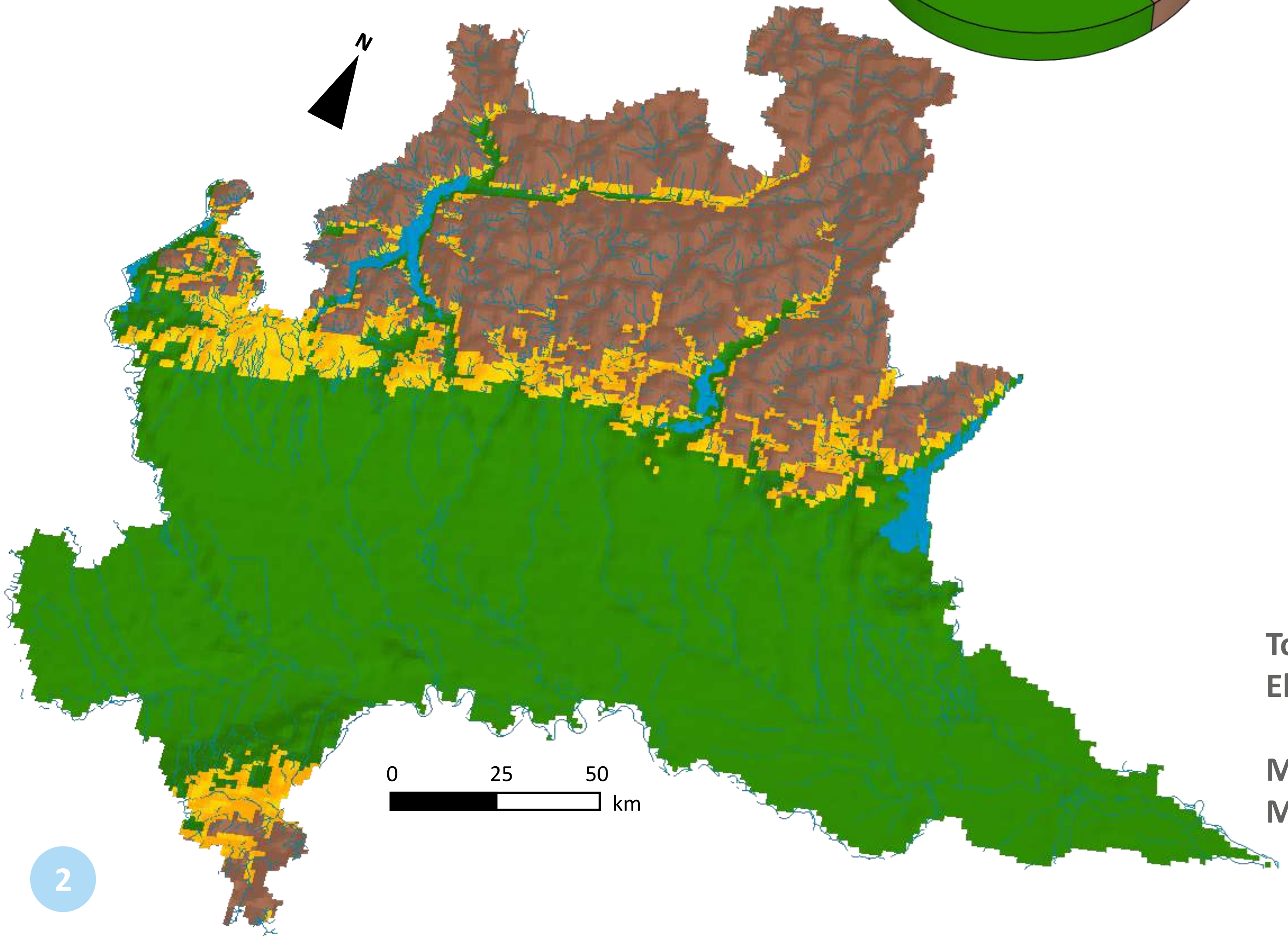
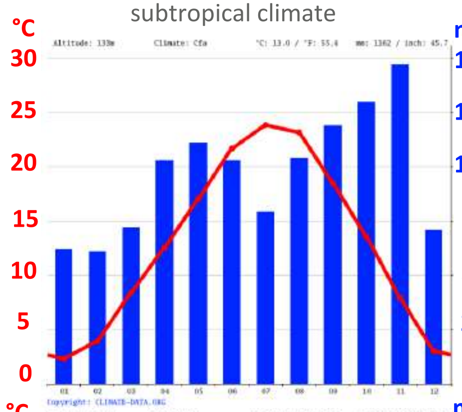
Study area

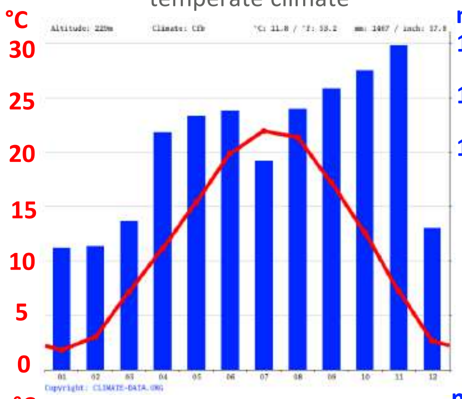


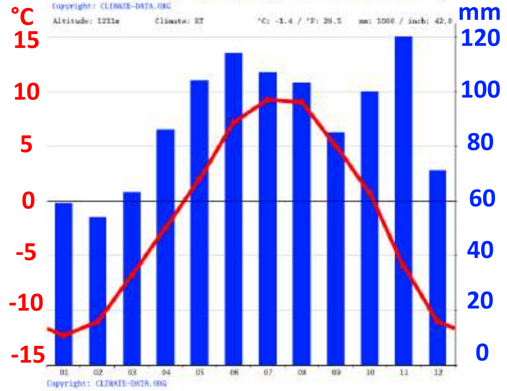


Milan
Cfa - humid
subtropical climate

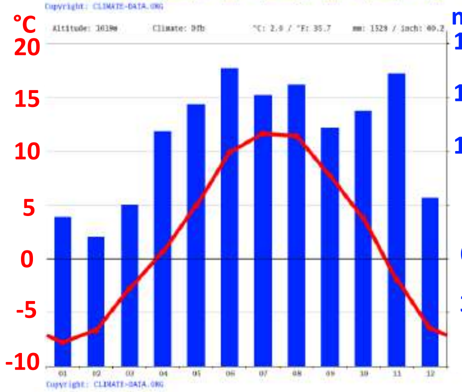


Como
Cfb - ocenaic
temperate climate





Bormio
Dfb - Severe winter
with no dry season
and warm summer



Madesimo
Dfc - Sub-Arctic
climate

Total area: 23864 km^2
Elevation: 6 – 3786 m a.s.l.

Mean temperature: 17°C/y
Mean precipitation: 947 mm/y

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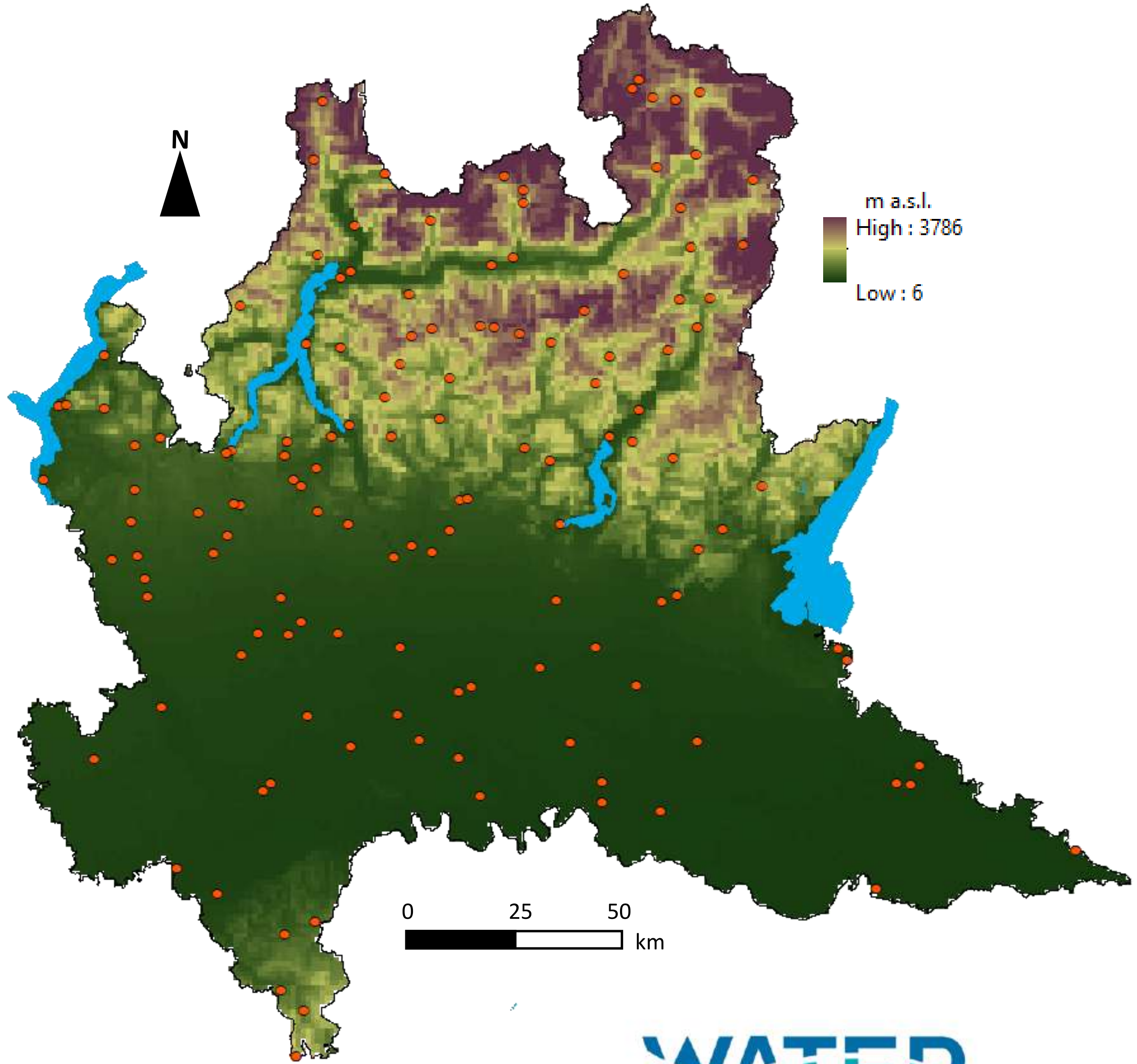
Weather stations

137 weather stations over the 10-year period **2011-2020** obtained from the **ARPA Lombardia** regional website.

Both **mean annual temperature** (°C) and **annual cumulative precipitation** (mm) for each weather station were considered.

LOMBARDIA
Agenzia Regionale per la Protezione dell'Ambiente



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Combiprecip

The CombiPrecip (CPC) product provides information on **hourly precipitation** levels at ground level (**1 km x 1 km resolution**). Using a geostatistical method, radar estimates are **combined with** data from **Swiss rain-gauges**. The CombiPrecip products cover the entire area monitored by the Swiss weather radar network, which includes Switzerland and its neighboring regions.

MeteoSwiss

Comparing the values in the cells where the 137 available stations are located, the radar underestimates the values by about 21% → **The radar needs to be corrected for a hydrological application**

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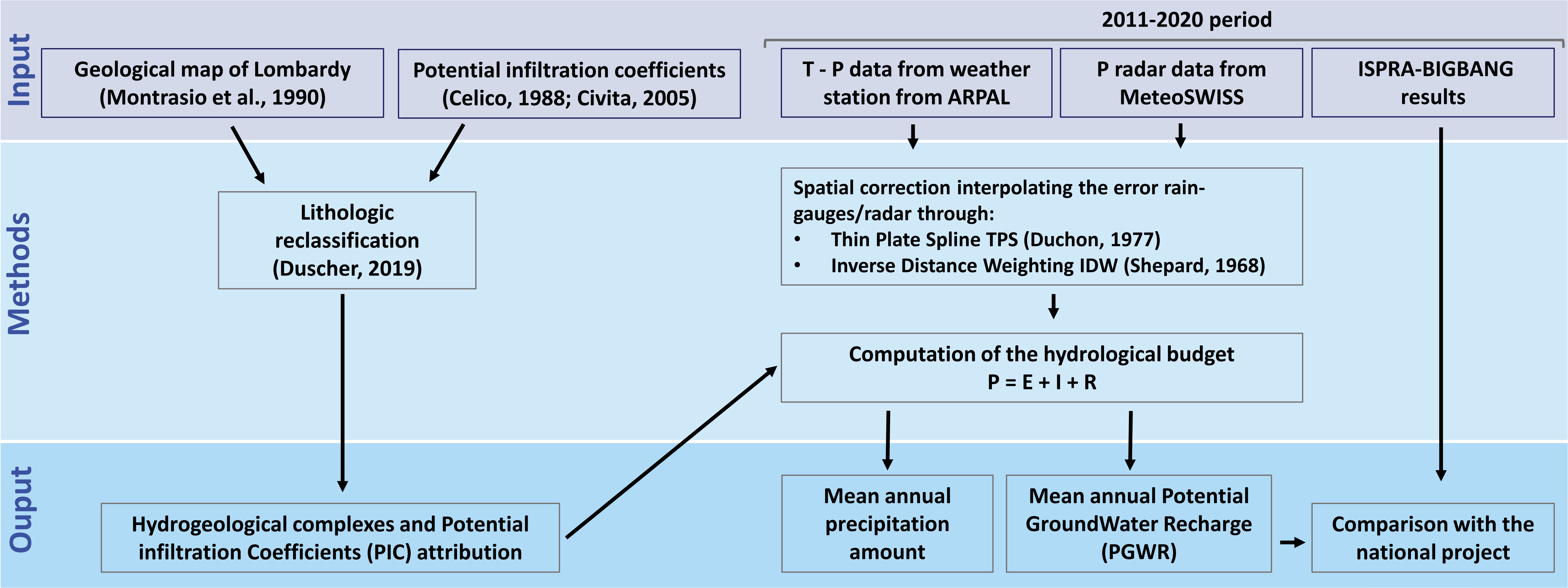
Monte Lema – 1626 m a.s.l.

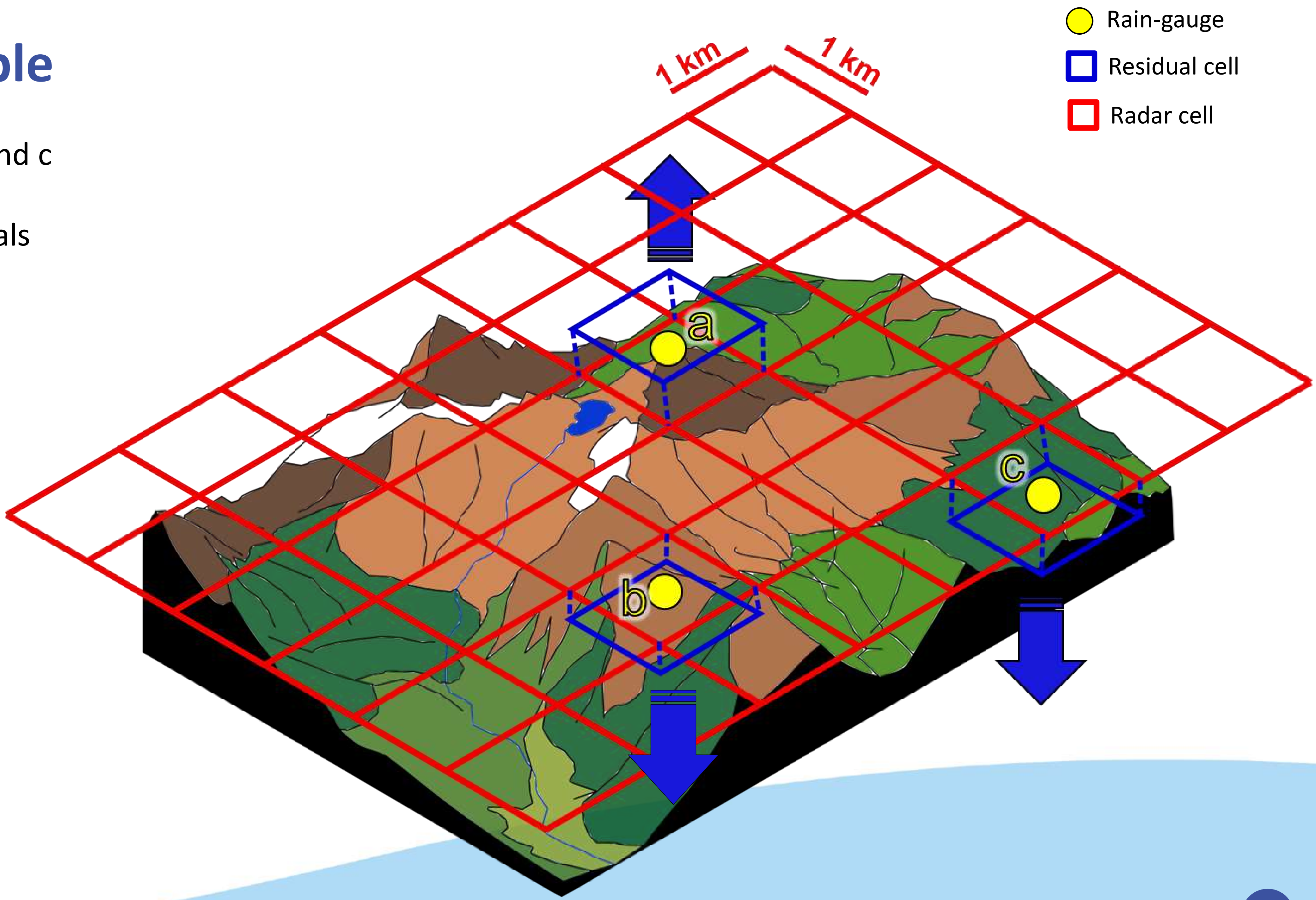
Credit: MeteoSwiss

Methods


Input
Methods
Ouput
2011-2020 period
Geological map of Lombardy (Montrasio et al., 1990)
Potential infiltration coefficients (Celico, 1988; Civita, 2005)
T - P data from weather station from ARPAL
P radar data from MeteoSWISS
ISPRA-BIGBANG results
Lithologic reclassification (Duscher, 2019)
Spatial correction interpolating the error rain-gauges/radar through:
• Thin Plate Spline TPS (Duchon, 1977)
• Inverse Distance Weighting IDW (Shepard, 1968)
Computation of the hydrological budget
P = E + I + R
Hydrogeological complexes and Potential infiltration Coefficients (PIC) attribution
Mean annual precipitation amount
Mean annual Potential GroundWater Recharge (PGWR)
Comparison with the national project

Methods - Example

- Three rain-gauges a, b, and c
- Gridded radar values
- Calculation of the residuals



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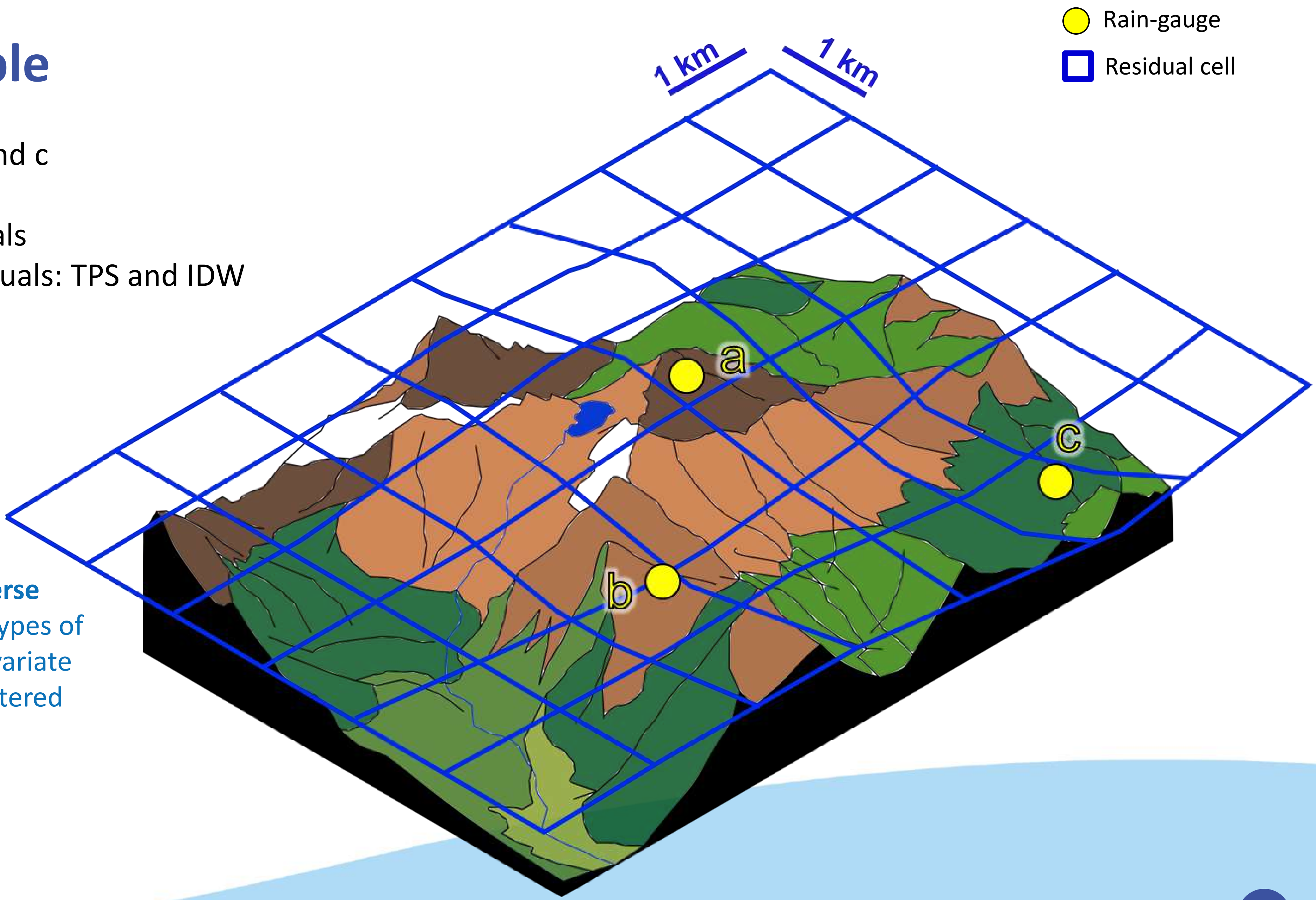
Methods - Example

- Three rain-gauges a, b, and c
- Gridded radar values
- Calculation of the residuals
- Interpolation of the residuals: TPS and IDW



Thin Plate Spline (TPS) and **Inverse Distance Weighting (IDW)** are types of deterministic method for multivariate interpolation with a known scattered set of points.

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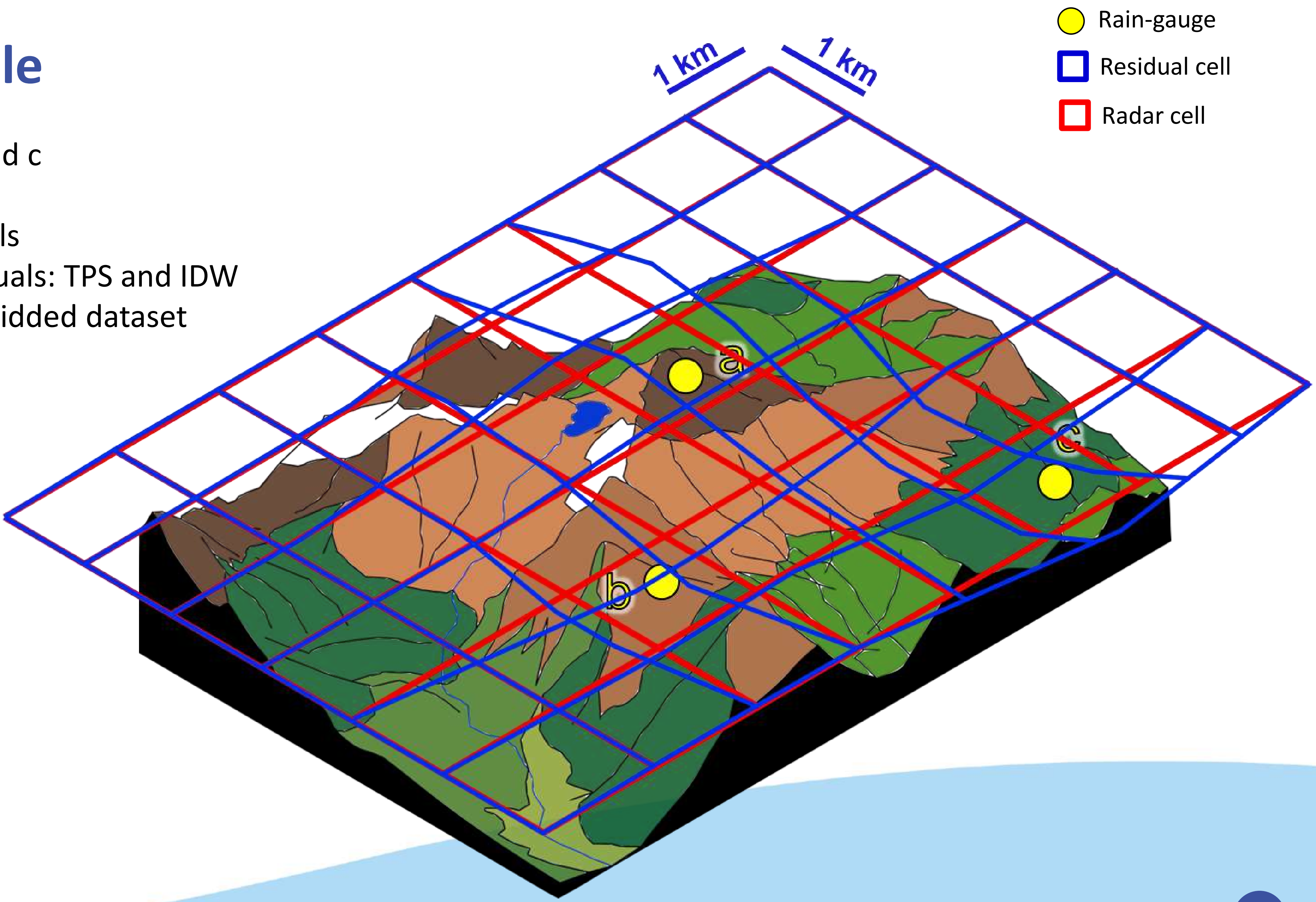
Methods - Example

- Three rain-gauges a, b, and c
- Gridded radar values
- Calculation of the residuals
- Interpolation of the residuals: TPS and IDW
- Aggregation of the two gridded dataset



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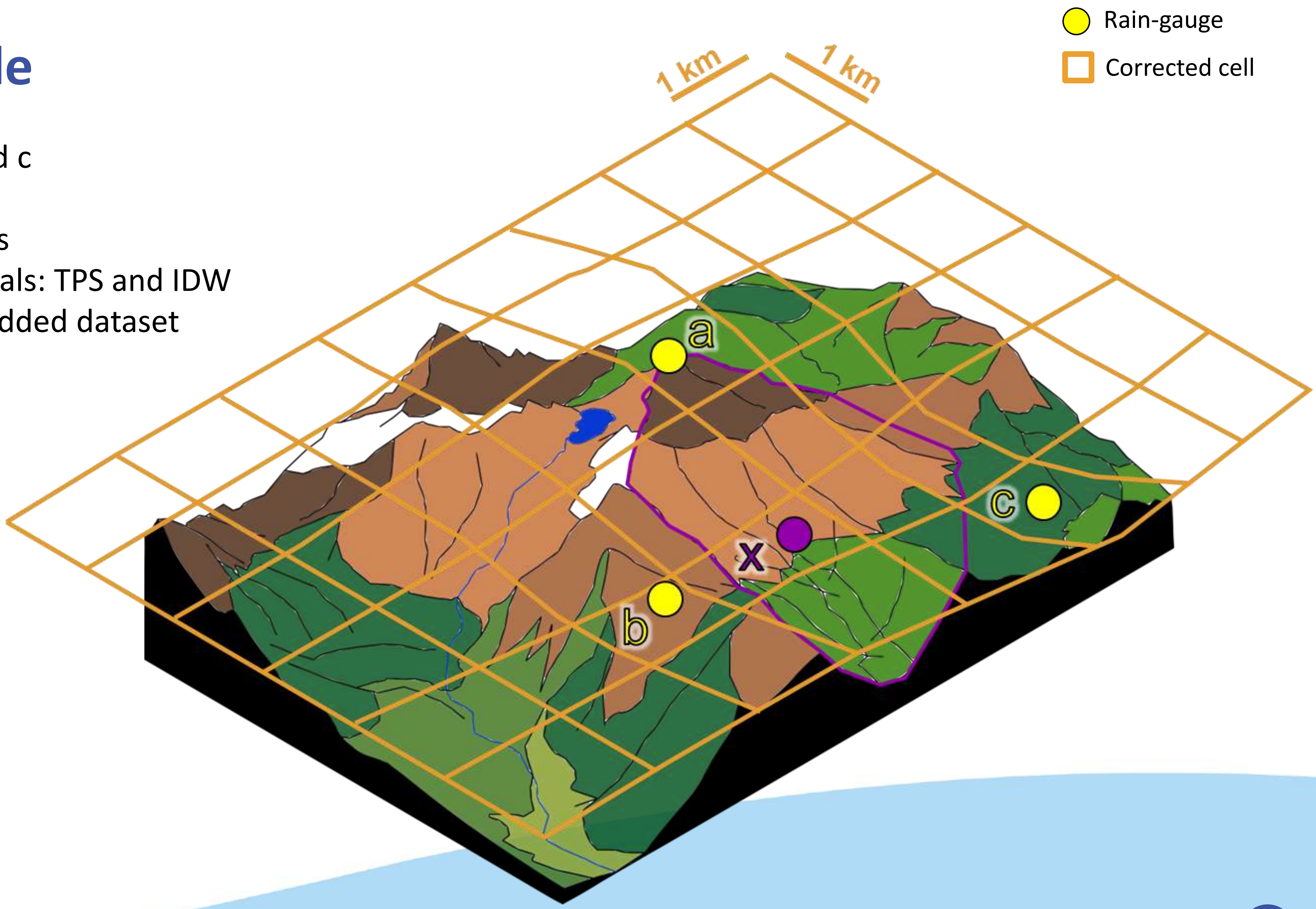
Methods - Example

- Three rain-gauges a, b, and c
- Gridded radar values
- Calculation of the residuals
- Interpolation of the residuals: TPS and IDW
- Aggregation of the two gridded dataset



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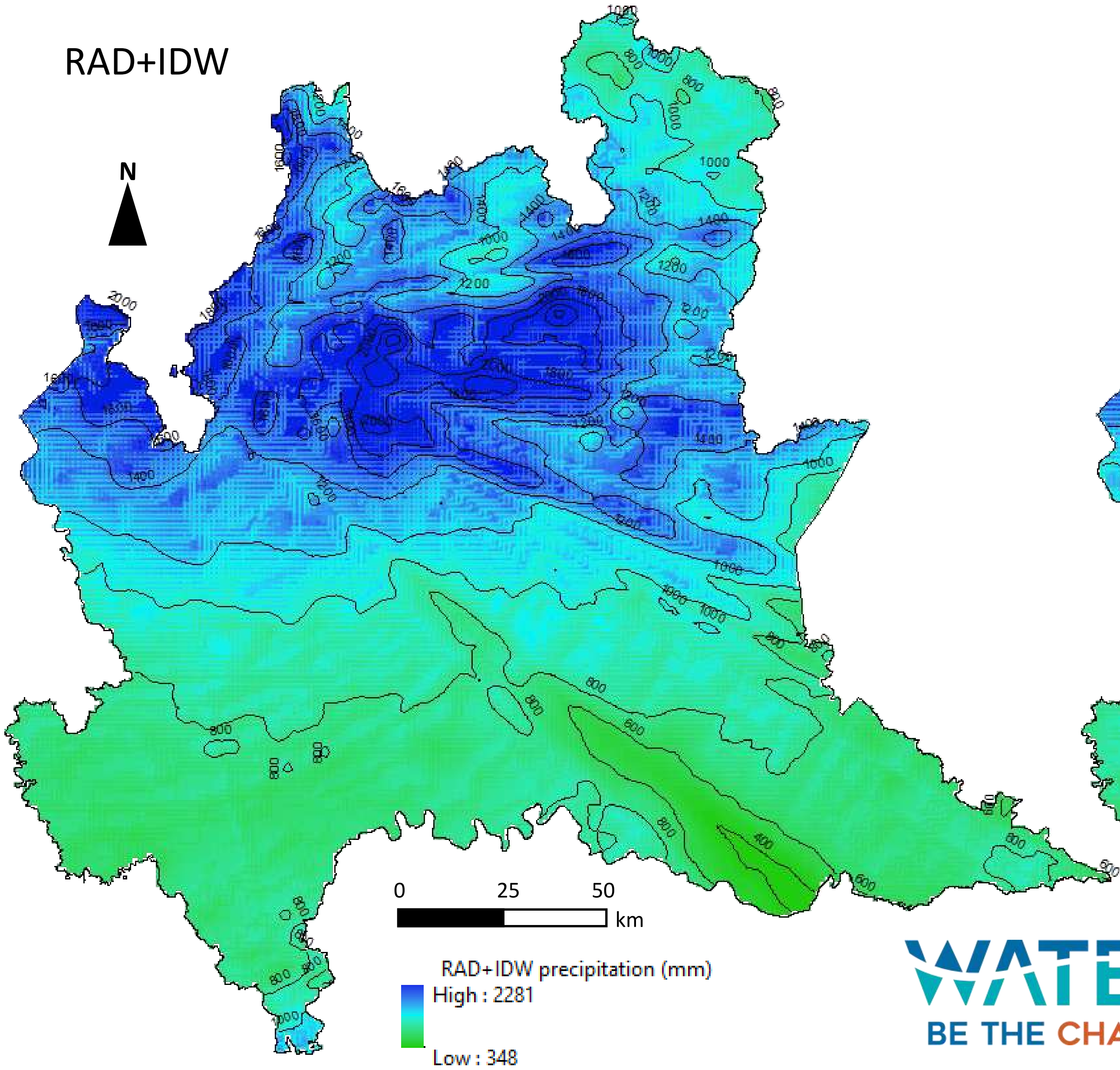
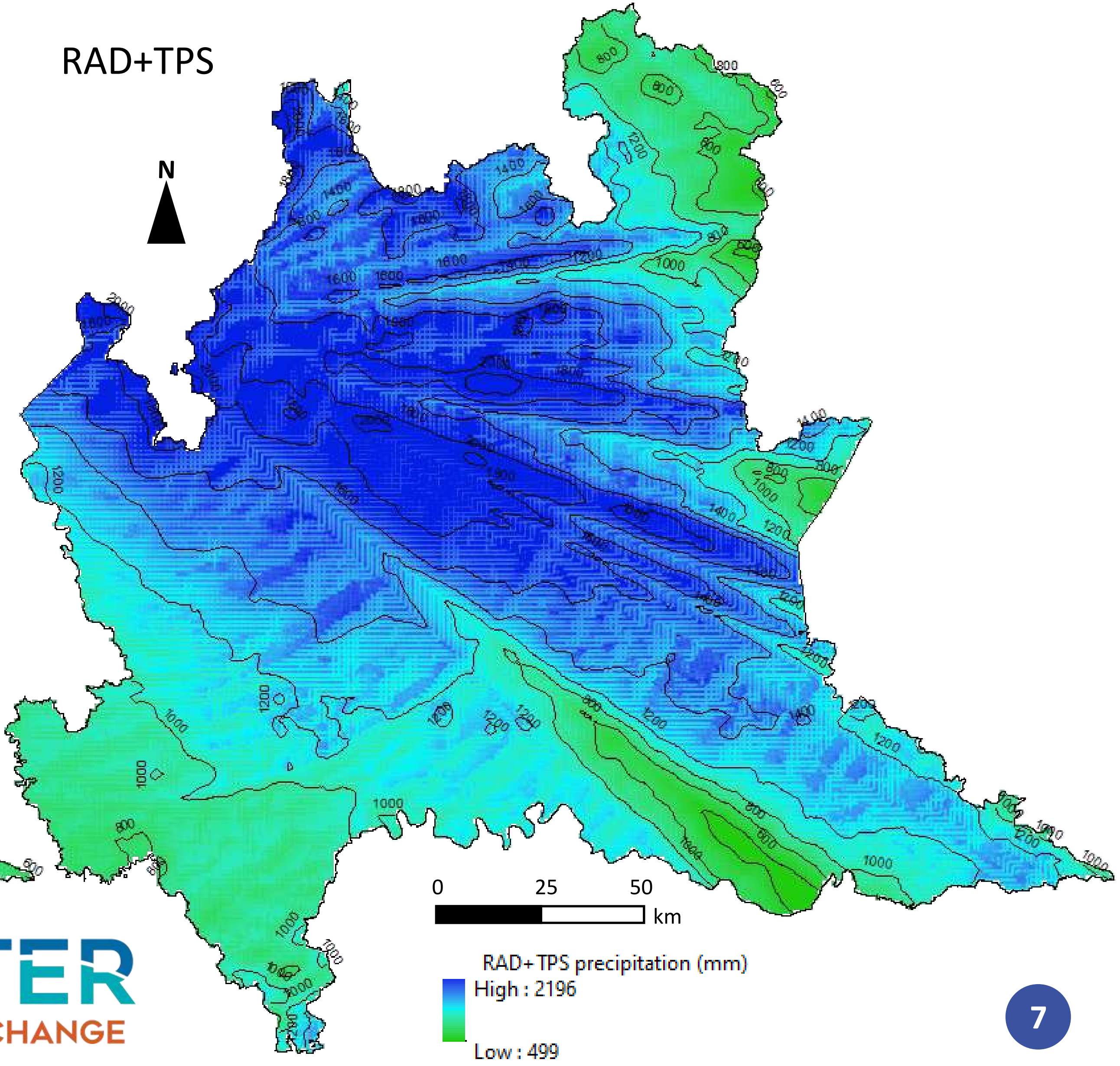
Results – Precipitation correction





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Results – Precipitation correction (LOO)

	RAD+IDW						RAD+TPS					
years	NSE_rad	NSE_sim	KGE_rad	KGE_sim	PBIAS_rad	PBIAS_sim	NSE_rad	NSE_sim	KGE_rad	KGE_sim	PBIAS_rad	PBIAS_sim
2011	-5.45	0.61	-0.08	0.75	-75.50	0.50	-5.45	0.29	-0.08	0.48	-75.50	0.10
2012	-0.08	0.70	0.48	0.81	-25.20	-0.40	-0.08	0.70	0.48	0.79	-25.20	0.10
2013	-0.45	0.54	0.45	0.72	-22.50	-0.50	-0.45	0.63	0.45	0.75	-22.50	0.20
2014	-0.24	0.70	0.53	0.82	-24.70	-0.60	-0.24	0.73	0.53	0.81	-24.70	0.20
2015	0.29	0.71	0.67	0.84	-16.50	-0.70	0.29	0.70	0.67	0.83	-16.50	0.20
2016	0.24	0.72	0.60	0.85	-15.80	0.00	0.24	0.72	0.60	0.80	-15.80	0.00
2017	0.52	0.81	0.67	0.90	-9.50	-0.70	0.52	0.82	0.67	0.88	-9.50	0.10
2018	0.20	0.62	0.51	0.79	-9.10	-0.60	0.20	0.69	0.51	0.81	-9.10	0.10
2019	0.31	0.59	0.62	0.79	-6.70	-0.60	0.31	0.71	0.62	0.82	-6.70	-0.10
2020	0.26	0.67	0.56	0.83	-8.40	-0.70	0.26	0.71	0.56	0.82	-8.40	0.10
Mean	-0.44	0.67	0.50	0.81	-21.39	-0.43	-0.44	0.67	0.50	0.78	-21.39	0.10

KGE index (Gupta et al., 2009) is an expression of the distance between the simulated point and the ideal model performance in the space

It varies $-\infty < KGE < 1$

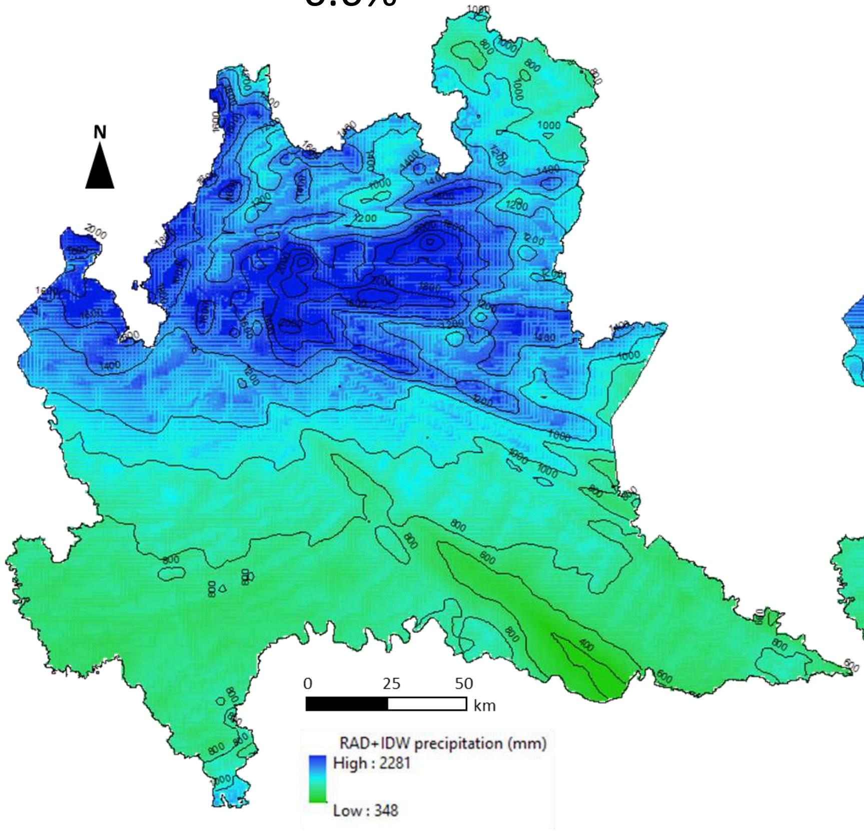
Towner et al. (2019)
Andersson et al. (2017)

KGE>0.75 → GOOD!
KGE<0.50 → BAD!

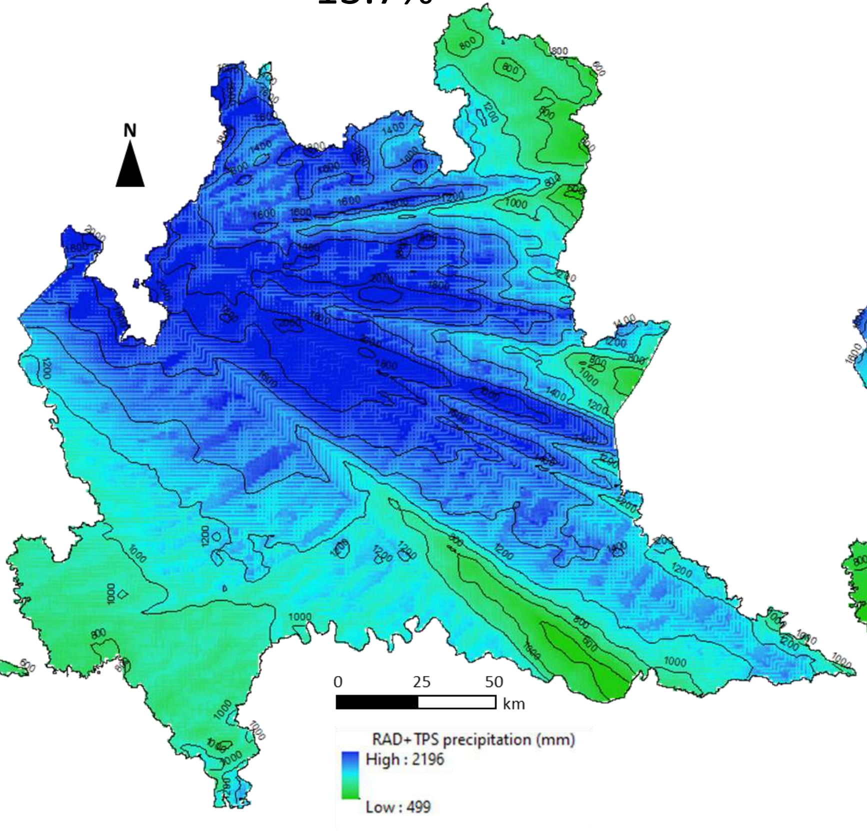
WATER BE THE CHANGE

Results – Precipitation correction

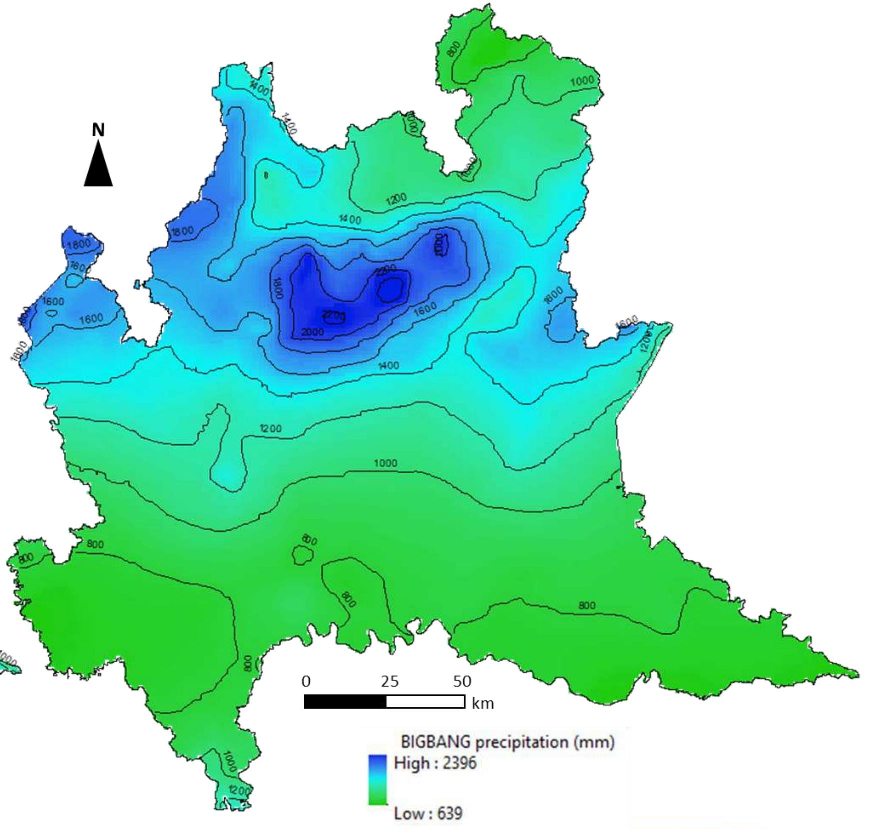
RAD+IDW 25.7 Bm^3 -6.6%



RAD+TPS 31.3 Bm^3 13.7%



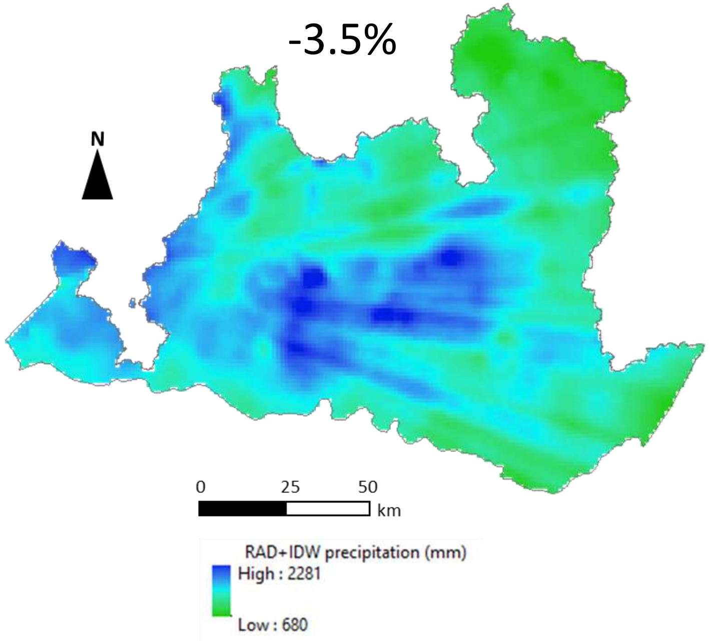
BIGBANG 27.5 Bm^3



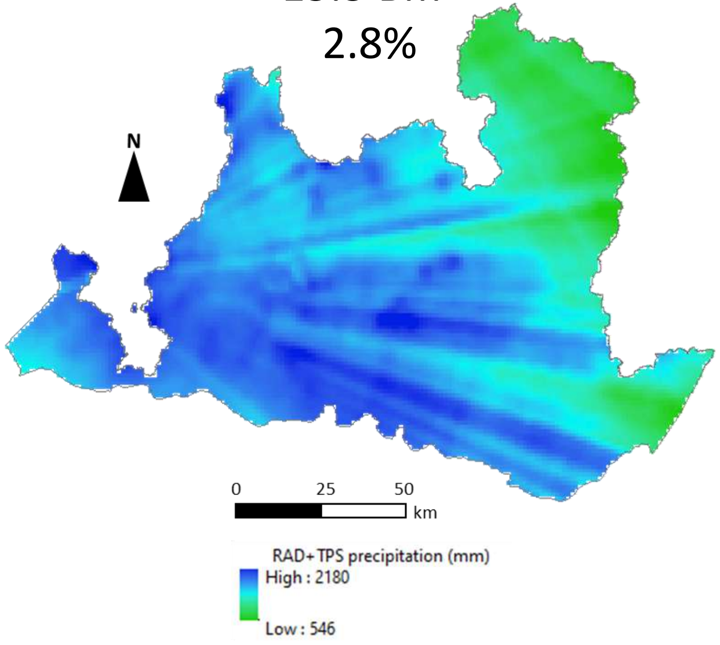
WATER BE THE CHANGE

Results – Precipitation correction

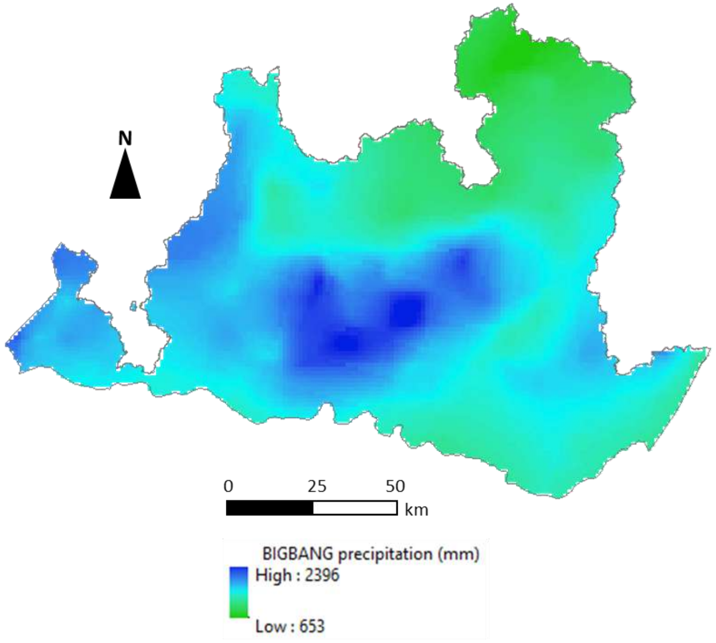
RAD+IDW 14.4 Bm^3
-3.5%



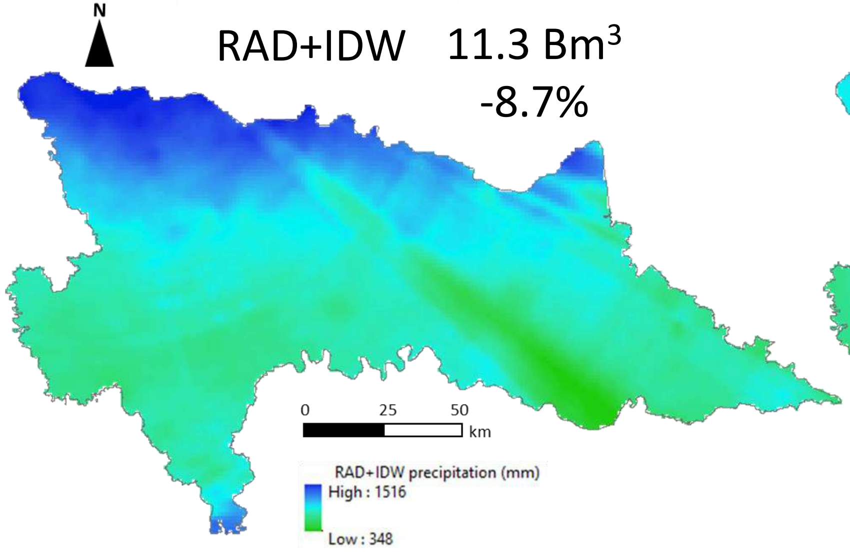
RAD+TPS 15.3 Bm^3
2.8%



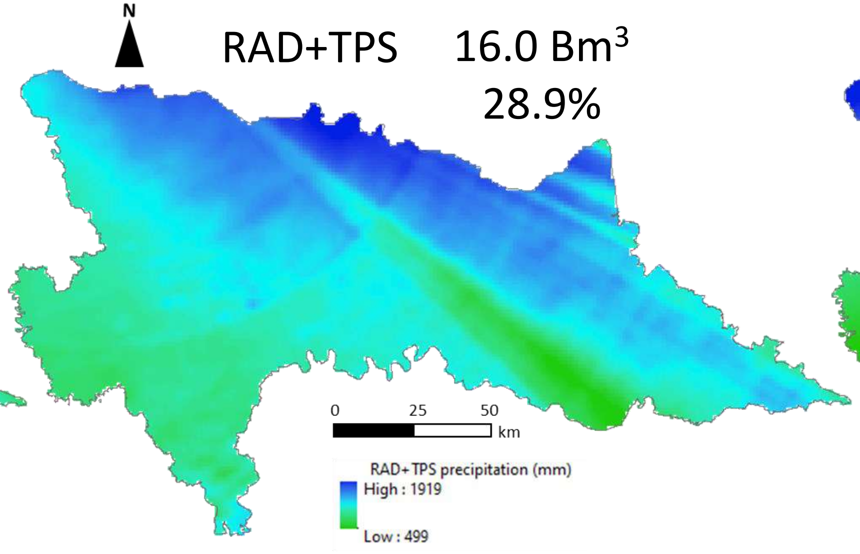
BIGBANG 14.9 Bm^3



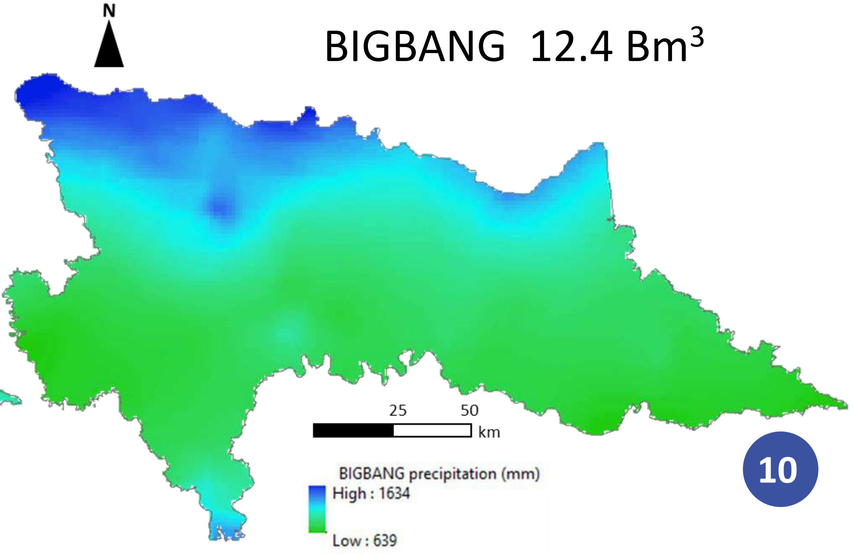
RAD+IDW 11.3 Bm^3
-8.7%



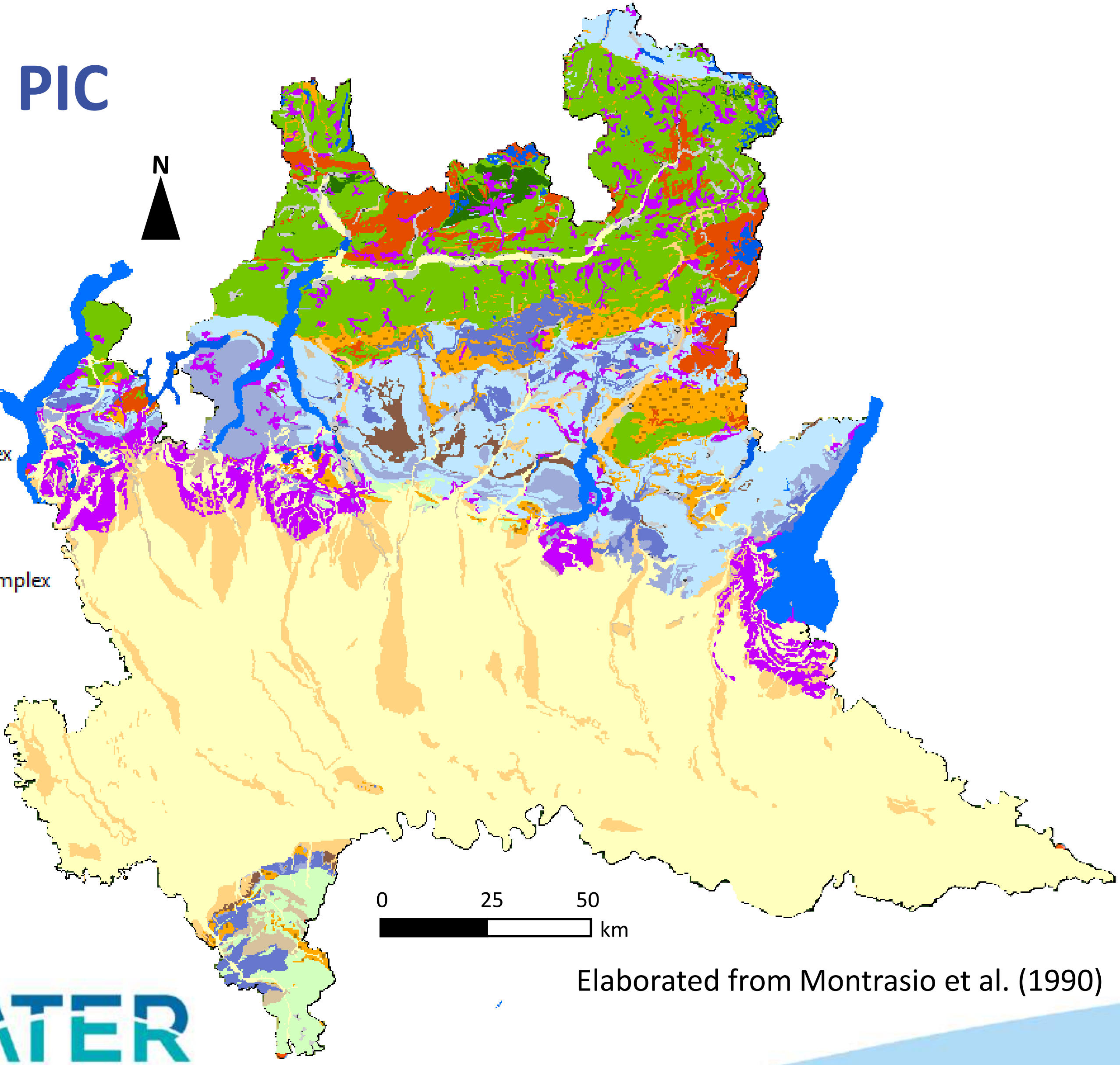
RAD+TPS 16.0 Bm^3
28.9%



BIGBANG 12.4 Bm^3



Results - PIC



Elaborated from Montrasio et al. (1990)

$$P = E + I + R$$

↓

$$E = \frac{P}{\sqrt{0{,}9 + \frac{P^2}{L^2}}}$$

Turc (1954)

$$L = 300 + 25 * T + 0{,}05 * T^3$$

Hydrological complexes

↓ ↓

$$ActualP = P - E$$

$$PIC\ (0 \div 1)$$

↓ ↓

PGWR= $ActualP \times PIC$

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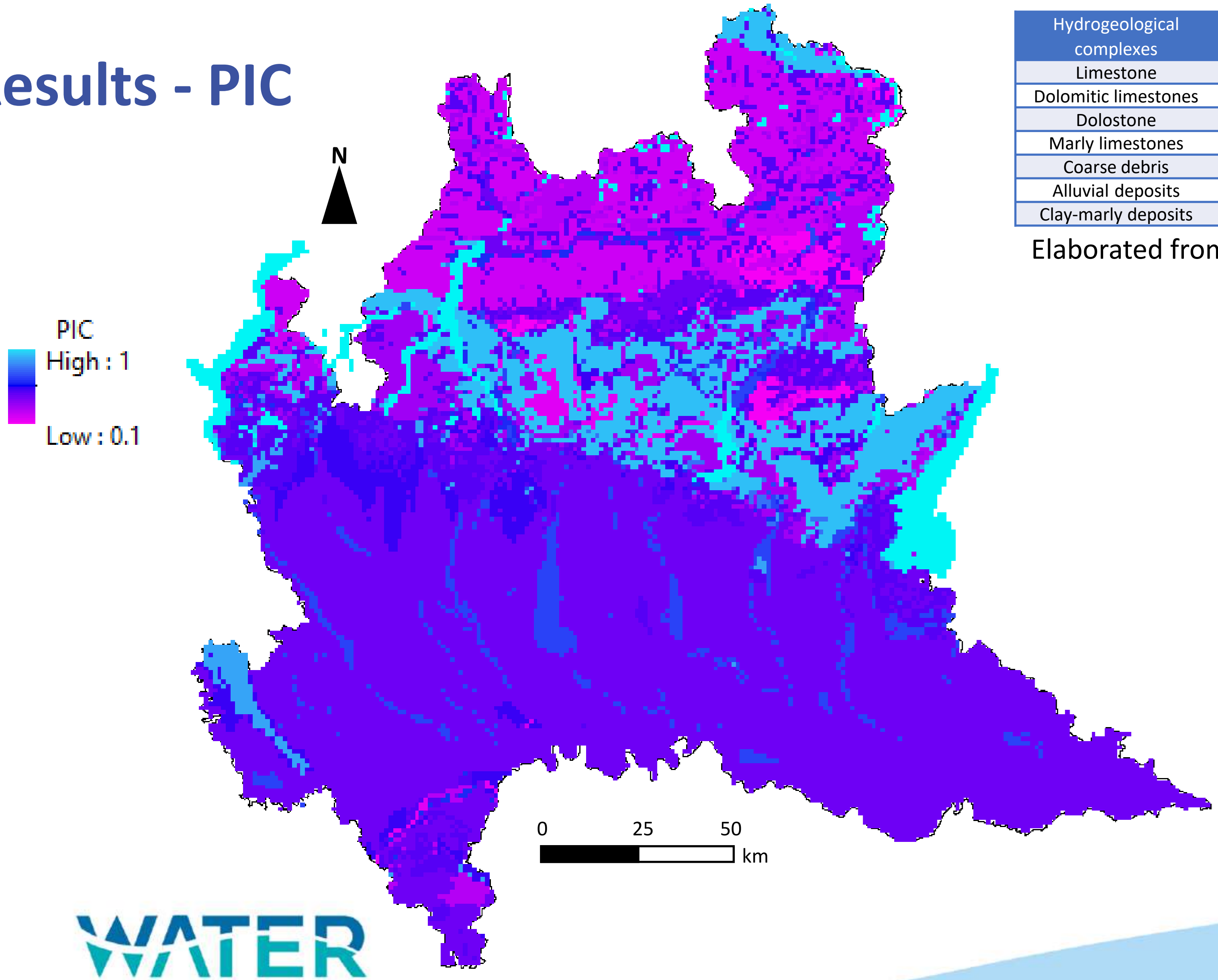
Results - PIC



Hydrogeological complexes	PIC	Suggested value	Hydrogeological complexes	PIC	Suggested value
Limestone	0.90-1.00	0.90	Volcanic deposits	0.90-1.00	0.95
Dolomitic limestones	0.70-0.90	0.80	Pyroclastic deposits	0.50-0.70	0.60
Dolostone	0.50-0.70	0.60	Pyro-volcanic deposits	0.70-0.90	0.80
Marly limestones	0.30-0.50	0.40	Intrusive rocks	0.15-0.35	0.25
Coarse debris	0.80-0.90	0.85	Metamorphic rocks	0.05-0.20	0.15
Alluvial deposits	0.80-1.00	0.90	Sands	0.80-0.90	0.85
Clay-marly deposits	0.05-0.25	0.15	Loamy sands	0.30-0.50	0.40

Elaborated from Celico (1988)

Hydrogeological complexes	PIC	Suggested value
Coarse alluvium	0.65-1.00	0.90
Sands	0.90-1.00	0.95
Sandy formations	0.75-0.90	0.80
Medium to fine alluvium	0.15-0.45	0.30
Clays. silts.	0.00-0.25	0.15
Coarse moraines	0.50-0.70	0.55
Fine moraines	0.15-0.25	0.20
Marls. Argillites	0.10-0.20	0.15
Marly limestone flysch	0.20-0.50	0.35
Marly arenaceous flysch	0.20-0.45	0.25
Sandstones. Conglomerates	0.30-0.50	0.40
Karst limestone	0.75-1.00	0.95
Fissured limestones	0.50-0.85	0.75
Marbles	0.90-1.00	0.95
Fissured dolostones	0.45-0.70	0.60
Acidic fissured volcanites	0.30-0.70	0.50
Basic fissured volcanites	0.75-1.00	0.85
Fine pyroclastites	0.15-0.25	0.20
Fissured plutonites	0.05-0.35	0.25
Phyllites	0.05-0.30	0.10
Gneiss	0.15-0.35	0.25

Elaborated from Civita (2005)

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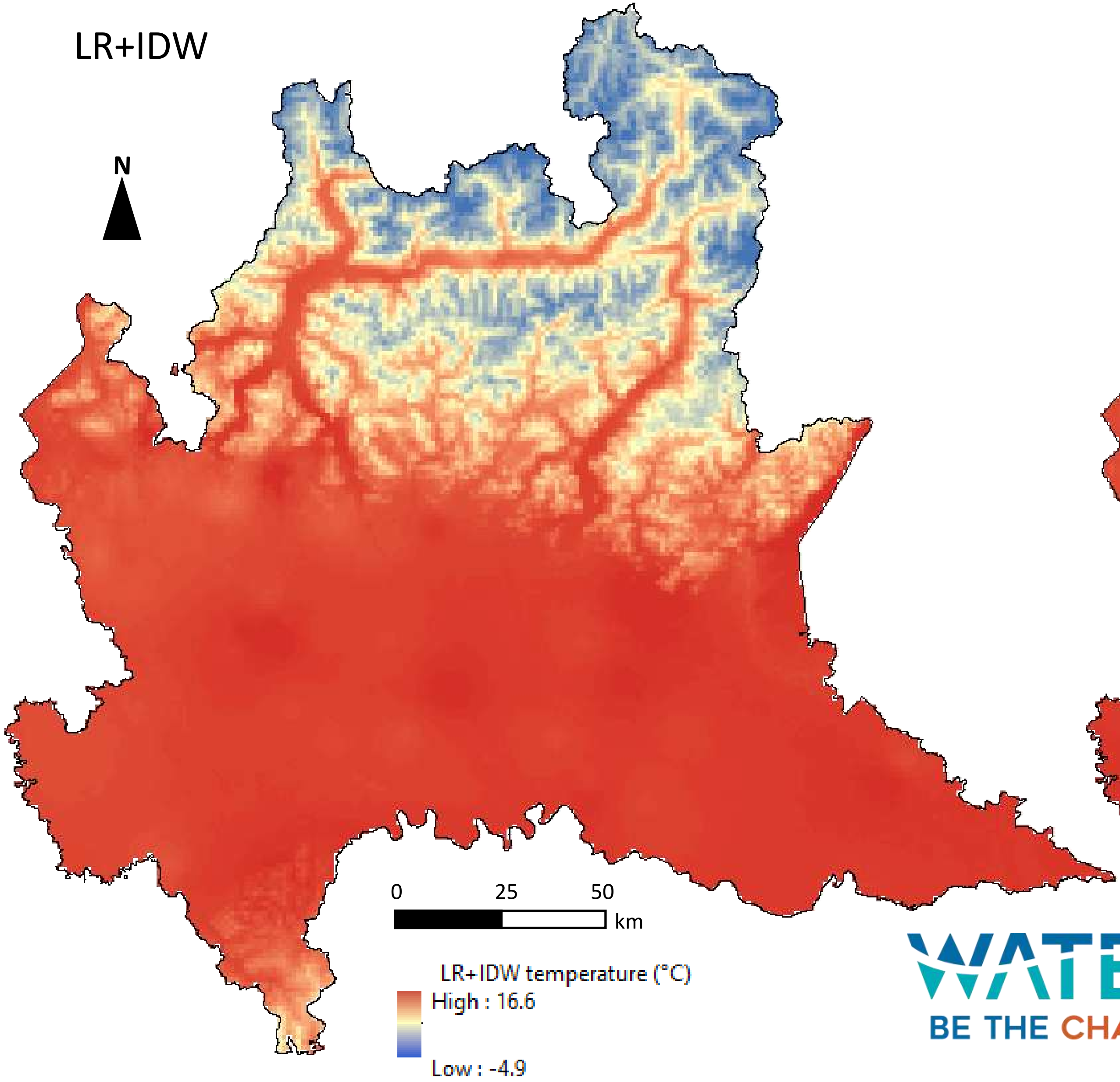
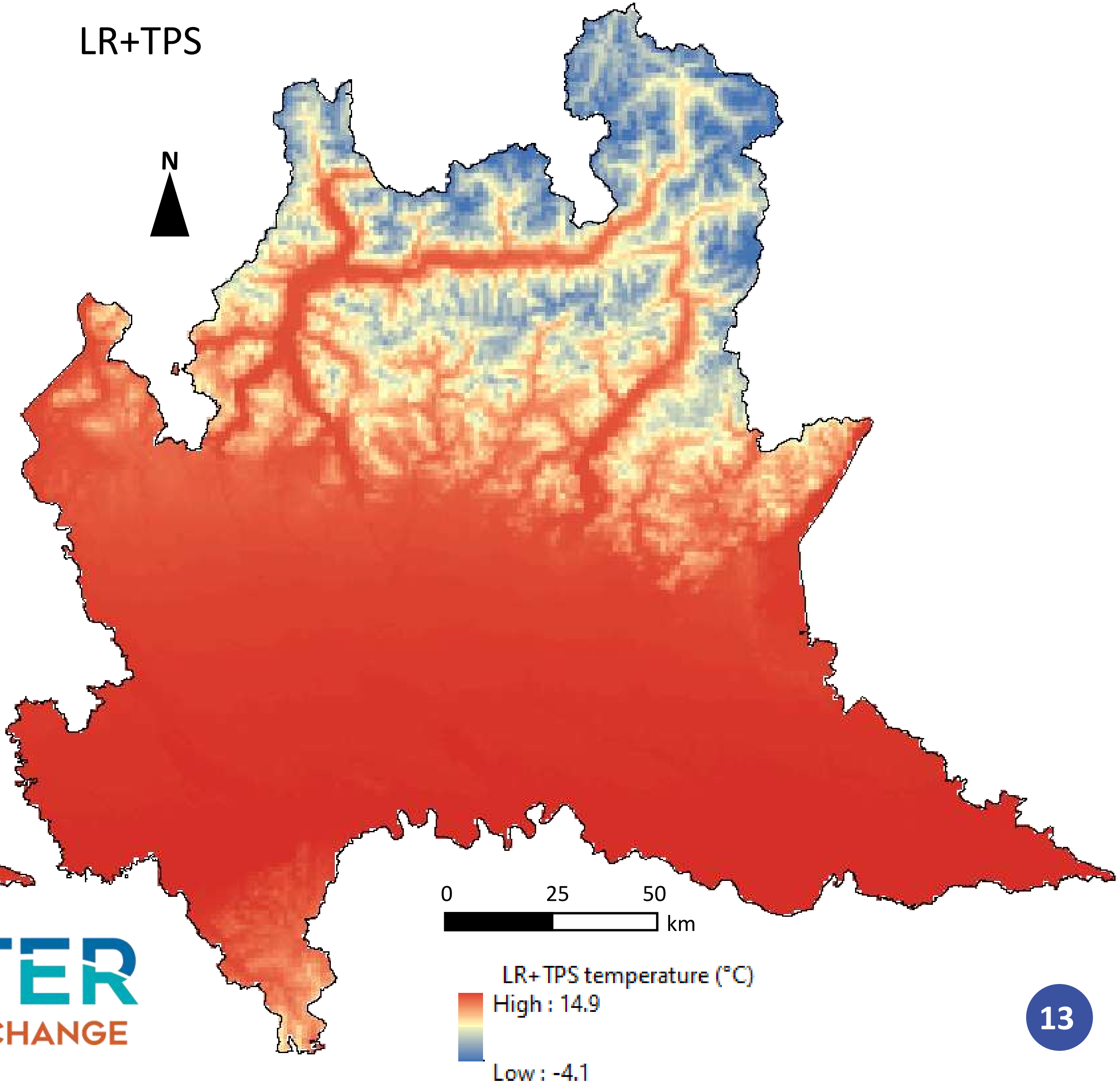
Results - Temperatures

LR+IDW



LR+TPS



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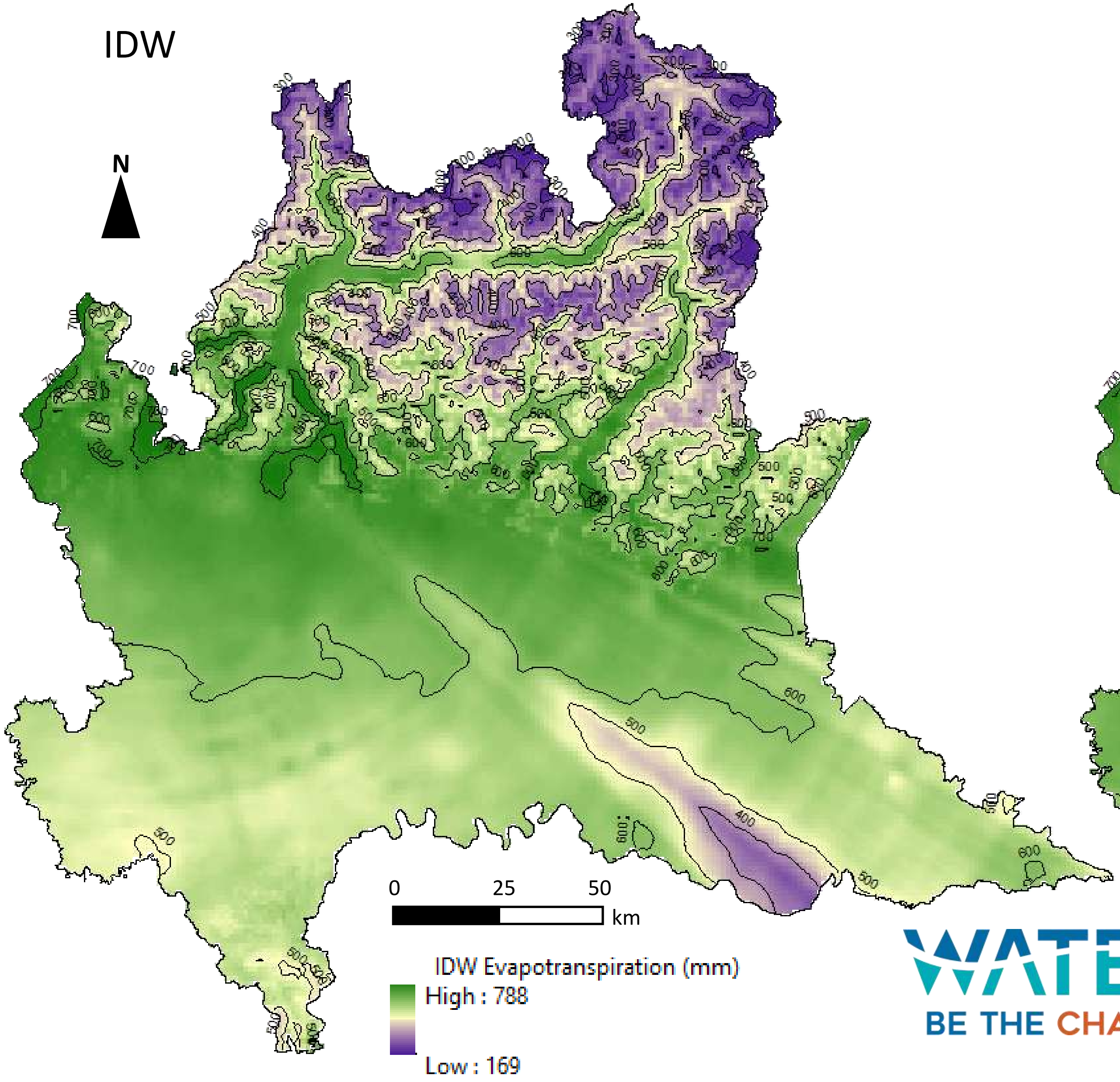
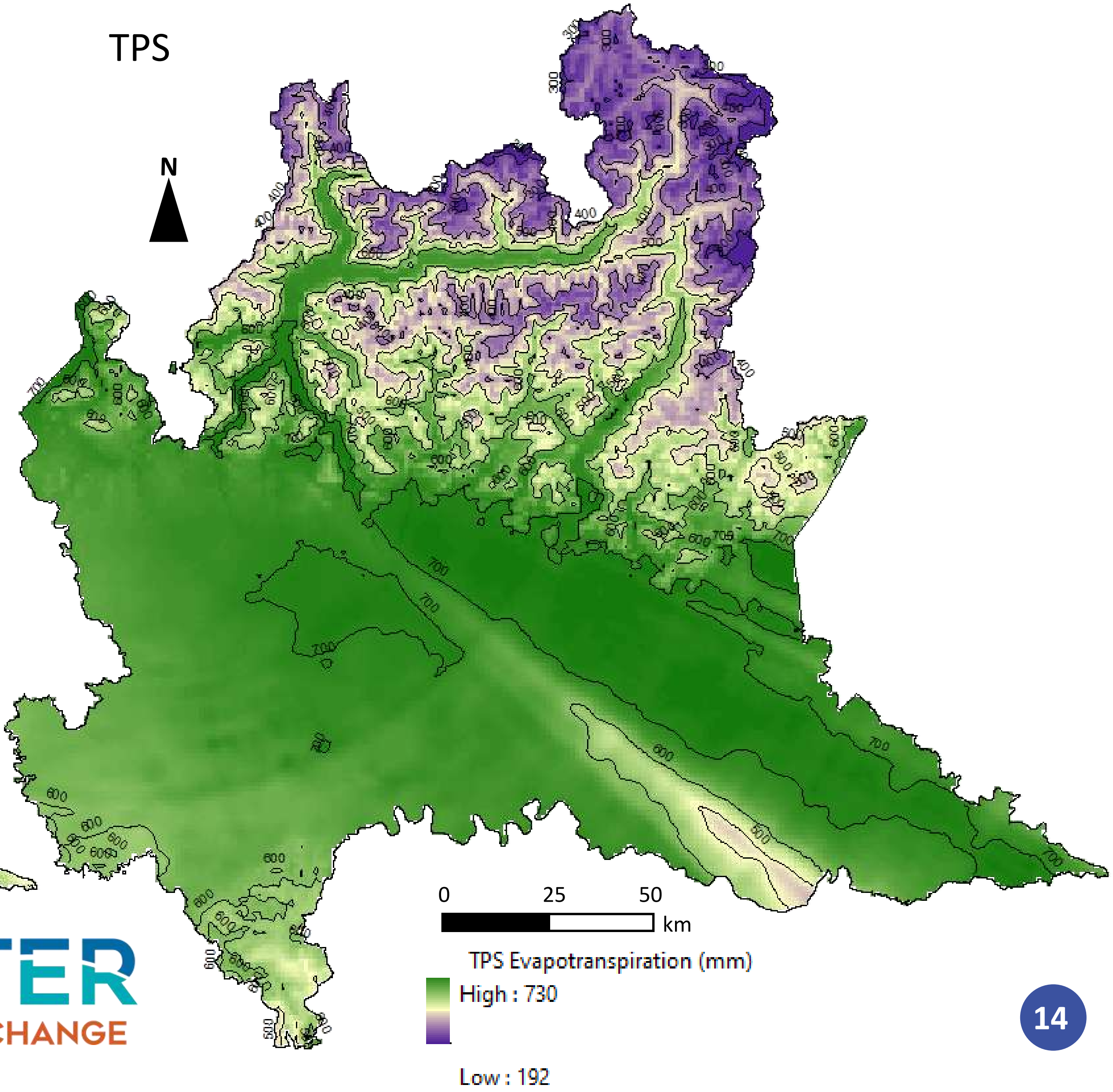
Results – Potential Evapotranspiration

IDW



TPS



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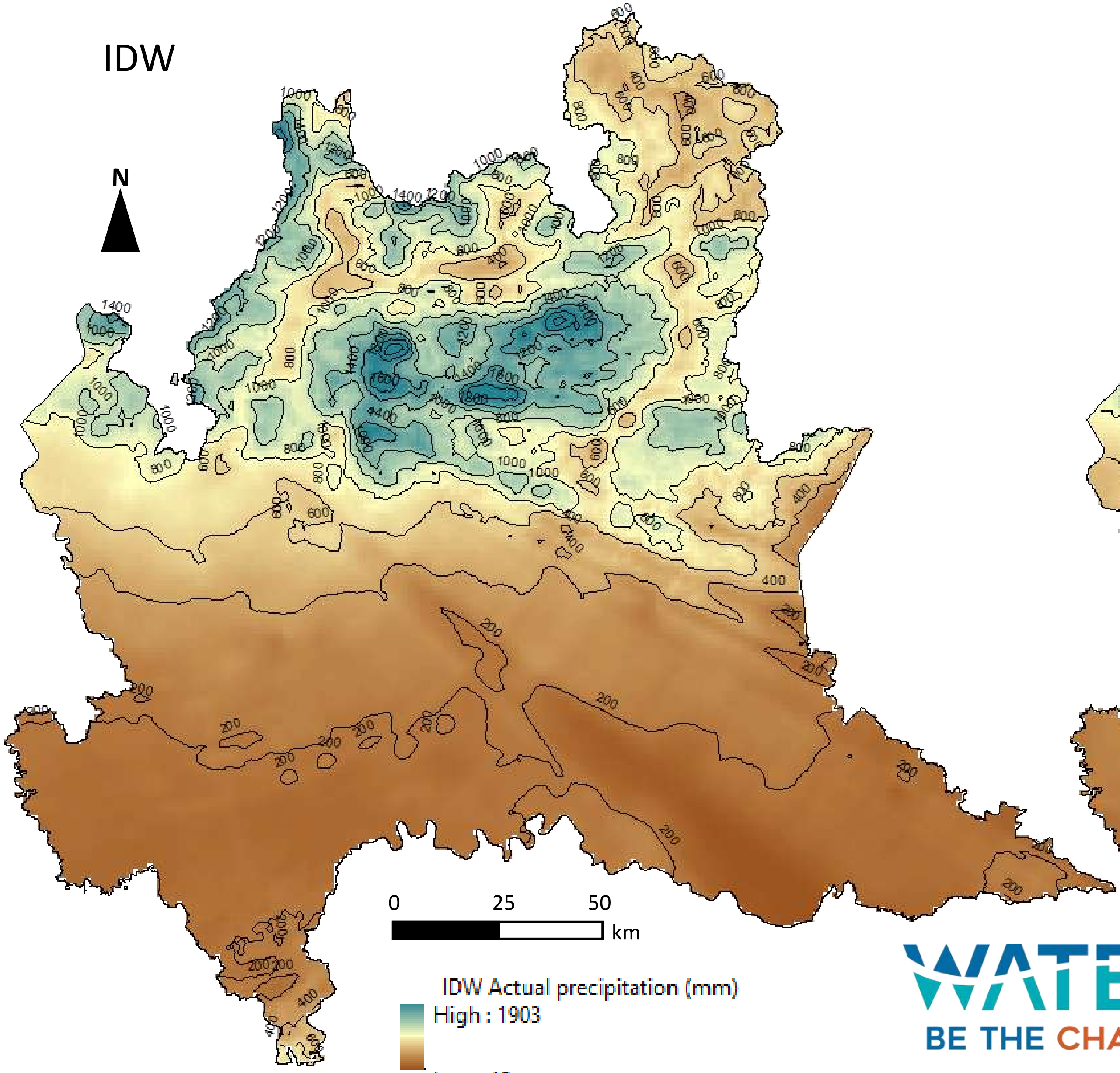
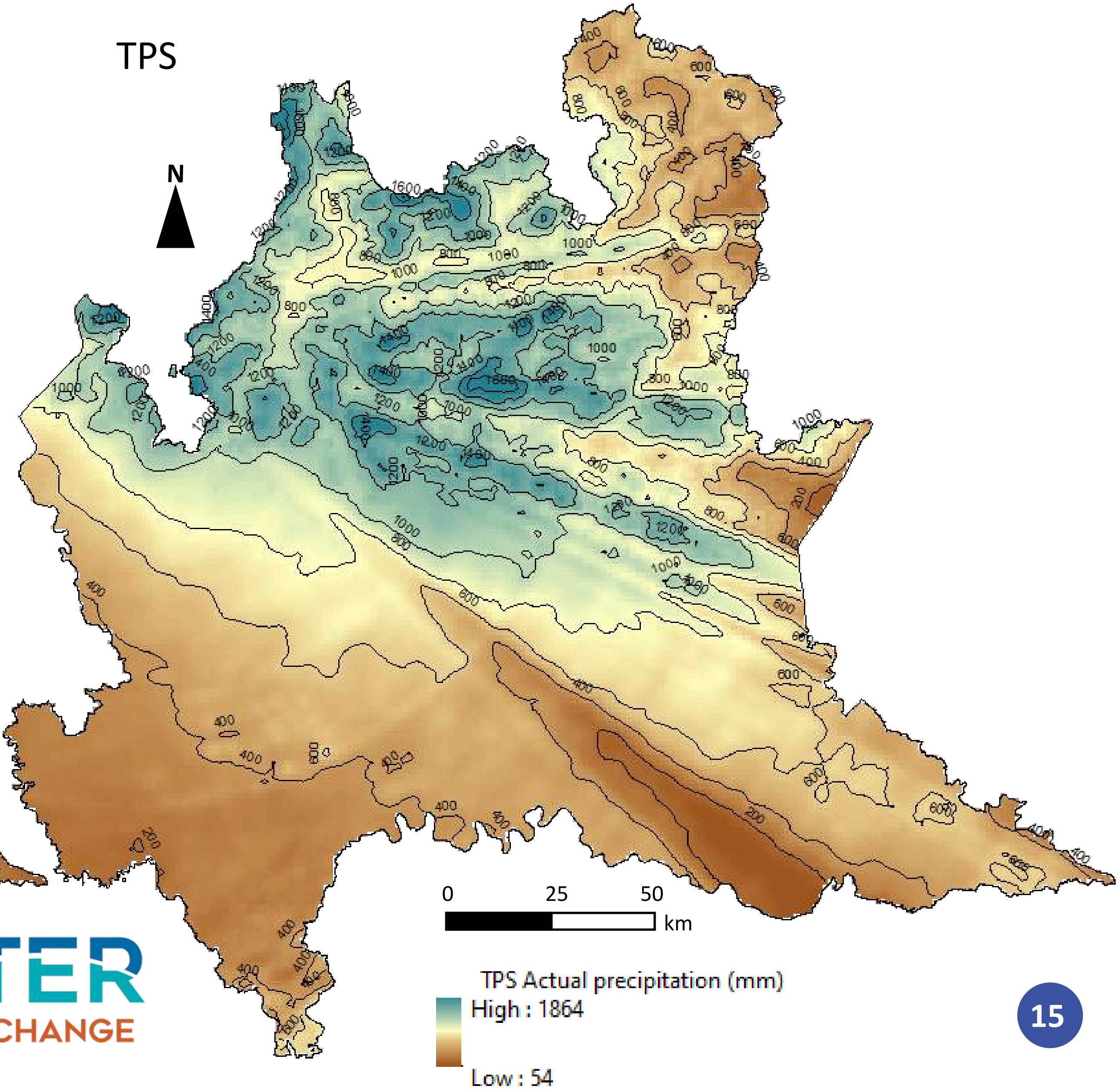
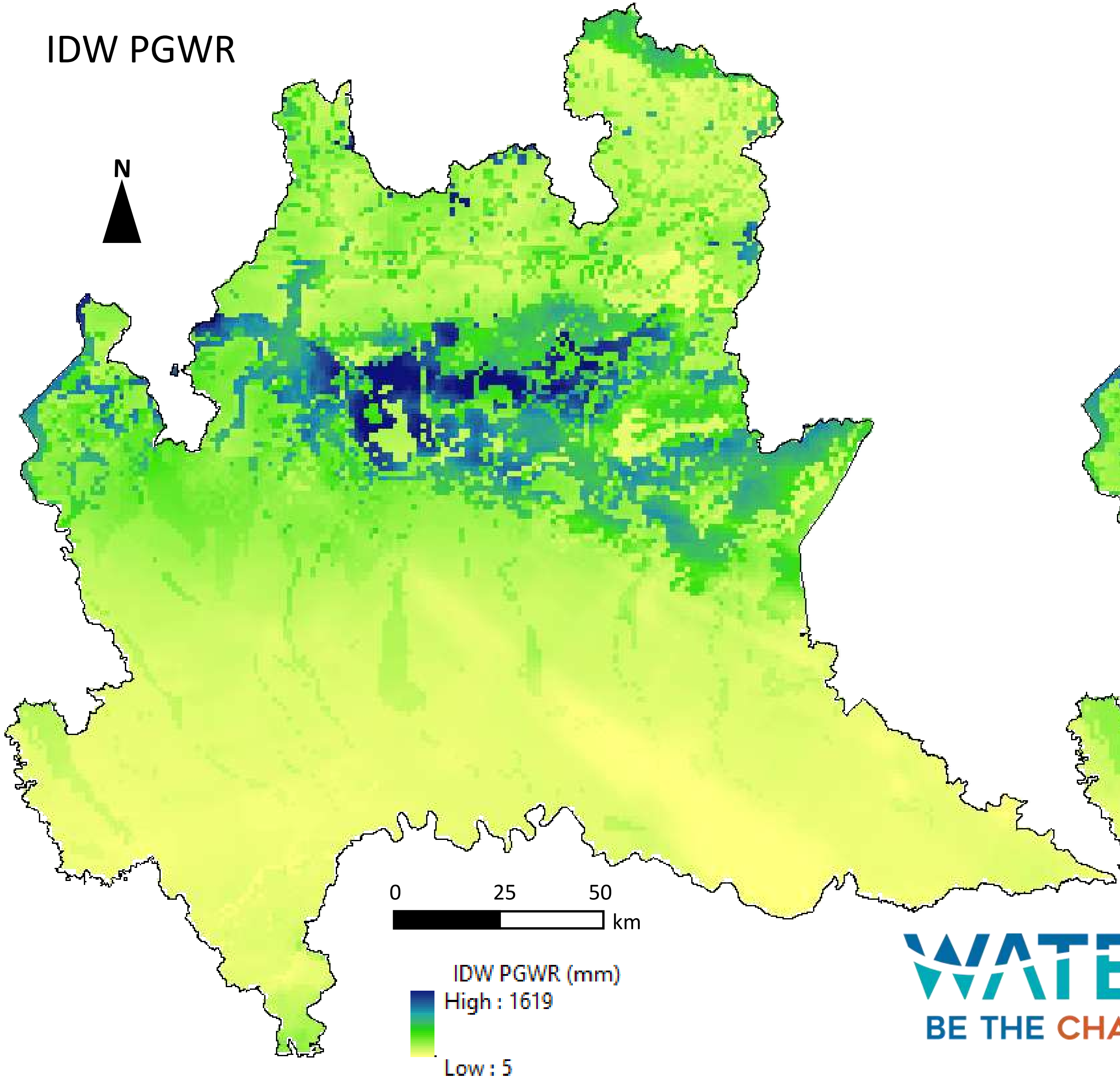
Results – Actual precipitation



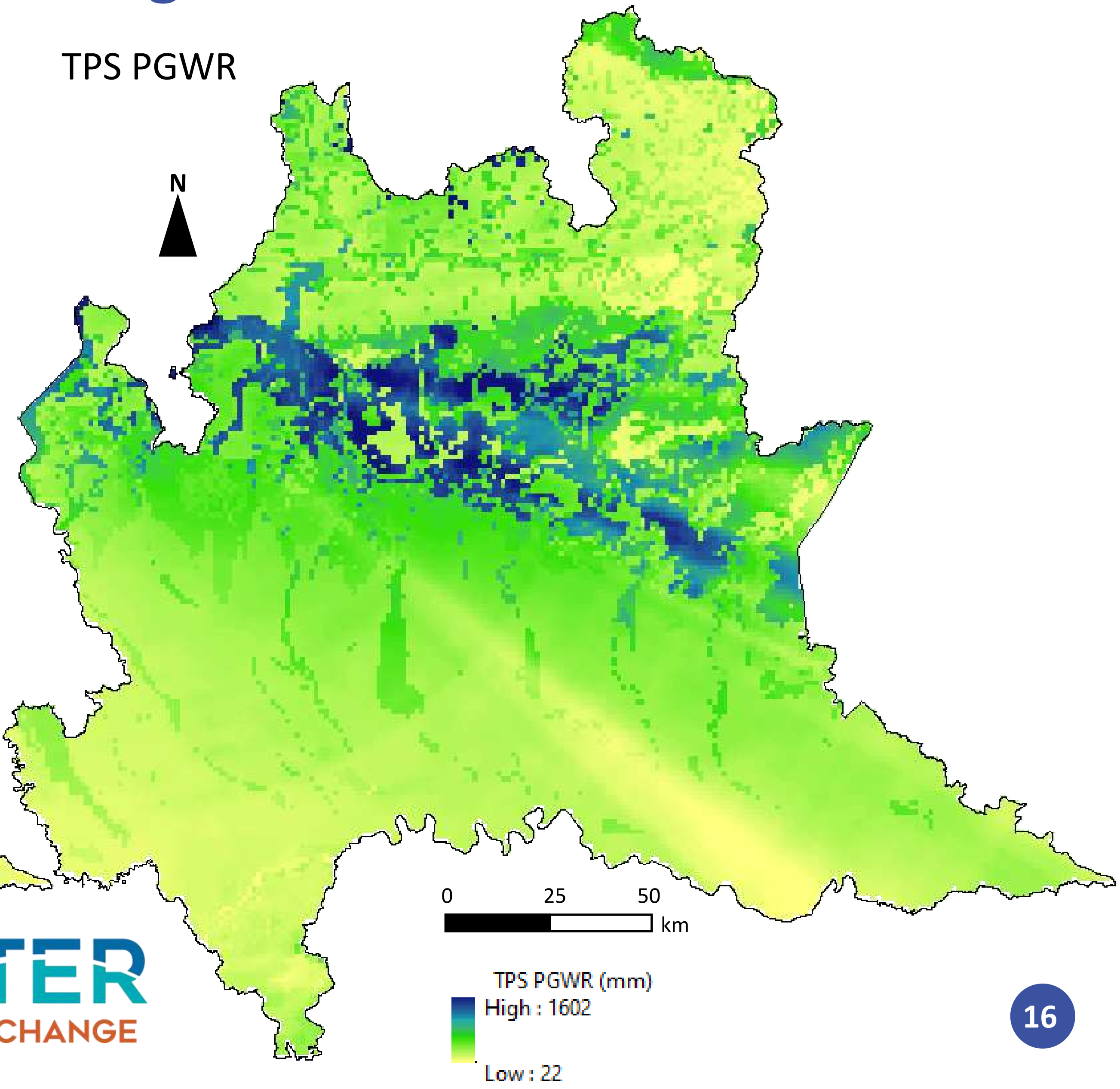


Results – Potential GroundWater Recharge PGWR

IDW PGWR



TPS PGWR



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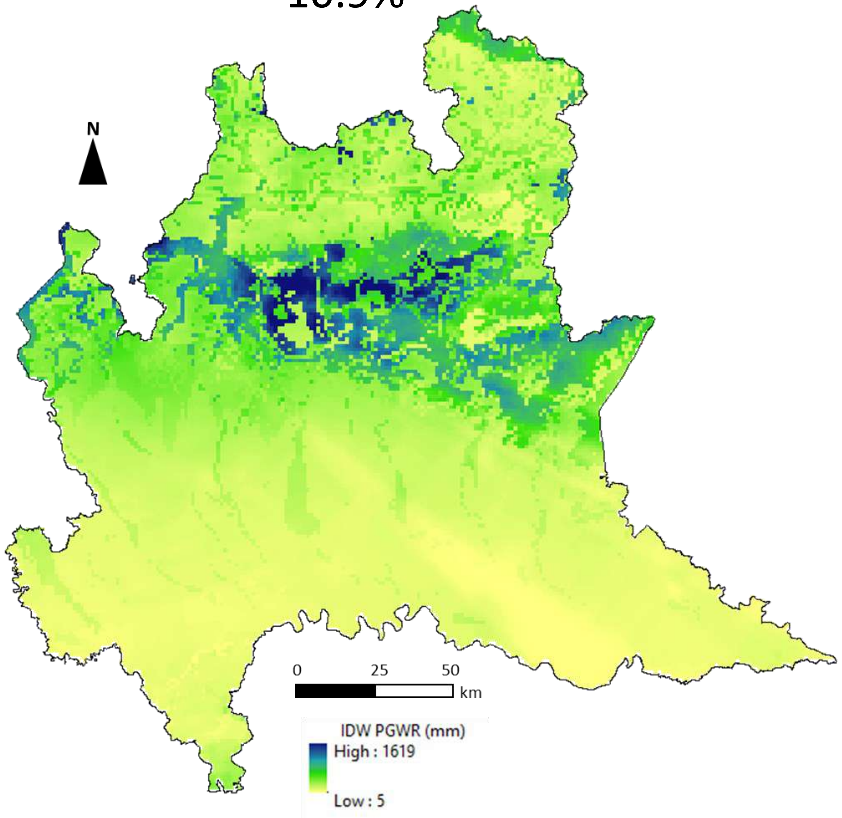
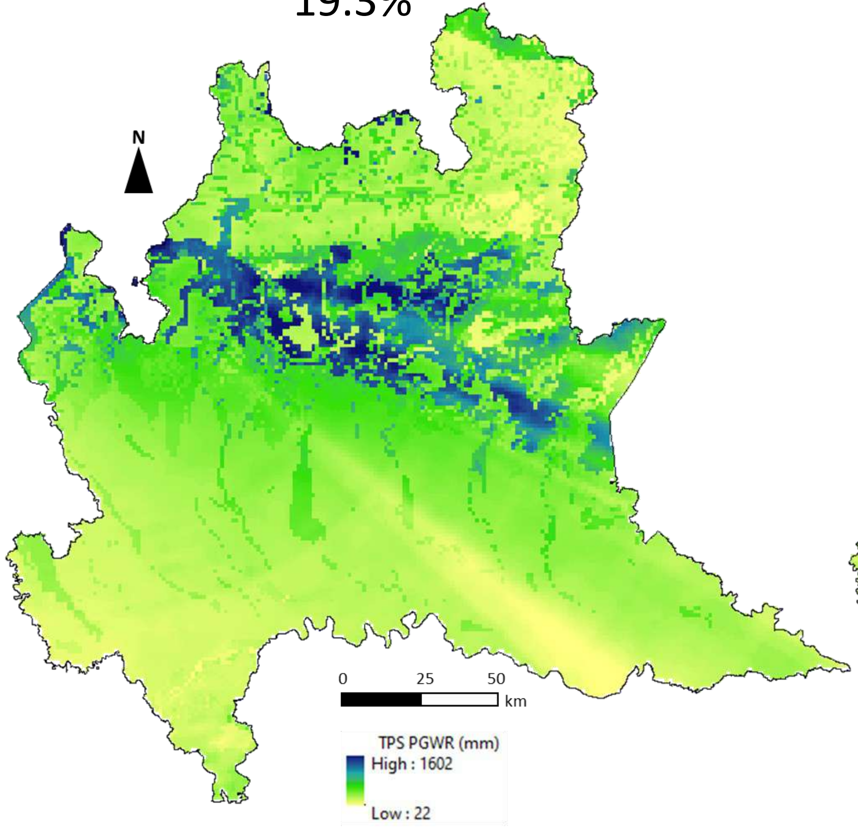
Results – Potential GroundWater Recharge PGWR

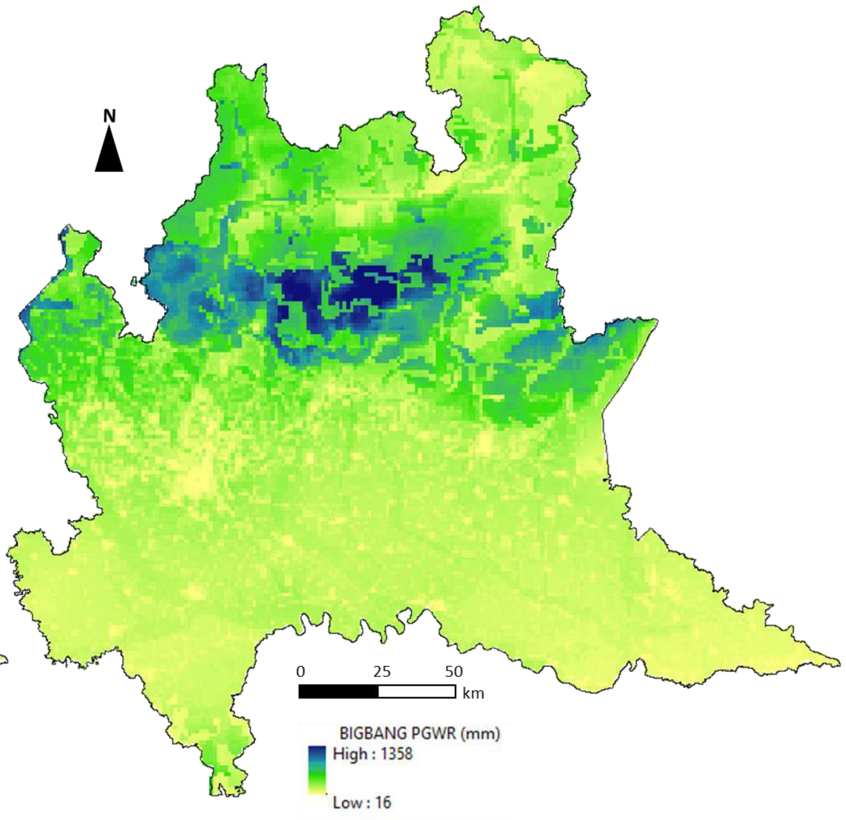
IDW PGWR 5.8 Bm^3
-10.9%



TPS PGWR 7.7 Bm^3
19.3%



BIGBANG PGWR 6.5 Bm^3



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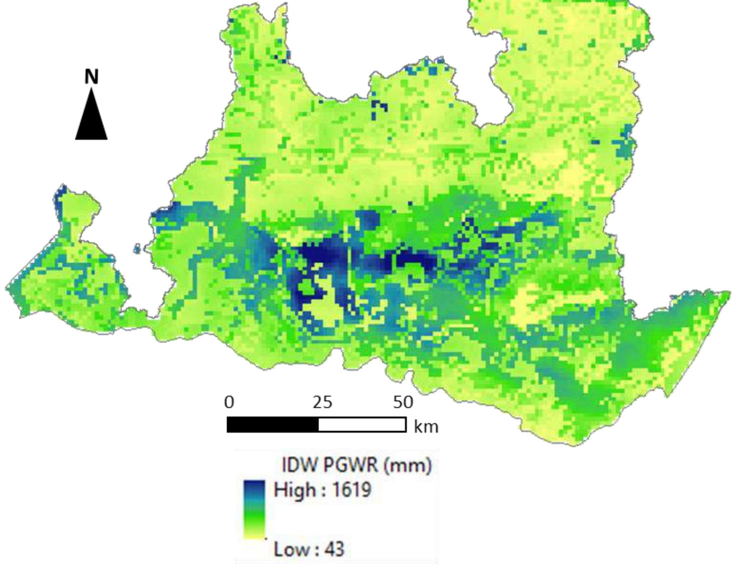
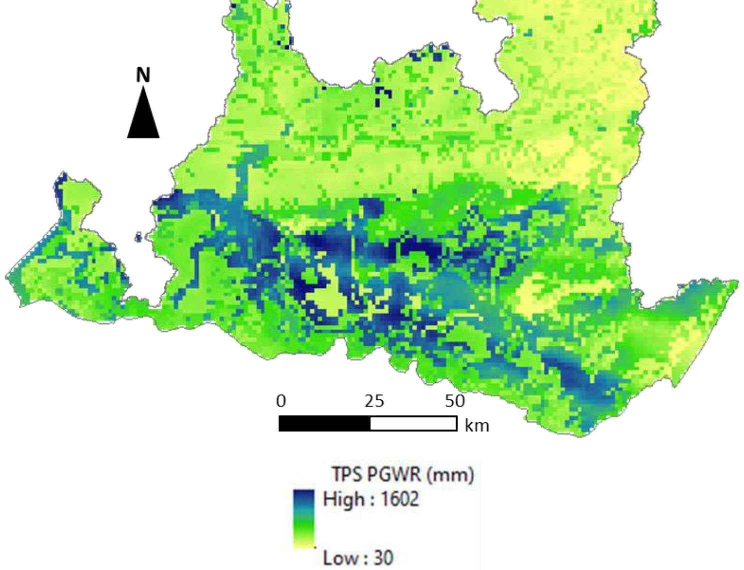
Results – Potential GroundWater Recharge PGWR

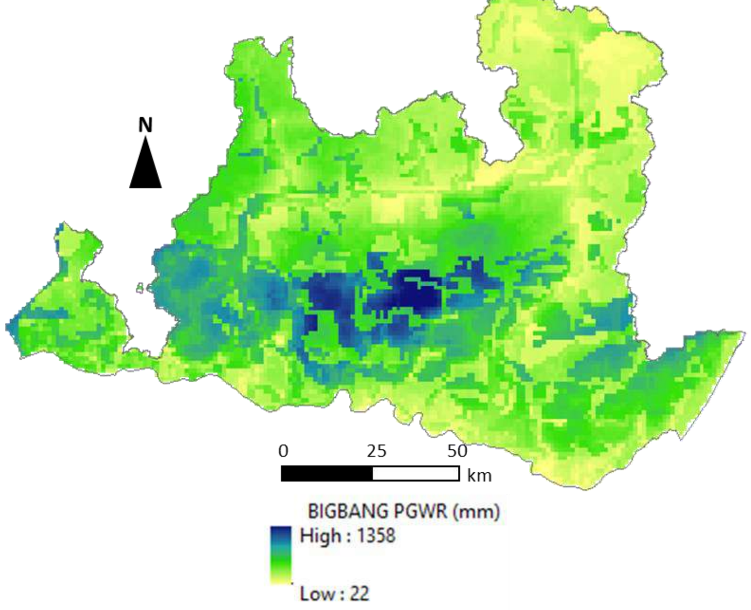
IDW PGWR 4.2 Bm^3 -1.7%



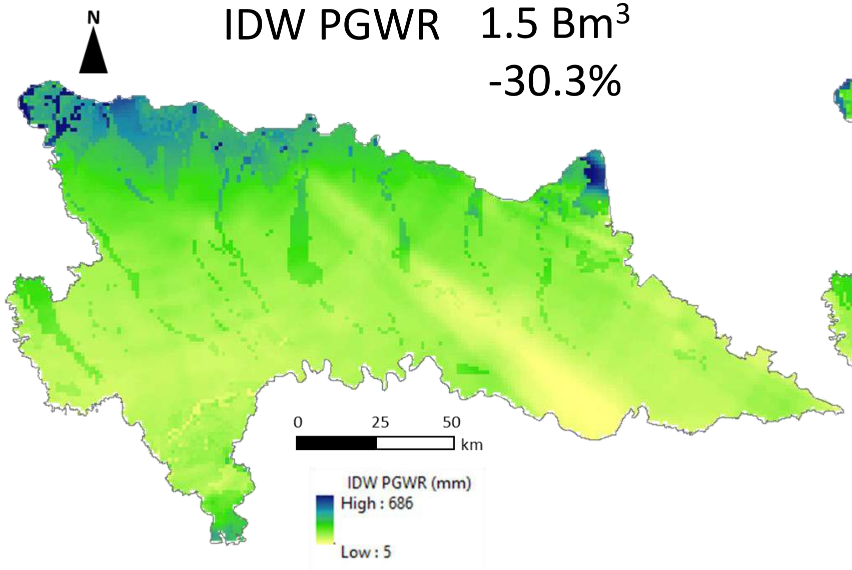
TPS PGWR 4.7 Bm^3 9.7%



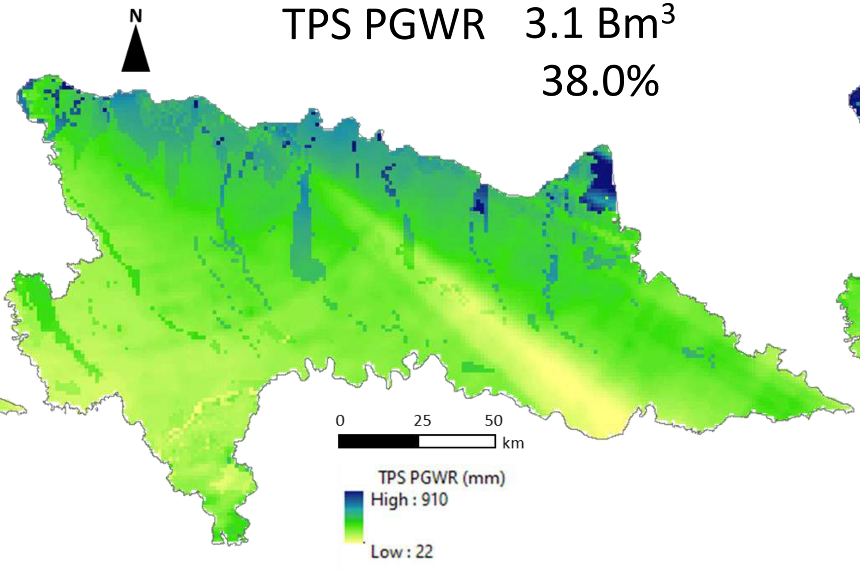
BIGBANG PGWR 4.3 Bm^3



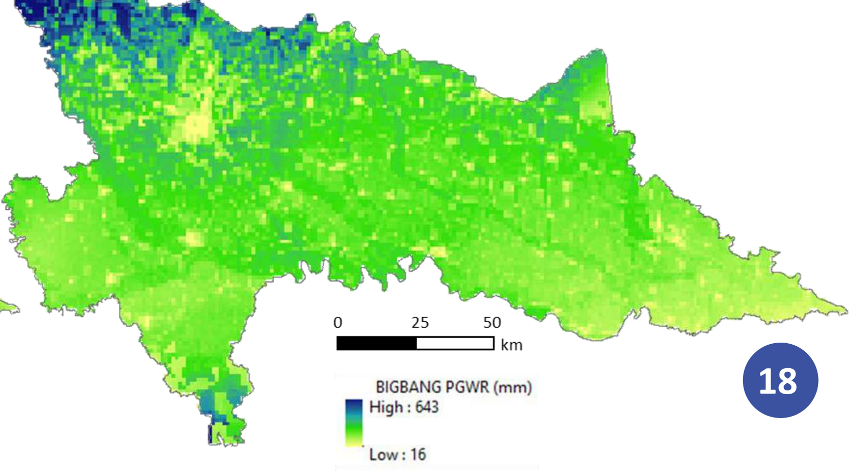
IDW PGWR 1.5 Bm^3 -30.3%



TPS PGWR 3.1 Bm^3 38.0%



BIGBANG PGWR 2.2 Bm^3



Final Remarks

- The mean annual cumulative **precipitation was** successfully **corrected** by integrating data from rain gauges of the Italian network. For instance, **KGE values increase** from 0.50 to 0.78-0.80.

- The **mean annual** Potential GroundWater Recharge (**PGWR**) in the study area in the **2011-2020 period ranges** between **5.8 Bm^3** (IDW) **and 7.7 Bm^3** (TPS).

- **Comparison with** ISPRA's national project - **BIGBANG** - revealed a **good agreement** with the research results from the point of view of the magnitudes involved, both for precipitation and PGWR, although two different computational methods have been used.

- By considering the precipitation entering the system, the **percentage of water available to infiltration** is around:

	IDW	TPS	BIGBANG
P (m^3)	2.57E+10	3.13E+10	2.75E+10
PGWR (m^3)	5.80E+09	7.70E+09	6.50E+09
%	**22.57**	**24.60**	**23.64**
P mount (m^3)	1.44E+10	1.53E+10	1.49E+10
PGWR mount (m^3)	4.2E+09	4.7E+09	4.3E+09
%	**29.17**	**30.72**	**28.86**
P plain (m^3)	1.13E+10	1.6E+10	1.24E+10
PGWR plain (m^3)	1.5E+09	3.1E+09	2.2E+09
%	**13.27**	**19.38**	**17.74**

which shows that, potentially, **more water is available in the mountainous area for infiltration** than in the lowlands. However, a more complex water balance equation and the introduction of other geomorphological variables (e.g., slope) should be considered to get a comprehensive view of the phenomenon.

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Next steps

This pilot case study in Lombardy Region **demonstrates the practical application of radar technology** and highlights its importance **for managing water resources.** To make this methodology as operational as possible, actions on several fronts are required. **A Master's thesis study** (Matilde Di Nardo) is currently testing multiple approaches to **improve the research project**:

The annual scale has been used for exploratory purposes only: it will **move down** in resolution **to the event scale**.

Other residual interpolation techniques (rain-gauges/radars), not only deterministic but also geostatistical (e.g., kriging) **will be tested**.

The weather station database will be expanded including rain-gauges at the border of the Region (Switzerland and neighboring Regions)

A more **elaborated water balance equation** will be applied **to obtain more accurate results** considering the complexity of the phenomenon.

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Thank you for the attention!

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The sustainable yield of a well in low-permeability fractured aquifers: new insights from pumping tests interpretation.

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2 Department of Geology, Hawassa University, Hawassa, Ethiopia;
3 Kataclima srl Società Benefit, Vetralla (VT), Italy.

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Groundwater sustainability

*"…development and use of groundwater in a manner that can be maintained for an indefinite time without causing unacceptable **environmental**, **economic**, or **social** consequences."* (Alley et al., 1999)

Sustainable pumping flow rate of a well:

- **Reliable yield of a well** (Misster and Beeson, 2000): considers the supply constraints and potential yield (well and aquifer characteristics);

- **Sustainable yield of a well** (Van Tonder et al. 2001): discharge rate that will not cause the water level in the well to drop below a prescribed limit.

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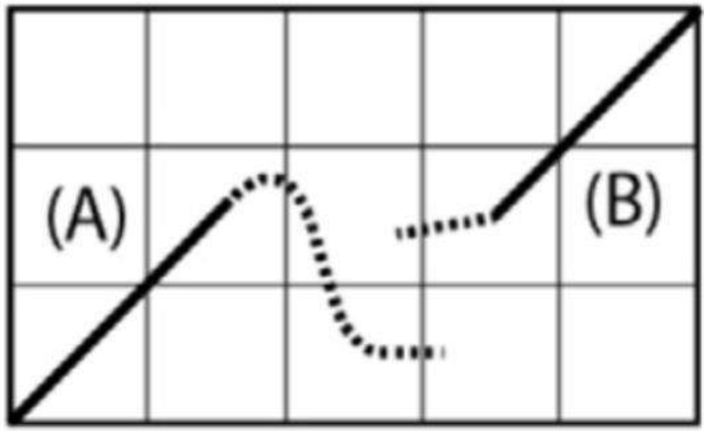
Pumping test interpretation

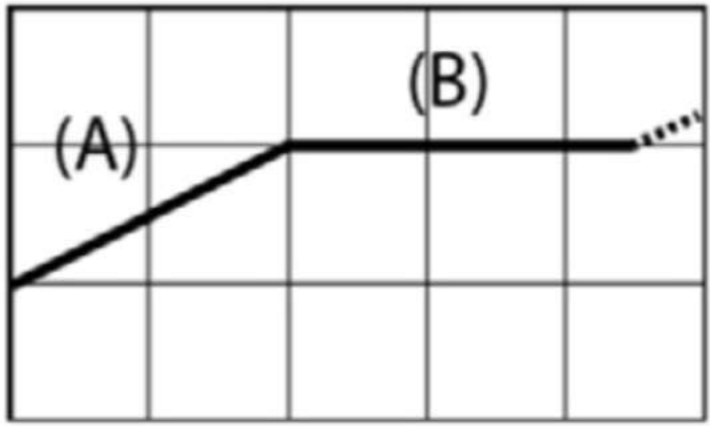
…few examples of sequential variation of flow dimensions (*n*), drawdown log-derivative signatures and associated conceptual models…



Unit positive slope

<u>Large channel model</u>:

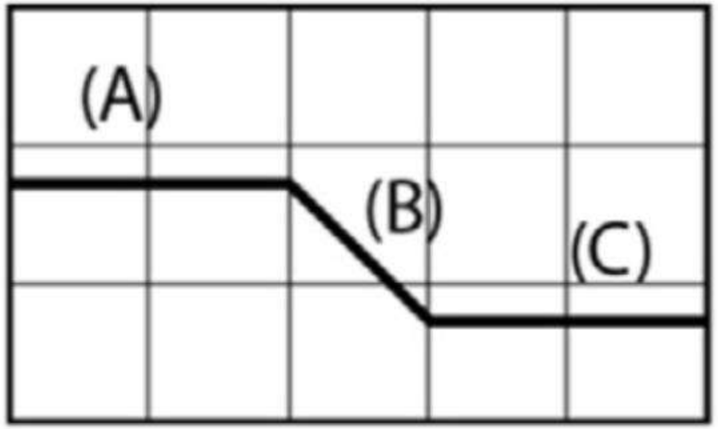
- Early time (A): wellbore effect;
- Late time (B): impermeable boundaries.



n=1 – n=2

<u>Sub-metric fracture in fractured rock aquifer model</u>:

- Early time (A): linear flow (fractures);
- Late time (B): radial flow.



n=2 + n=-1 + n=2:

<u>Contiguous aquifers model:</u>

- Early time (A): radial flow (less transmissive pumped aquifer);
- Transitional stage time (B): negative slope;
- Late time (C): radial flow (more transmissive non-pumped aquifer).

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mod. from Ferroud et al,. 2019

Aims of the study

- ✓ Analyses of pumping tests performed in low-diffusivity heterogeneous fractured aquifers;
- ✓ Assessment of the dependence of the sustainable yield of a well on drawdown trend over time;
- ✓ Definition of a cost-effective procedure to plan the first operation of a well in terms of flow rate and pumping time.

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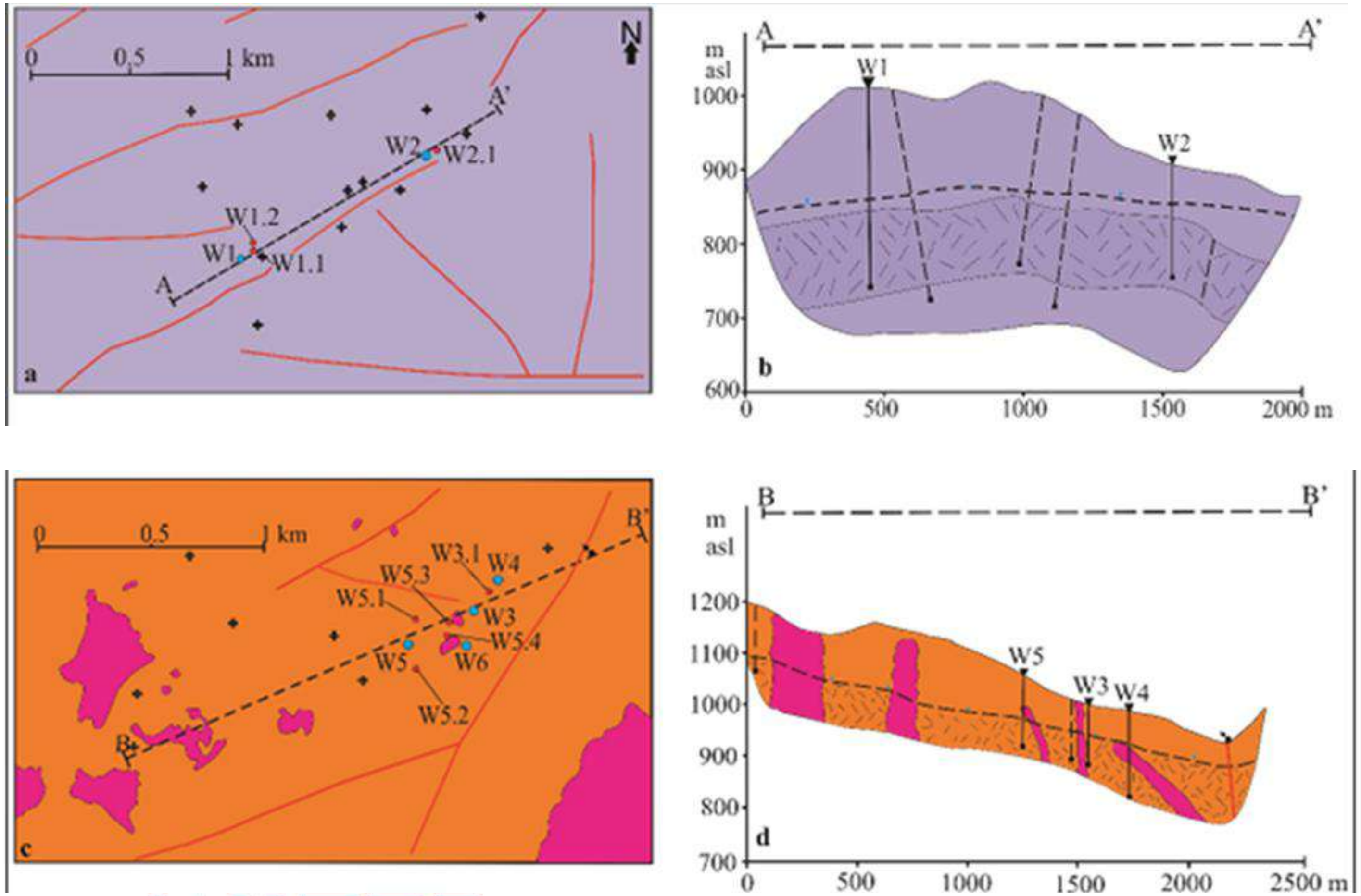
Study area: geological and hydrogeological setting



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Two test sites located in Western Turkey.

Firts test site (**AND site**):
- Lower-Middle Miocene volcanic sequence (andesitic and rhyodacitic lavas);
- RQD values ranging between 0 and 70%;
- Aquifer formation detected at 100-200 m depth (60-90 m thickness);
- 5-10% hydraulic gradient.

Second test site (**MET site**):
- Triassic metamorphic rocks with Early Miocene granodiorites intrusions;
- RQD values ranging between 0 and 60%;
- Aquifer formation detected around 100 m depth (50-60 m thickness);
- 5-22% hydraulic gradient.

Very low recharge contribution ≈ 56 mm/y

Field investigations and processing method steps

- Performance of 6 constant long term pumping tests (11 to 115 hours);
- Pre-processing of water level data to reduce the aquisition noise;
- Analyses of drawdown data versus time through semi-log plots;
- Representation on bi-log plots of both drawdown time series and its first derivative, smoothed by Spline function;
- Comparison of drawdown trends and derivative with theoretical curves to identify the flow regime through the flow dimension *n* and, consequently, the most consistent conceptual model;
- Determination of aquifer parameters (*T* and *S*);
- Selection of the most critical cases for long-term well productivity;
- Implementation of pumping scenarios starting from the long-term drawdown trend.

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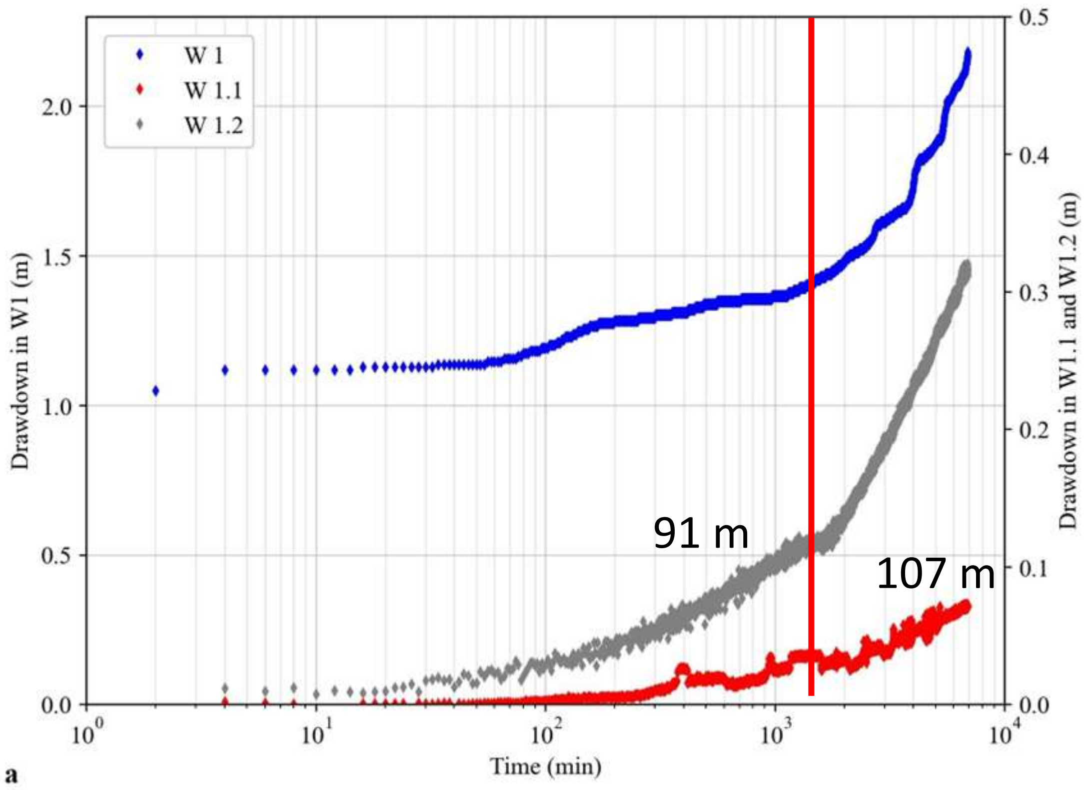
Results: pumping test interpretation

Pumping test performed in W1 at the AND site (constant flow rate 3.6 L/s for 6900 min)



- Similar trend for the three observation points;
- Significant change in drawdown-time trend after 1500 min;
- Determination of *T* and *S* in the 100-1500 time interval by using Cooper-Jacob method:

T_{W1} =3.5x10^{-3} m^2/s;

$T_{W1.1}$ =4.6x10^{-3} m^2/s and $S_{W1.1}$ =7.2x10^{-3};

$T_{W1.2}$ =7.8x10^{-3} m^2/s and $S_{W1.2}$ =7.9x10^{-3}

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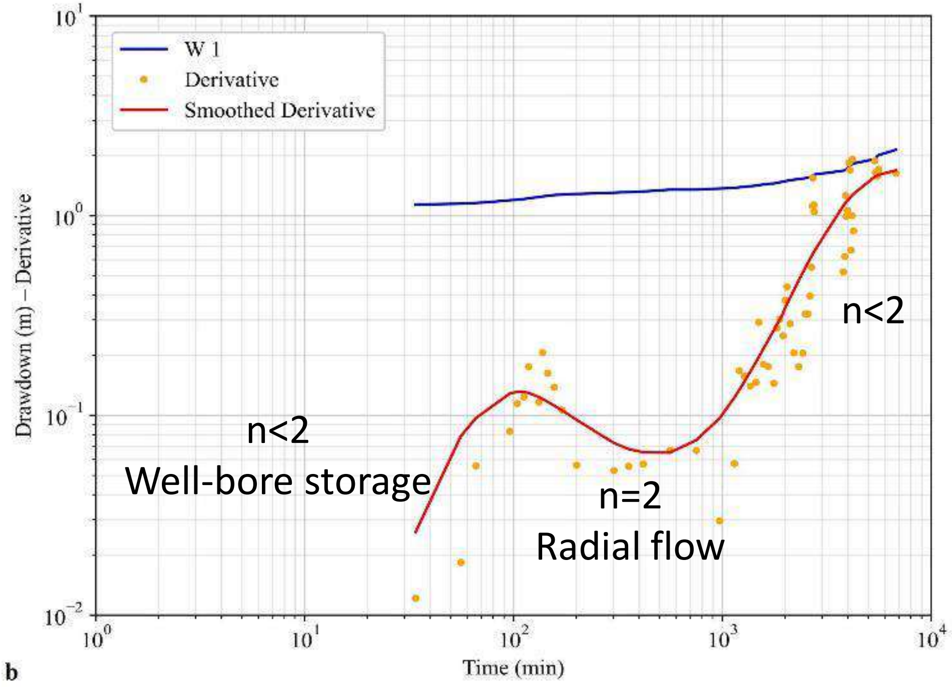
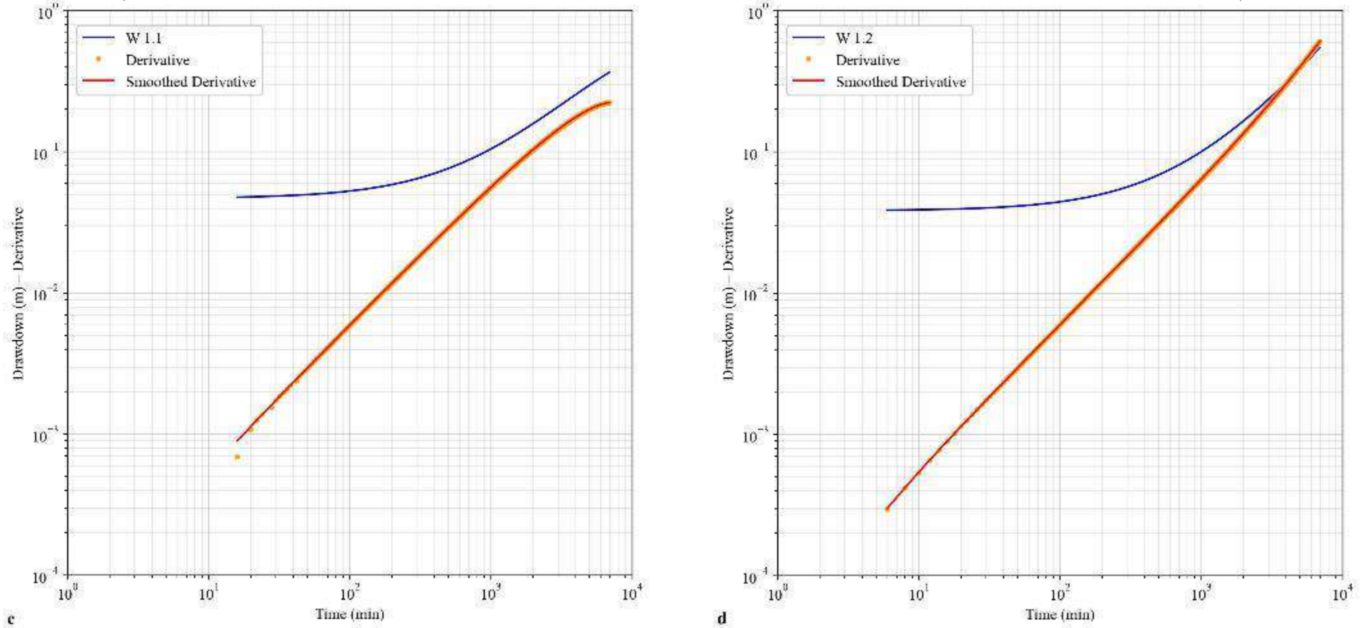
Results: pumping test interpretation

Pumping test performed in W1 at the AND site (constant flow rate 3.6 L/s for 6900 min)

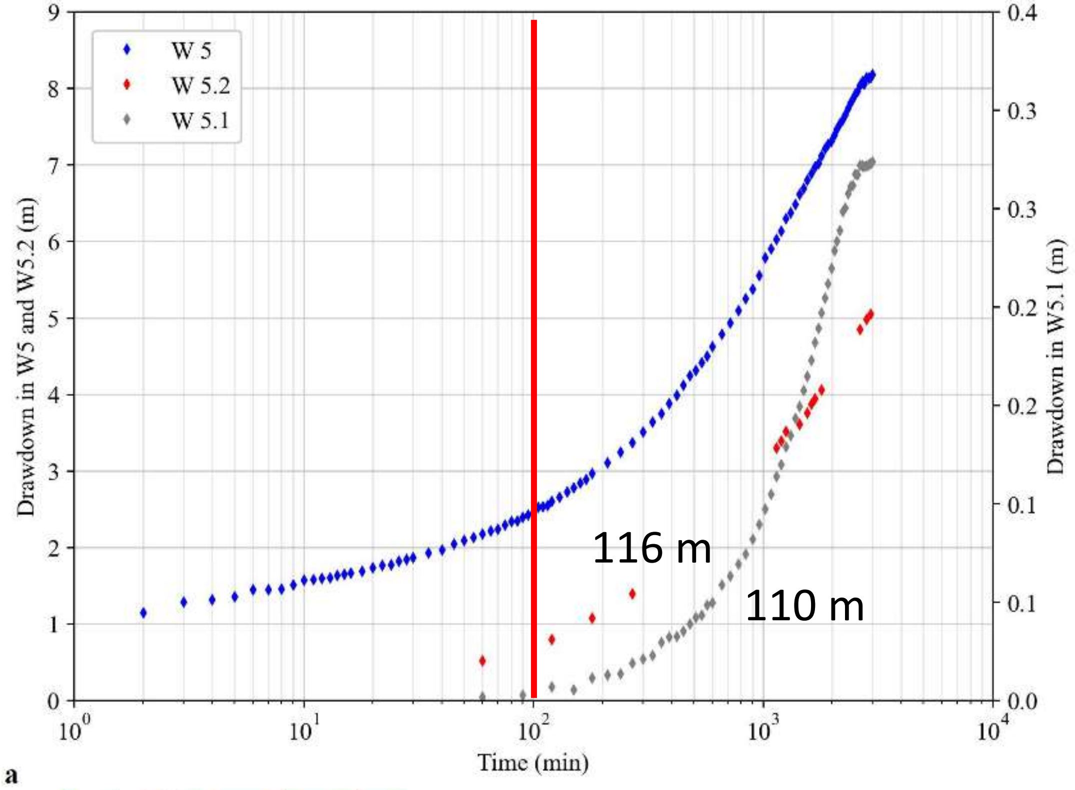


Unit positive slope: no-flow boundary



Results: pumping test interpretation

Pumping test performed in W5 at the MET site (constant flow rate 11.5 L/s for 3000 min)



- Similar trend for the three observation points;

- Significant change in drawdown-time trend after 100 min;
- Drawdown in W5.2 higher than drawdown in W5.1 (comparable distances);
- Determination of *T* and *S* also for recovery test:

→ T_{W5} =4.1x10^{-4} m^2/s and Tr_{W5} =4.8x10^{-4} m^2/s

$T_{W5.1}$ =1.3x10^{-3} m^2/s and $S_{W5.1}$ =3.2x10^{-2};

→ $T_{W5.2}$ =4.7x10^{-4} m^2/s and $S_{W5.2}$ =1.2x10^{-3}.

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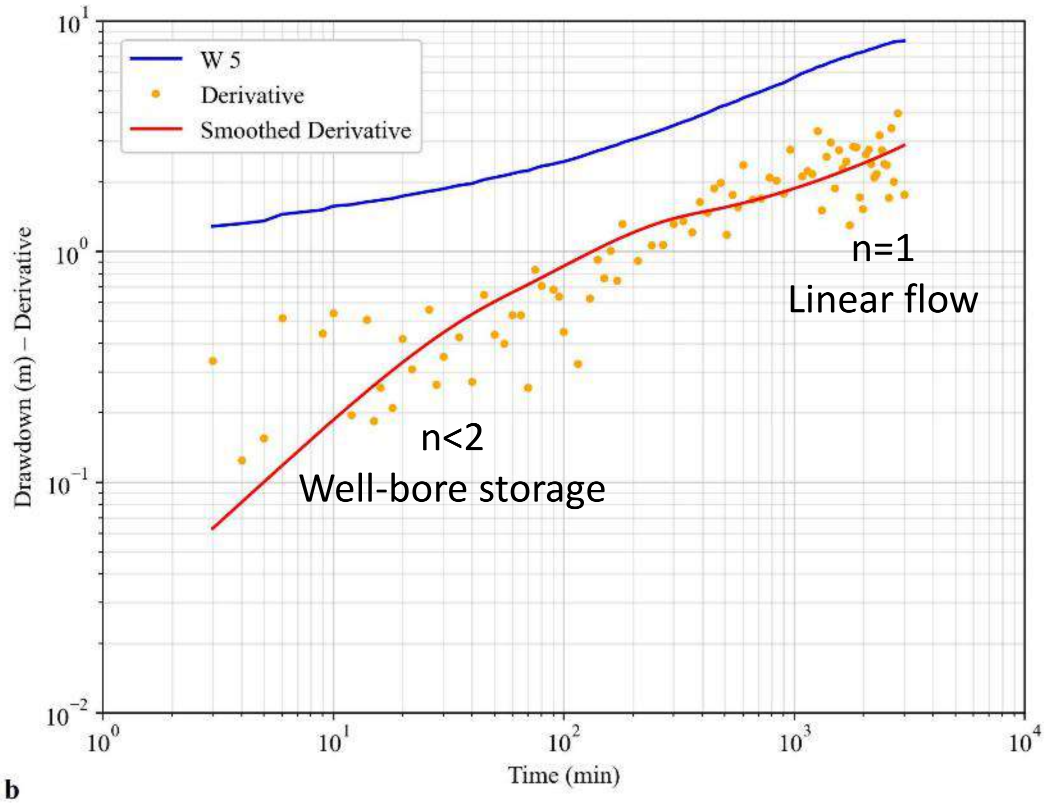
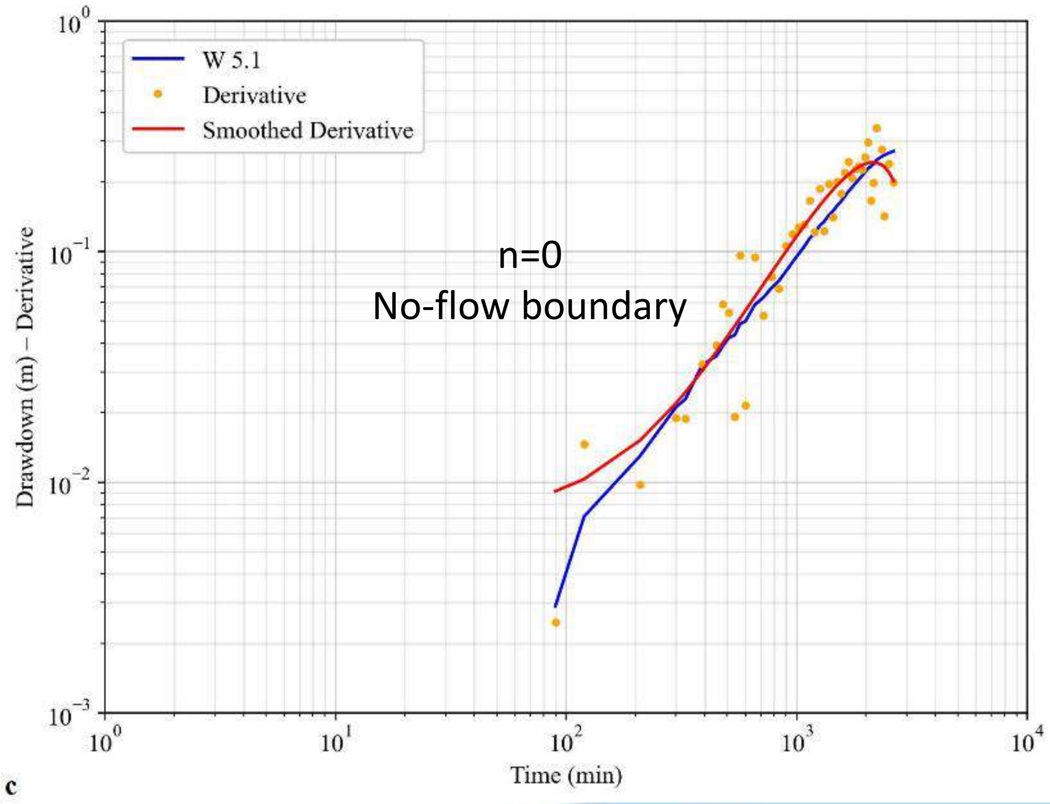
Results: pumping test interpretation

Pumping test performed in W5 at the MET site (constant flow rate 11.5 L/s for 3000 min)





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Discussion on response of aquifer and well to pumping

Strong heterogeneity of andesitic and metamorphic aquifers

T and *S* values variation covers three orders of magnitude

Often drawdown-time trend differs from pumping and observation wells

Sometimes there is no correlation between drawdown and distance from the well

Both pseudo-steady state and transient flow regime have been recognized among the pumping tests

Well specific capacity reflects the variability detected for T, ranging among three orders of magnitude

All the tests highlight the importance of **TEST TIME** in these heterogeneous fractured aquifers.

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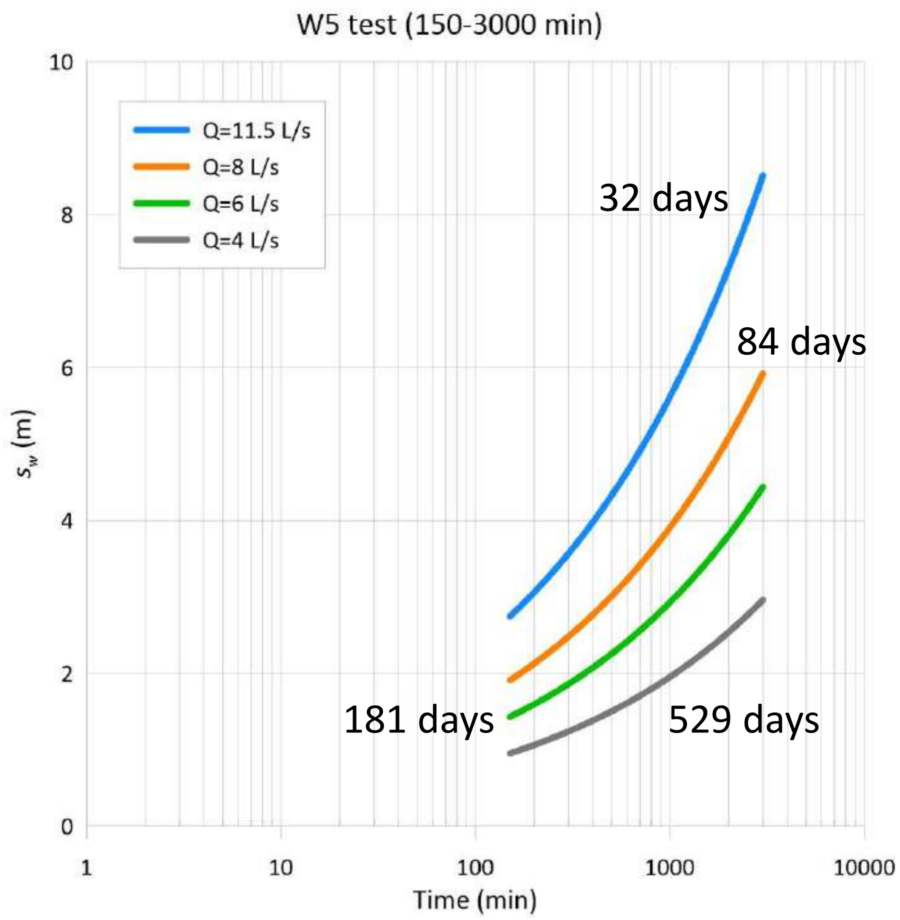
Operational approach for sustainable yield: W5



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Step 1: definition of the analytical function describing late drawdown – time trend

$$s_w = 0.088\, t^{0.378}$$

Step 2: definition of S_w as a function of Q

$$s_w = 7.652\, Q\, t^{0.378}$$

Step 3: definition of a range of alternative pumping rate

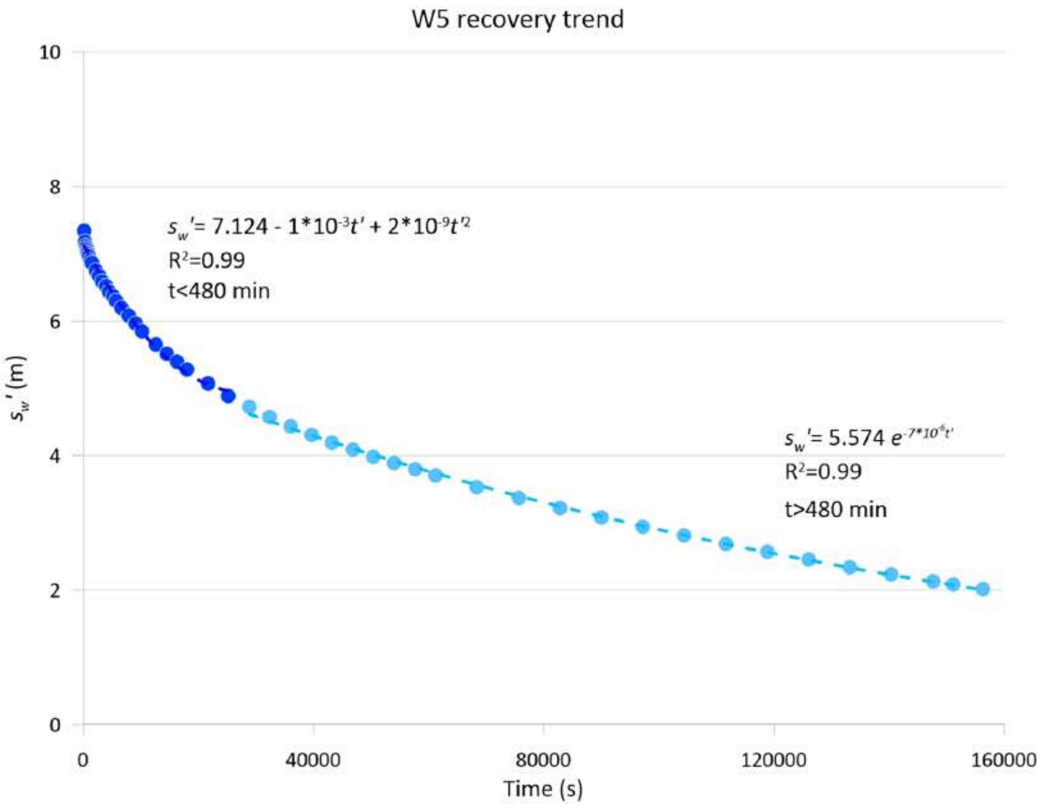
Step 4: definition of a prescribed limit of drawdown in the well

$$W_e = \frac{s_{wl}}{b}\, 100$$

Step 5: definition of possible operational time of continuous pumping

…….

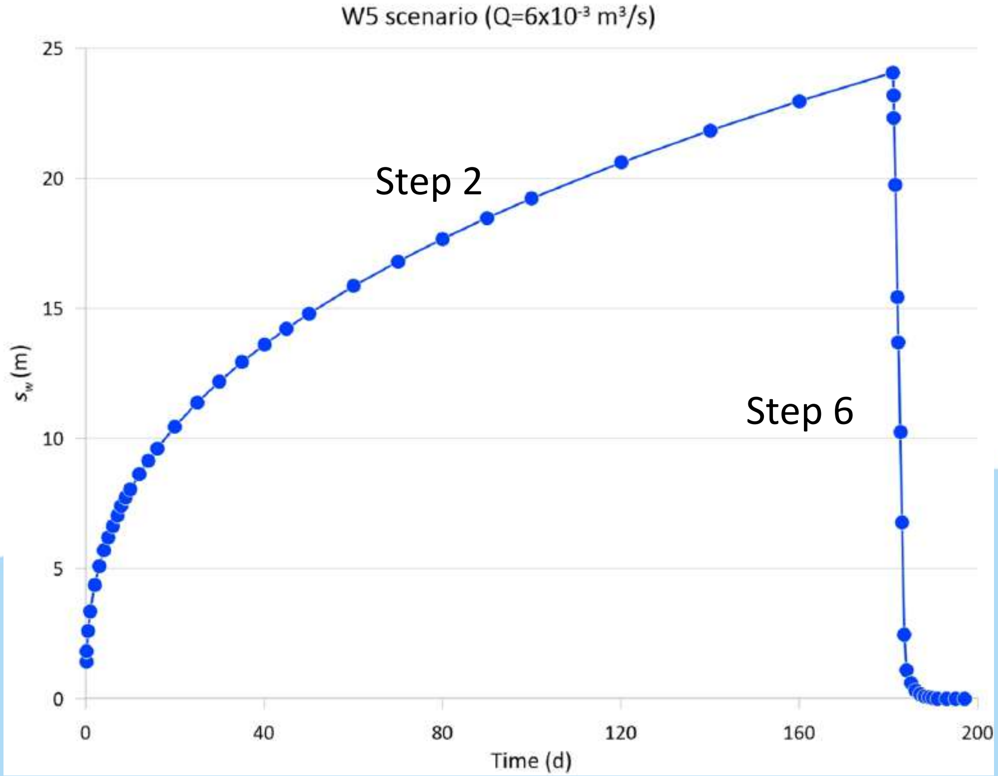
Operational approach for sustainable yield: W5



....

Step 6: definition of the analytical function/s describing residual drawdown – time trend/s

Step 7: by applying the equations defined in Steps 2 and 6 different scenarios of both drawdown and recovery can be easily simulated.



WATER
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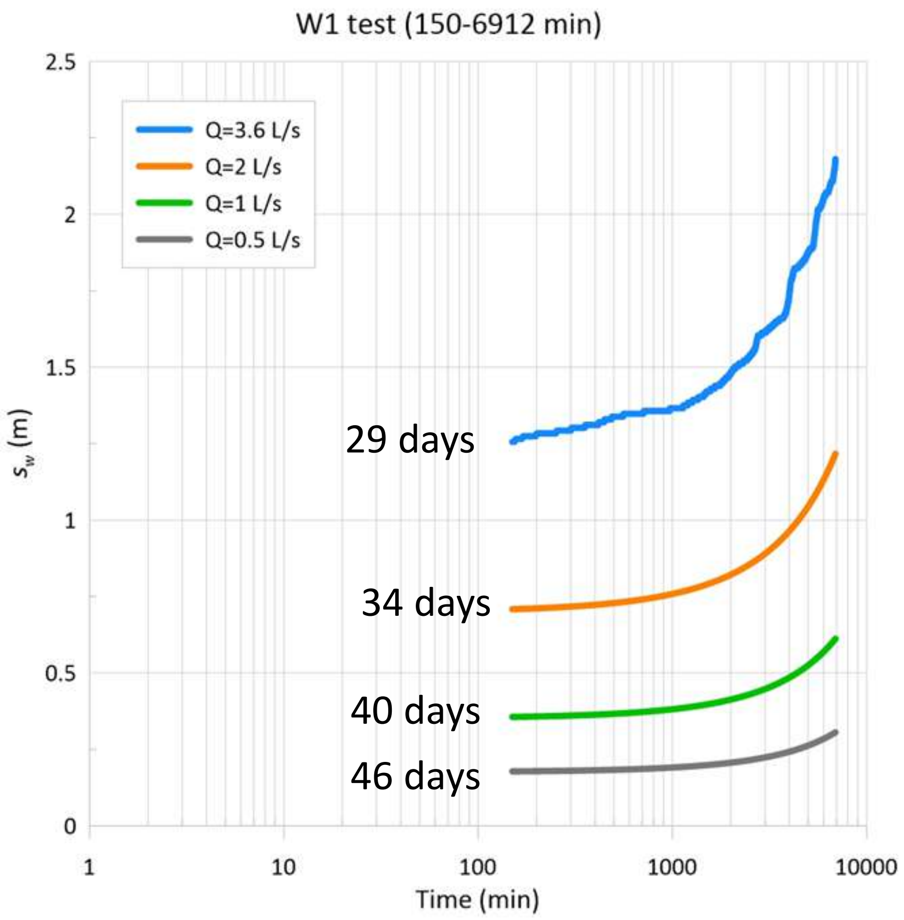
Operational approach for sustainable yield: W1



Step 1: definition of the analytical function describing late drawdown – time trend

$$s_w = 1.266e^{1.3\ 10^{-6}t}$$

Step 2: definition of S_w as a function of Q

$$s_w = 351.7\ Q\ e^{1.3\ 10^{-6}t}$$

Step 3: definition of a range of alternative pumping rate

Step 4: definition of a prescribed limit of drawdown in the well

$$W_e = \frac{s_{wl}}{b}\ 100$$

Step 5: definition of possible operational time of continuous pumping

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Conclusions

- The results of the pumping tests, interpreted in the specific hydrogeological context, allowed to obtain information on the response to pumping of the examined fractured aquifers, and directions on the sustainable yield of wells.
- The trend of drawdown over time measured 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.
- In these aquifer, characterized by low hydraulic diffusivity, is preferable to provide pumping tests at constant flow rate of significant duration (2 days) instead of the relatively short step-drawdown tests.
- The late drawdown-time curve and residual drawdown segment-curves during the recovery, approximated by different equations, combined with the definition of a drawdown limit in the well are essential to plan the first operation of the well in a relatively easy and cost-effective way.
- The definition of sustainable yield of a well in terms of pumping rate and time from these aquifers can be crucial in order to supply water for small communities, especially in the framework of ongoing climate changes.

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National Meeting on Hydrogeology

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Multidisciplinary investigation of groundwater flow in unsaturated slopes susceptible to shallow flowslides

Forte G.* , Pirone M.*, Di Maio R.,**
De Paola C., Salone R.**, Santo A.*, Urciuoli G.***

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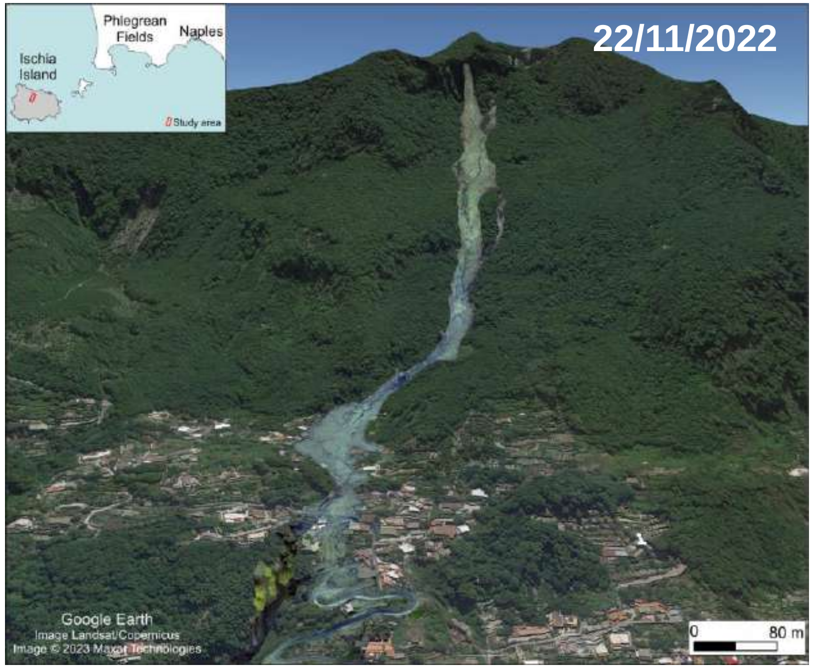
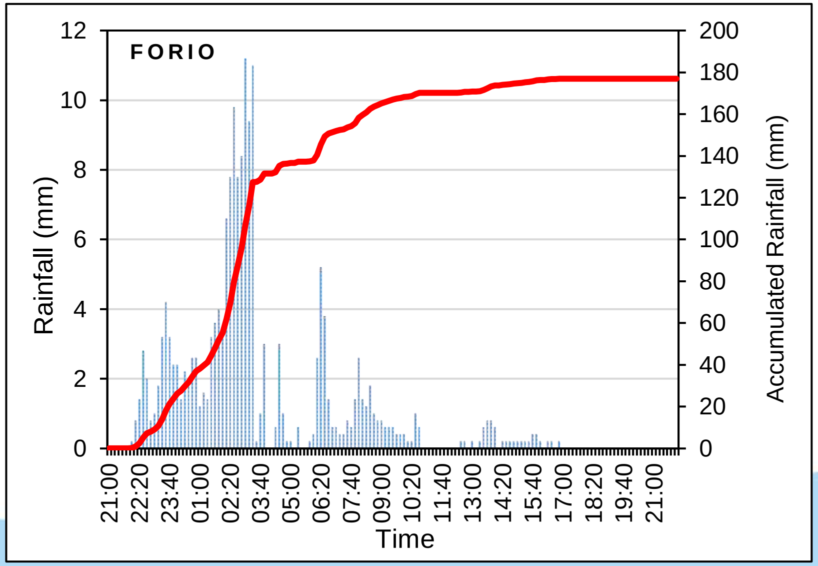
Università Degli Studi Di Napoli Federico II

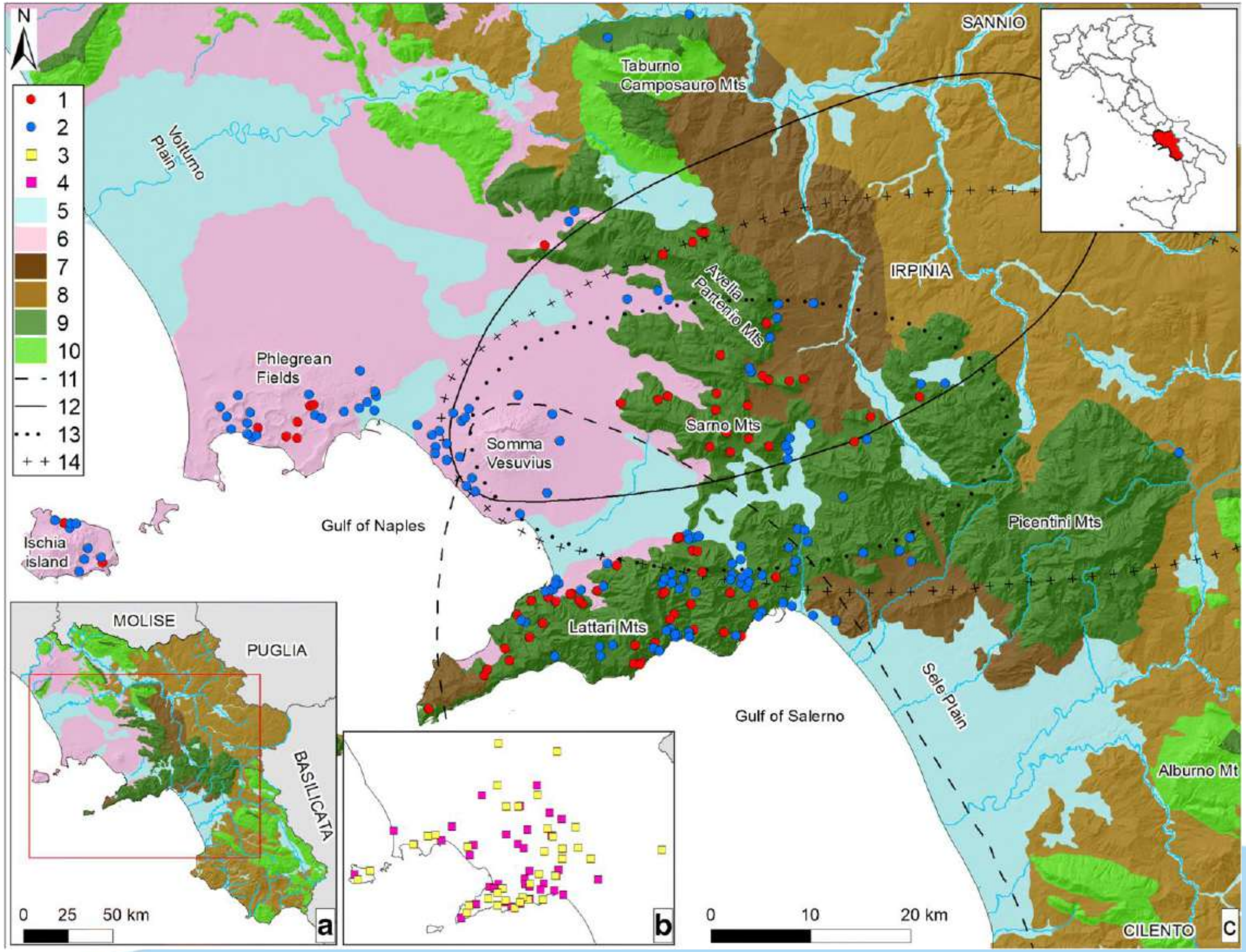
**D.I.C.E.A., Dipartimento d’Ingegneria Civile, Edile ed Ambientale*

*** D.I.S.T.A.R., Dipartimento di Scienze della Terra, dell’Ambiente e delle Risorse*

FLOWSLIDES IN CAMPANIA (SOUTH ITALY)

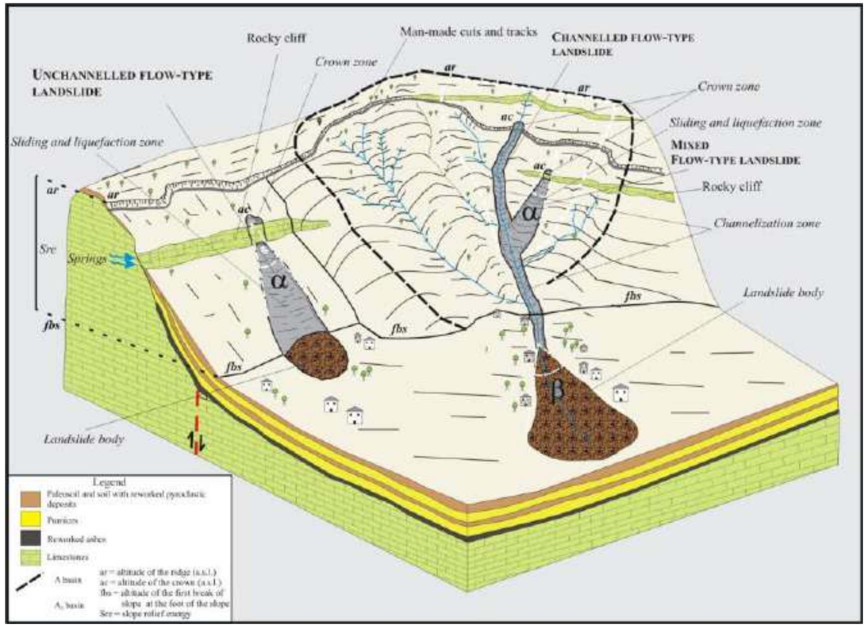






(1) flow-like landslides (FL); (2) flash floods (FF); (3) mechanical rain gauge; (4) automatic rain gauge; (5) alluvial plains; (6) volcanic slopes; (7) flysch/terrigenous slopes with pyroclastic soils; (8) flysch/terrigenous slopes; (9) carbonate ridges with pyroclastic soils; (10) carbonate ridges; dispersion axis of (11) 79 AD eruption; (12) Avellino eruption (3800 b.p.); (13) Ottaviano/Mercato eruption (8000 b.p.); (14) Sarno eruption (18.300 b.p.)

Main features of Flowslides



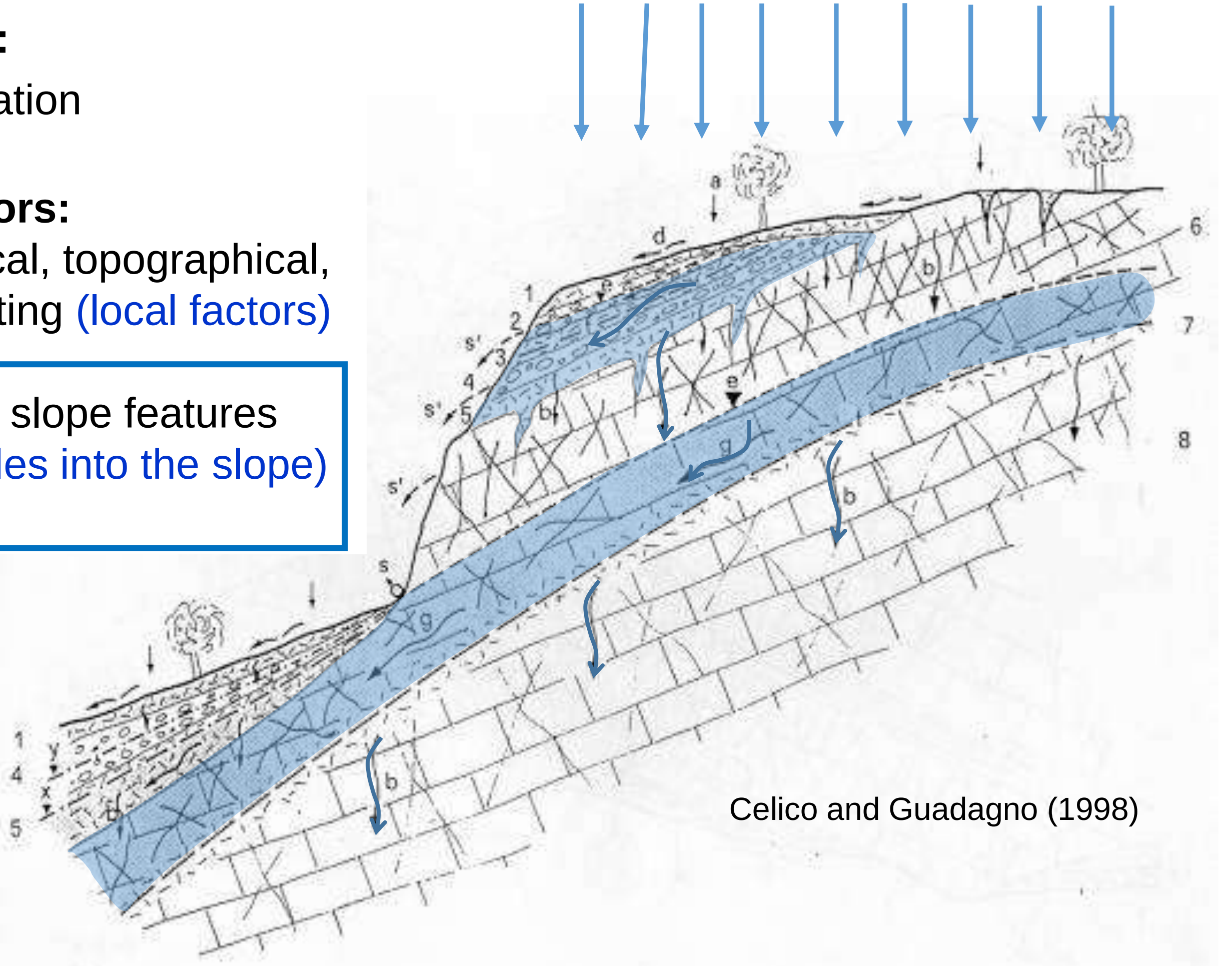
Triggering factors:

- ✓ Rainwater Infiltration

Predisposing factors:

- ✓ Geomorphological, topographical, stratigraphic setting (local factors)

- ✓ Hydrogeological slope features (hydraulic variables into the slope)



Celico and Guadagno (1998)

Nocera slope before 2005

Nocera flowslide (2005)

Characterization of the hydrogeologic behaviour of the pyroclastic slopes

↓

- **The role of variability of the different soil horizons in terms of continuity and thickness;**
- **What happens at the stratigraphic contact between soil cover and bedrock;**

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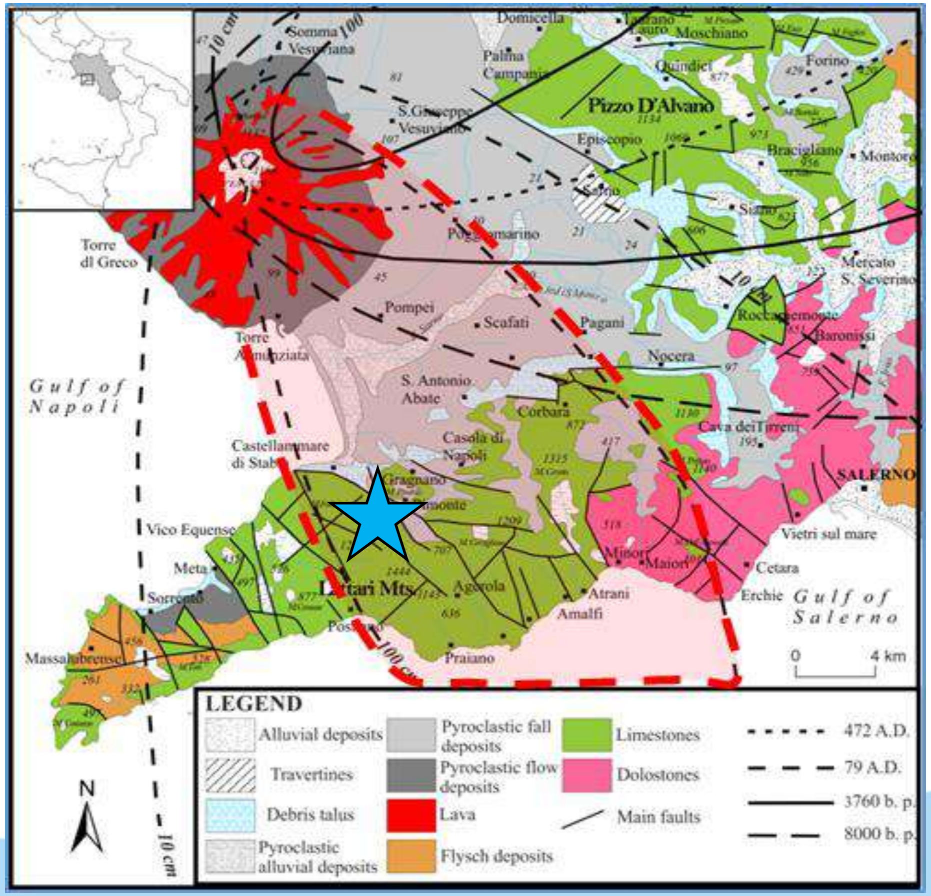
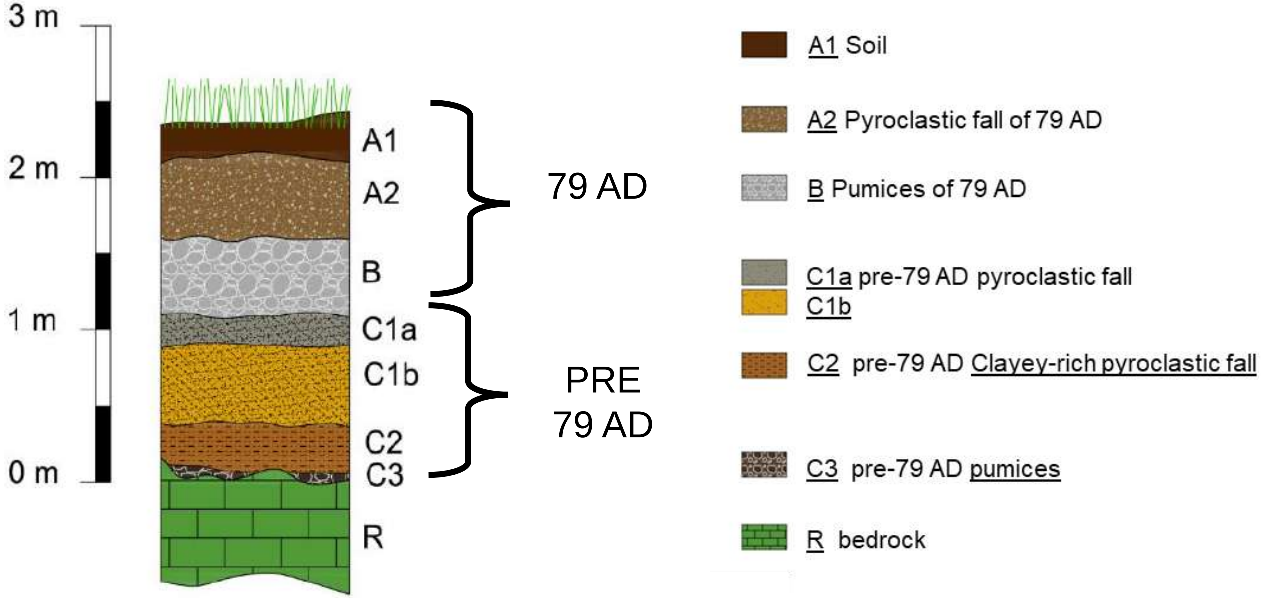
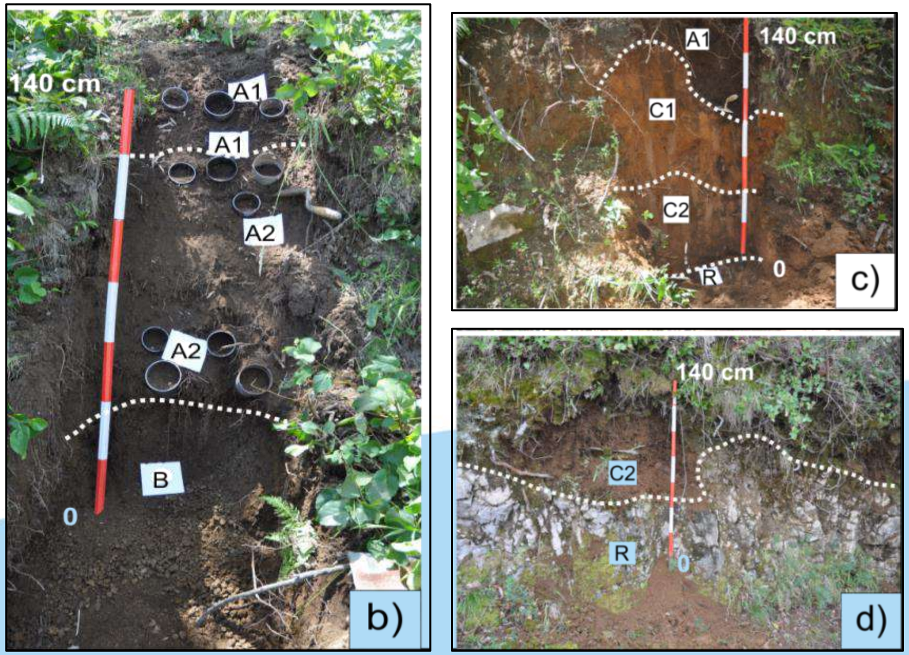
FAITO MT. TEST SITE







Forte G., Pirone M., Santo A., Nicotera M.V., Urciuoli G. (2019). Triggering and predisposing factors for flow-like landslides in pyroclastic soils: the case study of the Lattari Mts. (southern Italy). Engineering Geology, 257, 105137.

Characterization and Monitoring Equipment

Weather Station

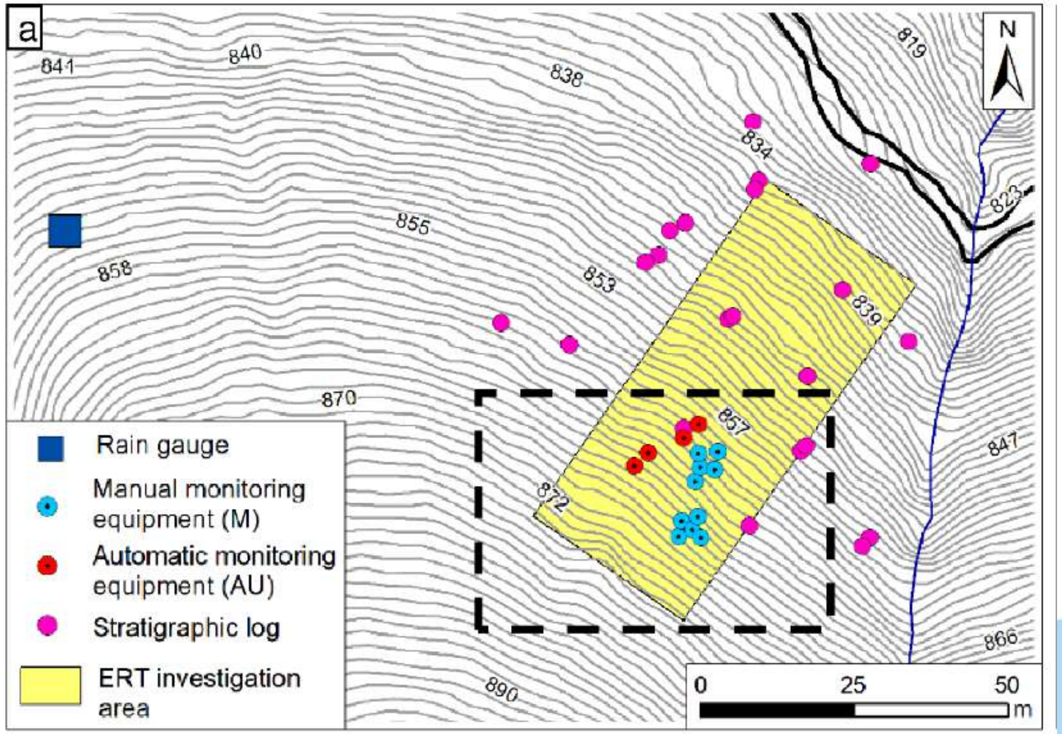
- Pluviometer
- Air Termoigrometer
- Radiometer
- Anemometer
- Gonioanemometer
- Soil Thermometer

Geological and geotechnical characterization

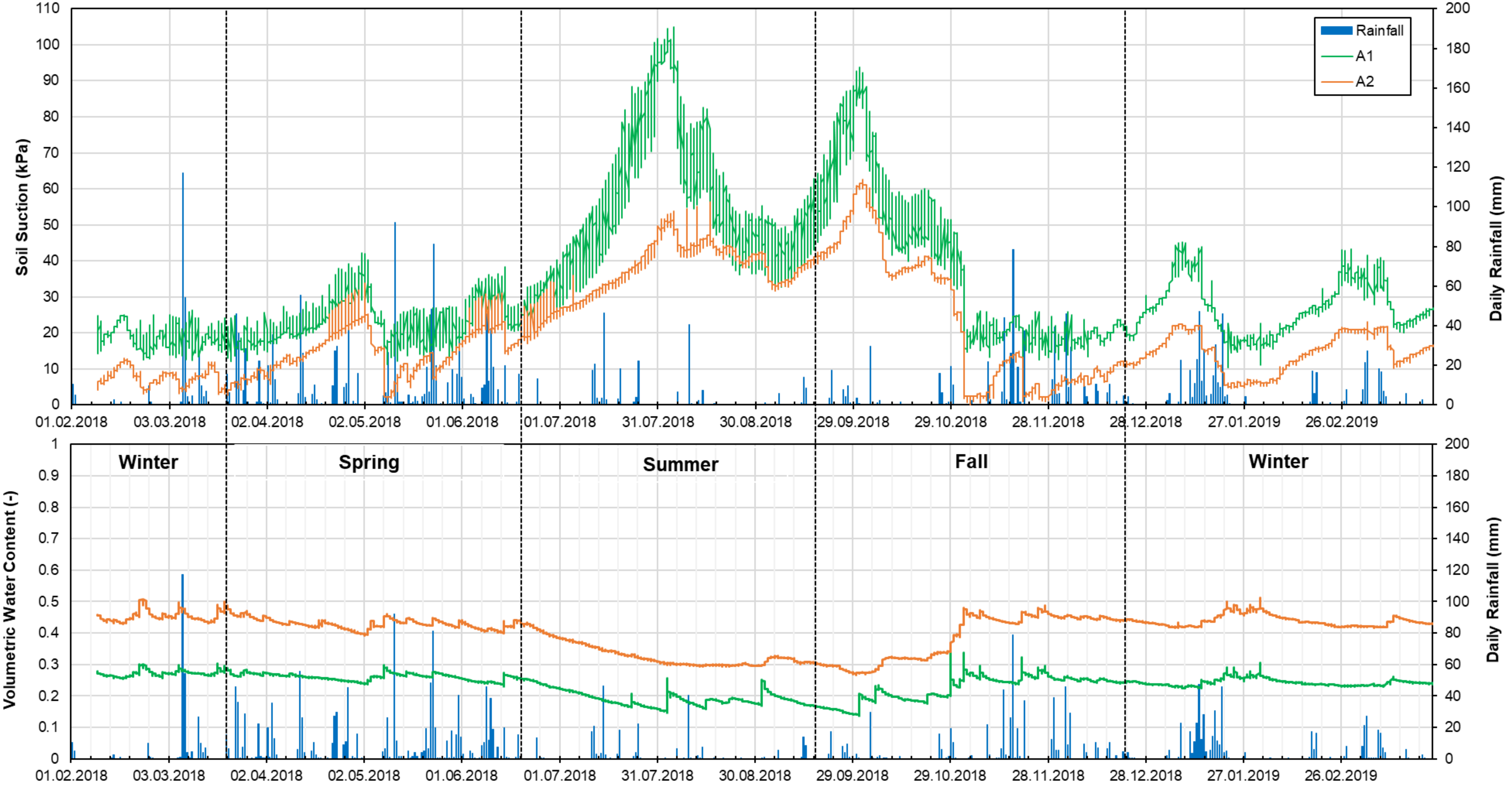
- 25 boreholes
- 6 trenches
- 9 ERT (Summer – Winter – Spring)
- Stratigraphic cross-sections
- Grain-sizes and physical properties assessment
- Laboratory tests

Manual and Automatic soil monitoring equipment

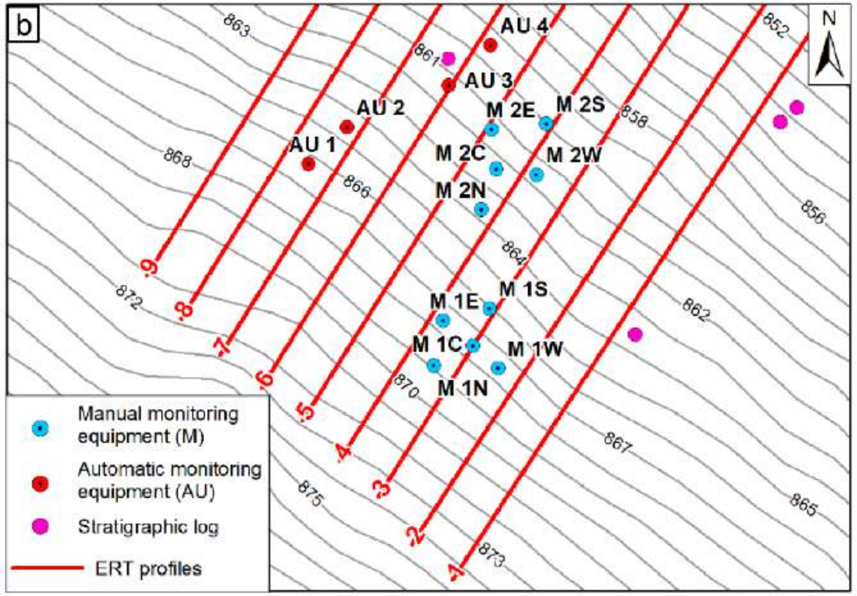
- Tensiometers
- TDR
- Triaxial accelerometers
- Digital thermometers
- Watermark sensors
- Decagon sensors

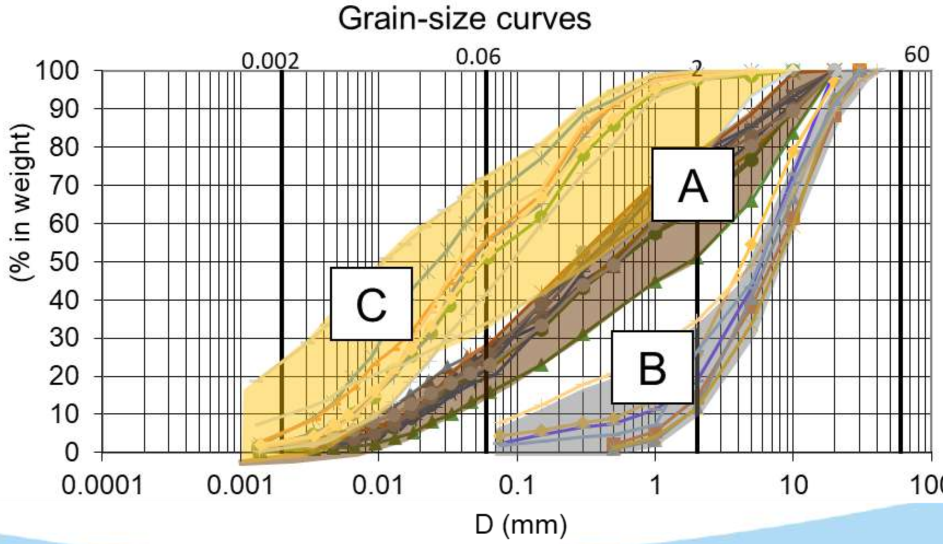


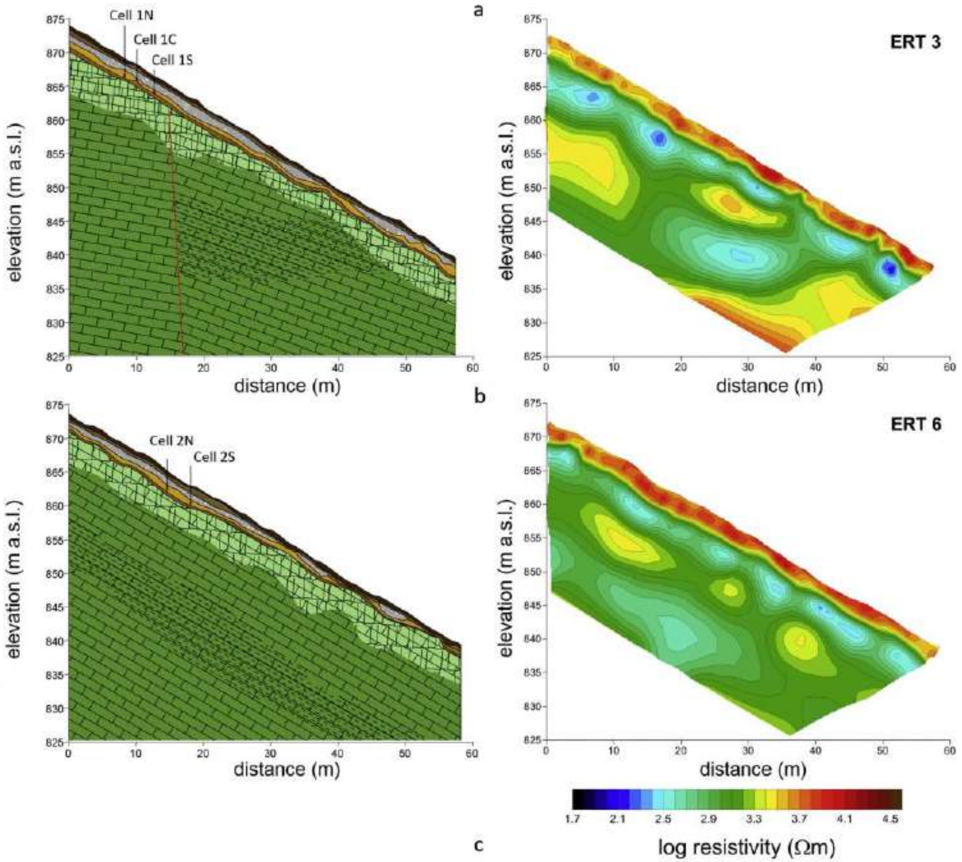
Field Monitoring

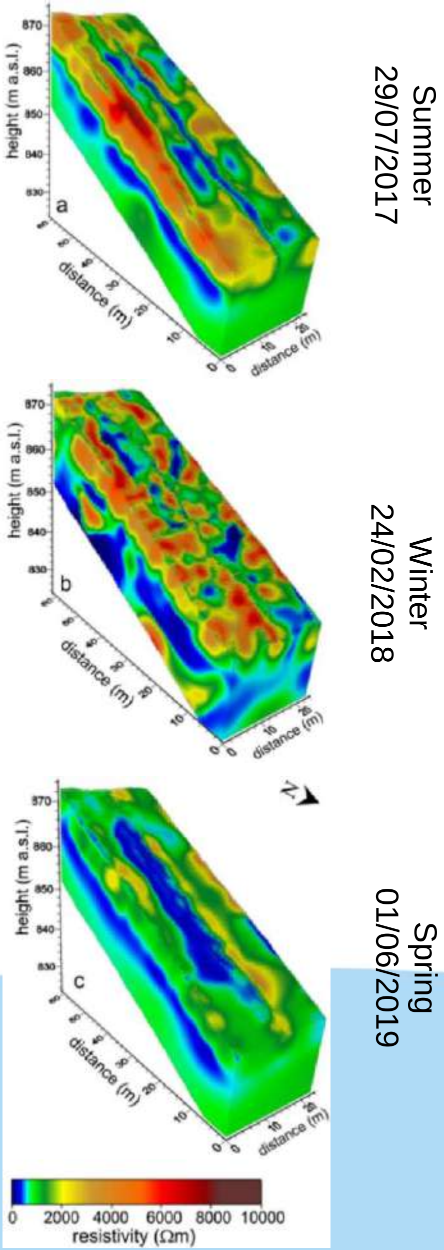


MULTIDISCIPLINARY CHARACTERIZATION









	Soil	n	Gs	γ_d (kN/m³)	ϕ (°)	c'(Kpa)	Ksat (m/s)	ρ (Ohm/m)
	A1	0.67	2.67	8.80	37	0	4.3E-07	430 - 4300
	A2	0.69	2.70	8.10	37	0	1.4E-06	3500 - 6000
	B	0.80	2.55	4.80	40	0	2.9E-04	6000 - 25000
	C1	0.72	2.62	7.34	36	0	6.6E-07	730 - 41500
	C2	0.46	2.65	14.18	36	8	6.4E-09	140 - 1900
	R	CARBONATE BEDROCK					E-03 – E-04	100 - 5000

ISSUE #1

- **The role of variability of the different soil horizons in terms of continuity and thickness**

- **What happens at the stratigraphic contact between soil cover and bedrock;**

→

- Steady State

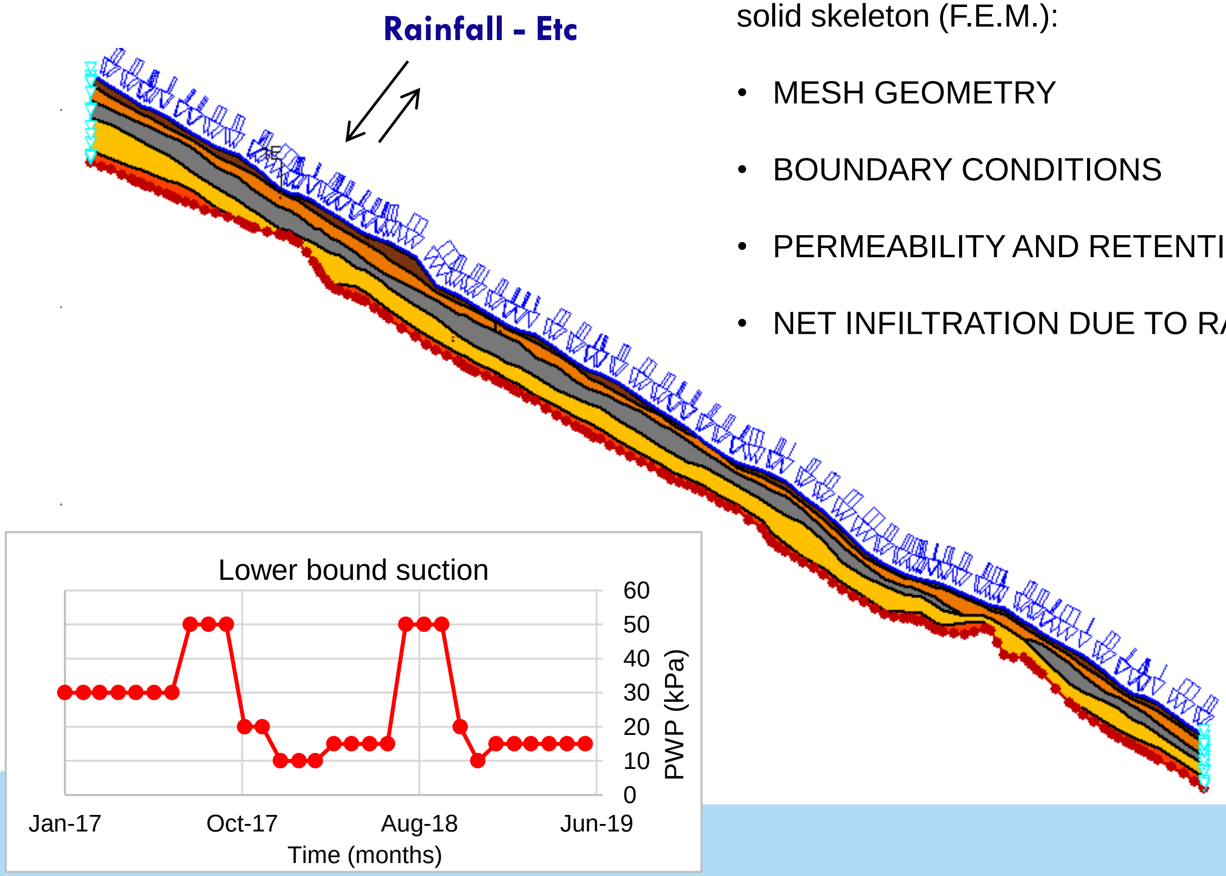
$$\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial x}\left(k_y \frac{\partial H}{\partial y}\right) + Q = 0$$

- Transient

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial x}\left(k_y \frac{\partial H}{\partial y}\right) + Q = \frac{\partial \theta}{\partial t}$$

U< 0, Q=0;

U = 0, Q≠0;



The model solves the water continuity equation in 2D assuming the soil as a continuous medium with a rigid solid skeleton (F.E.M.):

- MESH GEOMETRY
- BOUNDARY CONDITIONS
- PERMEABILITY AND RETENTION CURVES
- NET INFILTRATION DUE TO RAINFALL

SEEP/W™

GeoStudio®

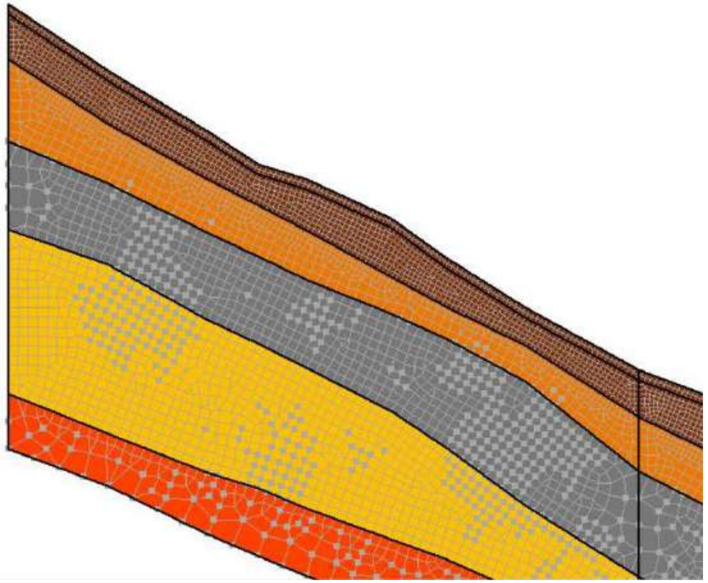
U< 0, Q=0;

U = 0, Q≠0;

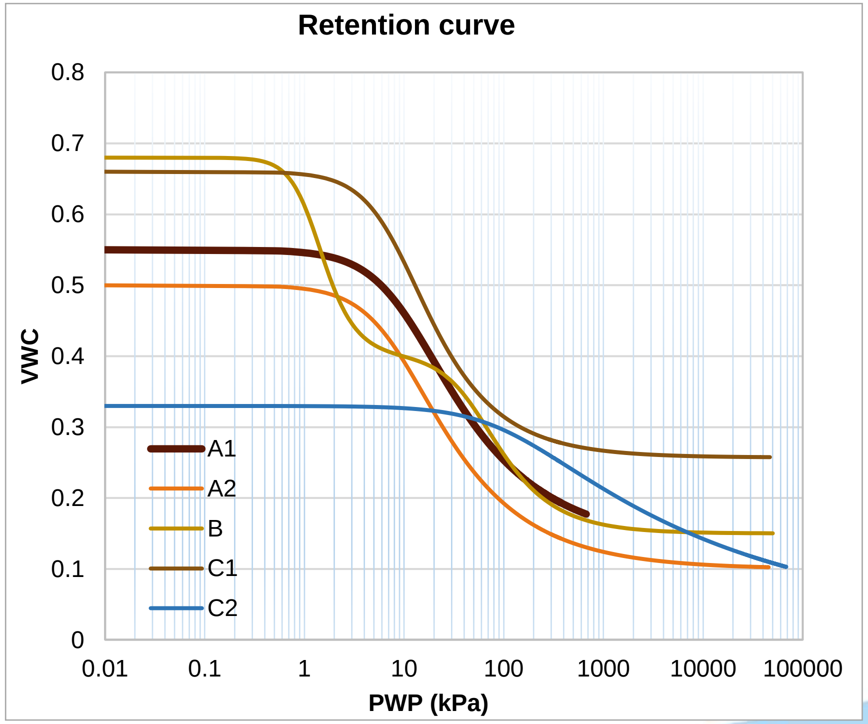
ISSUE #1: SET UP OF THE FEM MODEL

- **The role of variability of the different soil horizons in terms of continuity and thickness**

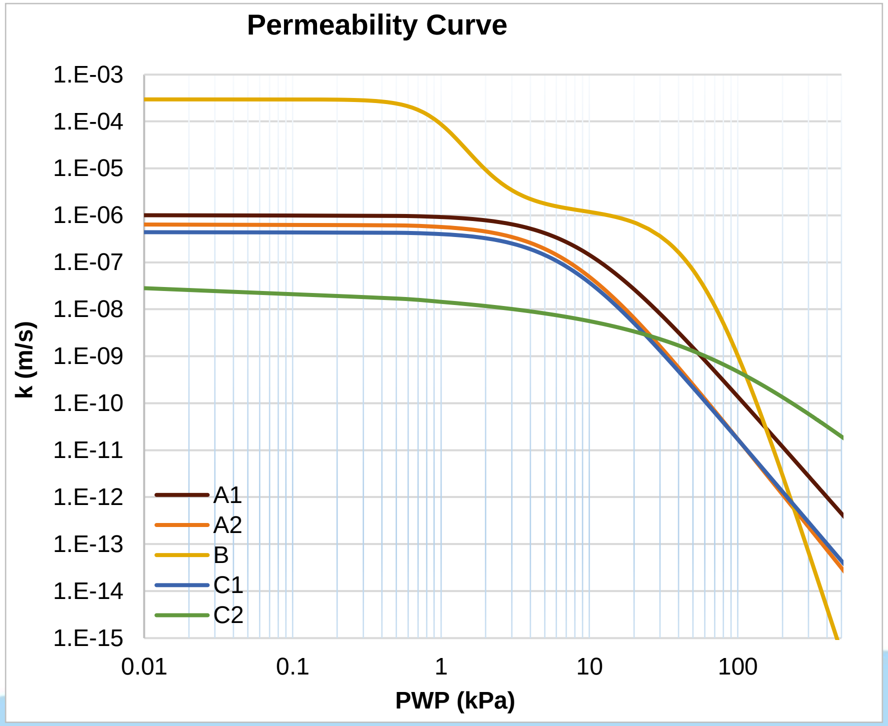
➢ **0,05** m	➢ **0,05** m **A1**
➢ **0,10m**	➢ **0,10m A2**
➢ **0,25m**	➢ **0,25m B**
➢ **0,10m**	➢ **0,10m C1**
➢ **0,25m**	➢ **0,25m C2**



Van Genuchten



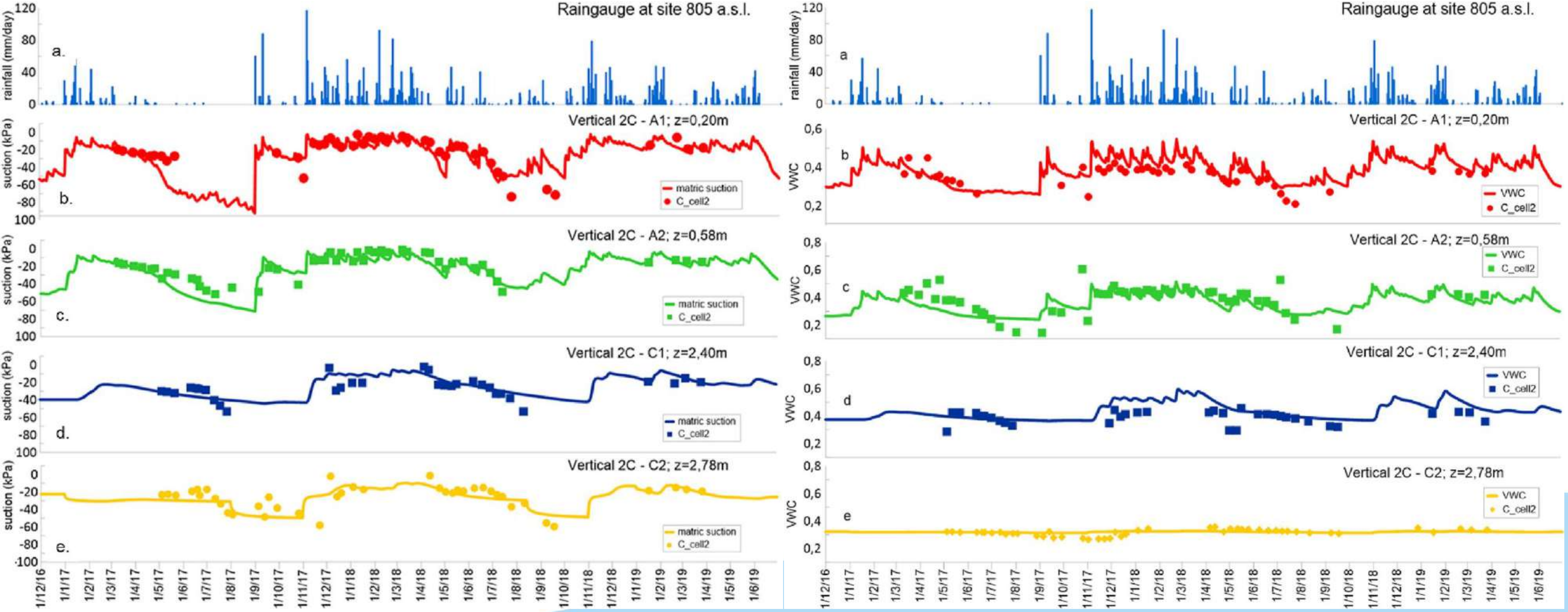
Mualem and Van Genuchten



Pirone M., Di Maio R., Forte G., De Paola C., Di Marino E., Salone R., Santo A., Urciuoli G. (2023). Study of the groundwater regime in unsaturated slopes prone to landslides by multidisciplinary investigations: Experimental study and numerical modelling. Engineering Geology, 107045. DOI 10.1016/j.enggeo.2023.107045

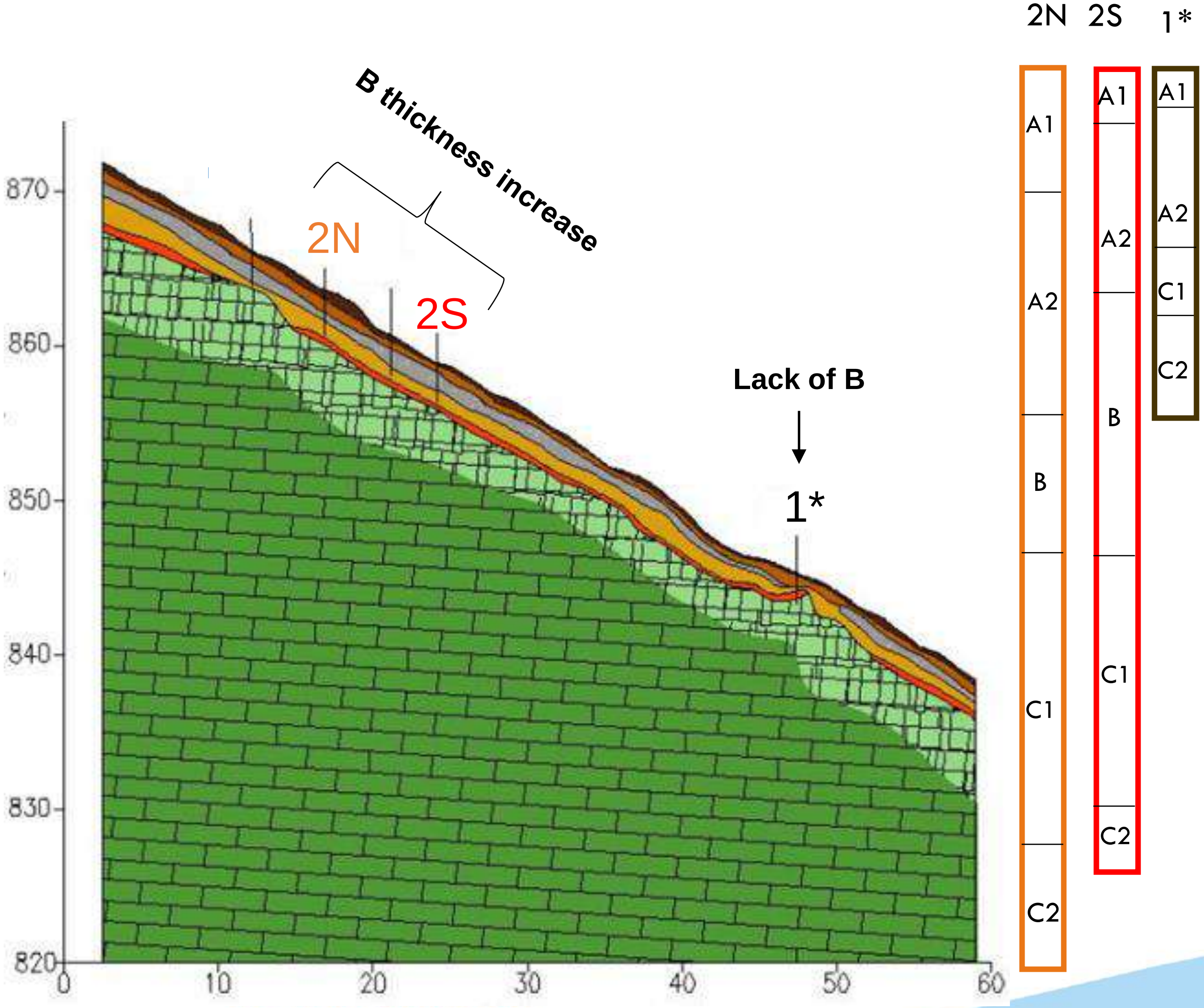
ISSUE #1: CALIBRATION

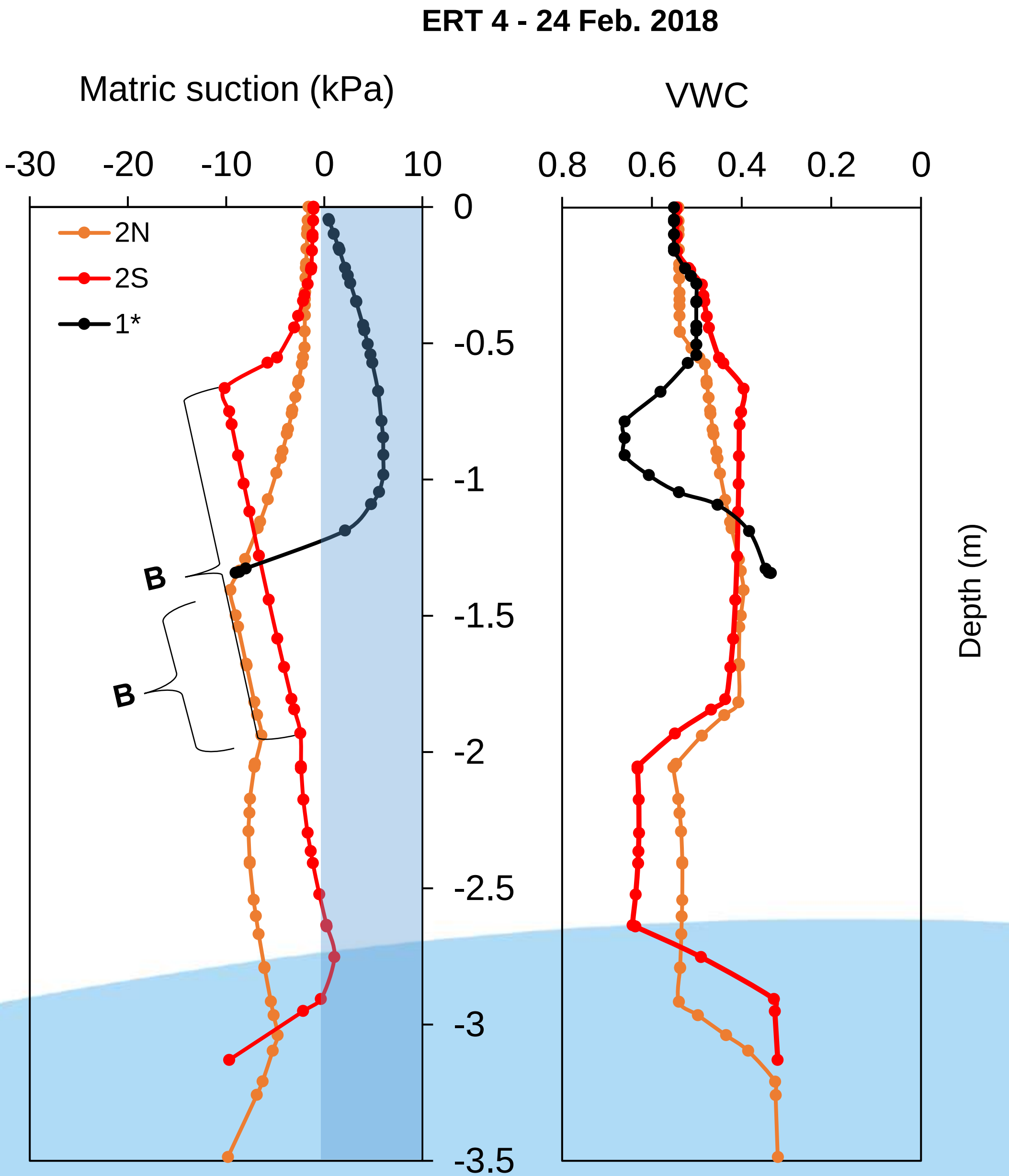
- **The role of variability of the different soil horizons in terms of continuity and thickness**



Pirone M., Di Maio R., Forte G., De Paola C., Di Marino E., Salone R., Santo A., Urciuoli G. (2023). Study of the groundwater regime in unsaturated slopes prone to landslides by multidisciplinary investigations: Experimental study and numerical modelling. Engineering Geology, 107045. DOI 10.1016/j.enggeo.2023.107045

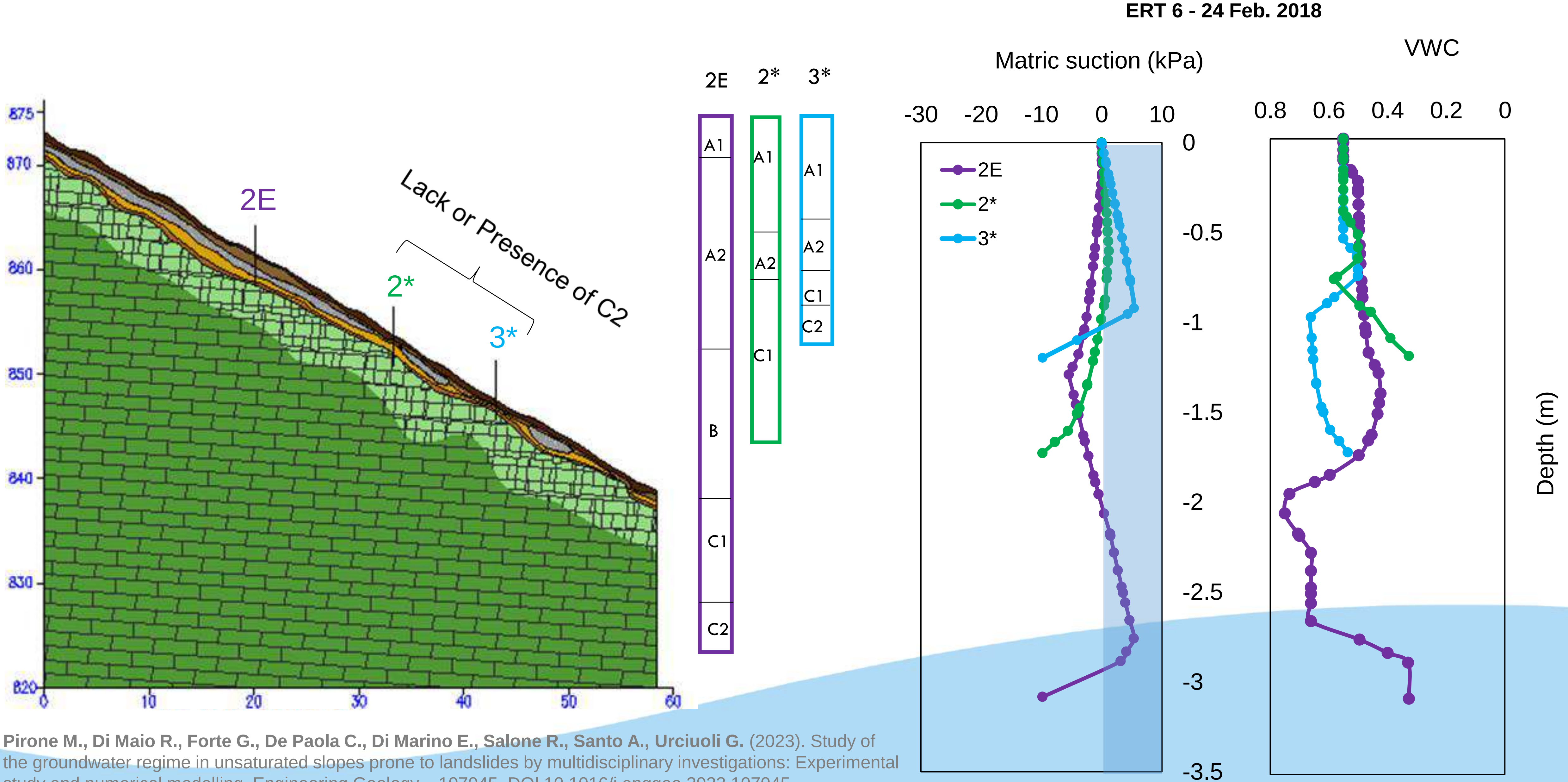
ISSUE #1: VARIABILITY OF SOIL HORIZONS IN TERMS OF CONTINUITY AND THICKNESS





Pirone M., Di Maio R., Forte G., De Paola C., Di Marino E., Salone R., Santo A., Urciuoli G. (2023). Study of the groundwater regime in unsaturated slopes prone to landslides by multidisciplinary investigations: Experimental study and numerical modelling. Engineering Geology, 107045. DOI 10.1016/j.enggeo.2023.107045

ISSUE #1: VARIABILITY OF SOIL HORIZONS IN TERMS OF CONTINUITY AND THICKNESS



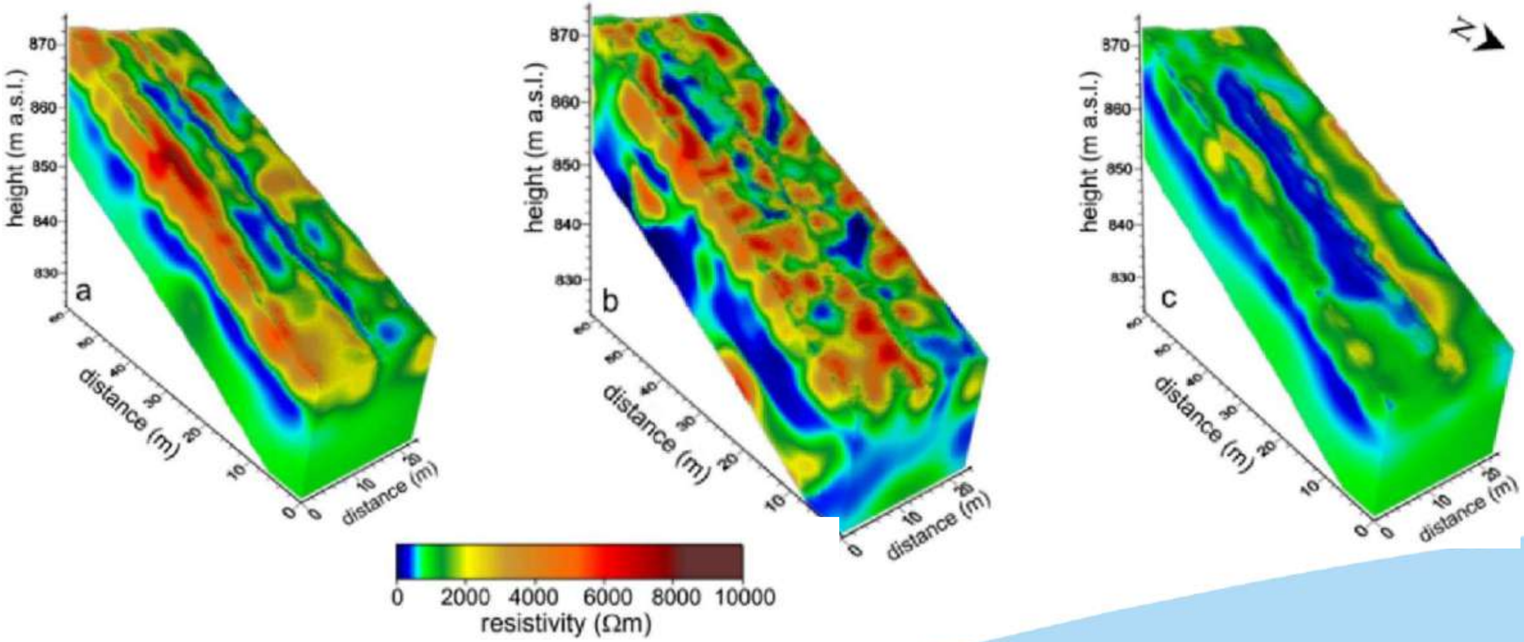
Pirone M., Di Maio R., Forte G., De Paola C., Di Marino E., Salone R., Santo A., Urciuoli G. (2023). Study of the groundwater regime in unsaturated slopes prone to landslides by multidisciplinary investigations: Experimental study and numerical modelling. Engineering Geology, 107045. DOI 10.1016/j.enggeo.2023.107045

ISSUE #2

- The role of variability of the different soil horizons in terms of continuity and thickness

- **What happens at the stratigraphic contact between soil cover and bedrock;**

Summer 29/07/2017 | Winter 24/02/2018 | Spring 01/06/2019

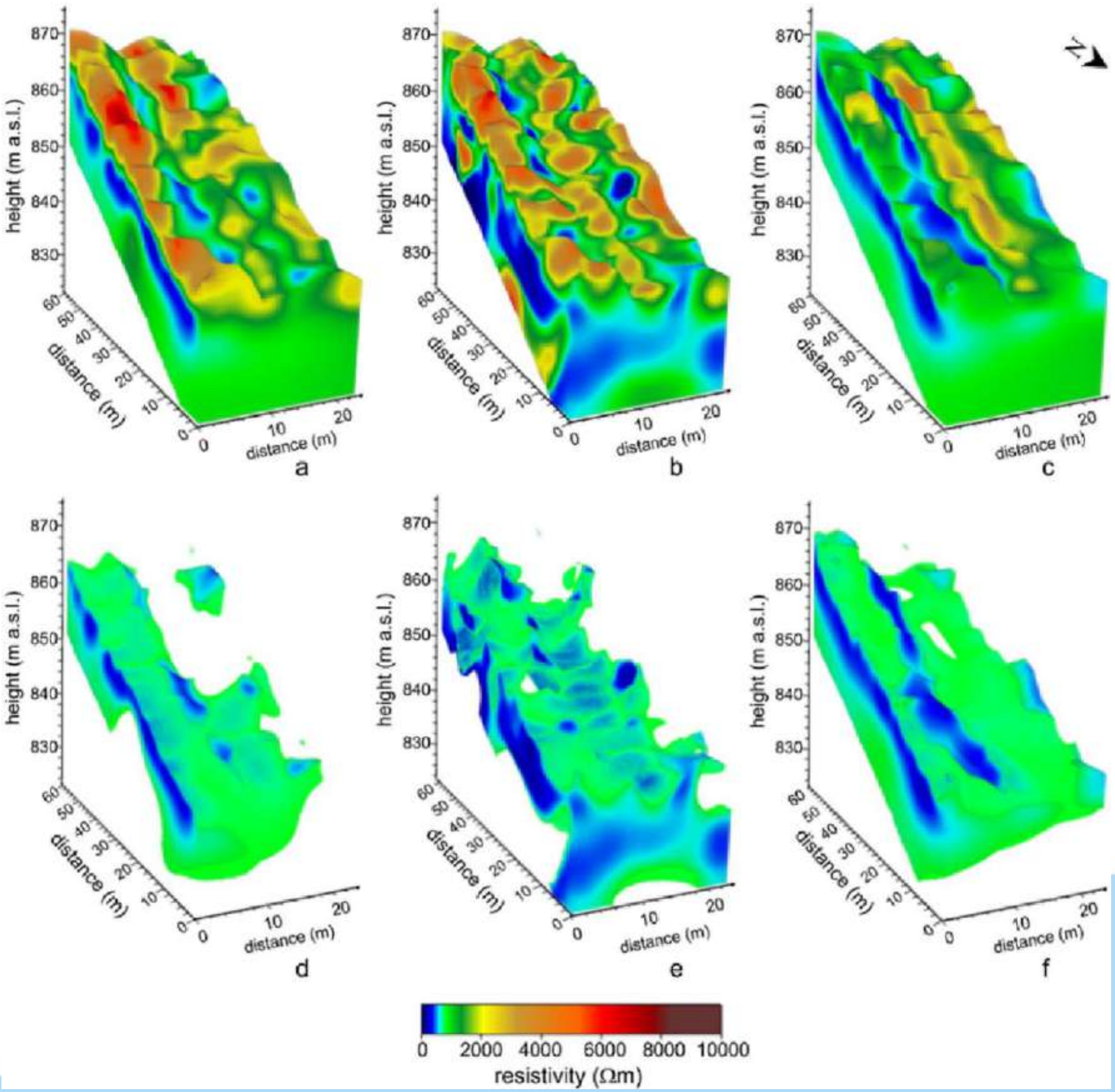


- An unconventional 3D electrode geometry;
- Three parallel profiles 70.5 m long and spaced 12 m apart (profiles 1, 5 and 9)
- multi-electrode cables with an inter-electrode spacing of 1.5 m

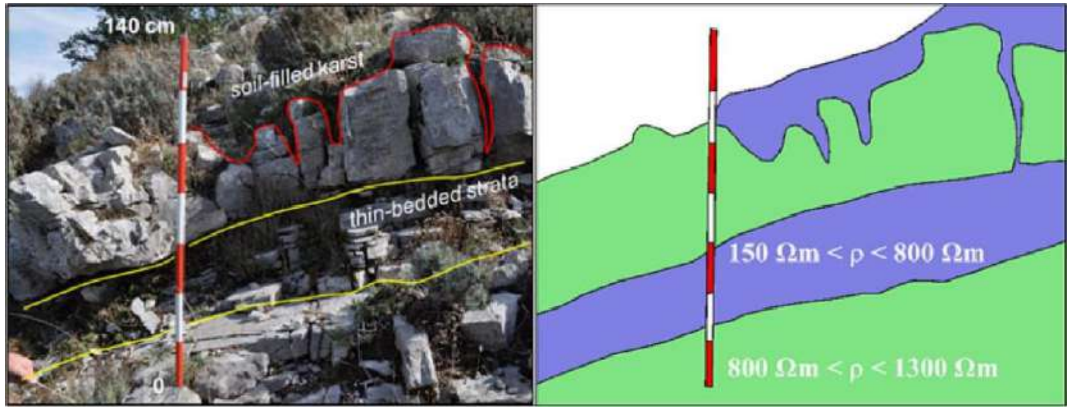
Pirone M., Di Maio R., Forte G., De Paola C., Di Marino E., Salone R., Santo A., Urciuoli G. (2023). Study of the groundwater regime in unsaturated slopes prone to landslides by multidisciplinary investigations: Experimental study and numerical modelling. Engineering Geology, 107045. DOI 10.1016/j.enggeo.2023.107045

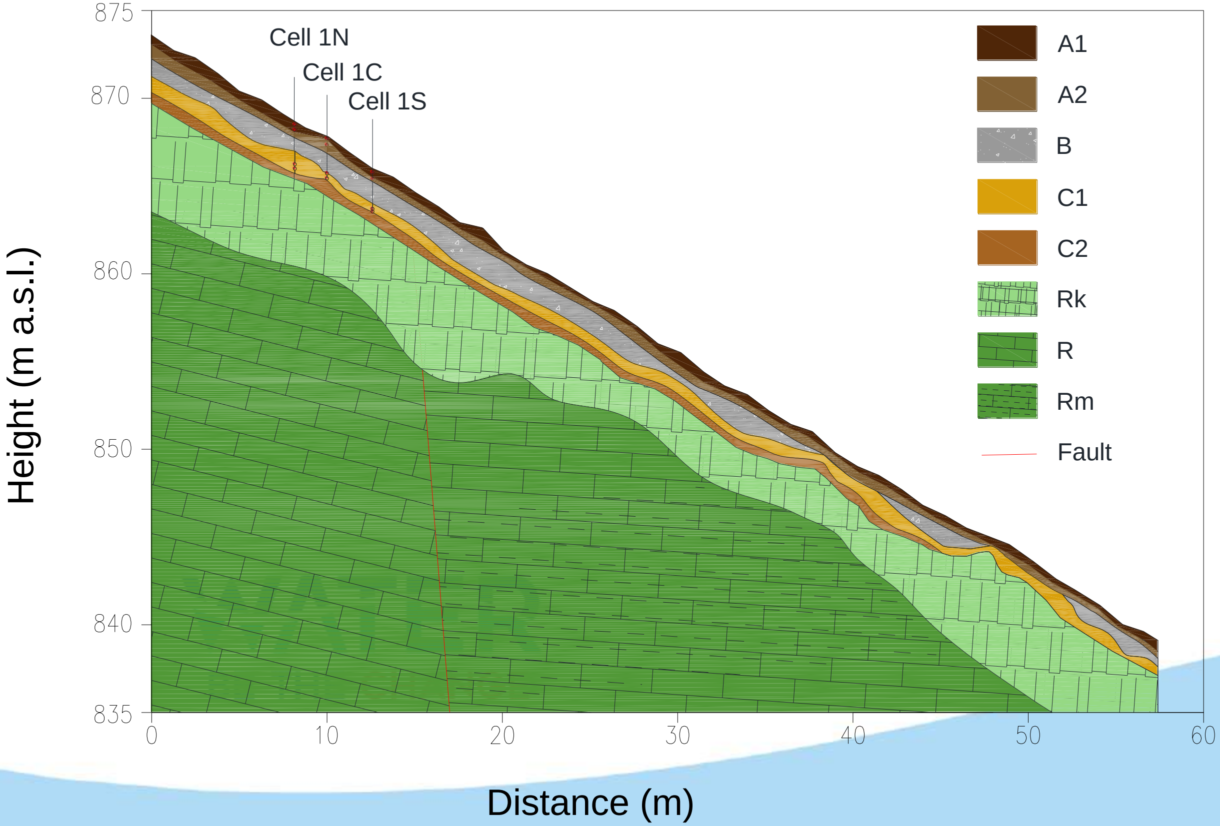
ISSUE #2: WHAT HAPPENS AT THE STRATIGRAPHIC CONTACT BETWEEN SOIL COVER AND BEDROCK

	Summer 29/07/2017	Winter 24/02/2018	Spring 01/06/2019
Soil Cover + Bedrock			
Bedrock			

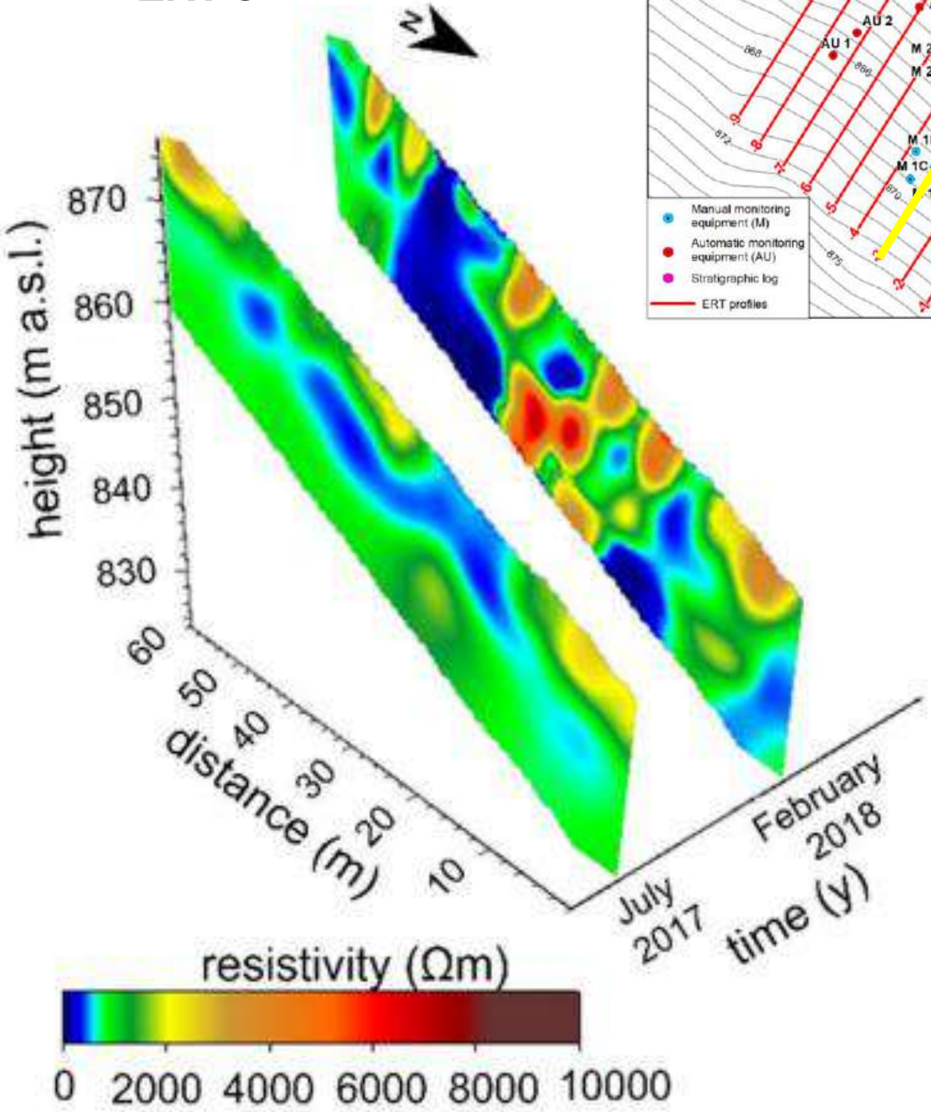


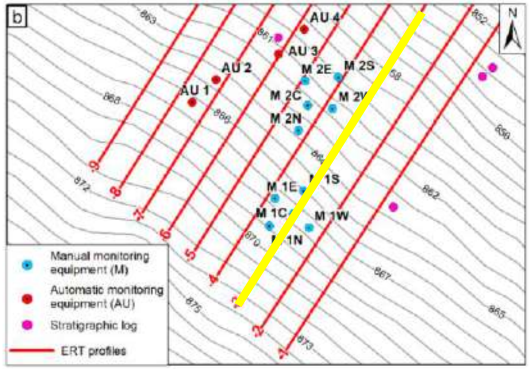
ISSUE #2: WHAT HAPPENS AT THE STRATIGRAPHIC CONTACT BETWEEN SOIL COVER AND BEDROCK





ERT 3





CONCLUSIONS

- **The role of variability of the different soil horizons in terms of continuity and thickness:**
  - **The pumice layer B drains the waters downward reducing the VWC of the upper layers and increasing that of the lower ones**
  - **The higher the thickness of B the lower is VWC of the upper layers**
  - **The lack of continuity of B can cause the formation of suspended water lenses along the slope**
  - **C2 is an aquitard that permits the formation of a suspended groundwater table increasing the VWC**
- **What happens at the stratigraphic contact between soil cover and bedrock:**
  - **C2 filling the fractures provides a hydraulic connection that permits the infiltration of groundwater in the bedrock with a delay**
  - **Groundwater distribution is also controlled by the buried paleo-morphology of the bedrock**

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iah aih Italian Chapter

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flowpath Malta 2023

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New insights on groundwater flow of the Tavo tapped karst springs (Gran Sasso aquifer, Central Apennines) using tracer tests

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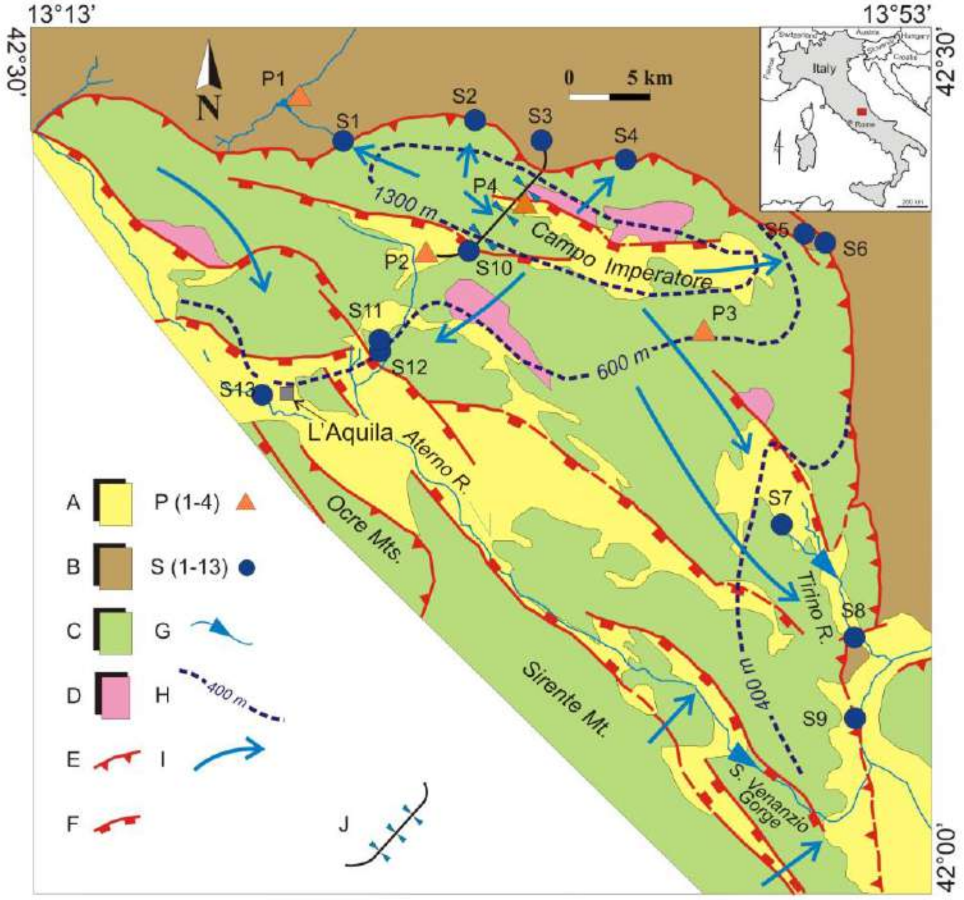
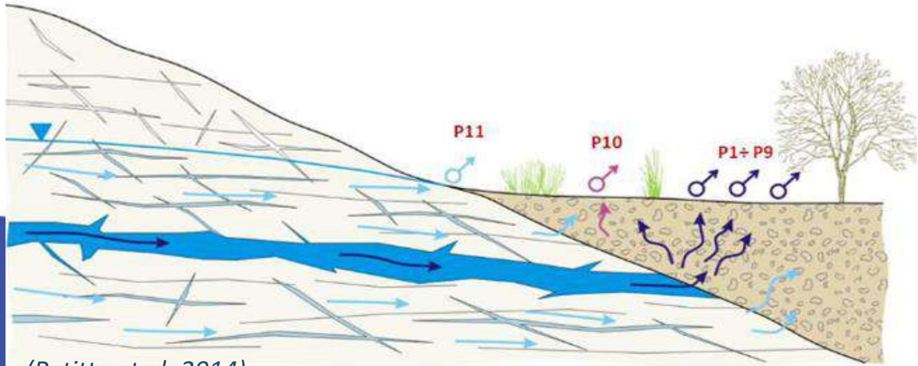
Hydrogeological setting of the Gran Sasso aquifer, Central Italy



Simplified hydrogeological setting of the Gran Sasso aquifer. A) Aquitard (continental detrital units of intramontane basins, Quaternary), B) aquiclude (terrigenous turbidites, Mio-Pliocene), C) aquifer (calcareous sequences, Meso-Cenozoic), D) low permeability bedrock (dolomite, upper Triassic), E) main thrust, F) main extensional fault, P(1-4) selected climatic gauges, S(1-13) main springs, G) streambed spring, H) presumed water table elevation (m a.s.l.), I) regional groundwater flowpath, J) highway tunnel drainage (modified from Petitta et al., 2015)

- Calcareous-karstic ridge >1000 km^2
- Total spring discharge : 18 m^3/s - 25 m^3/s
- Springs do not show typical karst features and discharge regimen is steady (limited changes during the year)
- Groundwater feeds the springs by two different flowpaths in the carbonate aquifer: the fracture network (light blue arrows) and the buried karst (or high-fractured) system (dark blue arrows)
- Main faults represent groundwater divides separating main flowpaths
- Endorheic basin having glacial-tectonic-karst origin (Campo Imperatore basin, 1650 m a.s.l.) acts as preferential recharge area
- It is a National Park and a highway tunnel is crossing and draining the aquifer



(Petitta et al.,2014)

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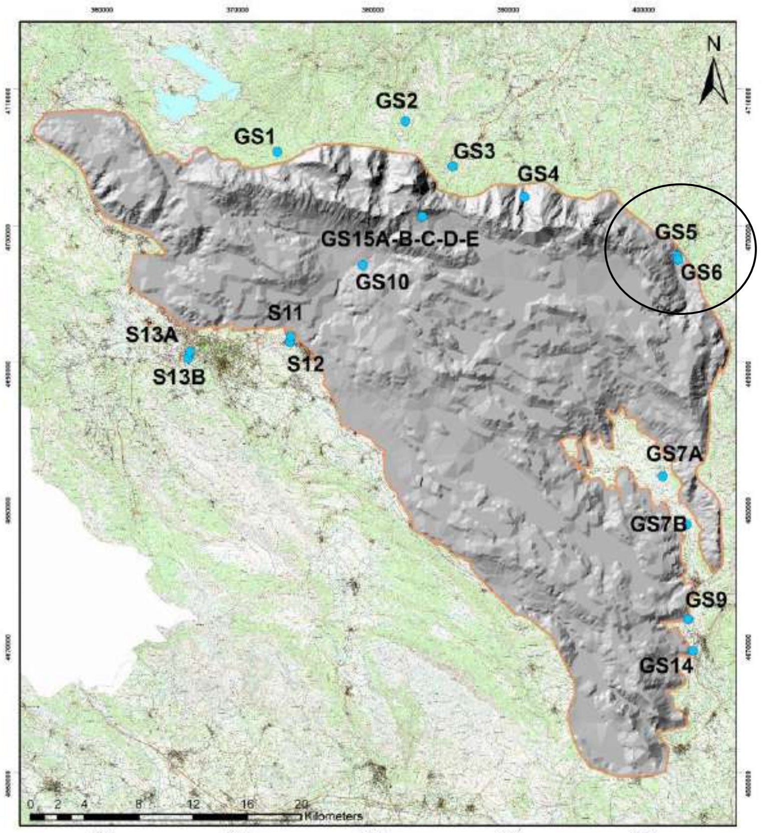
Tracer test in the Gran Sasso aquifer (05.04.22-07.04.22)



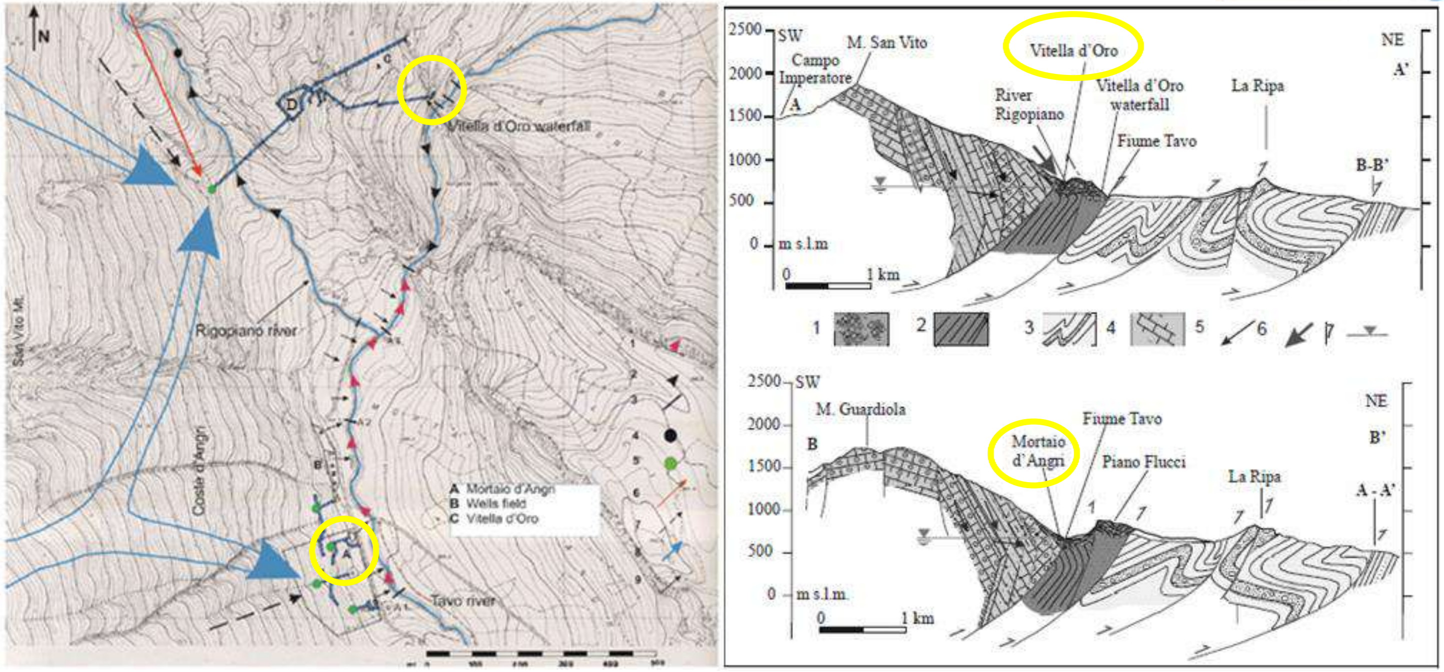


Figure 2: On the left side: hydrodynamic scheme. A) Mortaio d'Angri, B) Wells field, C) Vitella d'Oro, D) Vitella D'oro spring catchment tank 1) Linear springs, 2) decrease of discharge, 3) sections of discharge measurement, 4) swallow hole, 5) catchments, 6) karstic circuit responsible of turbidity from Rigopiano river, 7) karstic circuit, 8) directions of the basal flow, 9) groundwater interactions between the carbonate and Rigopiano conglomerate complexes (Rusi et al., 2016). On the right side: Geologic - hydrogeologic cross-sections. 1) Conglomerate of Rigopiano complex, 2) Calcareniti di M.Fiore complex, 3) Laga and Cellino complex, 4) calcareous complex, 5) karstic conduits responsible of the floods, 6) karstic conduits responsible of turbidity, 7) Springs altitude (661,4 m Vitella d'Oro - 675 m Mortaio d'Angri)(Ferracuti et al., 2006; Rusi et al., 2016)

GS5: The Vitella d'Oro spring

- **Fed partly by the basic carbonate aquifer and partly by direct infiltration into the Rigopiano Conglomerates**. The latter causes the **activation of the karst network** of the Rigopiano ditch, which is often accompanied by **increases in turbidity**.

- The spring system therefore presents several weak points due to the different nature of the feeding aquifers (discharge: 303 l/s)

GS6: The Mortaio d'Angri spring

- **Outlet of the regional aquifer**
- **Fed by groundwater flows from the Campo Imperatore** (discharge: 250 l/s)

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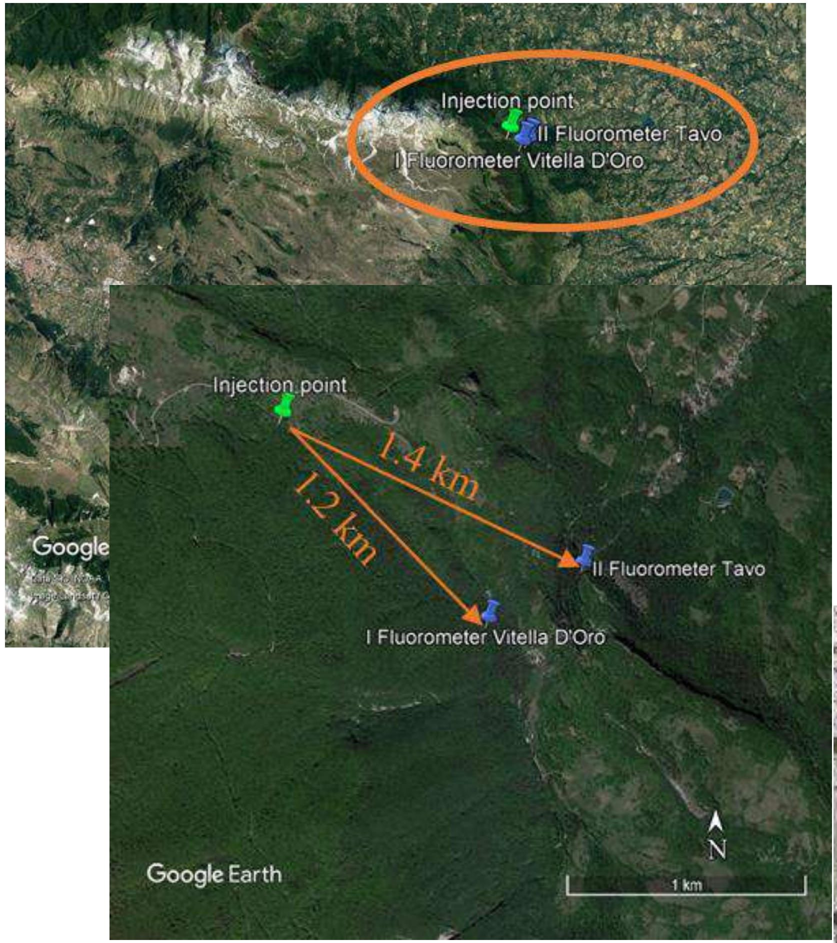
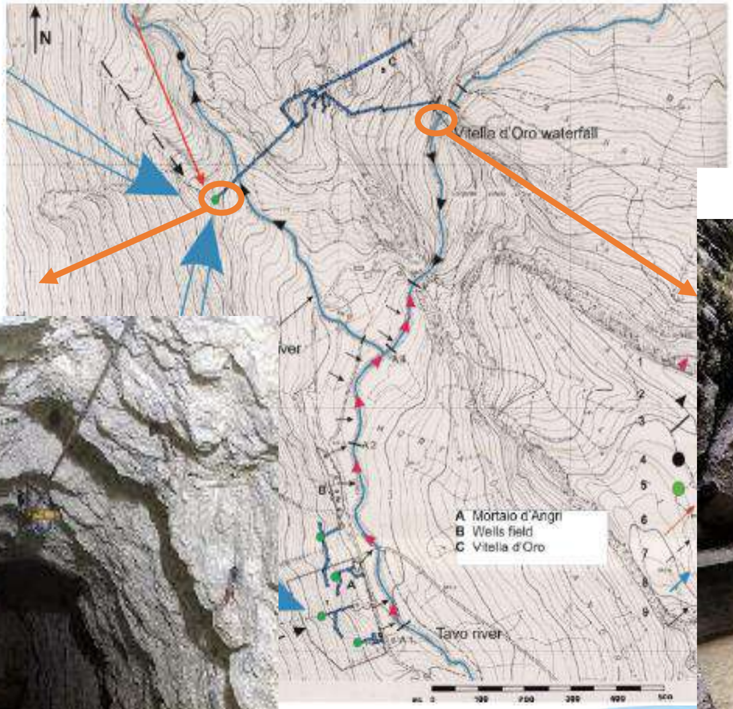
Tracer test in the Gran Sasso aquifer (05.04.22-07.04.22)

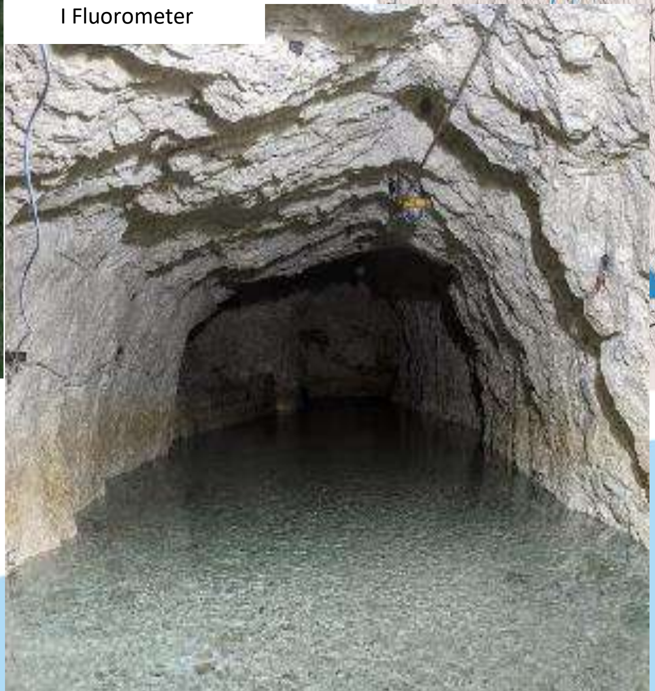
- **Injection point**: Rigopiano ditch (1045 m s.l.m.)
- Distance injection point- I Fluorometer (Vitella d'Oro spring catchment area, 748 m asl): **1.2 km**
- Distance injection point- II Fluorometer (Tavo River, 610 m asl): **1.4 km**





(Rusi et al., 2016)

I Fluorometer



II Fluorometer

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Tracer test in the Gran Sasso aquifer (05.04.22-07.04.22)

- 2 Tracers:
- 20 g *Uranine (diluited in 2L of water)* → **Injection starts at 8:15**
- 100 g *Naphtionate (diluited in 2L of water)* → **Injection starts at 9:15**

- **Albillia FL30 Fluorometer probe** (2). The acquisition time of the field fluorometer was set every 5 minutes.

- **Traditional sampling** with amber glass bottles

- **Charcoal bags** installed near the monitoring and injection points. **After the end of the test, the used charcoal bags have been collected and replaced with new ones at the same points,** in the event that the tracer arrived even after the end of the test, due to the activation of karst conduits.

Discharge on the day of the tracer test:

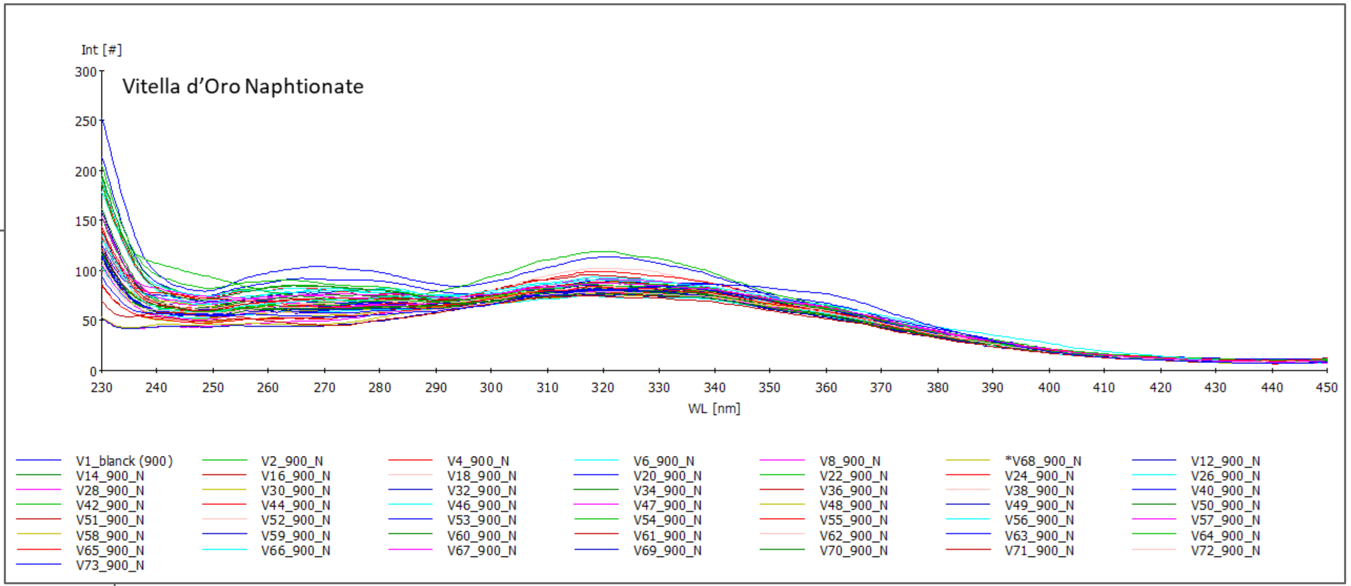
- *439 l/s* at the Tavo River
- *378 l/s* at the Vitella d'Oro spring
- *32 l/s* at the injection point

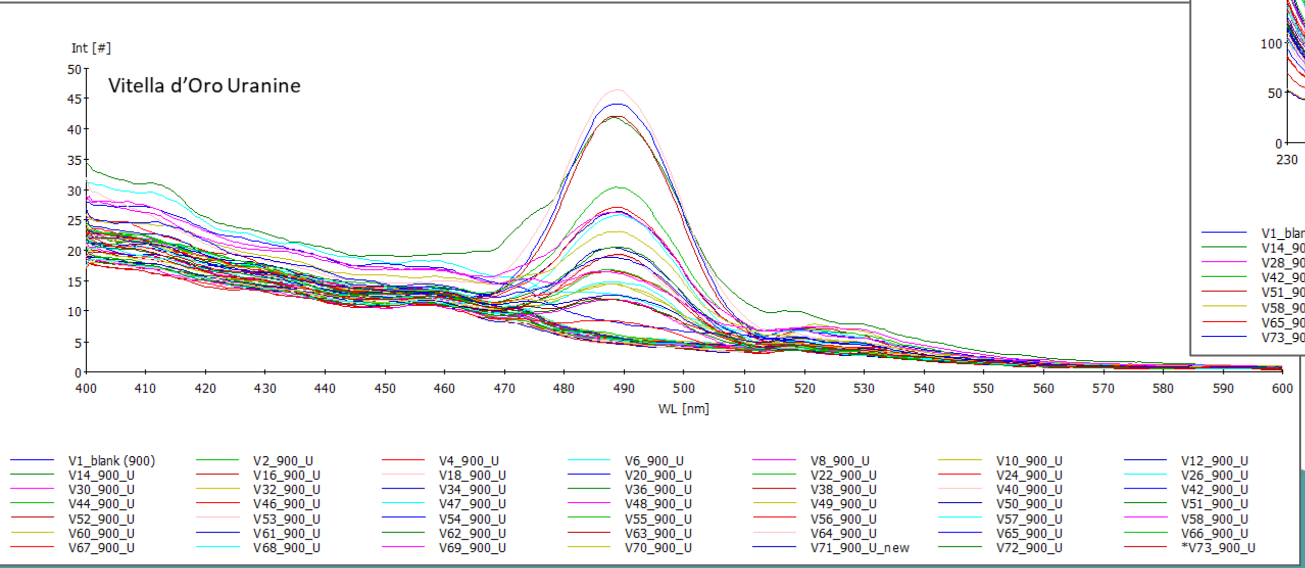
Tracer test in the Gran Sasso aquifer (05.04.22-07.04.22)

The collected water samples have been analysed using the *Perkin Elmer LS-55* laboratory fluorometer in the laboratory of the University of Karlsruhe Institute of Technology (KIT) in Germany.

The LS-55 is a fluorescence spectrophotometer that uses a pulsed xenon lamp as the excitation source.

The presence of a dye in a sample is indicated by the appearance of the respective peak in the sample spectrum. The absorption maxima of Uranine and Naphthionate are at 490 nm and 320 nm, respectively.





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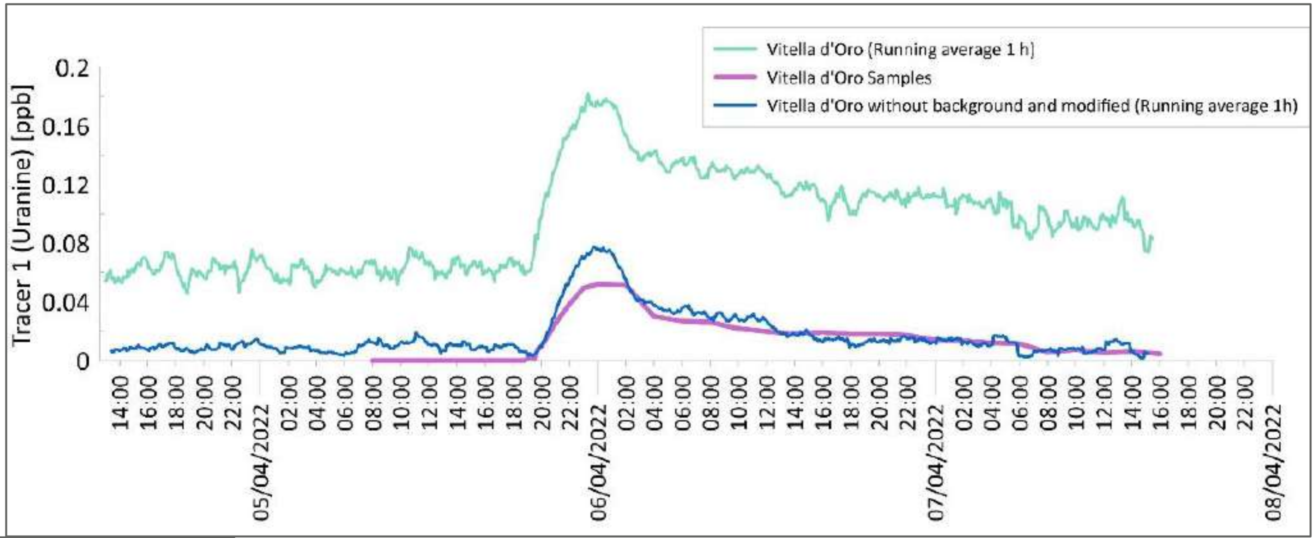
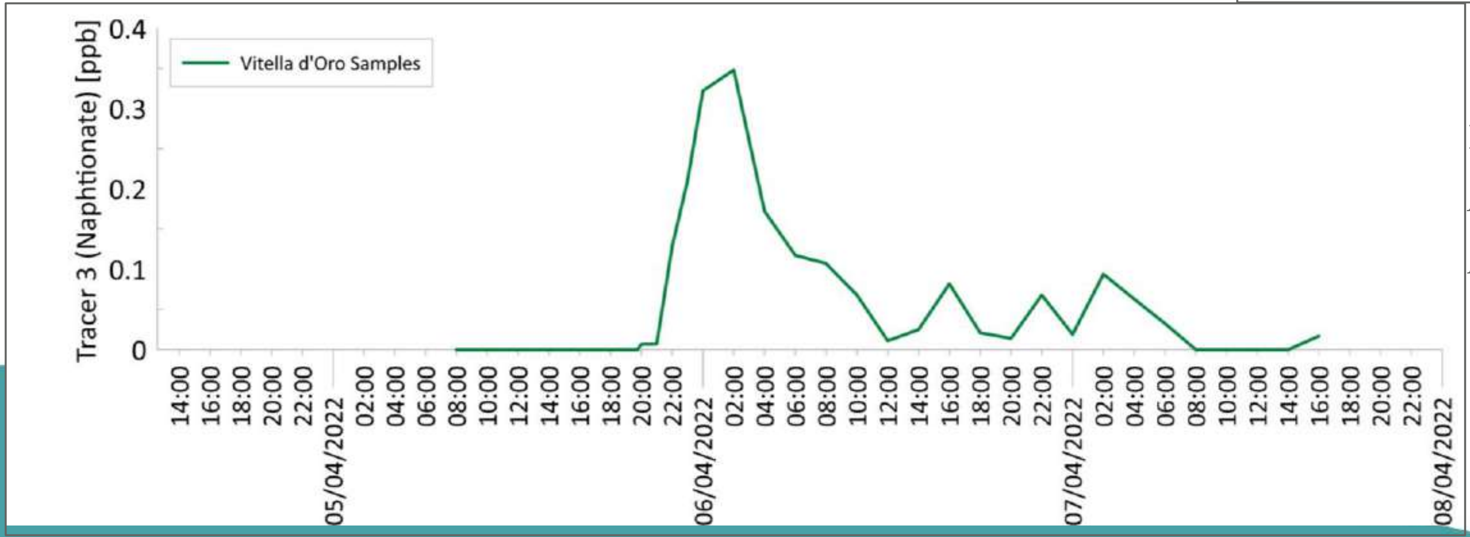
Tracer test in the Gran Sasso aquifer - **Vitella d'Oro Results**

Arrival of both tracers approx. 11 hours after the injection of the tracers at the Rigopiano ditch

Uranine

- *Arrival*: 05.04.2022 at 19:15
- *Maximum peak*: 06.04.2022 at 00:00 **(0.052 μg/L)**





Naphthionate

Arrival: 05.04.2022 at 20:00

Maximum peak : 06.04.2022 at 02:00 **(0.35 μg/L)**

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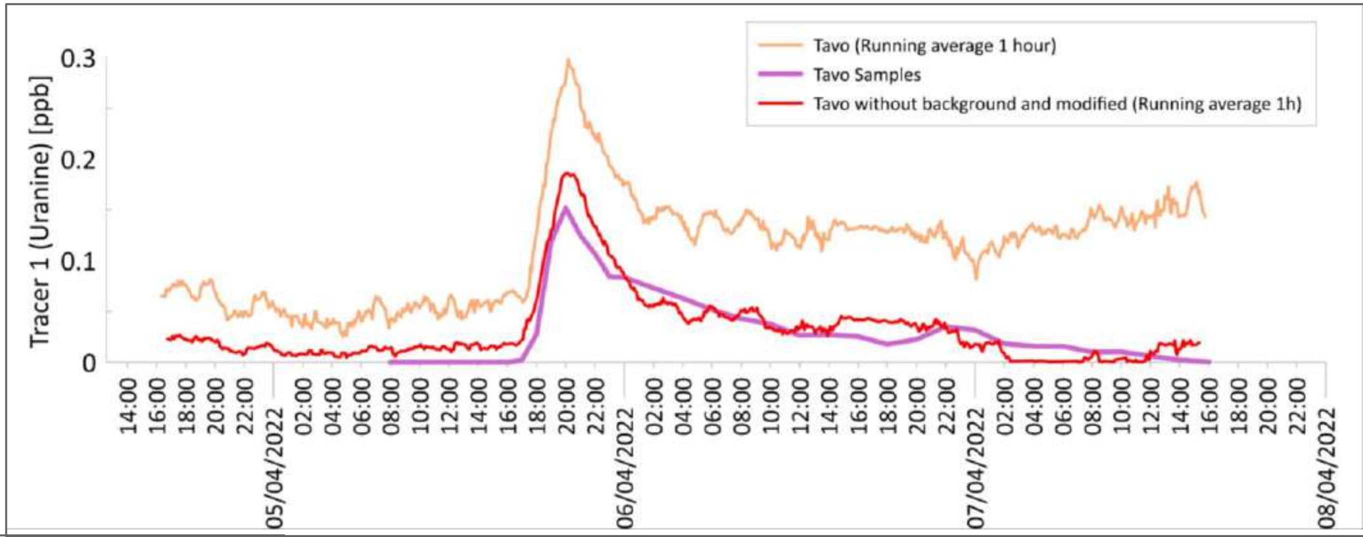
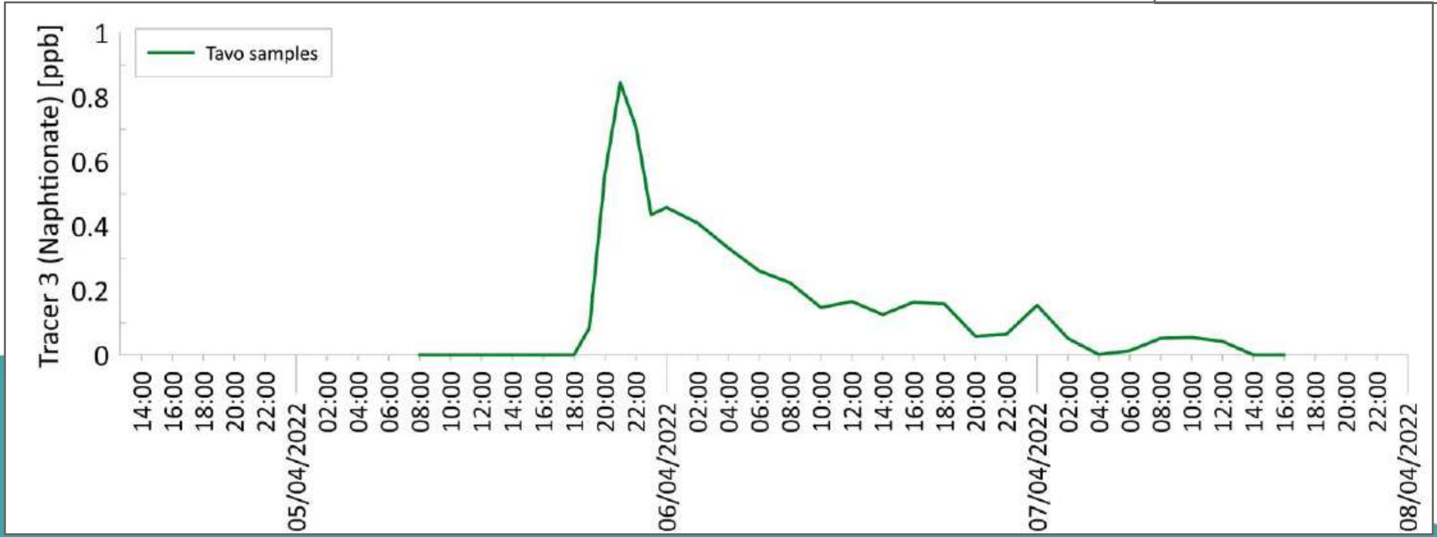
Tracer test in the Gran Sasso aquifer - **Tavo River Results**

Arrival of both tracers approx. 9.45 hours after the injection of the tracers at the Rigopiano ditch



Uranine

- *Arrival*: 05.04.2022 at 18:00
- *Maximum peak*: 05.04.2022 at 20:00 **(0.15 μg/L)**



Naphthionate

Arrival: 05.04.2022 at 19:00

Maximum peak : 05.04.2022 at 21:00 **(0.85 μg/L)**

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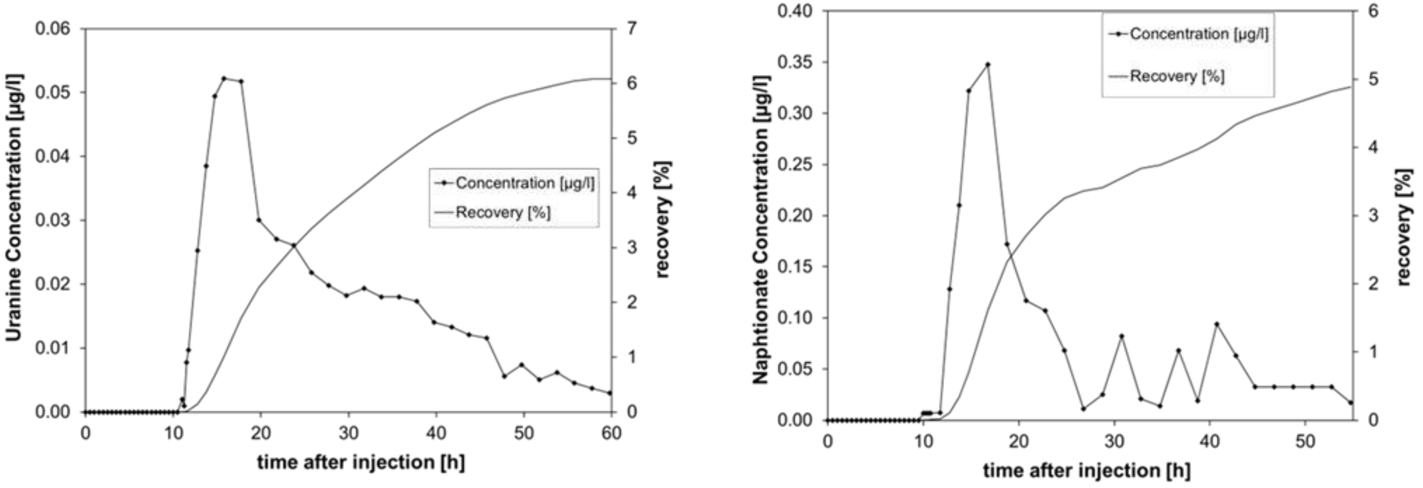
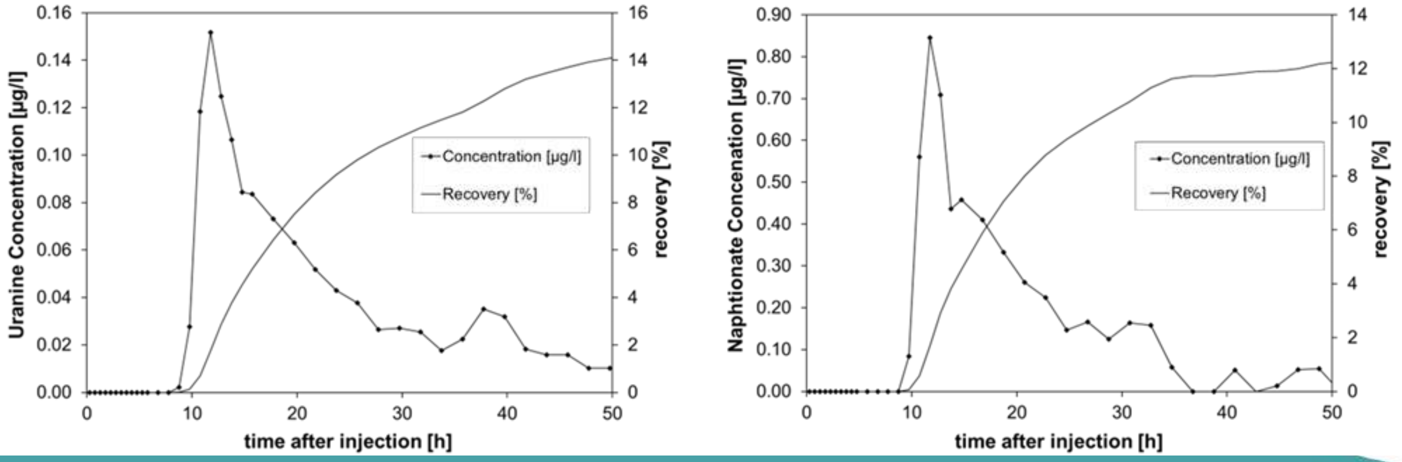
Tracer test in the Gran Sasso aquifer - **BTCs**

The KARMA Project

Recovery tracer: Vitella d'Oro



Recovery tracer: Tavo



The final product of quantitative tracing is a **tracer breakthrough curve** (BTC).

	Injection time		Arrival tracer		Maximum peak	
	VO	TA	VO	TA	VO	TA
U	05.04.2022 at 8:15		After 11h	After 9h45	06.04.2022 at 00:00 **(0.052 µg/L)**	05.04.2022 at 20:00 **(0.15 µg/L)**
Na	05.04.2022 at 9:15		After 11h	After 9h45	06.04.2022 at 02:00 **(0.35 µg/L)**	05.04.2022 at 21:00 **(0.85 µg/L)**

	Recovery (%)		V (m/h)		D	
	VO	TA	VO	TA	VO	TA
U	6.1	14.3	37	61	498	441
Na	4.9	12.3	30	70	339	332

*VO: Vitella d'Oro spring
TA: Tavo River

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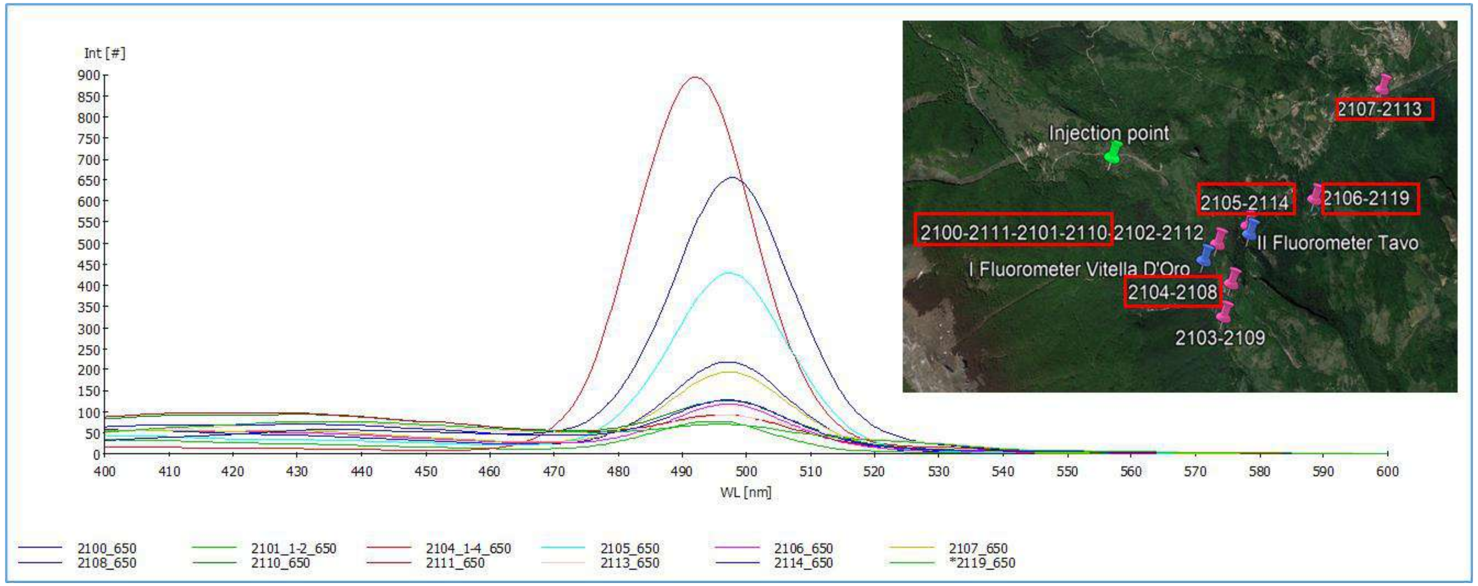
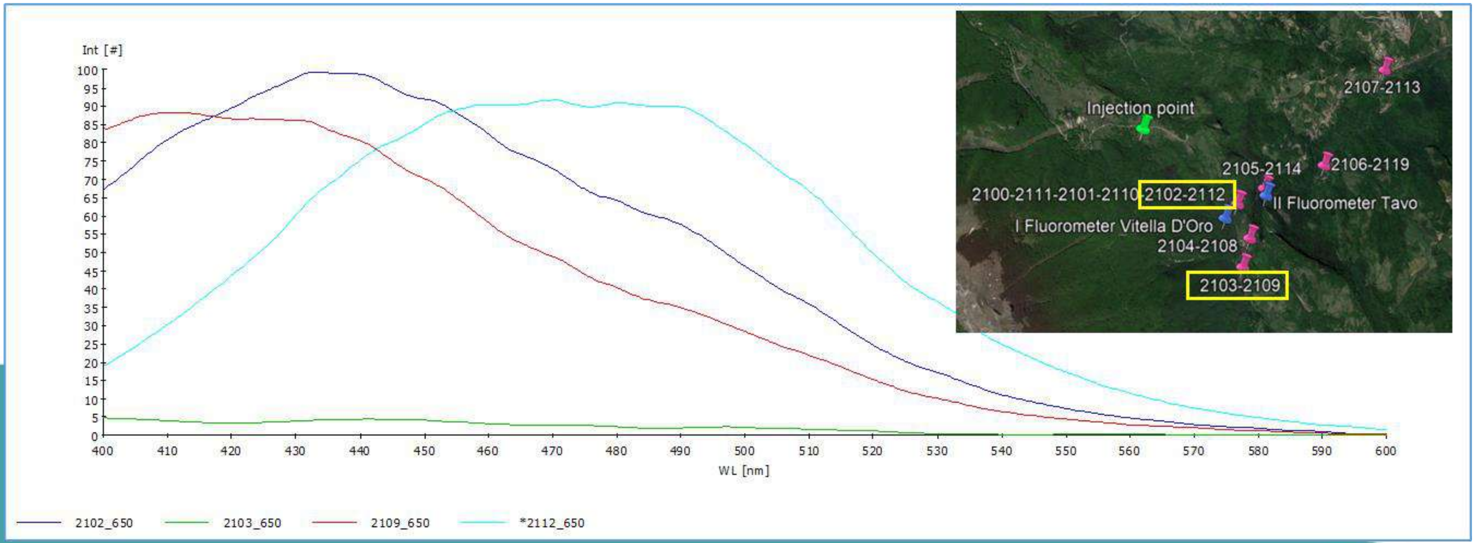
Tracer test in the Gran Sasso aquifer: **Charcoal bags**



Uranine has been detected in 6 out of 8 monitoring points. The tracer has been also detected in the charcoal bags installed after the test, a clear sign of the presence of two groundwater circuits with different response times.



At two monitoring points (Mortaio d'Angri spring) **no tracer has been detected** either during or after the test.

Conclusion

- The Mortaio d'Angri spring is only recharged by the **regional-scale aquifer**, fed by the base flow.
- The **Vitella d'Oro spring** is characterised by a relatively **complex groundwater basin**. The presence of **karst networks** and **karst conduits** determines a **rapid response to meteoric events.**
- **The tracer reaches the tunnel of the Vitella d'Oro spring with a longer response time than the Tavo River**. **Tracer does not flow freely on the surface water but infiltrates into the ground, reaching the aquifer under the Rigopiano ditch, and then re-emerges in the confluence area between the Rigopiano ditch and the Tavo River**.
- The water coming from the Rigopiano ditch arrives with reduced percentages at the Vitella d’Oro spring and Tavo River (**recovery rate around 20%**) and the other 80% of spring discharge would coming from the regional base flow.
- The **presence** of a **longer** and **more complex pathway into the karst system,** feeding both the Vitella d'Oro spring and the Tavo River, **with delayed response times**, is also demonstrated by the presence of tracer in the charcoal bags in the period following the test.
- These results show how the Vitella d’Oro **spring** is particularly **sensitive** to both basin-scale variations and extremely local recharge conditions, thus considering the spring **vulnerable to discharge reduction/exhaustion in a potential climate change scenario**.

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Modelling transient groundwater flow dynamics in the Tabriz unconfined aquifer near Urmia Lake (Iran)

Abdollahi Z., Feizizadeh B., Shokati B., **Gaiolini M.***, Busico G., Mastrocicco M., Colombani N.*

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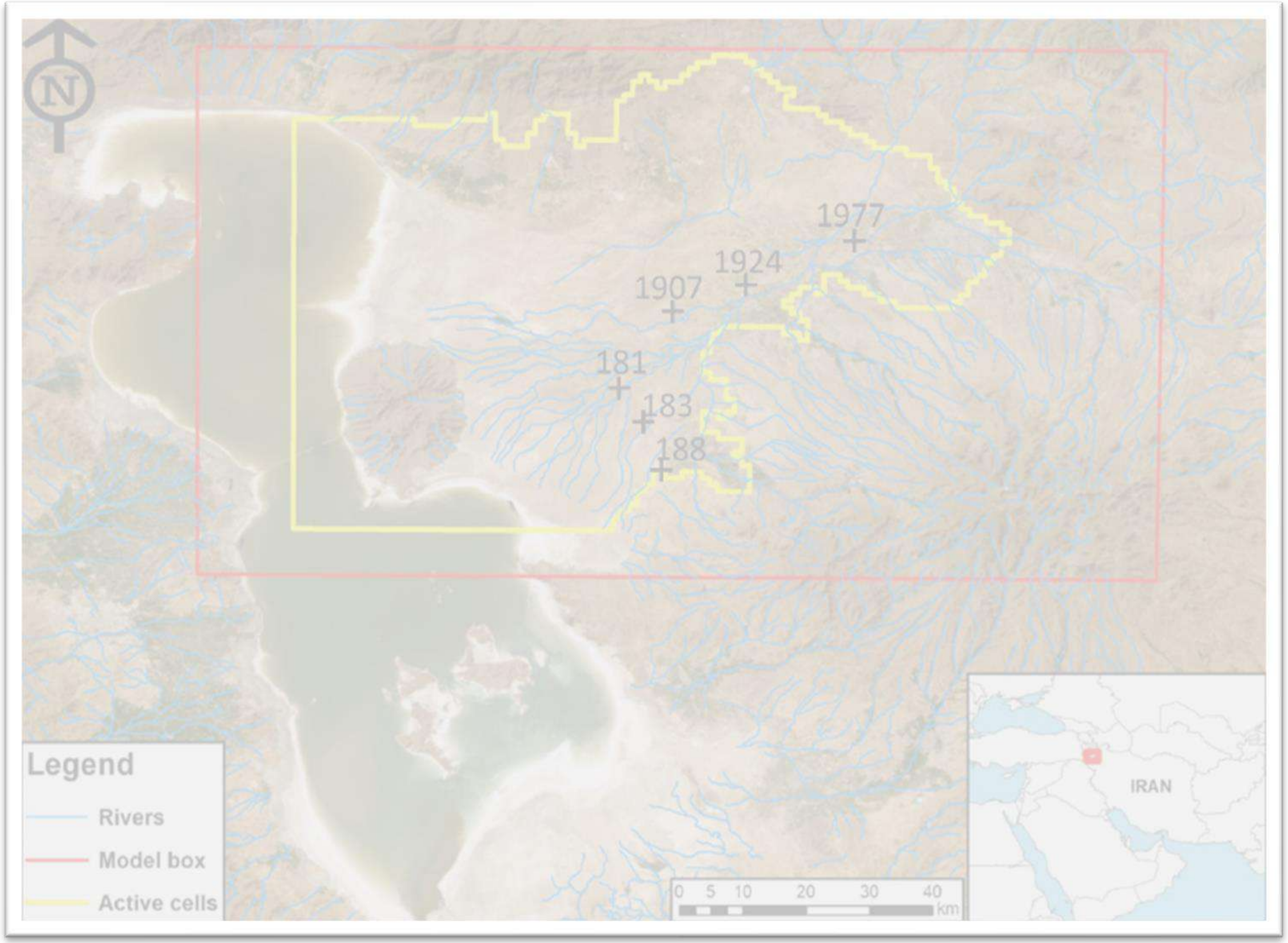
Research questions

General:

- *Estimate climate changes impacts on groundwater resources at the aquifer scale.*

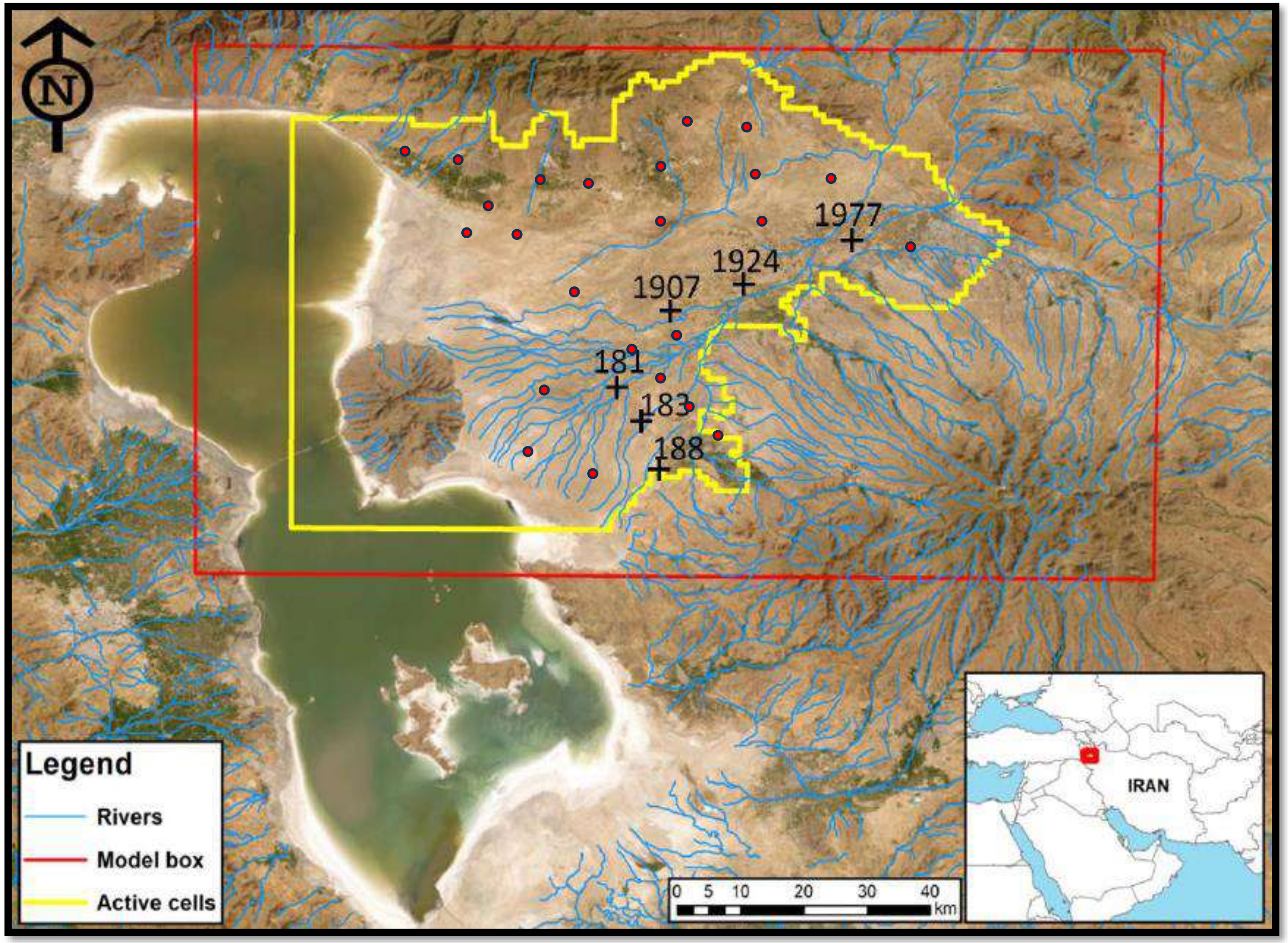
Specific:

- *Include remotely sensed evapotranspiration rates to accurately simulate this component.*
- *Quantify groundwater exploitation impact on groundwater balance.*



The study area

- *The Urmia Lake basin is located in north-western Iran and covers an area of about 52,000 km² (ULRP 2017).*
- *The increasing anthropization has led to an increasing use of available water resources and land for drinking and agriculture use.*
- *The drying up of the lake has led the groundwater resources to experience quality deterioration and quantity depletion.*



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Input datasets

- *Model stresses and boundary conditions were implemented with specific remotely sensed data downloaded from national and worldwide databases.*

Regional Water Company of East Azerbaijan → Wells

ULRP → Urmia Lake levels

MODIS → EVT

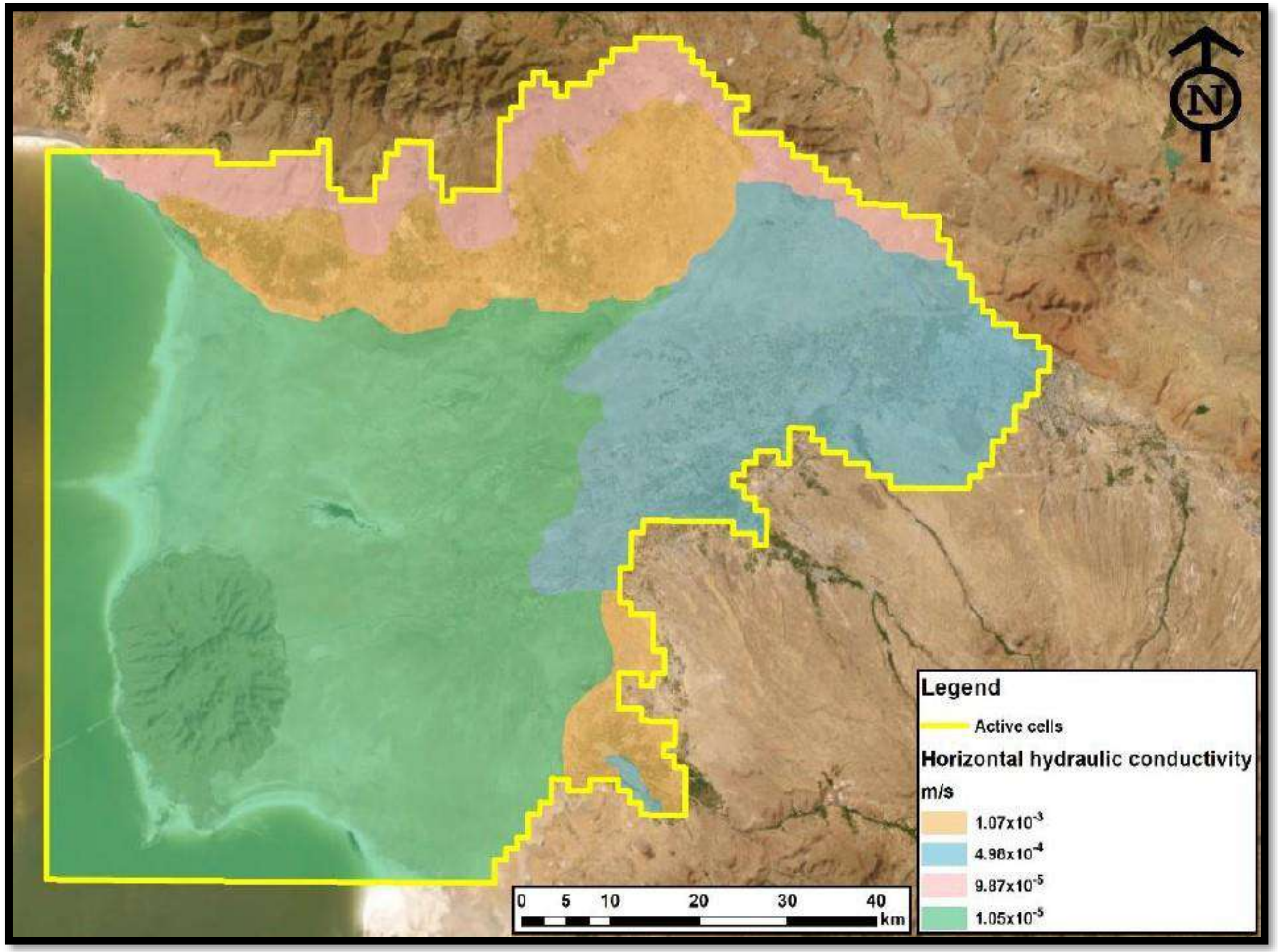
General Meteorological Department of East Azerbaijan → Precipitation → RCH

Modelling phase

- *The flow simulation was carried out via PM11, using the MODFLOW-2005 NWT code (Harbaugh, 2005).*

2000 2016

- *The model domain consisted of 110 rows, 155 columns, and 1 layer with variable width and thickness. 68 stress periods of seasonal length were used.*
- *The SRTM Digital Terrain Model with a spatial resolution of 20x20 m cells was used.*
- *Values of hydraulic conductivity have been averaged to get a representative value for each geological formation.*



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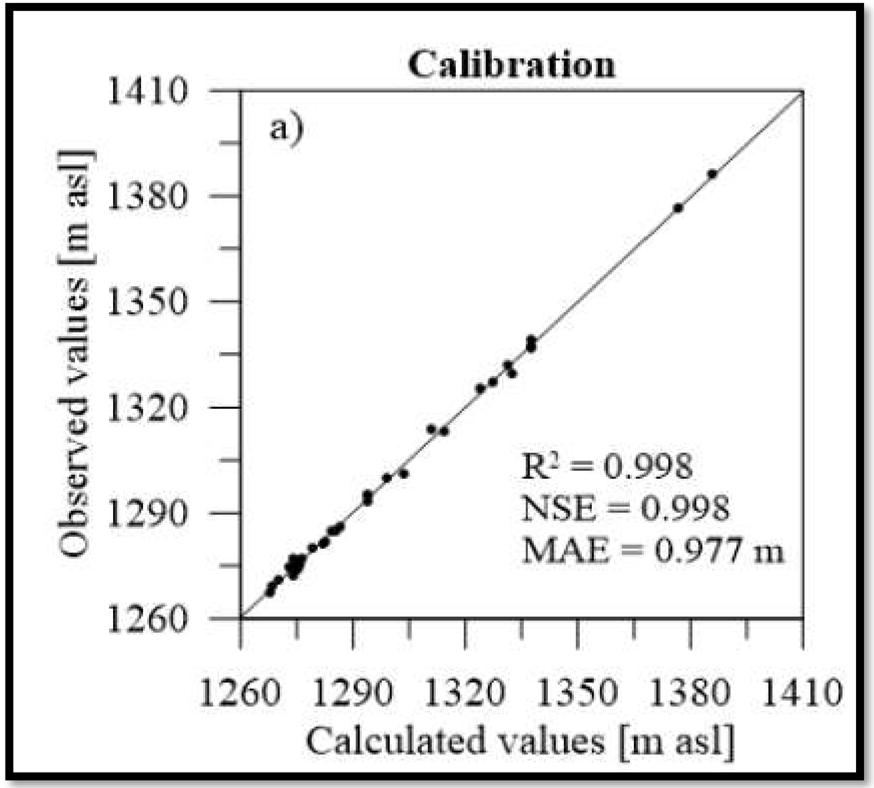
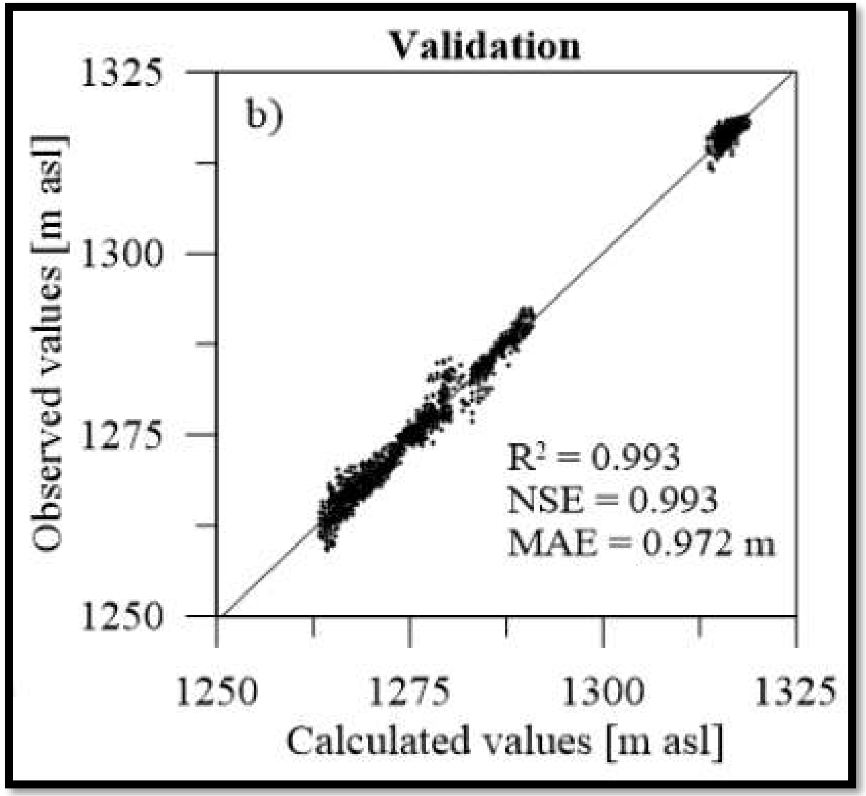
Calibration and validation

- *The steady-state simulation has been calibrated via PEST (Doherty 2010) against observed heads for the year 2000.*



- *The validation was performed by exploiting the widespread network of monitoring wells measuring hydraulic heads over the simulation time.*



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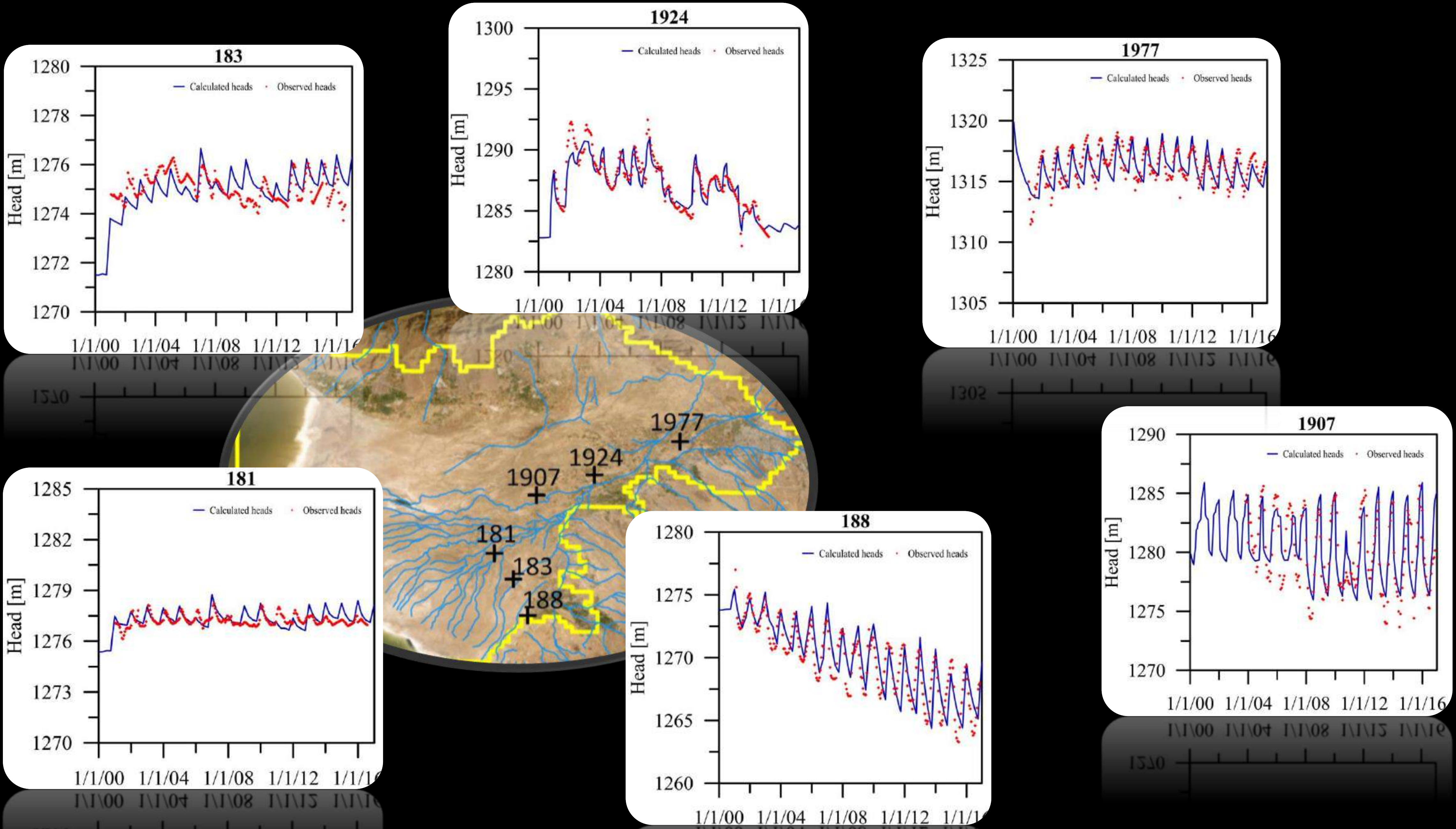
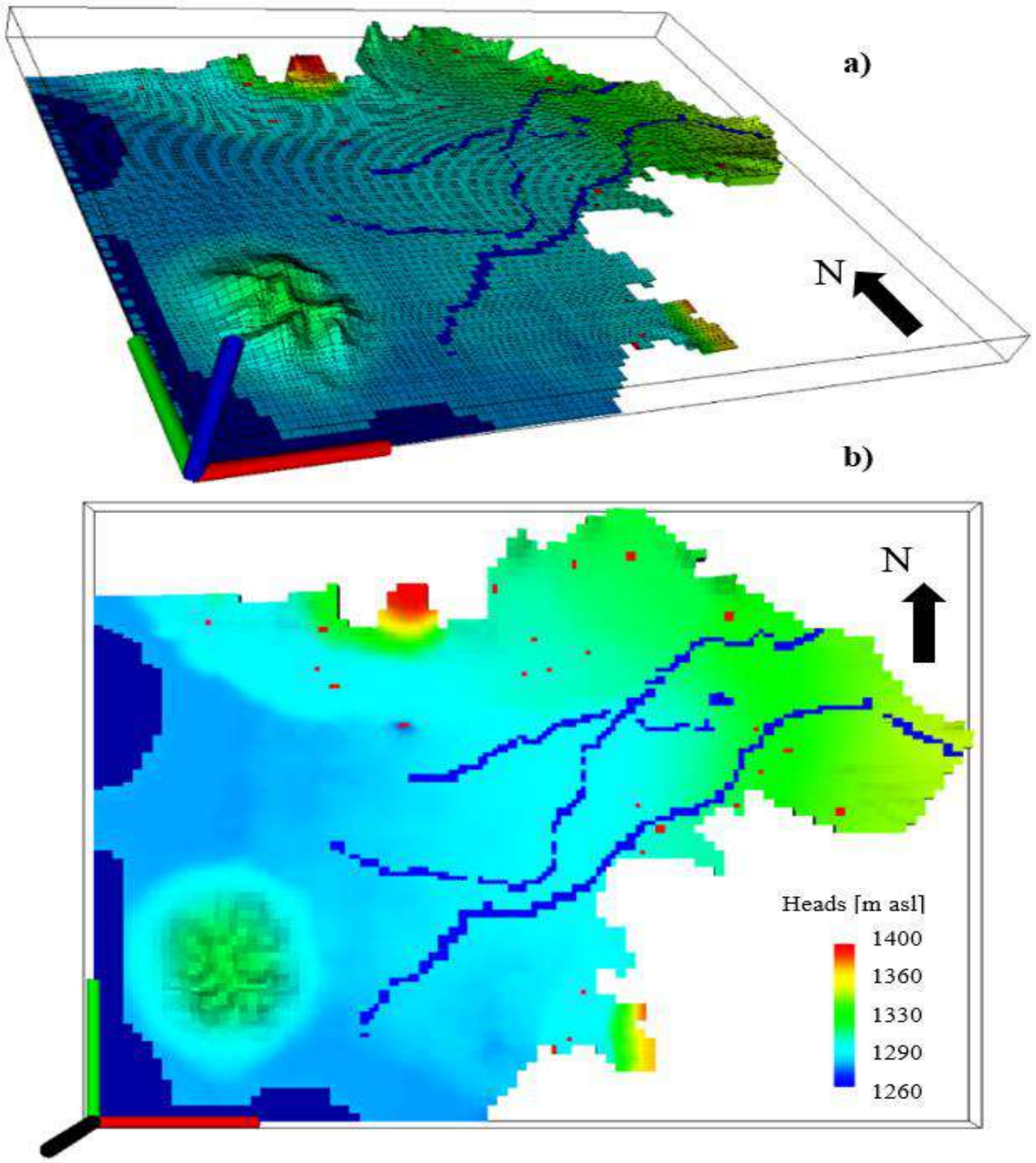
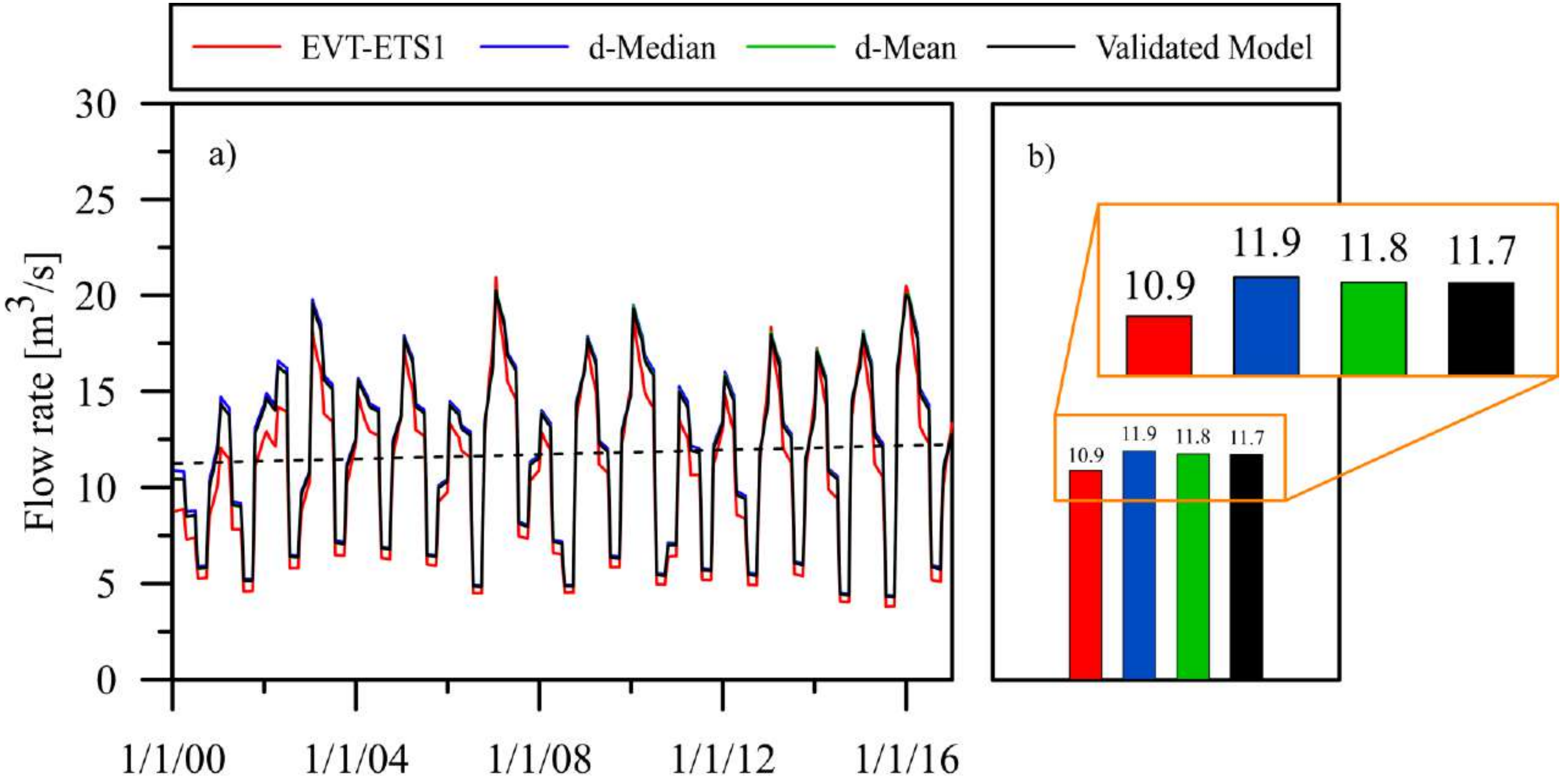

183
Calculated heads
Observed heads
Head [m]
1270
1272
1274
1276
1278
1280
1/1/00
1/1/04
1/1/08
1/1/12
1924
Calculated heads
Observed heads
Head [m]
1280
1285
1290
1295
1300
1/1/00
1/1/04
1/1/08
1/1/12
1977
Calculated heads
Observed heads
Head [m]
1305
1310
1315
1320
1325
1/1/00
1/1/04
1/1/08
1/1/12
1/1/16
1907
Calculated heads
Observed heads
Head [m]
1270
1275
1280
1285
1290
1/1/00
1/1/04
1/1/08
1/1/12
1/1/16
181
Calculated heads
Observed heads
Head [m]
1270
1273
1276
1279
1282
1285
1/1/00
1/1/04
1/1/08
1/1/12
188
Calculated heads
Observed heads
Head [m]
1260
1265
1270
1275
1280
1/1/00
1/1/04
1/1/08
1/1/12
1977
1924
1907
181
183
188

Calculated water balance

Flow Term	IN (m^3/s)	OUT (m^3/s)	IN+OUT (m^3/s)
STORAGE	3.740	7.290	- 3.550
WEL	0.000	1.024	- 1.024
RIV	2.370	1.360	+ 1.011
EVT	0.000	11.75	- 11.75
GHB lake	2.976	0.582	+ 2.394
RCH	12.93	0.000	+ 12.93
Sum	22.01	22.00	+ 0.01



EVT scenarios



- *d-Median*
- *d-Mean (averaged value of the evapotranspiration extinction depth over the model domain)*
- *EVT-ETS1 (Evapotranspiration Segment Package)*

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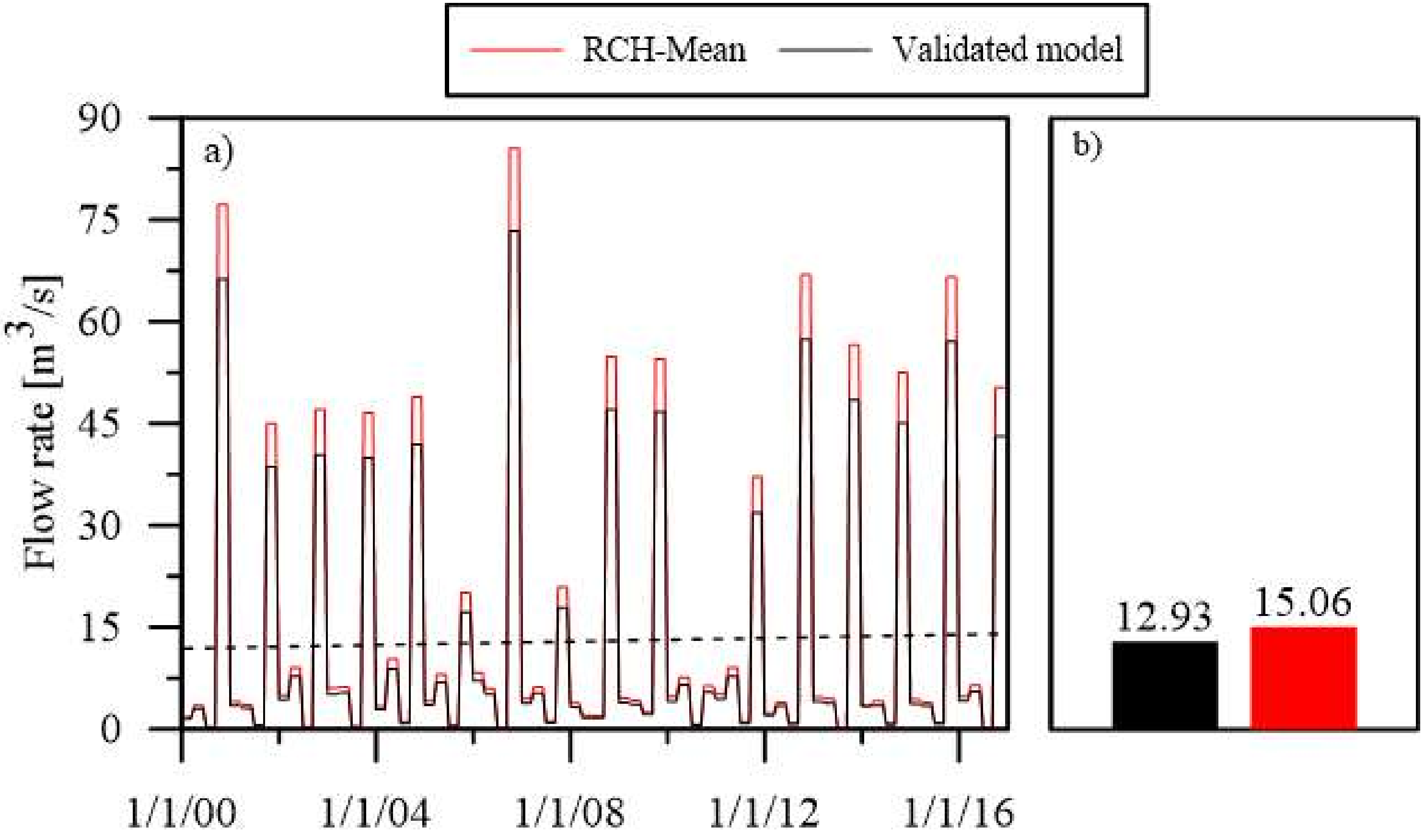
RCH scenarios

- *RCH-Mean scenario leads to a non-negligible overestimation of up to 7 m^3/s during wet periods and on average of 2 m^3/s.*



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Impact on the model performances

Scenario	R^2 (-)	NSE (-)	MAE (m)
Validated Model	0.993	0.993	0.972
d-Mean	0.993	0.993	0.972
d-Median	0.993	0.993	0.985
EVT-ETS1	0.992	0.987	1.430
RCH-Mean	0.991	0.987	1.309

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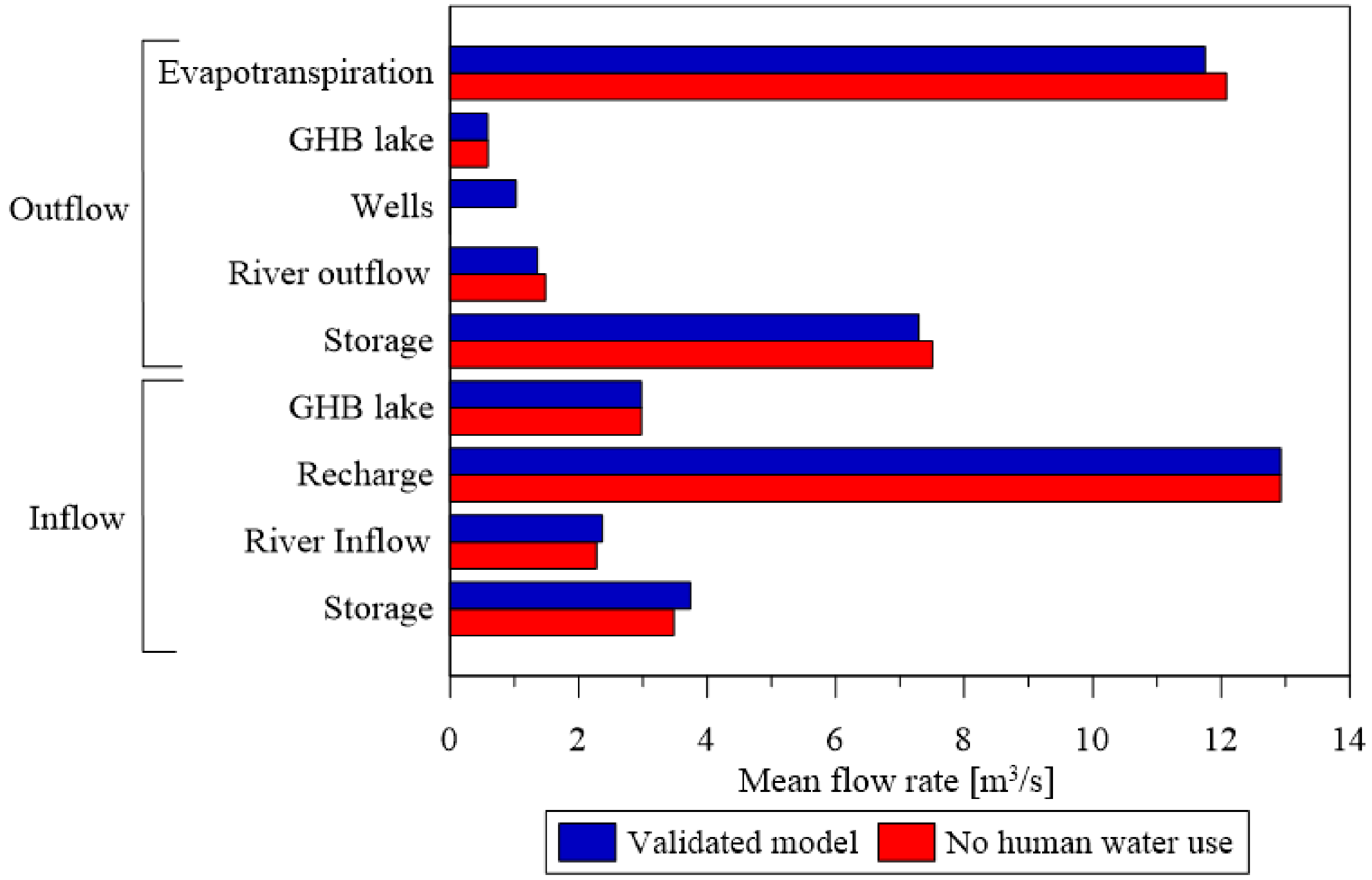
No human water use scenario

- *No water exploitation from wells was considered.*
- *A new two-dimensional matrix was constructed accounting for both land use and soil texture changes.*



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Conclusions

Specific:

- *The evapotranspiration turned out to be one of the major causes of the groundwater decline during dry periods, playing a major contribution in the groundwater budget.*
- *High resolution spatialization of the extinction depth over the domain did not lead to significative better results in terms of model performance, thus at the aquifer scale such resolution resulted redundant.*
- *The scenario without human stressor did not produce significative groundwater budget changes, while groundwater heads increased just near pumping wells.*

General:

- *The long term groundwater decline is driven by climate changes, while human stressor is a minor but non-negligible component (approx. 5%).*

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THANK YOU!

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Climate change resilience in the poor hydrogeological setting of the Northern Apennines: the case of the Nadìa spring

Maria Filippini, Tommaso Casati, Enrico Dinelli, Michele Failoni, Francesca Stendardi, Beatrice Tiboni, Alessandro Gargini.

Alma Mater Studiorum, University of Bologna - Department of Biological, Geological and Environmental Sciences, Italy

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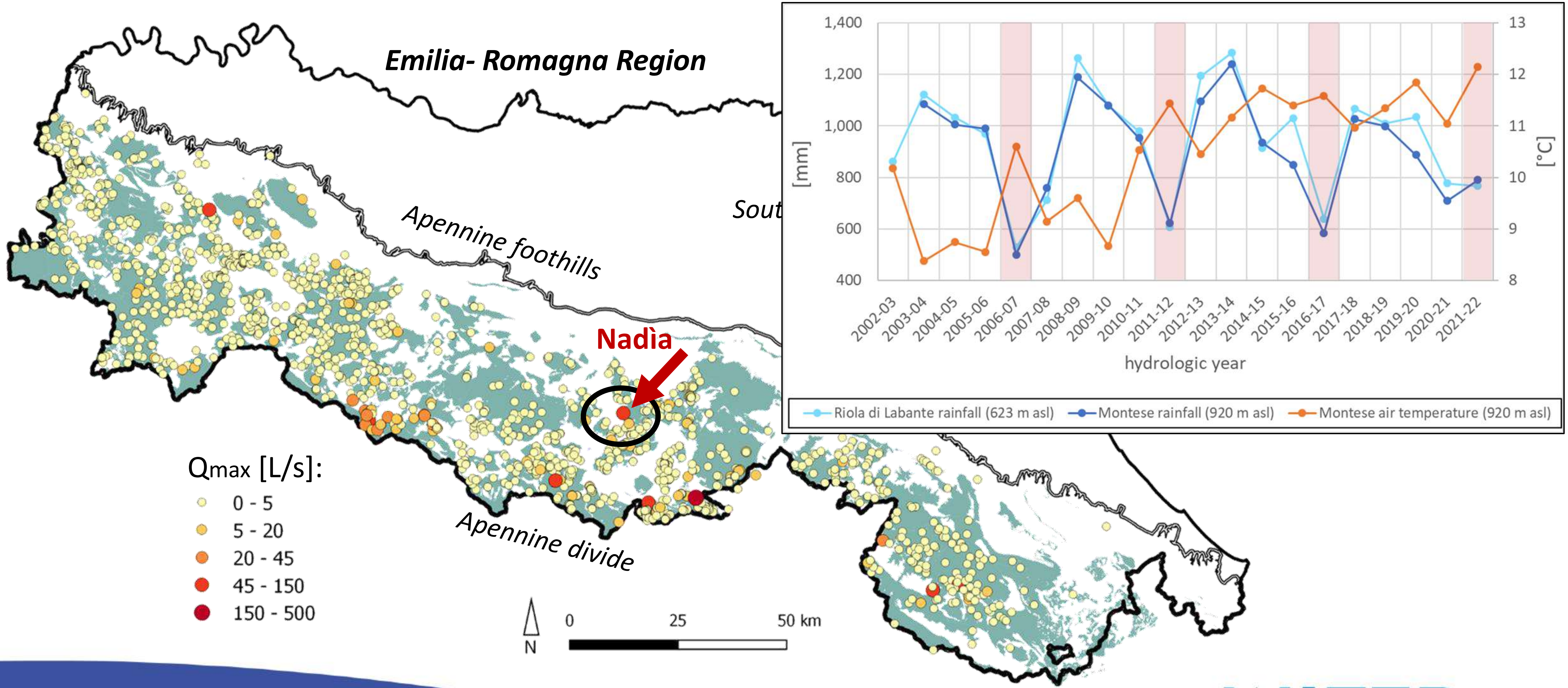
Regional distribution of tapped springs



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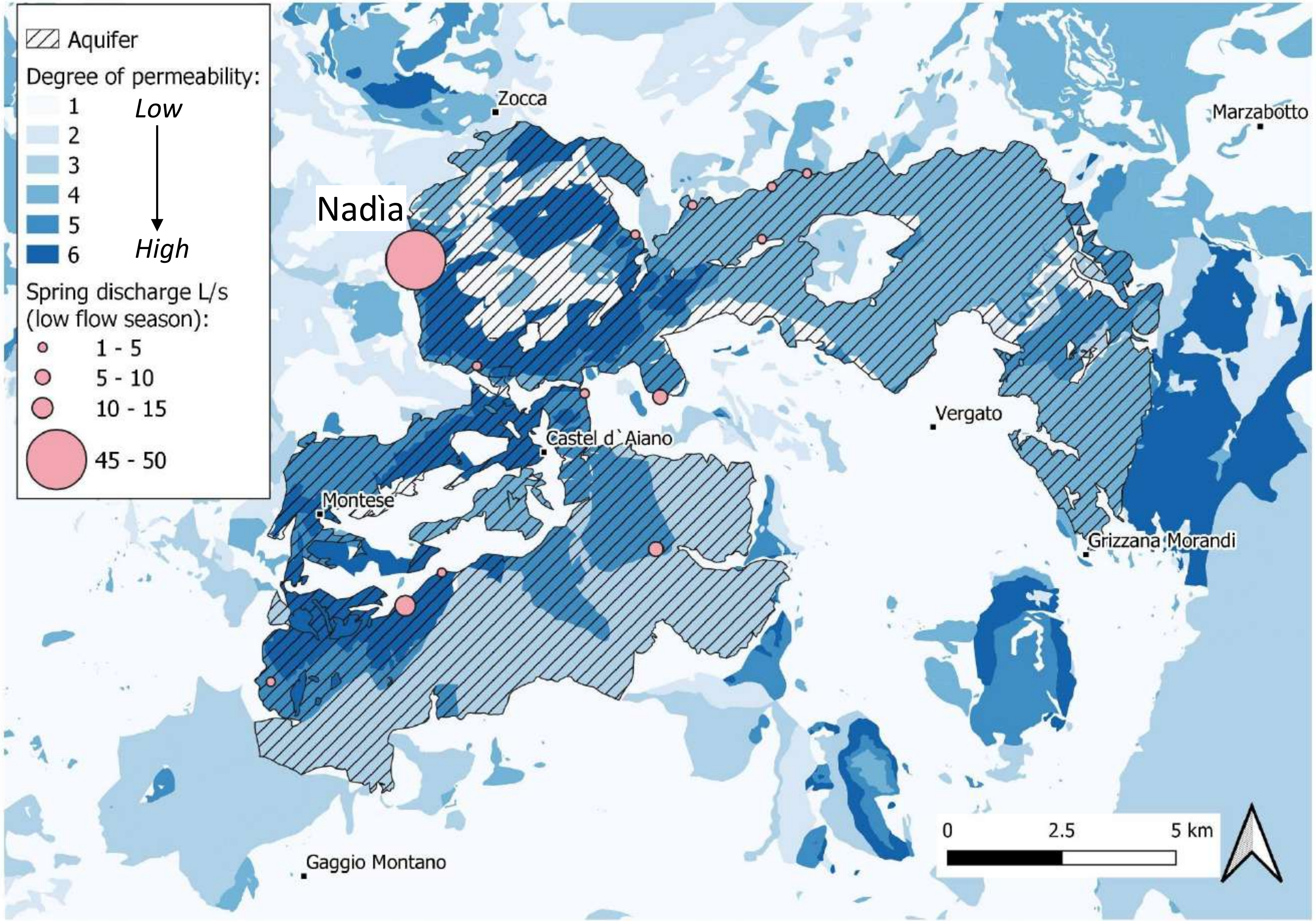
The aquifer of the Nadìa spring



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Field data collection (2020-22)

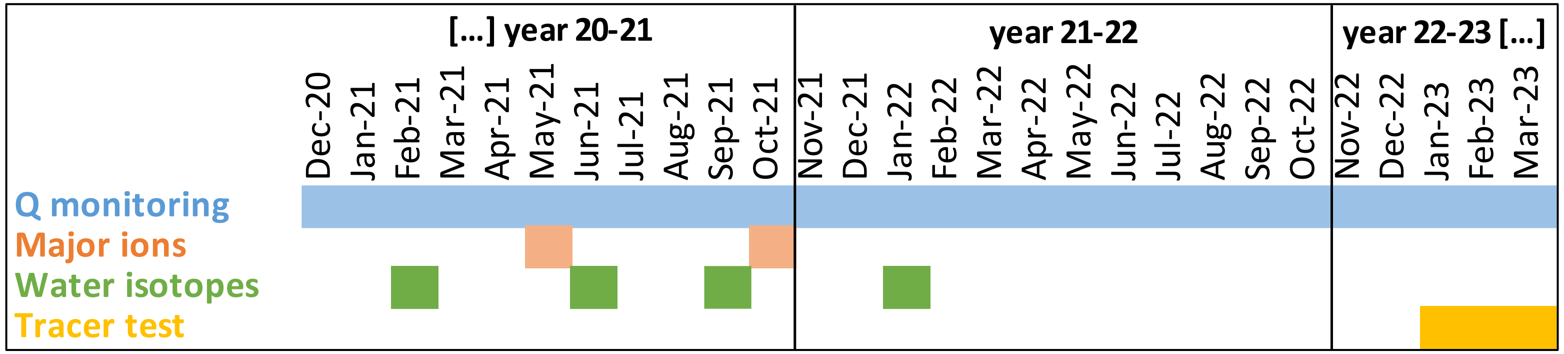
-structural and geomorphological surveys to verify/integrate the existing geological maps

-continuous coring of the aquifer down to 80 m b.g.s. (7 km southward from the Nadìa spring - same geological formation)

-continuous monitoring of the spring discharge

-spring water sampling for major ion and water isotope analyses

-tracer test from “cave” to spring



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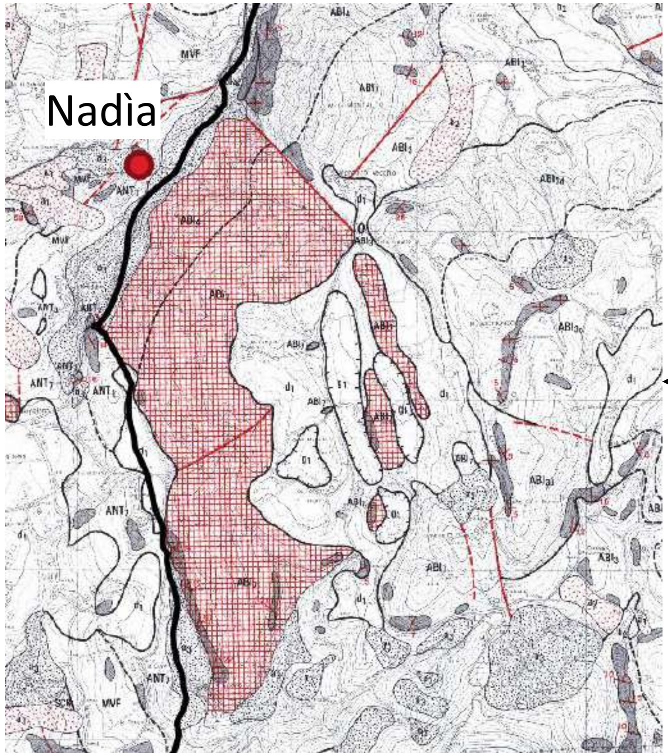
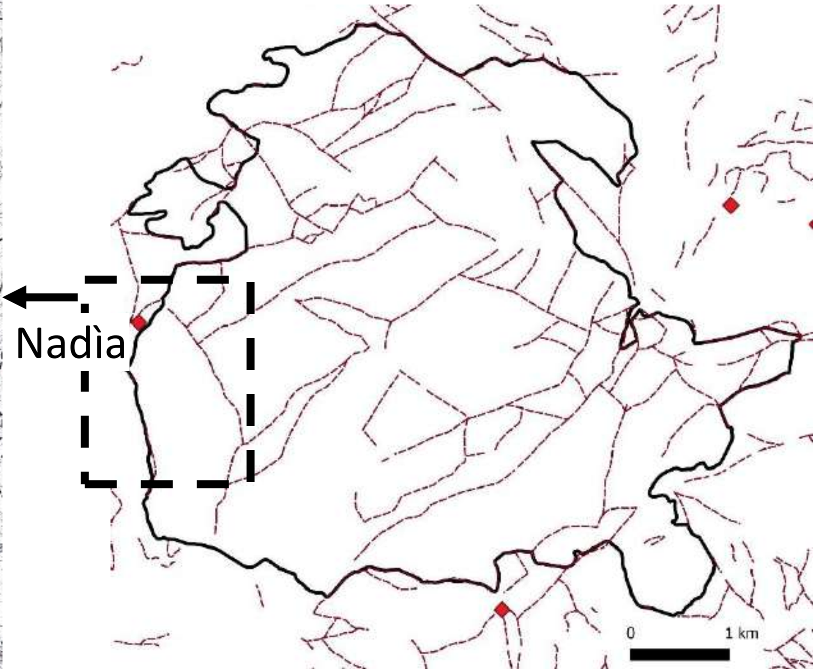
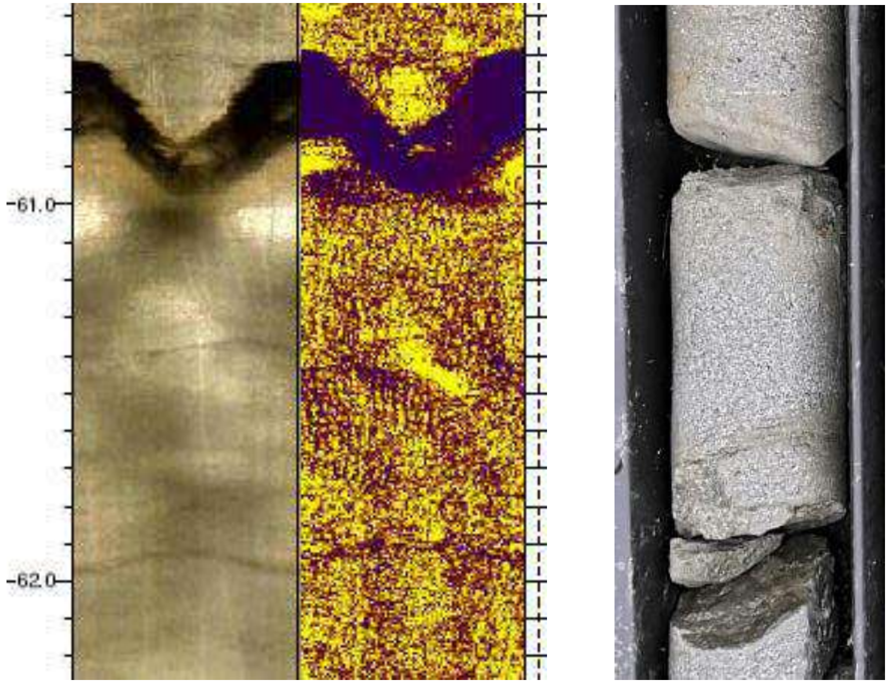
Geomorphological and structural observations

Geomorphology

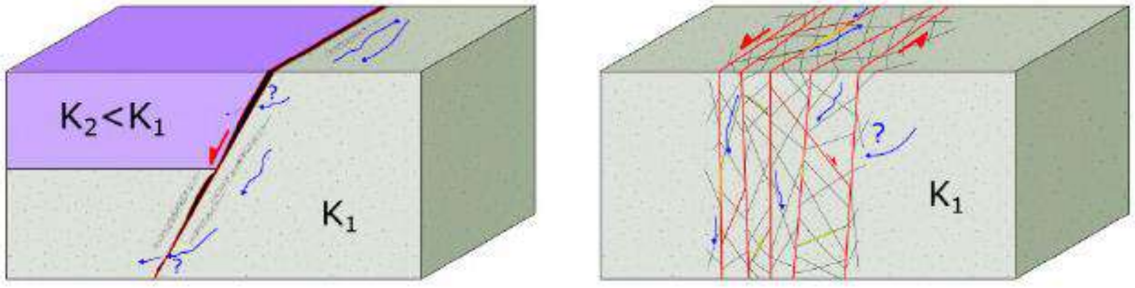




Coring



Structural styles



Type A

Type B

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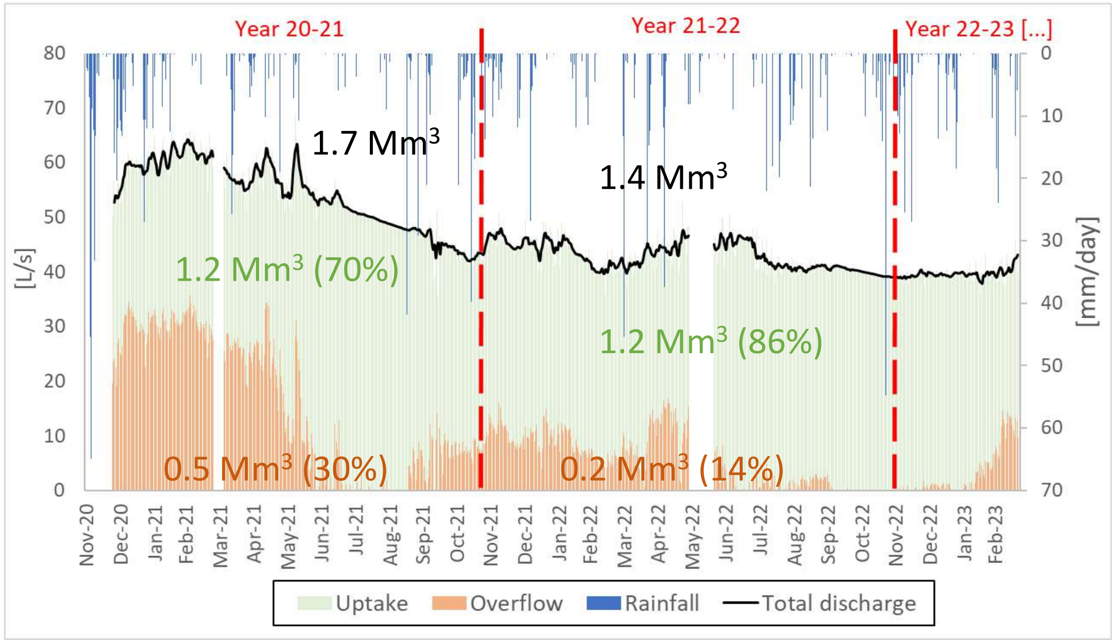
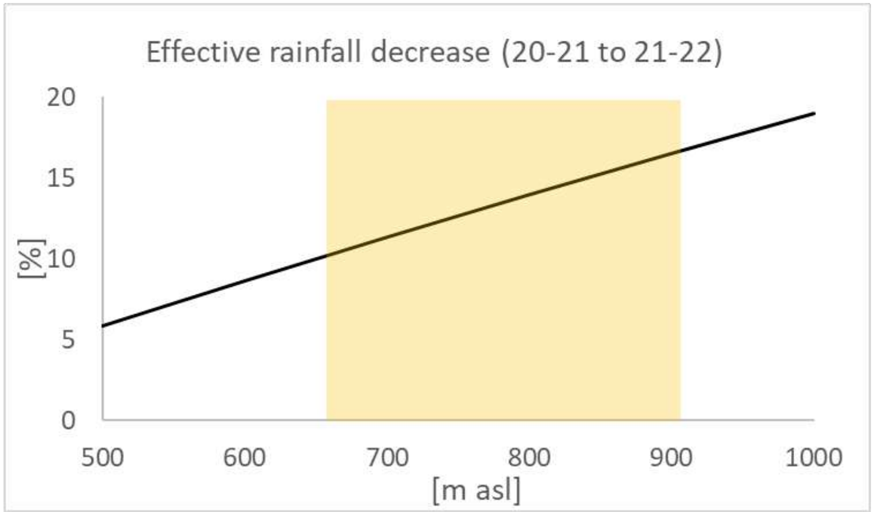
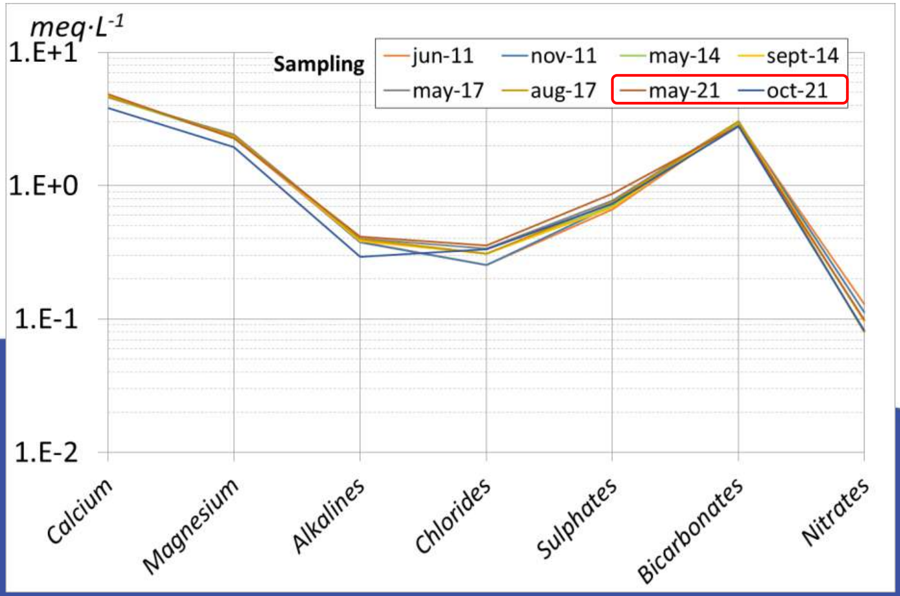
Hydrological and geochemical observations

HYDROGRAPH

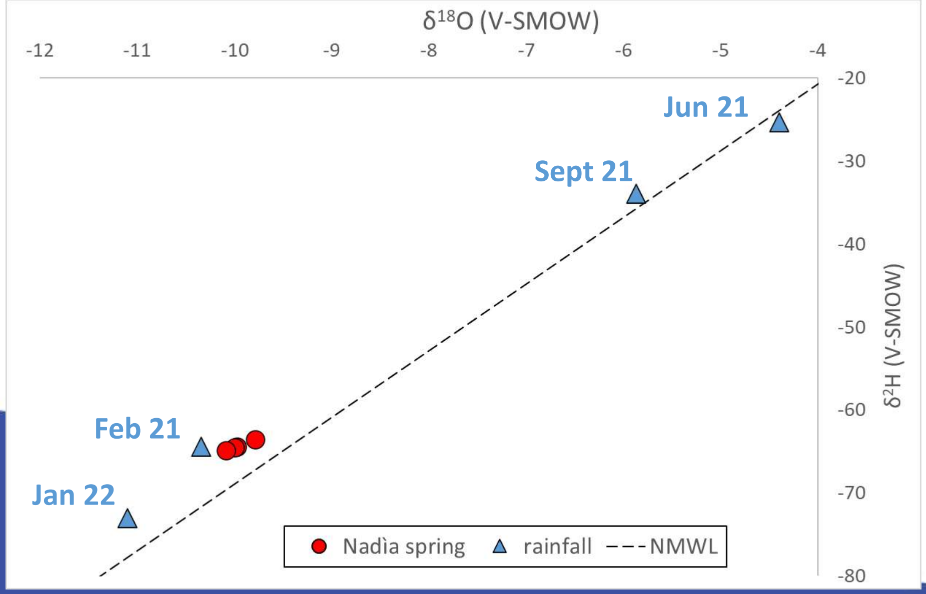




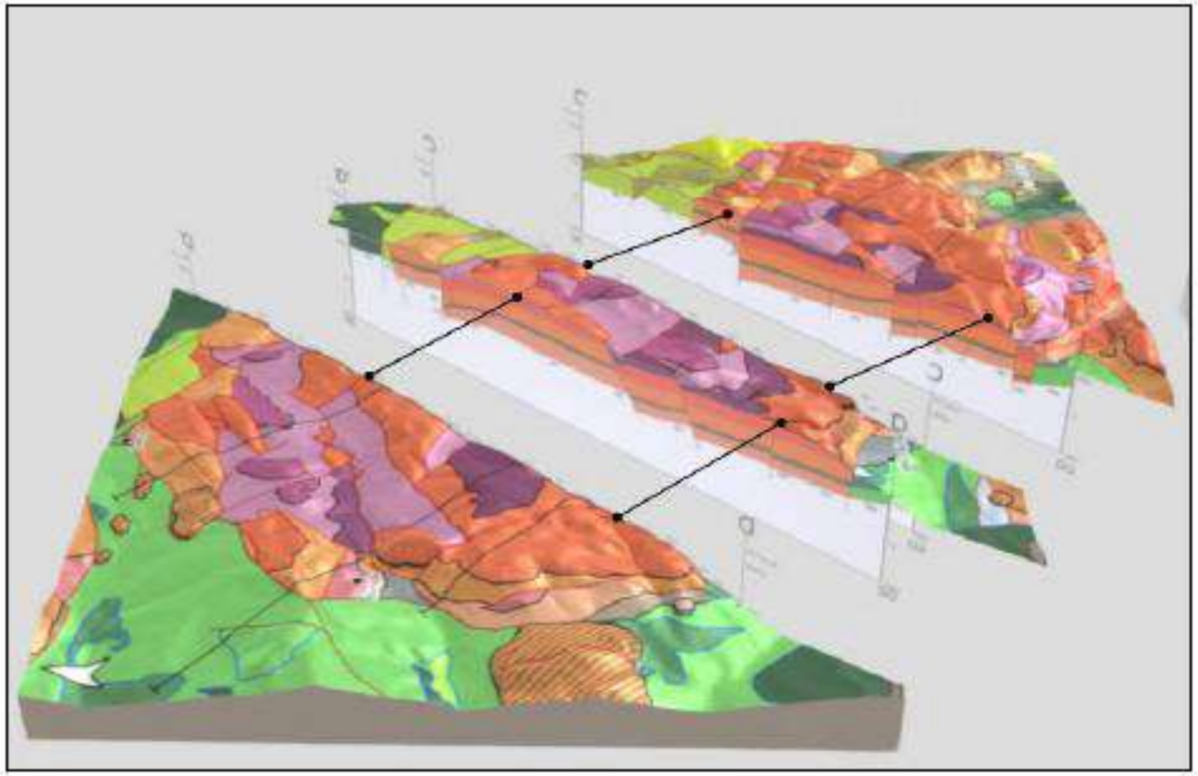
MAJOR IONS

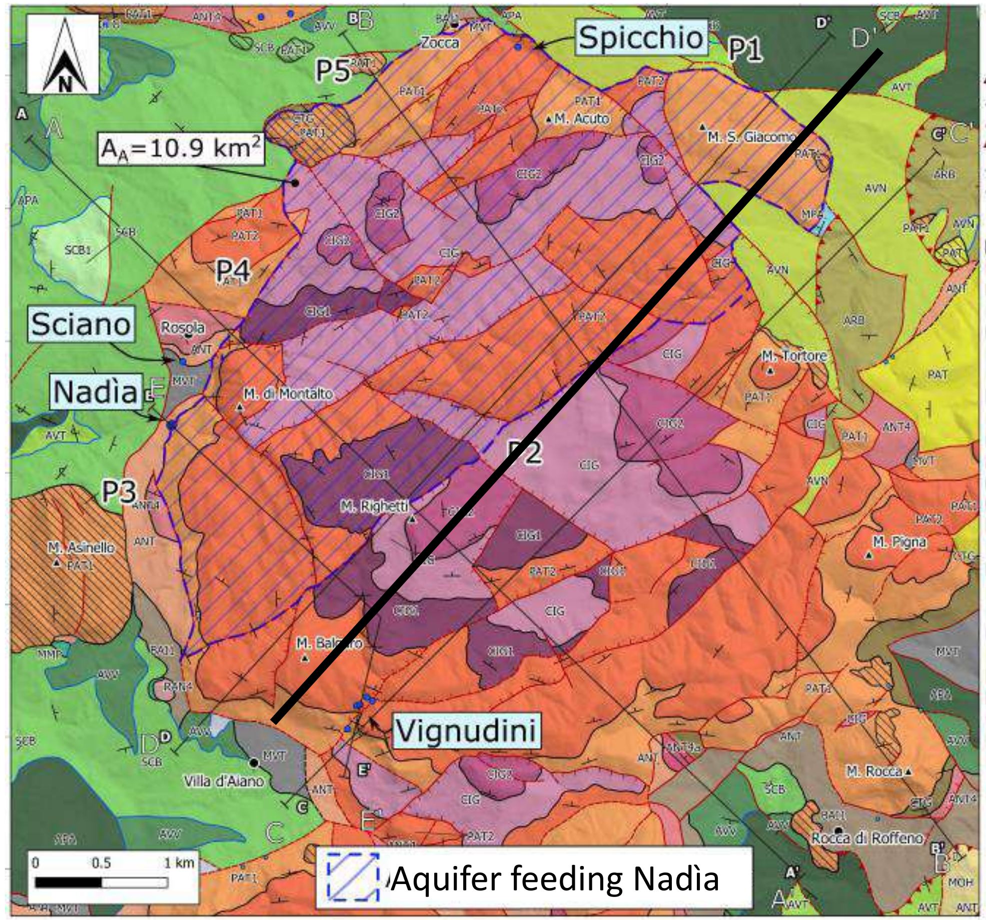


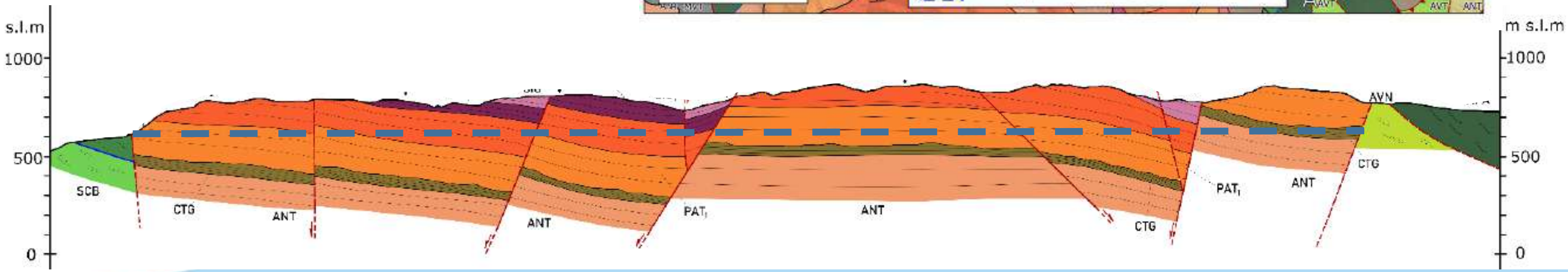
WATER STABLE ISOTOPES



Hydrogeological reservoir feeding the Nadìa spring







Altitude of the Nadìa spring

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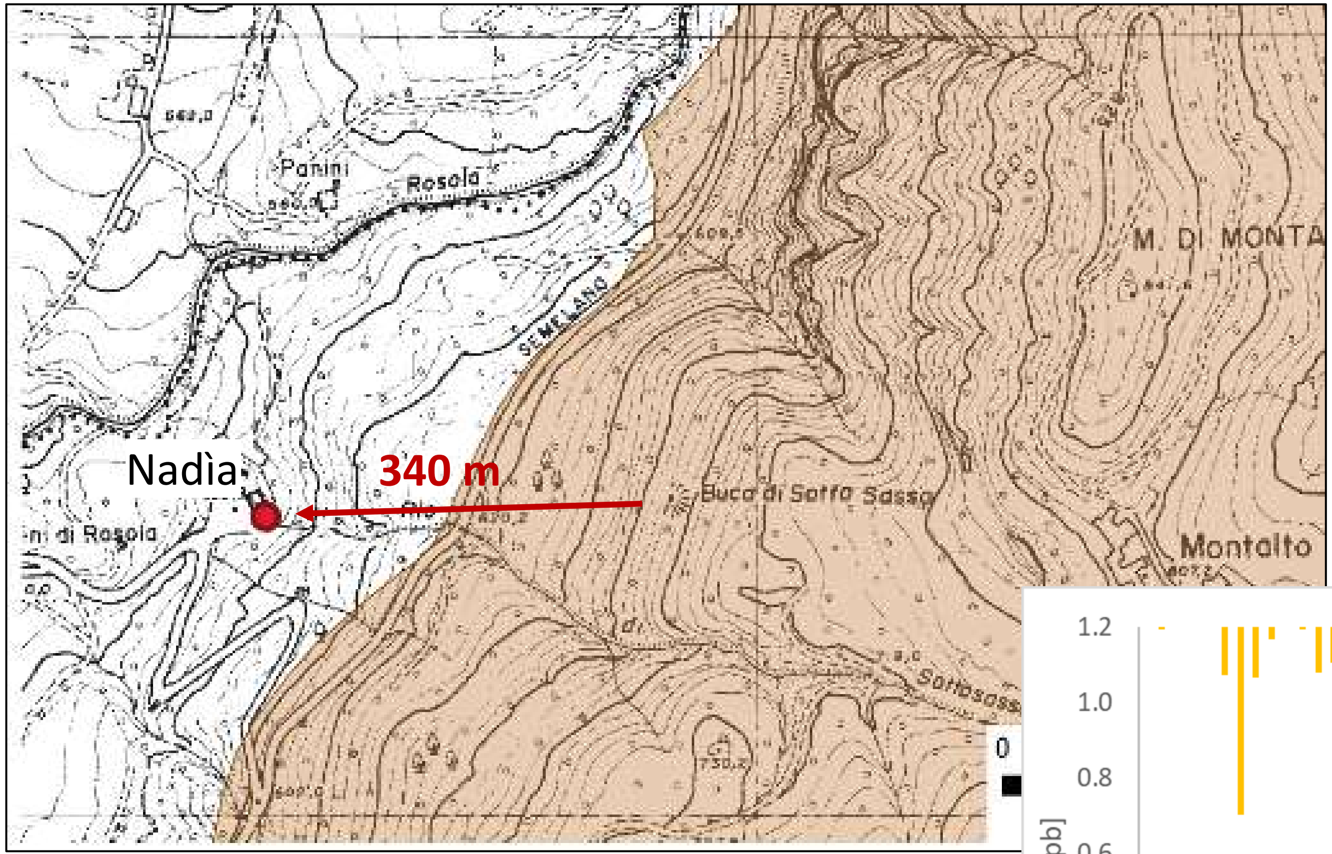
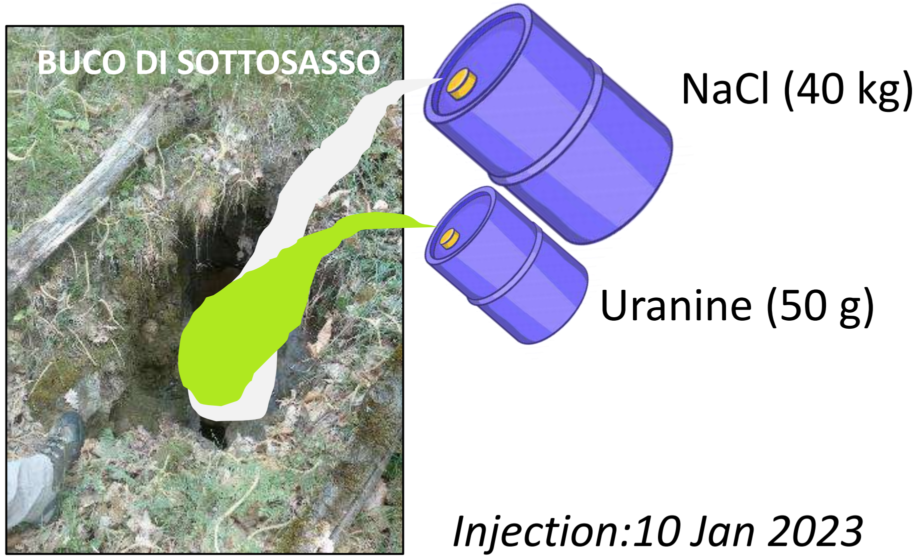
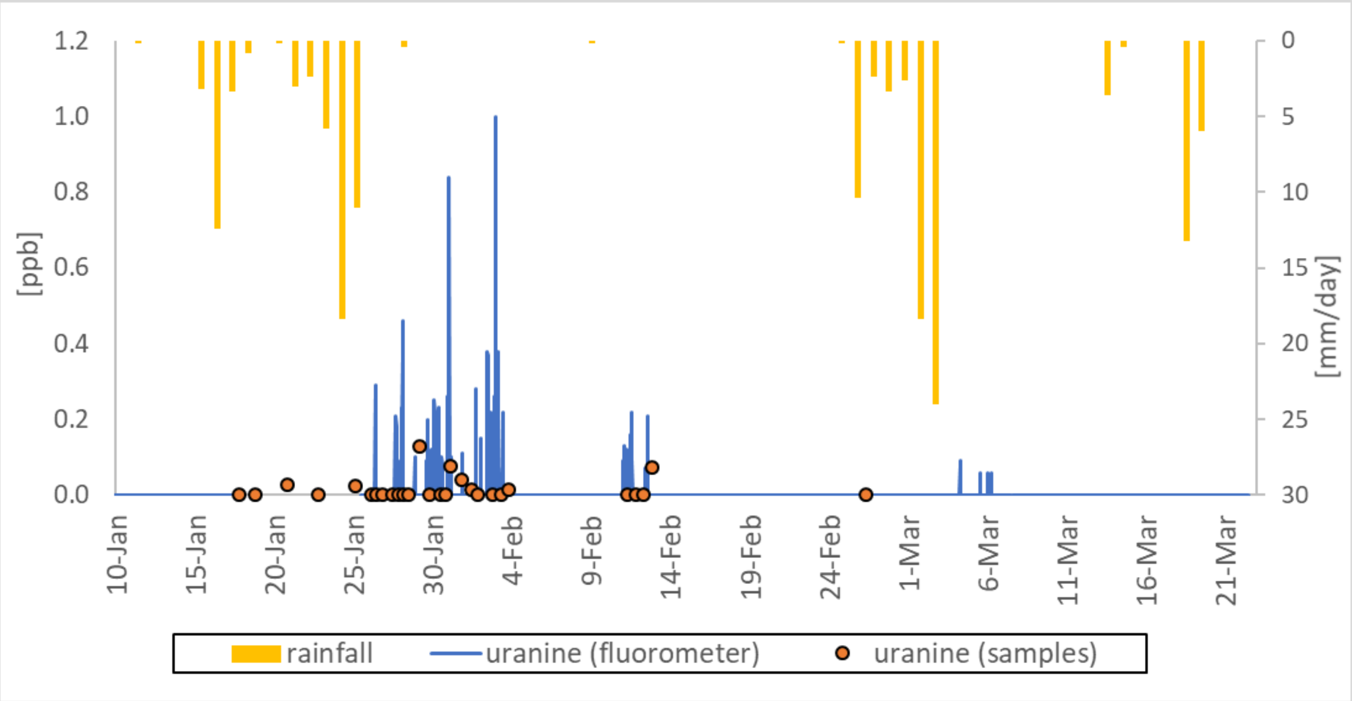
Tracer test





Injection:10 Jan 2023



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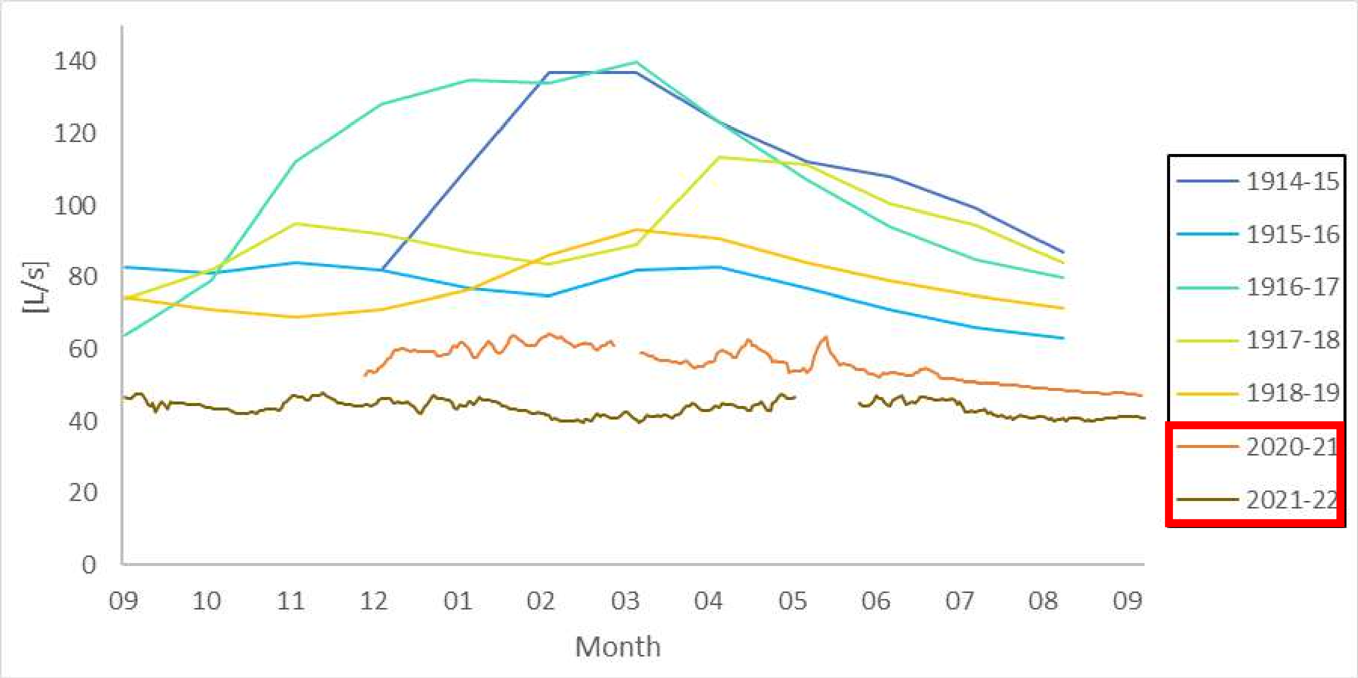
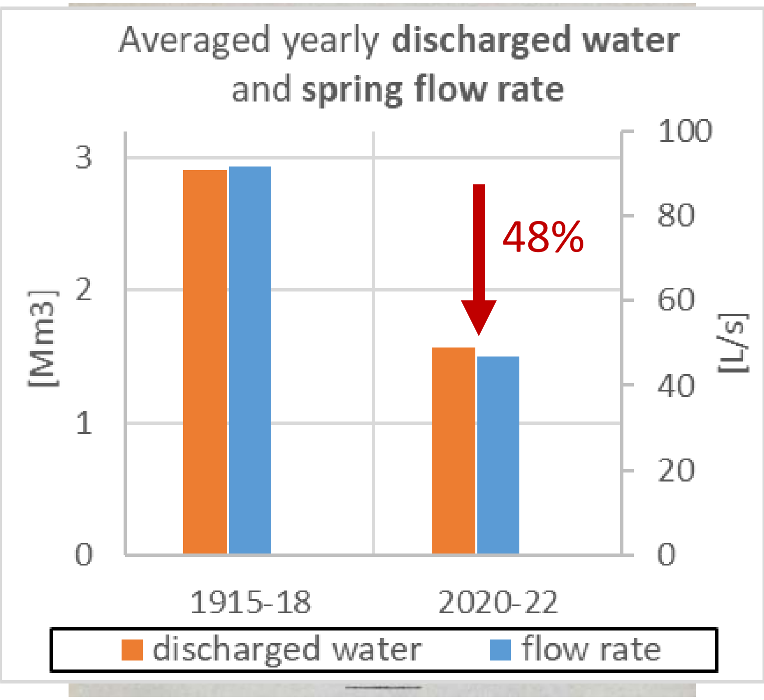
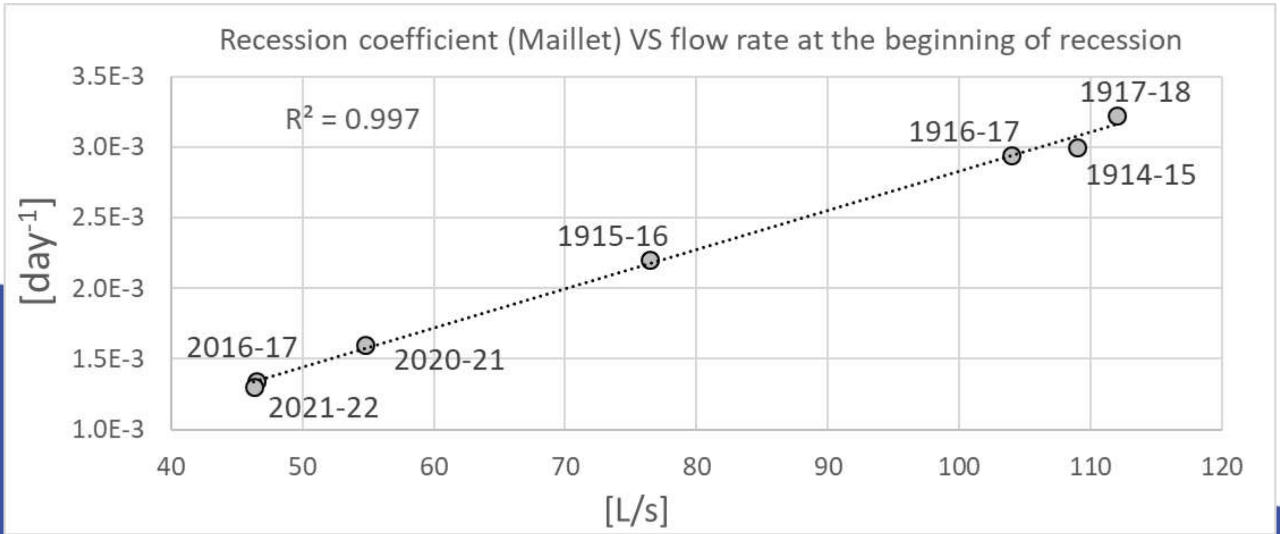
Spring discharge over centuries







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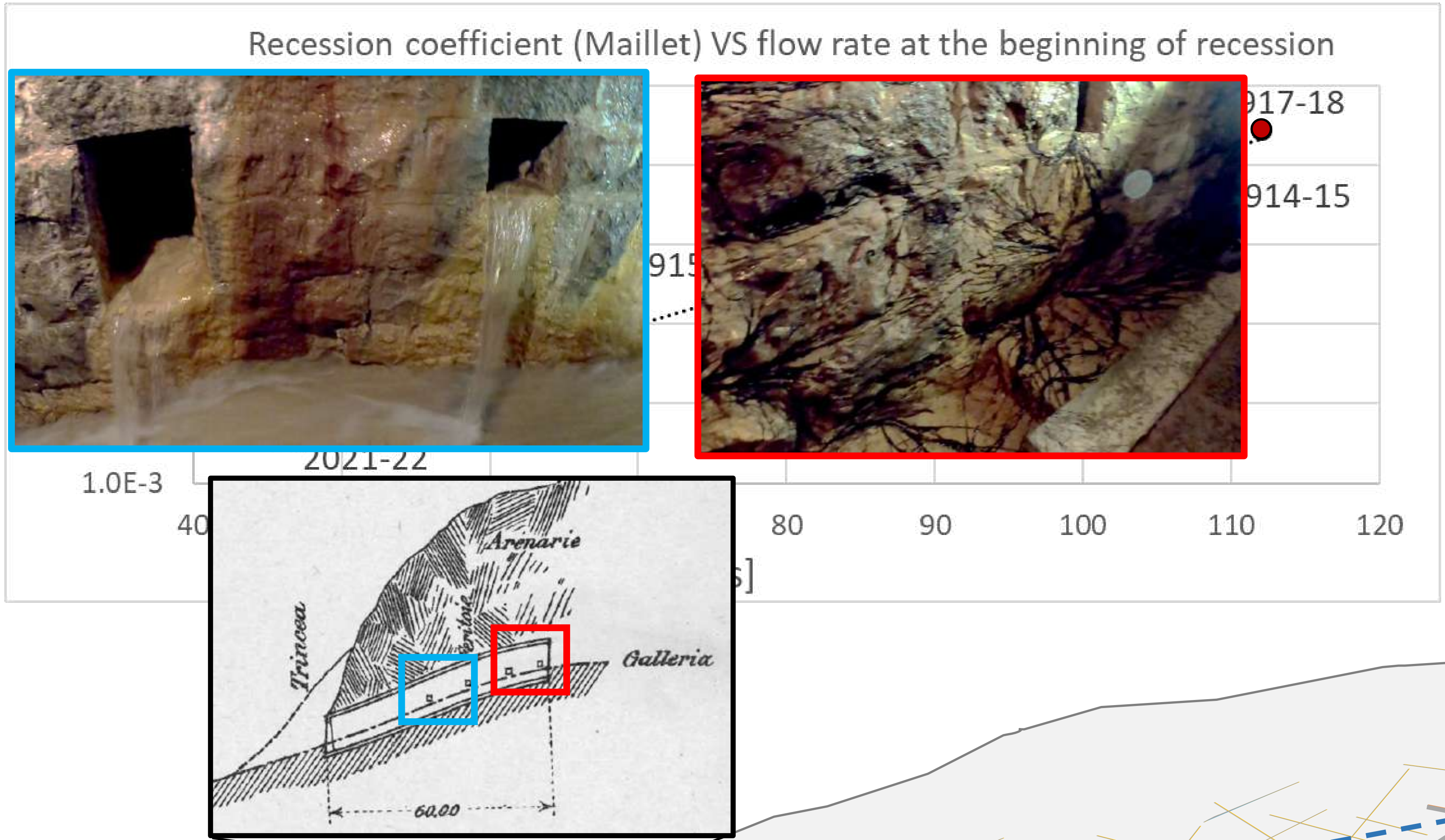
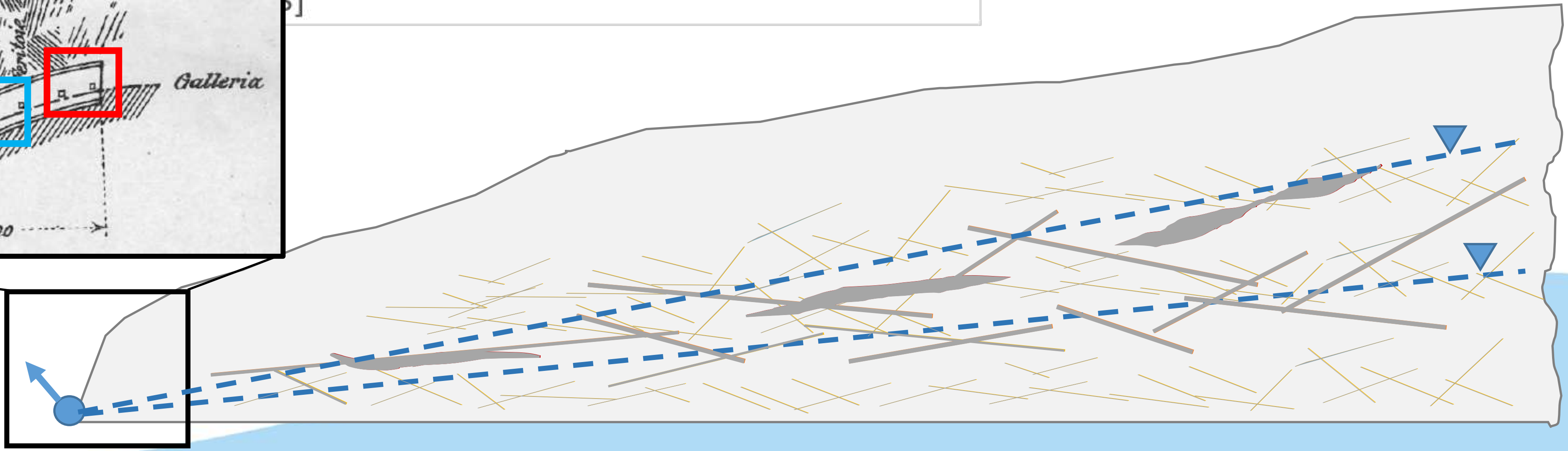
Spring discharge over centuries





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Conclusions

-Nadìa is the **base spring of a large reservoir** hosting homogenized groundwater

-the **aquifer permeability is locally increased** due to geomorphological, structural, and karst phenomena

→These two elements provide high resilience to recharge decrease in the short term (single drought years)

-the reservoir of the spring is characterized by **multiple drainage systems** and the "lamination capacity" increases with decreasing flow rate

→This suggests higher resilience to recharge decrease in the future centuries compared to the past

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Università degli Studi di Padova

Dipartimento di Geoscienze

Autorità di bacino distrettuale delle Alpi Orientali

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FIRST HYDROGEOLOGICAL WATER BALANCE IN THE HIGH AND MIDDLE VENETIAN PLAIN BETWEEN MINCIO AND TAGLIAMENTO RIVERS (NE, ITALY)

D. Cappellari, R. Tonucci, L. Piccinini, A. Braidot, A. Cisotto, N. Dalla Libera, P. Fabbri

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A.M.A.R.O.N.E. Project

- Study of the water resources of the high and middle Venetian Plain
- Collaboration between University of Padova and Eastern Alps Water Authority

1. Data collection
2. Aquifers reconstruction
3. Hydrogeological and Hydrological Balance
4. Numerical model implementation
5. Sustainability assessment

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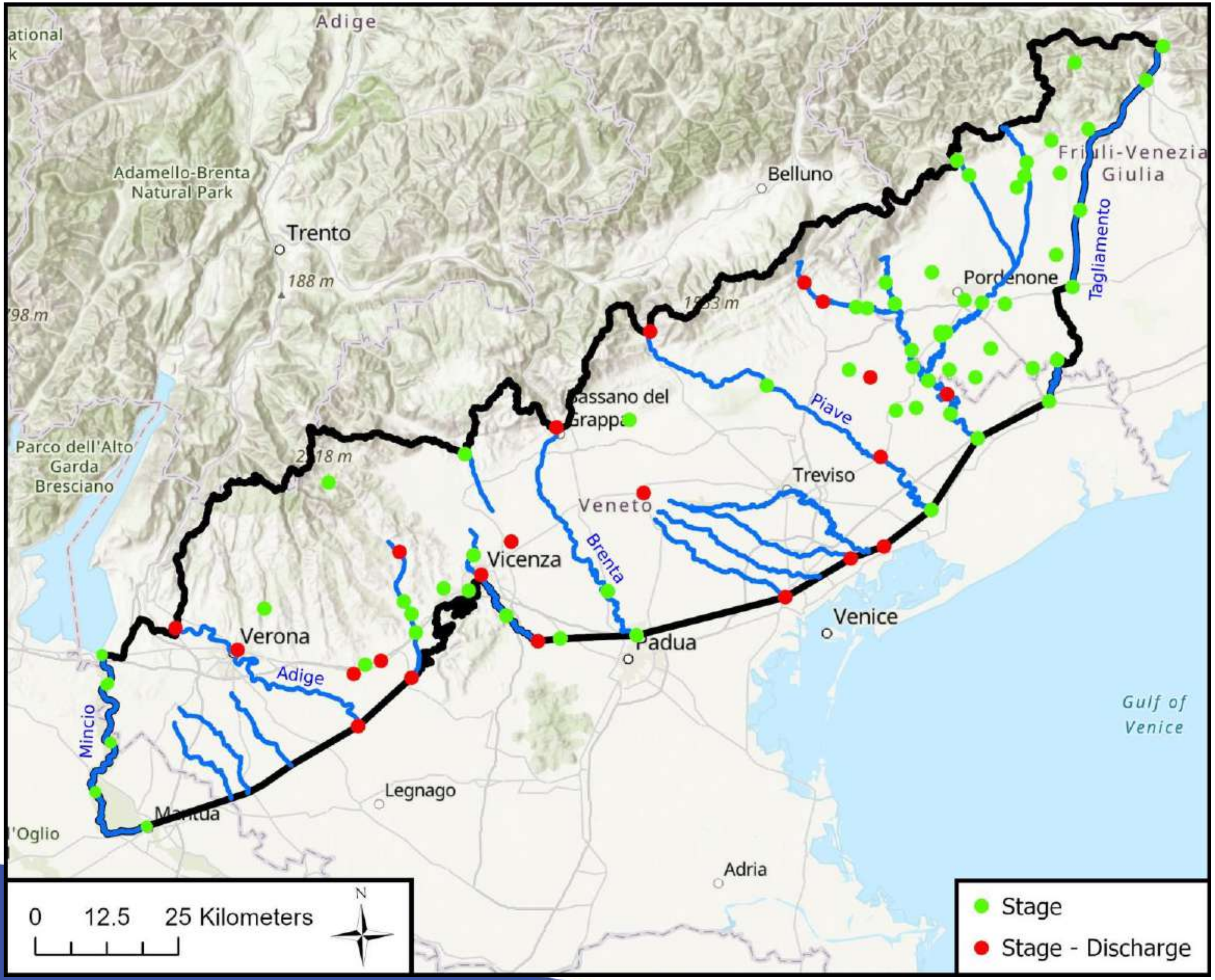
Study area

Borders	
North	Mountain basins draining to the Venetian plain
West	Mincio River
East	Tagliamento River
South	Outflows measuring stations

8648 km^2



Hydrogeological Balance

- Average year over the period 2010-2022
- Monthly-based

$$P - EVT = I + R$$

Weather stations
Data collection

Precipitation
Interpolation

Evapotranspiration
FAO Penman-Montheit

Effective Precipitation

Coefficient of Potential Infiltration (CPI)
Litology

Infiltration

Runoff

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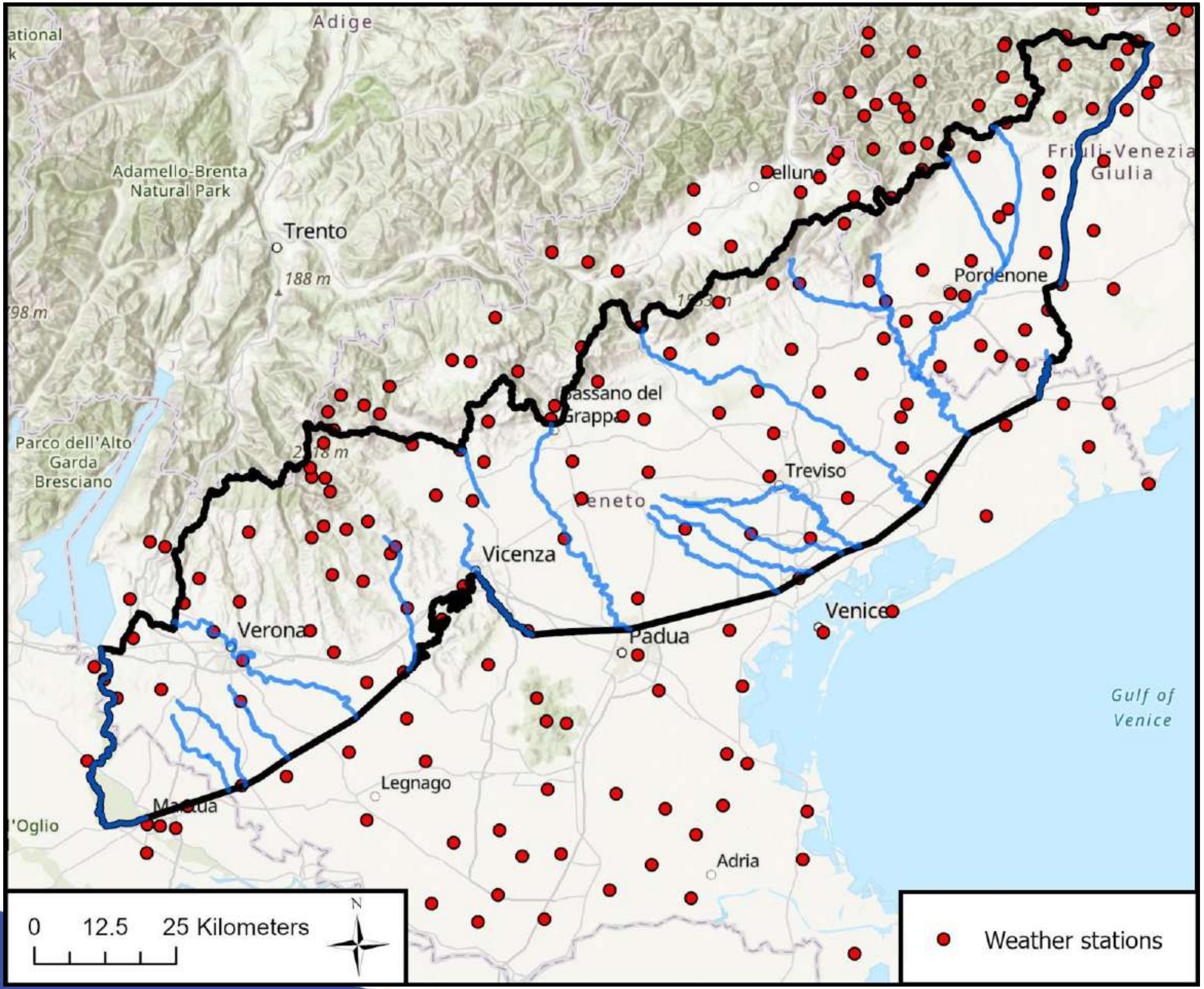
Meteorological data

- 229 weather stations

- Precipitation
- Temperature
- Solar Radiation
- Wind Speed

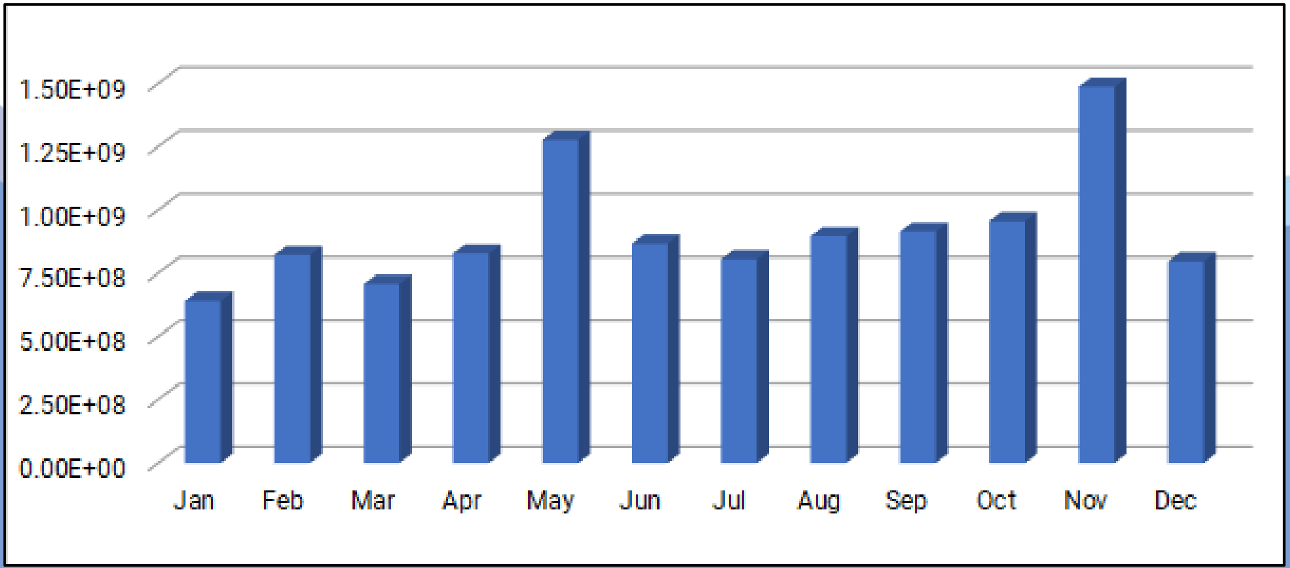
- At least 6 years of measurement

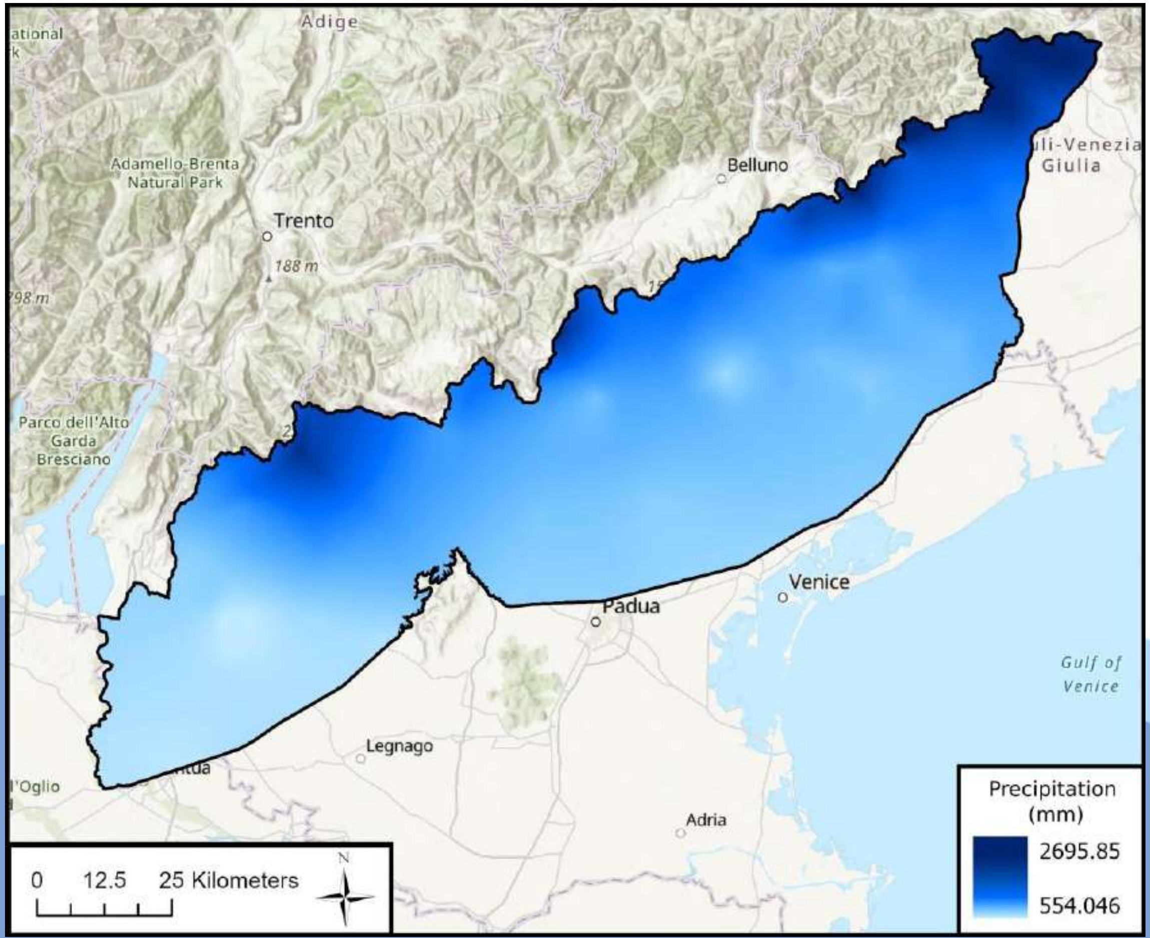


Precipitation

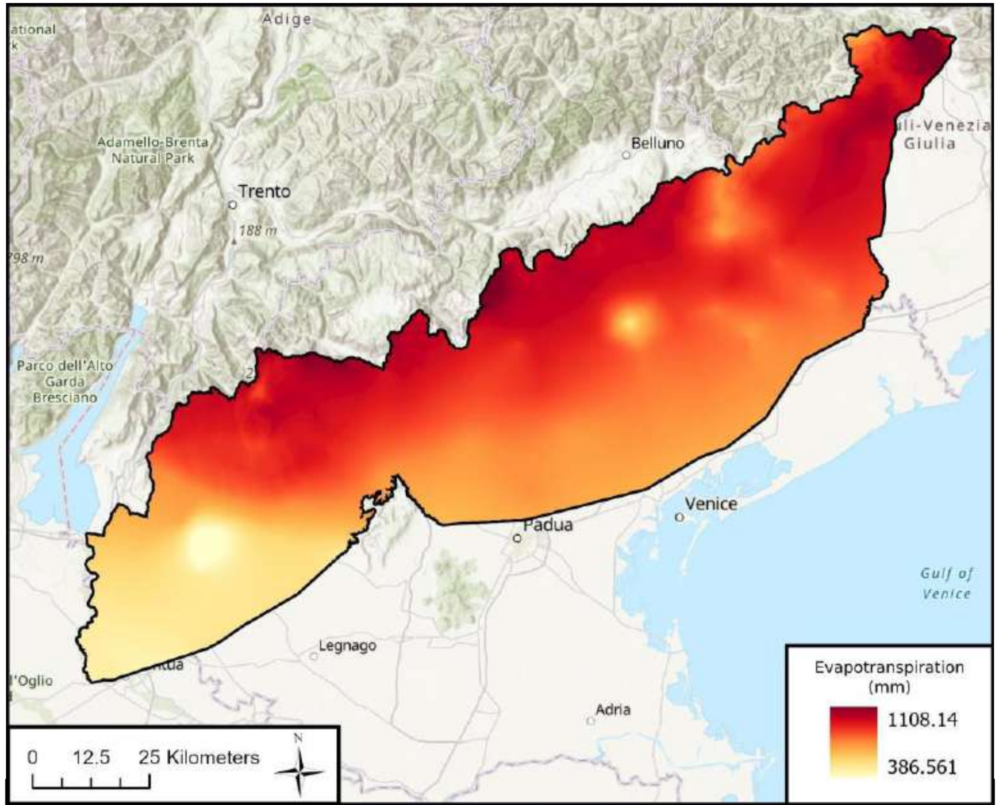
11 BCM/year

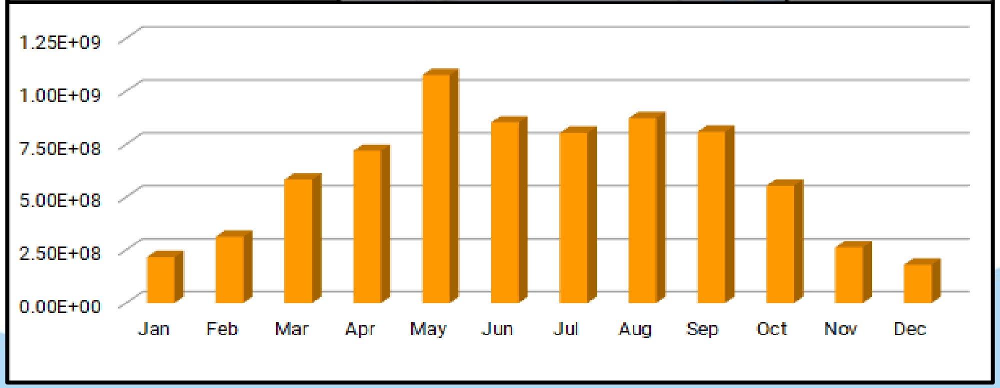
- Natural Neighbour Interpolation
- Cell size 100 x 100 m
- 864807 cells





Evapotranspiration → 7.24 BCM/year





FAO Penman-Montheit

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

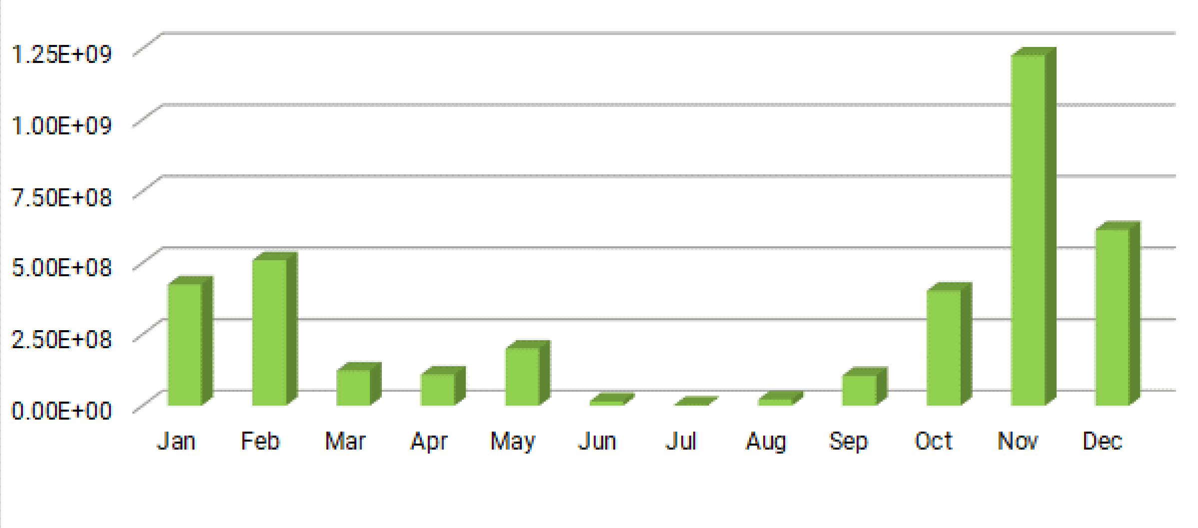
- ET_0 = reference potential evapotranspiration (mm)
- R_n = net solar radiation (MJ m^{-2})
- G = soil heat flux (MJ m^{-2})
- u_2 = wind speed at 2 m height (m s^{-1})
- es = saturation vapour pressure (kPa)
- ea = actual vapour pressure (kPa)
- Δ = slope vapour pressure curve (kPa $°C^{-1}$)
- γ = psychrometric constant (kPa $°C^{-1}$)

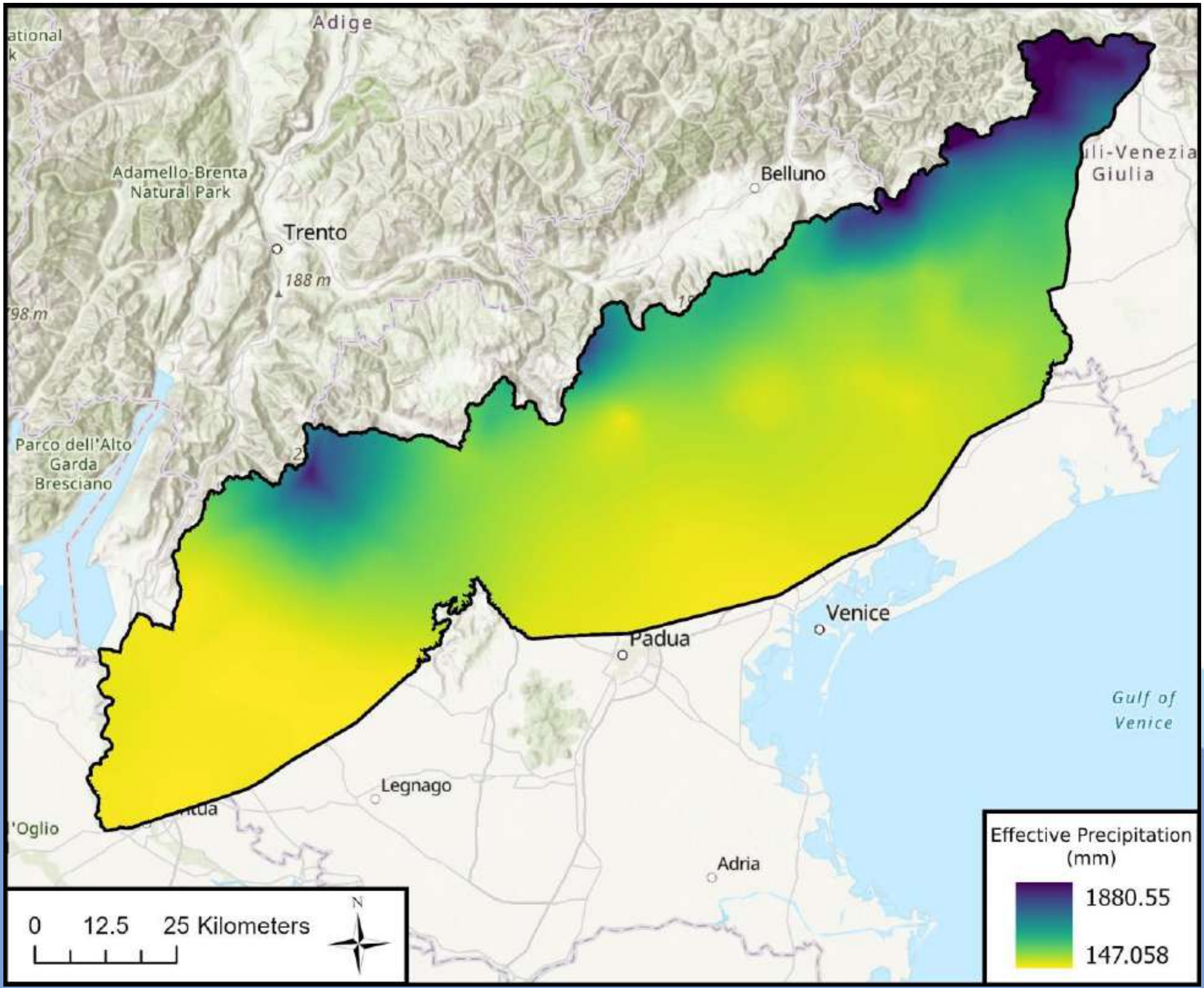
Effective Precipitation

→ 3.76 BCM/year

$$EP = P - ET_0$$

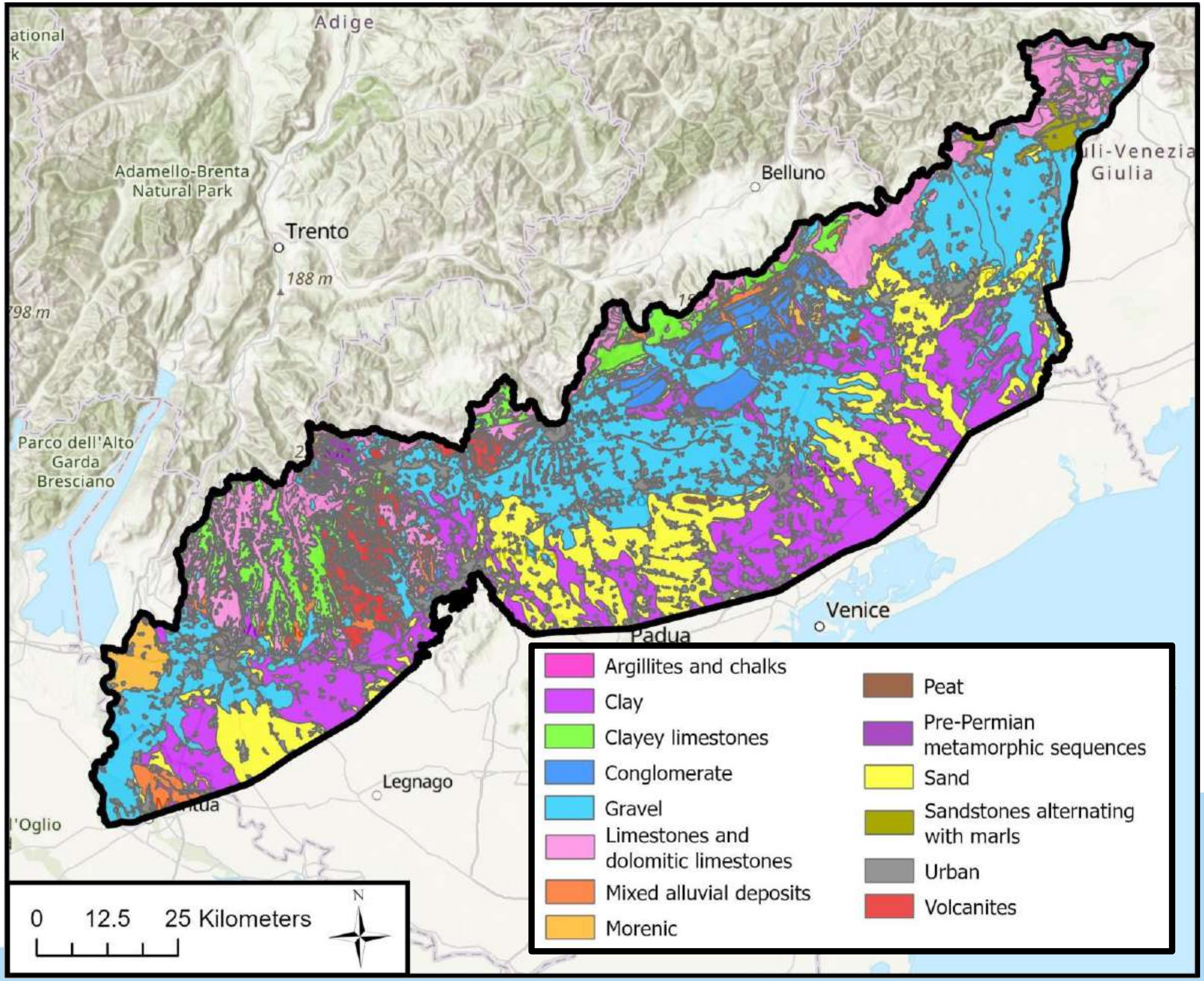
- Precipitation reaching the soil
- Divided into infiltration and surface runoff
- Distribution defined by soil permeability





Lithology

Area	Lithology
Lessini mountains	Volcanites Limestones
Prealps	Limestones
Montello	Conglomerate
Garda Lake	Morainic
High Plain	Gravel Sand
Low Plain	Sand Silt Clay



Coefficient of Potential Infiltration (CPI)

Hydrogeological Complex	Range CPI	Guide Value
Coarse alluvial material	0.65 – 1.00	0.90
Pure loose sands	0.90 – 1.00	0.95
Sandy formations	0.75 – 0.90	0.80
Medium-fine alluvial material	0.15 – 0.25	0.30
Clays, silts, peats	0.00 – 0.25	0.15
Predominantly coarse moraines	0.50 – 0.70	0.55
Predominantly fine moraines	0.15 – 0.25	0.20
Marls, mudstones	0.10 – 0.20	0.15
Alternations, marly limestone flysch	0.20 – 0.50	0.35
Alternations, marly arenaceous flysch	0.20 – 0.45	0.25
Sandstones, conglomerates	0.30 – 0.50	0.40
Karstified limestones	0.75 – 1.00	0.95
Fractured limestones	0.50 – 0.85	0.75
Marbles	0.90 – 1.00	0.95
Fractured dolomite	0.45 – 0.70	0.60
Acid fissured volcanites	0.30 – 0.70	0.50
Basic fissured volcanites	0.75 – 1.00	0.85
Predominantly fine pyroclastites	0.15 – 0.25	0.20
Fractured plutonites	0.05 – 0.35	0.25
Fissured metamorphites (phyllites)	0.05 – 0.30	0.10
Fissured metamorphites (gneiss)	0.15 – 0.35	0.25

(Civita M., 2005)

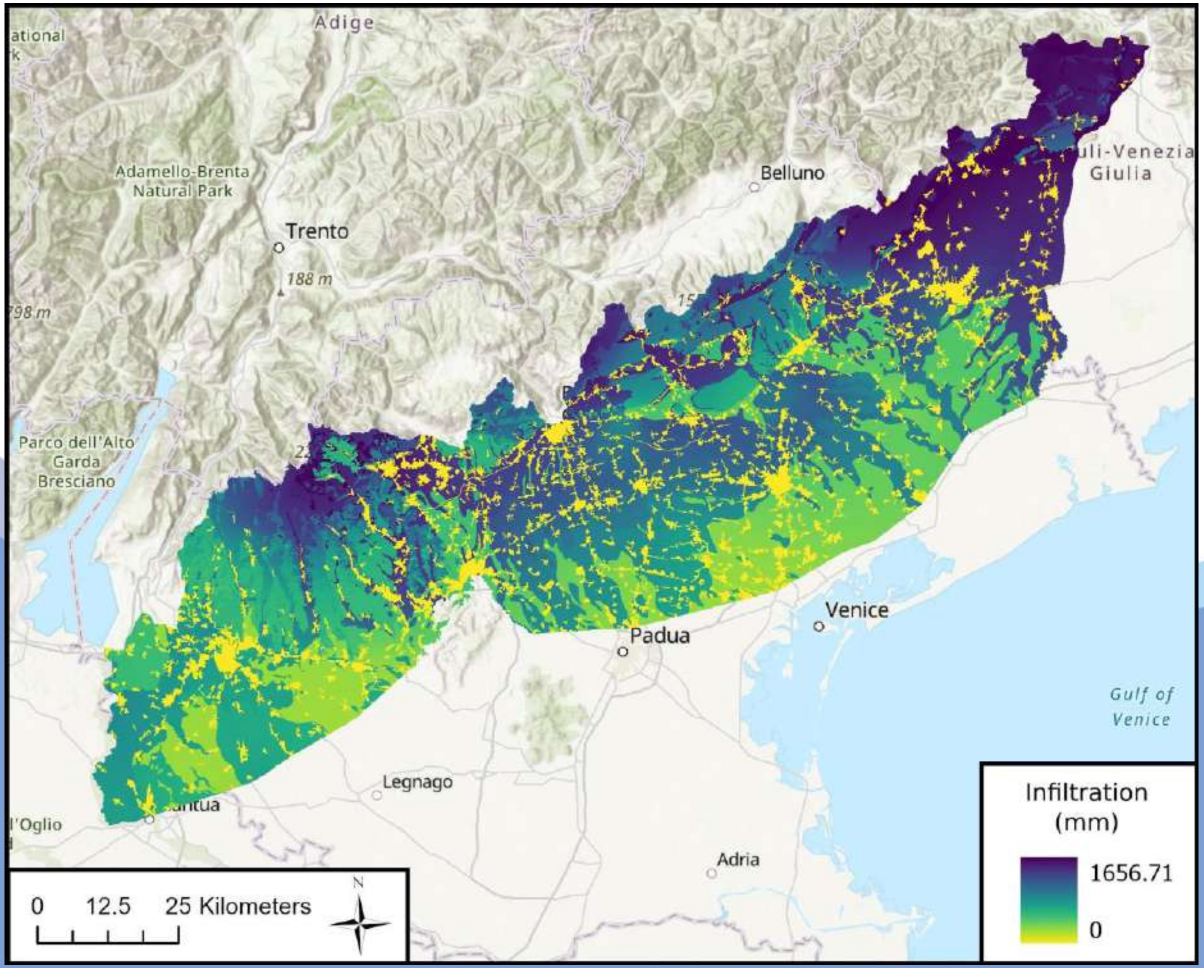
→

Lithology	CPI
Argillites and chalks	0.15
Clay	0.15
Clayey limestones	0.35
Conglomerate	0.4
Gravel	0.9
Limestones Dolomitic limestones	0.5
Mixed alluvial deposits	0.9
Morenic	0.375
Peat	0.15
Pre-Permian metamorphic	0.1
Sand	0.8
Sandstones alternating with marls	0.25
Volcanites	0.25
Urbanized soil	0

$$I = EP \times CPI$$

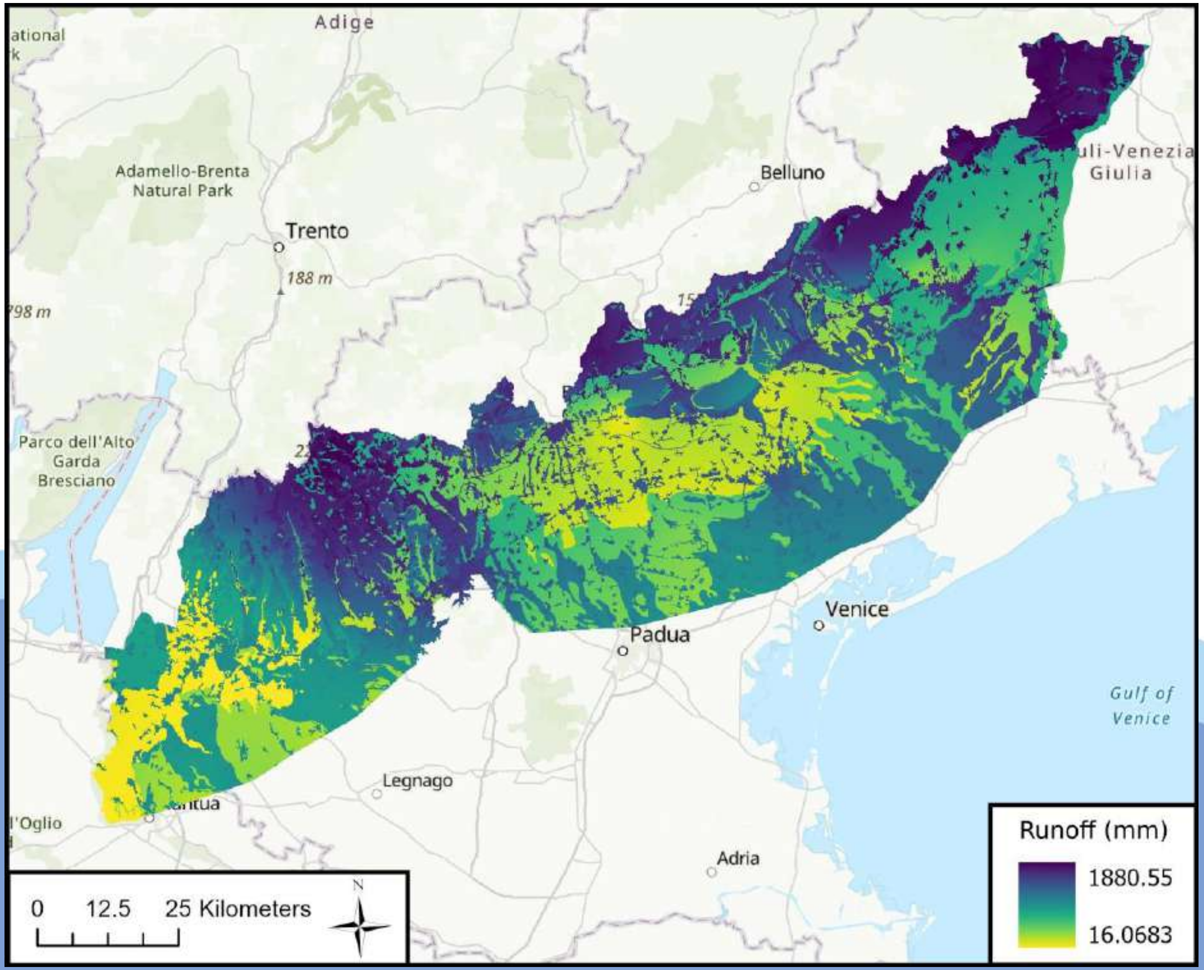
Infiltration

1.94 BCM/year



Runoff

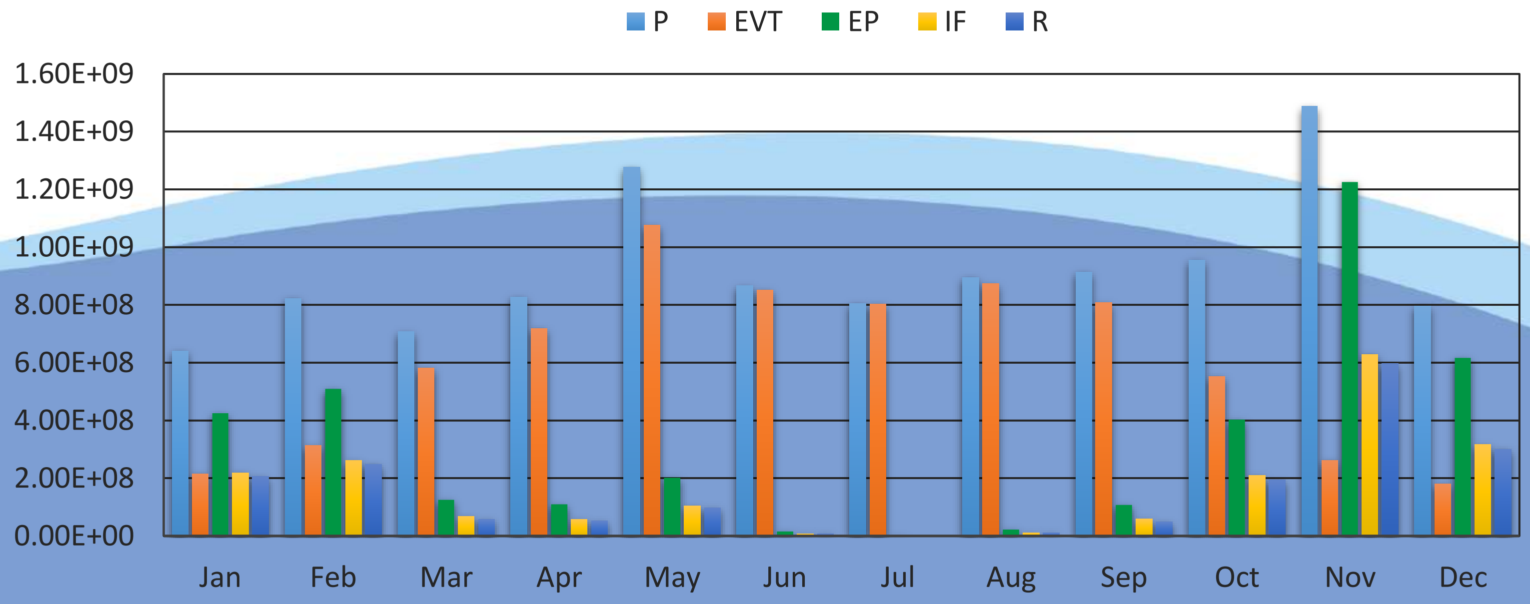
1.82 BCM/year



Conclusions

- Magnitude and distribution of the quantity involved
- High percentage of evapotranspiration
- March to September ⟶ lower groundwater recharge
- October to February ⟶ higher groundwater recharge

Budget term	BCM/year
P	11
ET_0	7.24
EP	3.76
I	1.94
R	1.82



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Unravelling the aquifer-scale competition for organic substrate in a polluted aquifer by interpreting multivariate statistics through scenario-based hydrogeochemical modeling

Diego Di Curzio, Sergio Rusi, Boris M. van Breukelen

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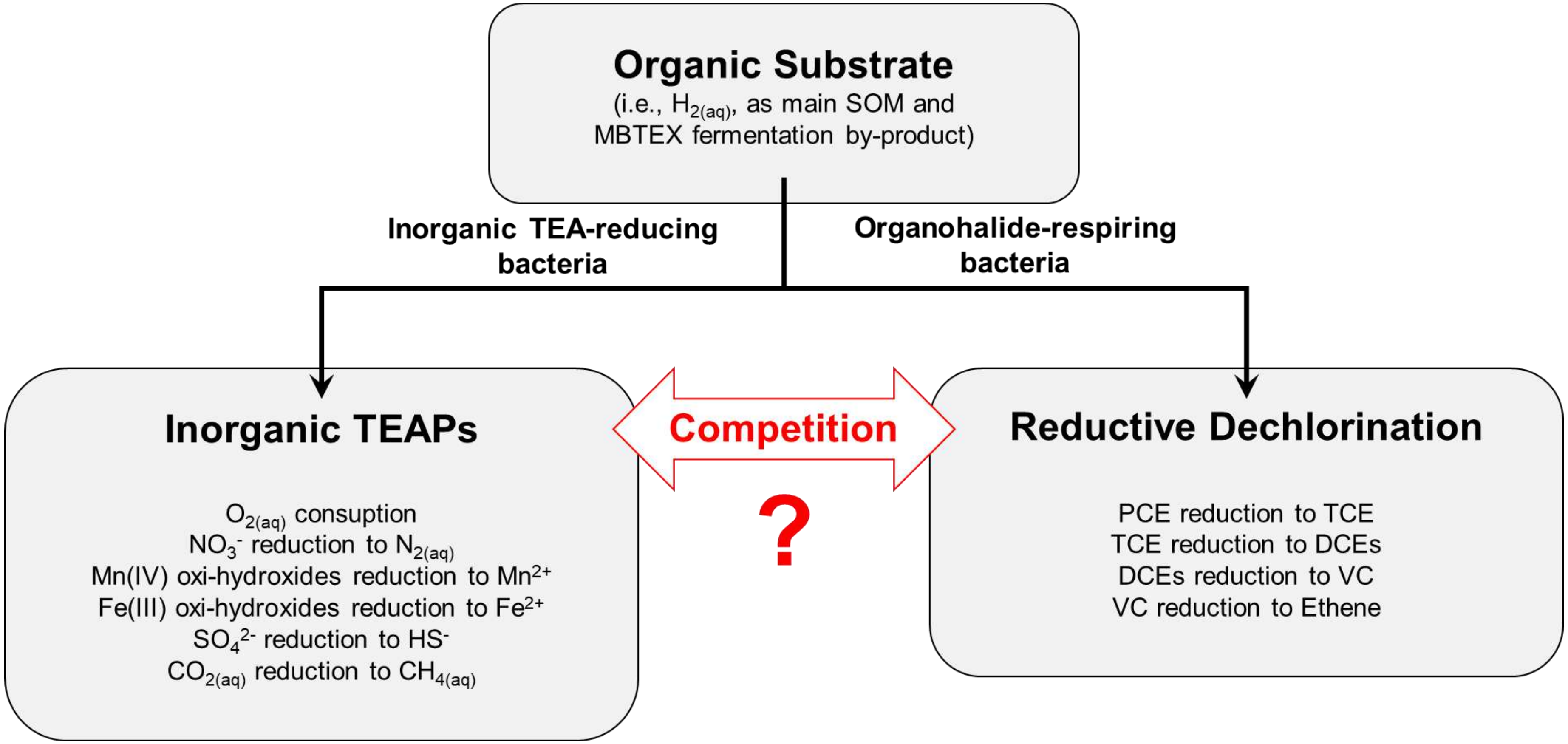
COMPETITION FOR SUBSTRATE: WHAT DO WE MEAN?



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WHAT ISSUES WITH SPARSE DATASETS?

	Round 1	Round 2	Round 3	Round 4	Round 5
Period	06/2012	08/2012	02/2014	03/2014	10/2014
# of MWs	21	3	30	5	17
pH	21	3	30	5	17
NO_3^-	21	3	30	5	5
Mn	21	3	30	5	5
Fe	21	3	30	5	5
SO_4^{2-}	21	3	30	5	5
MTBE	21	3	30	5	17
Benzene	21	3	30	5	17
Toluene	21	3	30	5	17
Ethylbenzene	21	3	30	5	17
Xylene	21	3	30	5	17
PCE	21	3	29	4	15
TCE	21	3	29	4	15
DCE	21	3	29	4	15
VC	21	3	29	4	15

Lack of spatiotemporal consistency

+

Incomplete sets of parameters

Multivariate statistics → **Biased inference**

Reactive transport modeling → **Unreliable results**

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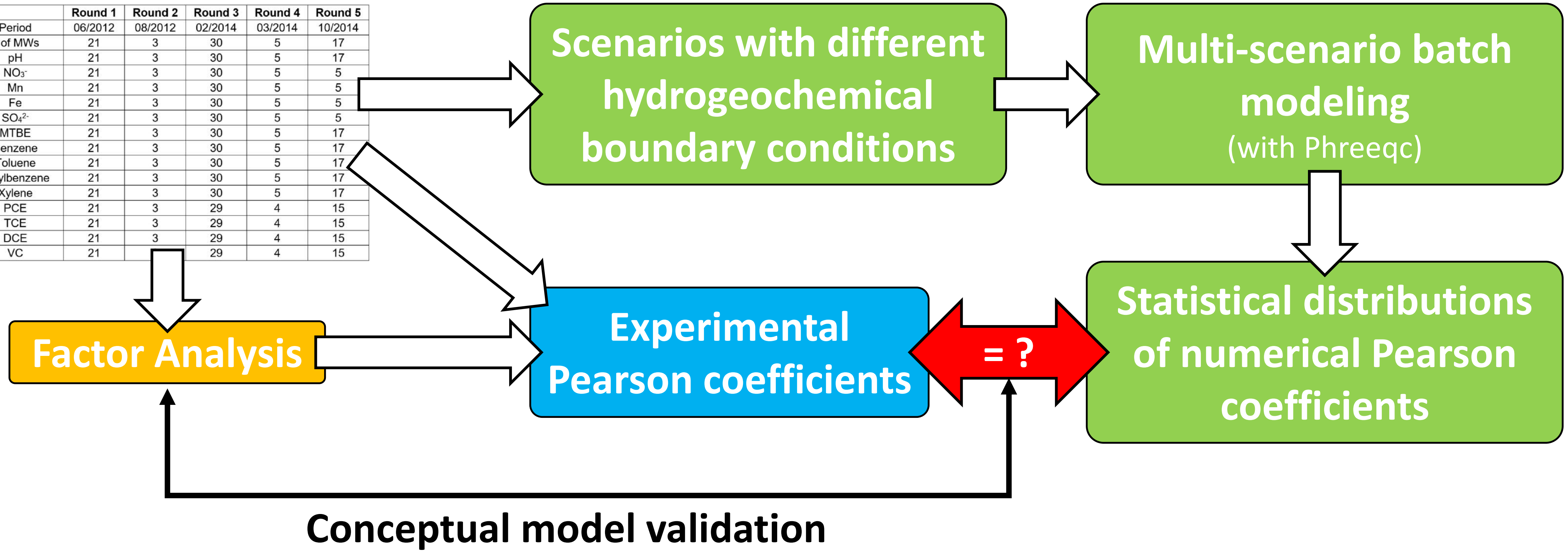
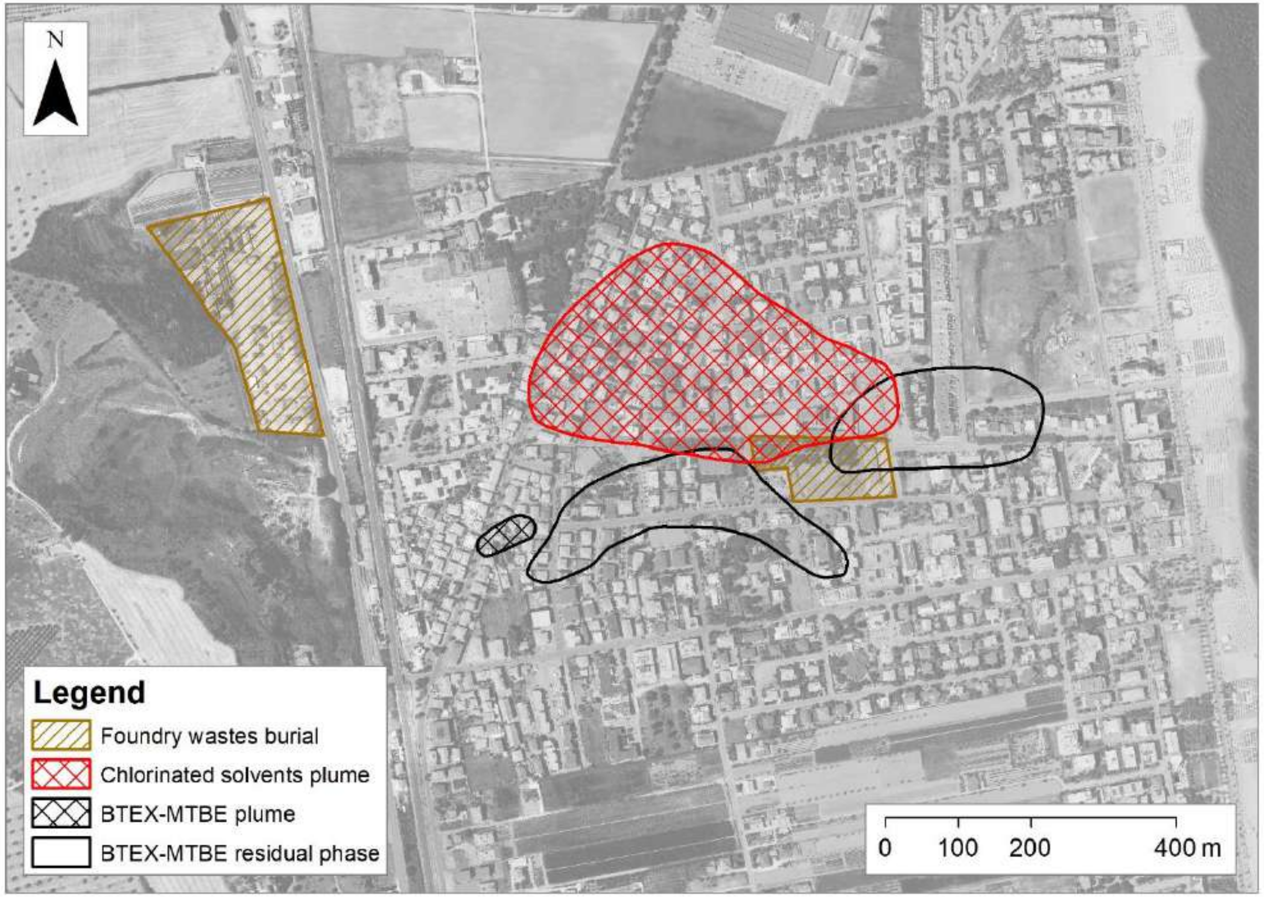
METHODOLOGICAL APPROACH

Sparse dataset

	Round 1	Round 2	Round 3	Round 4	Round 5
Period	06/2012	08/2012	02/2014	03/2014	10/2014
# of MWs	21	3	30	5	17
pH	21	3	30	5	17
NO_3^-	21	3	30	5	5
Mn	21	3	30	5	5
Fe	21	3	30	5	5
SO_4^{2-}	21	3	30	5	5
MTBE	21	3	30	5	17
Benzene	21	3	30	5	17
Toluene	21	3	30	5	17
Ethylbenzene	21	3	30	5	17
Xylene	21	3	30	5	17
PCE	21	3	29	4	15
TCE	21	3	29	4	15
DCE	21	3	29	4	15
VC	21	[illegible]	29	4	15



CASE STUDY



- **<u>Several known foundry wastes burials</u>** (unknown burials likely present)
- **<u>A fuel spill</u>** with a floating fuel pool → **<u>MTBE and BTEX</u>** (MBTEX) **<u>plume</u>**
- **<u>A chlorinated ethene</u>** (CEs) **<u>plume</u>** (unknown source).
- **<u>Possible interaction (?)</u>**

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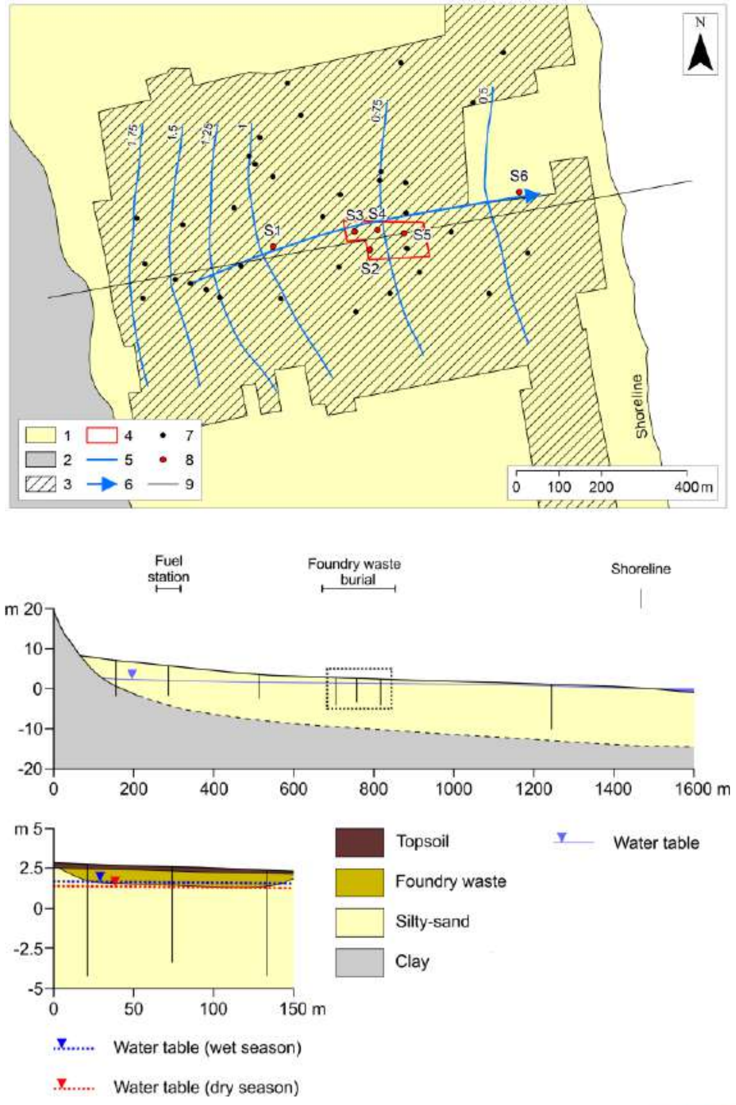
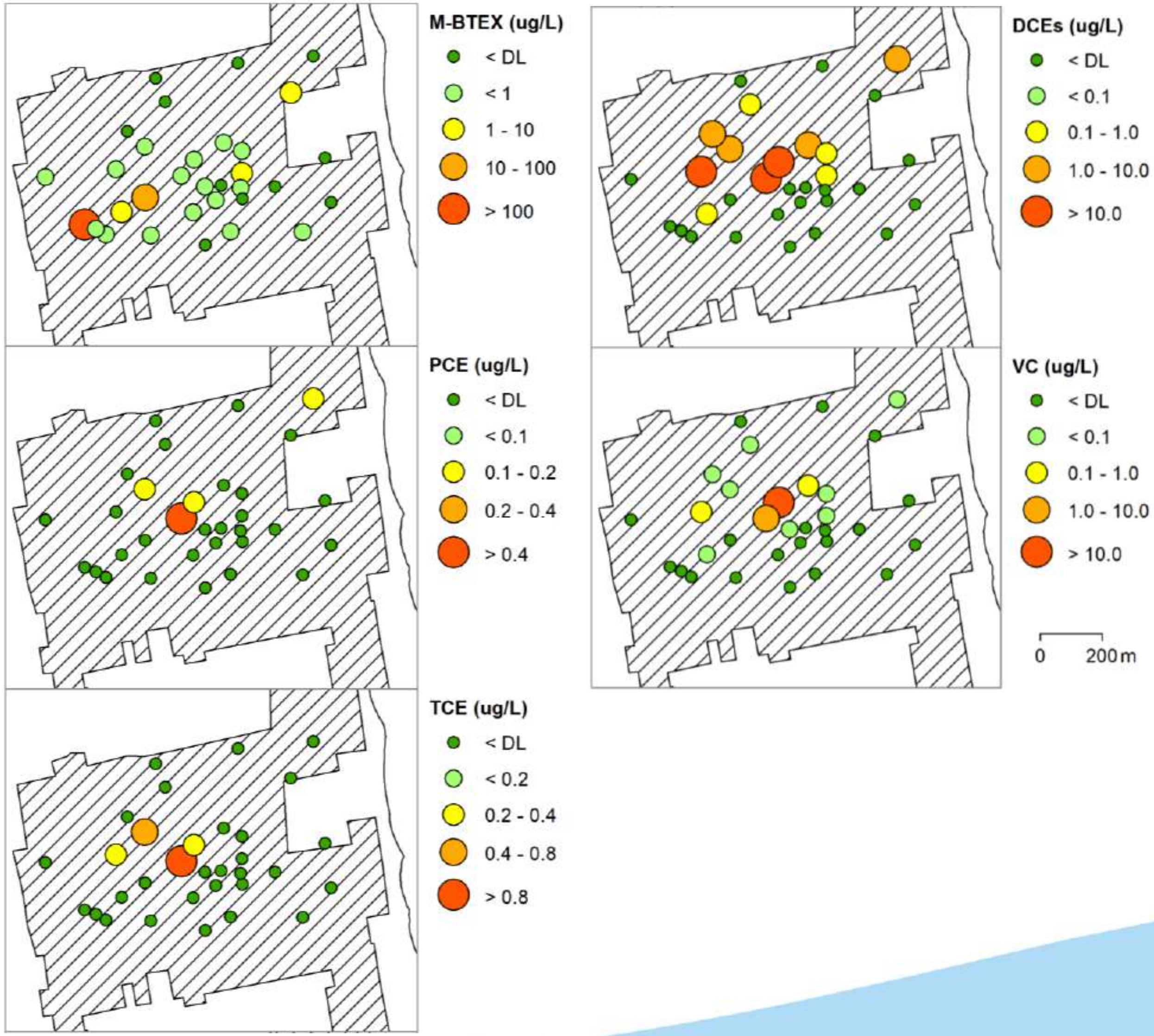
CASE STUDY



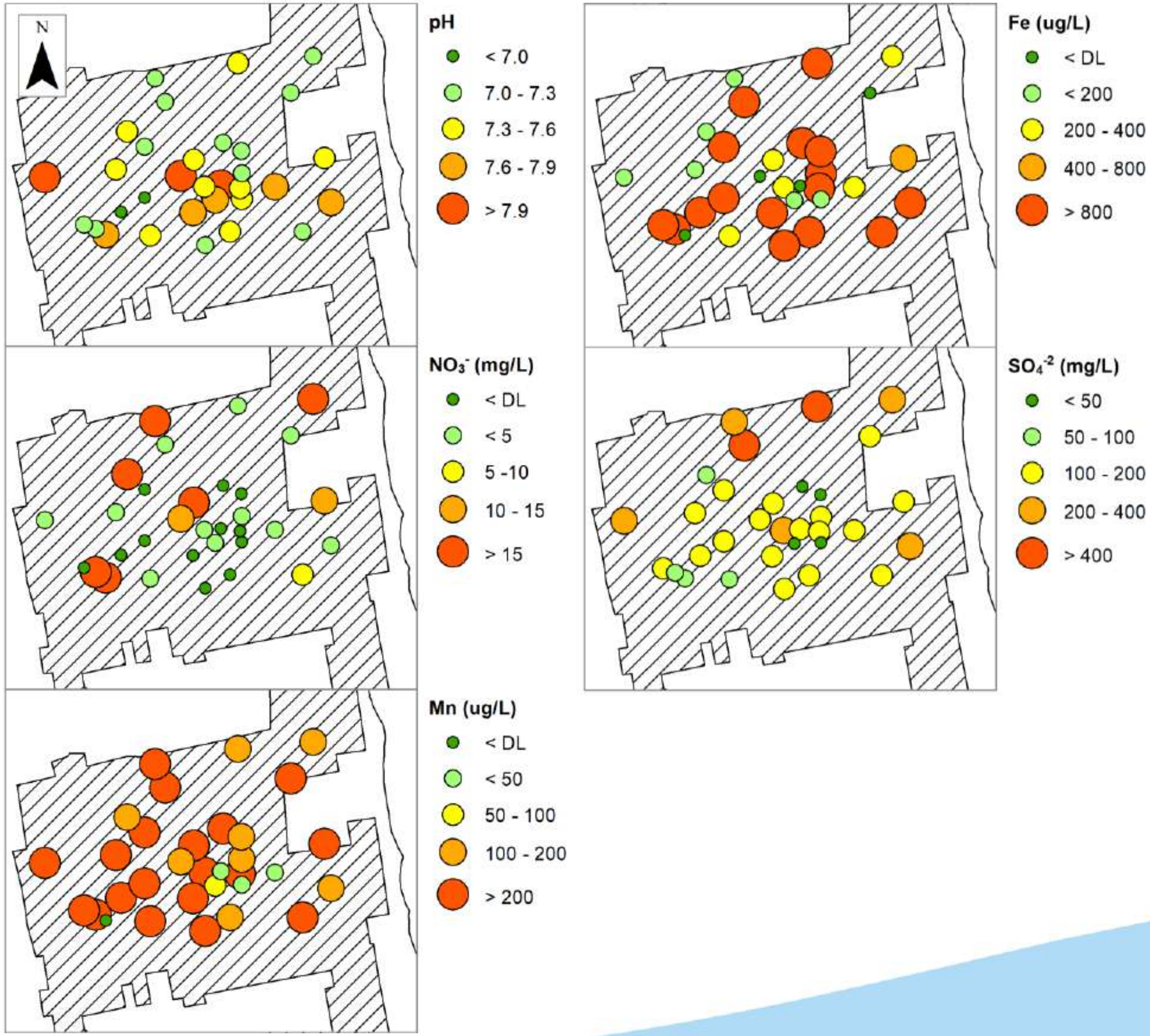
- **10-to-15-meter-thick sandy-silty coastal aquifer**, with sedimentary organic matter
- **Recharged by** direct **rainfall infiltration**
- Hydraulic gradents is very low and decreases toward the shoreline → **groundwater flow rate decreases downstream**
- GW table is very shallow → **foundry wastes and/or sewage system at least temporary in the saturated zone**

GROUNDWATER QUALITY/1



- **<u>MBTEX plume</u>**:
    - **<u>Core</u>** → C in the order of thousands of ug/L
    - **<u>External part</u>** → C in the order of a few ug/L
- **<u>CEs plume</u>** in a very limited area, **<u>with abundant daughter products</u>** (i.e., DCEs and VC)

GROUNDWATER QUALITY/2



- Both **Mn and Fe very abundant within the plume**, with **peak concentrations** immediately **downstream the foundry waste dump**
- **Nitrate and sulfate concentrations the lowest within the plume**
- **Nitrate shows «hotspots»** (secondary sources?)

MULTIVARIATE STATISTICAL EVIDENCE

Factor Analysis to interpret correlations (Pearson coefficients) among variables of interest

	pH	NO_3^-	Mn	Fe	SO_4^{2-}	PCE	TCE	DCE	VC	MBTEX
pH	1.000									
NO_3^-	-0.039	1.000								
Mn	**-0.501**	-0.192	1.000							
Fe	-0.217	-0.262	0.159	1.000						
SO_4^{2-}	-0.104	-0.075	0.082	**0.354**	1.000					
PCE	-0.059	0.108	0.157	-0.179	-0.113	1.000				
TCE	-0.019	0.074	0.155	-0.205	-0.095	**0.867**	1.000			
DCE	-0.069	**0.540**	-0.038	-0.191	-0.124	**0.413**	**0.360**	1.000		
VC	-0.068	**0.389**	-0.054	-0.144	-0.099	0.195	0.116	**0.906**	1.000	
MBTEX	-0.188	-0.105	**0.499**	-0.099	-0.098	-0.079	-0.085	-0.071	-0.049	1.000

	Entire dataset			
	F1	F2	F3	F4
pH	-0.158	-0.034	**-0.687**	0.344
NO_3^-	**0.716**	-0.031	-0.125	0.139
Mn	-0.124	0.186	**0.868**	-0.111
Fe	-0.165	-0.133	0.117	**-0.785**
SO_4^{2-}	-0.059	-0.046	-0.011	**-0.756**
PCE	0.151	**0.943**	0.049	0.079
TCE	0.076	**0.956**	0.022	0.097
DCE	**0.918**	0.297	0.025	0.063
VC	**0.904**	0.067	0.043	0.028
MBTEX	-0.107	-0.176	**0.751**	0.367
Eigenvalue	2.283	1.984	1.824	1.492
% total variance	22.8	19.8	18.2	14.9
Cumulative %	22.8	42.7	60.9	75.8

- **F1 → accumulation of RD by-products due to nitrate (competition for substrate?)**
- **F2 → Co-occurrence of parent chlorinated ethenes**
- **F3 → Reductive dissolution of Mn oxi-hydroxides during MBTEX degradation**
- **F4 → iron-sulfur minerals precipitation (?)**

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SCENARIO-BASED BATCH MODEL IMPLEMENTATION

- Initial equilibration with **Calcite**, **Dolomite**, **Gypsum**, **$CO_{2(g)}$**, and **$O_{2(g)}$**
- **Inorganic TEAPS** & **secondary reactions** → **Partial Equilibrium Approach**
- **Degassing** of redox-sensitive gases
- **MBTEX degradation** → **Monod kinetics***
- **Reductive dechlorination** → **Monod kinetics with substrate limitation***:

$$\frac{dCEs}{dt} = rate_{Monod} \boxed{\frac{H_2}{H_2 + K_{H_2}}}$$

Variable	Description	Level	Value
MBTEX	Total molality (i.e., sum of all the group members), with the same proportion as in field data	Low	0.1 mmol/L
		High	1 mmol/L
Chloroethenes	Total molality (i.e., sum of all the group members), with the same proportion as in field data	Low	0.01 µmol/L
		High	0.1 µmol/L
Nitrate	Total molality	Low	0.01 mmol/L
		Intermediate	0.1 mmol/L
		High	1 mmol/L
Mn(IV) oxi-hydroxides	Solubility (log k)	Low	15 (Pyrochroite-like)
		Intermediate	30 (Manganite-like)
		High	45 (Pyrolusite-like)
Fe(III) oxi-hydroxides	Solubility (log k)	Low	9 (Hematite-like)
		Intermediate	12 (Goethite-like)
		High	15 (Ferrihydrite-like)

⇩

108 scenarios for each of the hypotheses
(competitive and non-competitive conditions)

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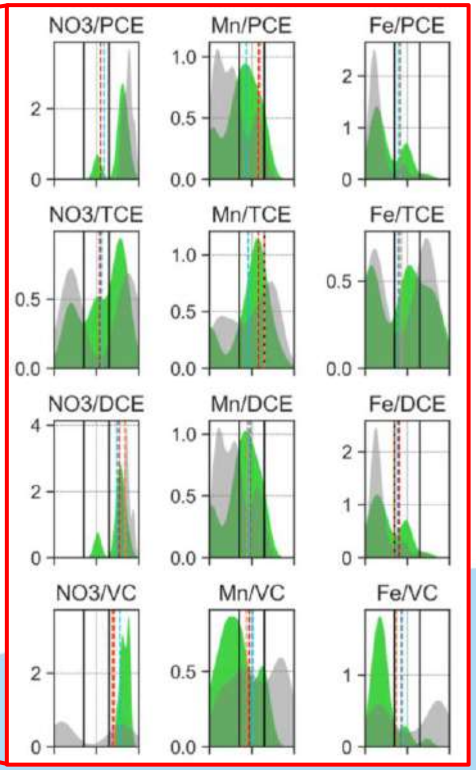
*Kinetic equation were calibrated on field measurements

MODELING RESULTS

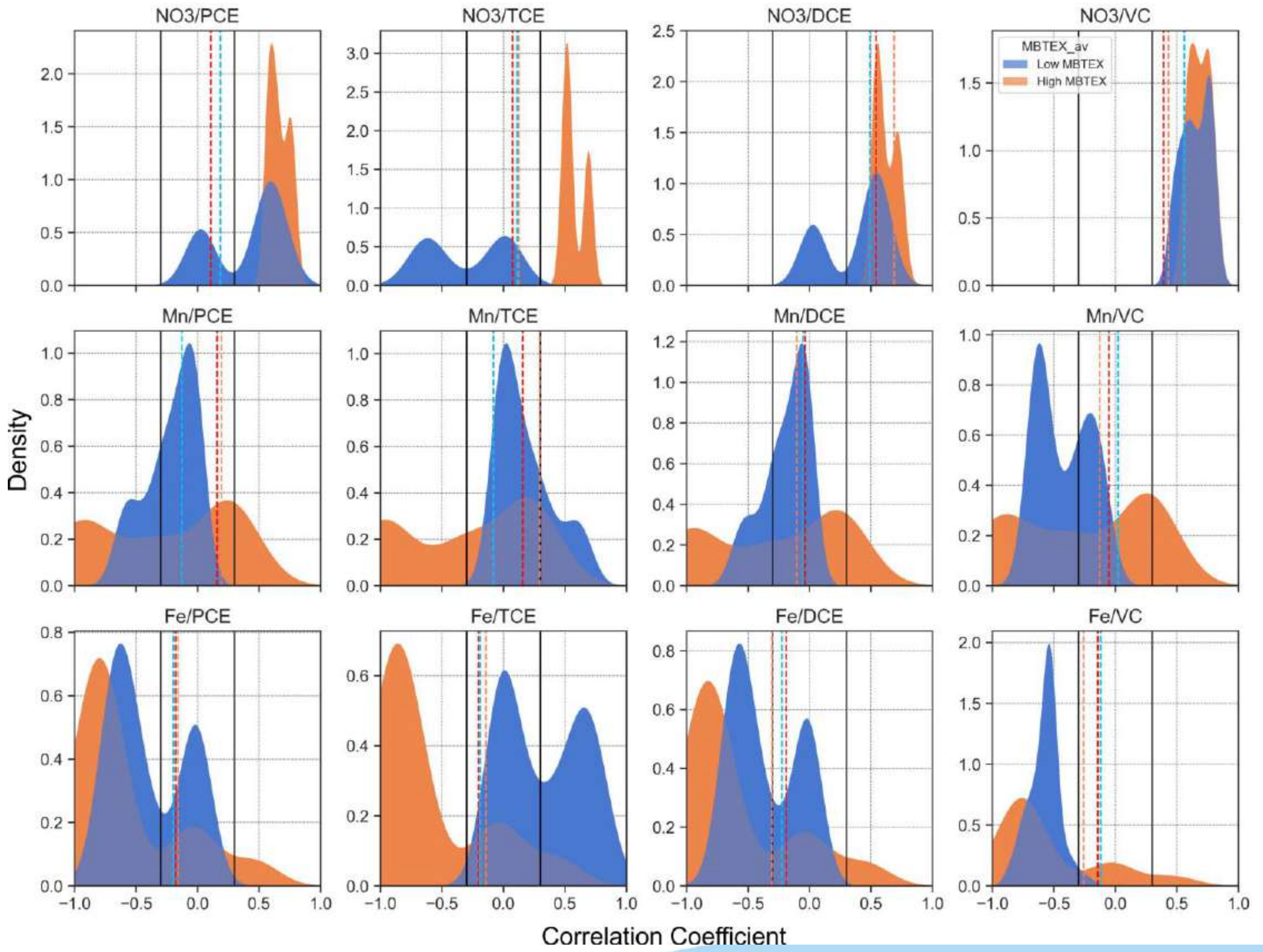
- **<u>Green plots → competitive conditions</u>**
- **<u>Gray plots → non-competitive conditions</u>**

<u>Comparison between experimental correlations and the statistical distribution of Pearson coefficients obtained from</u> the 108 scenario **<u>models</u>**.



- **<u>Orange dashed lines → June 2012</u>**
- **<u>Cyan dashed lines → February 2014</u>**
- **<u>Red dashed lines → whole dataset</u>**

THE EFFECT OF MBTEX AVAILABILITY

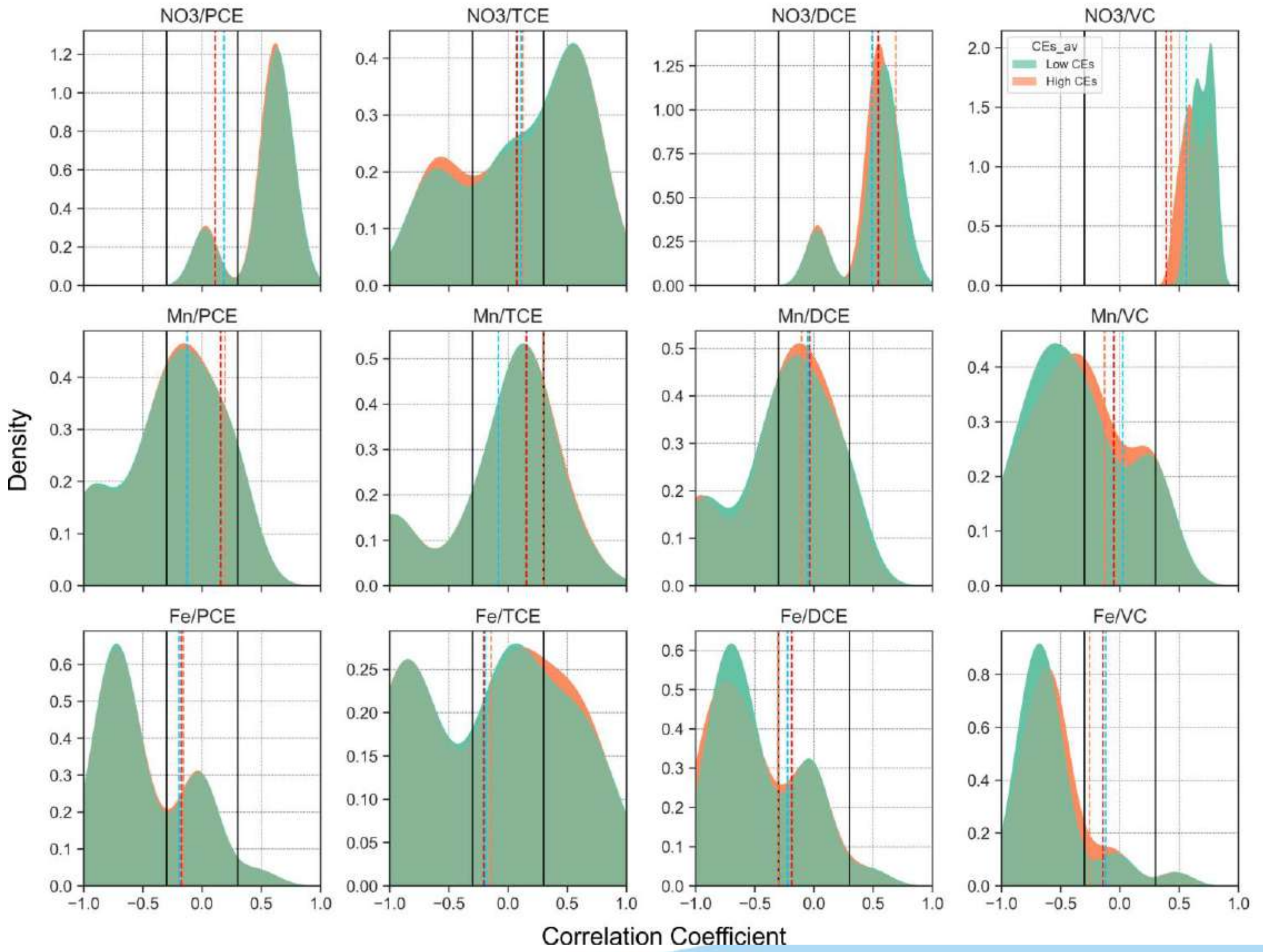


<u>At low MBTEX concentrations</u>, <u>good match</u> between the numerical result correlations and the experimental ones

⇩

<u>Substrate limitation causes competition</u> between inorganic TEAPs and reductive dechlorination

THE EFFECT OF CHLORINATED ETHENES AVAILABILITY

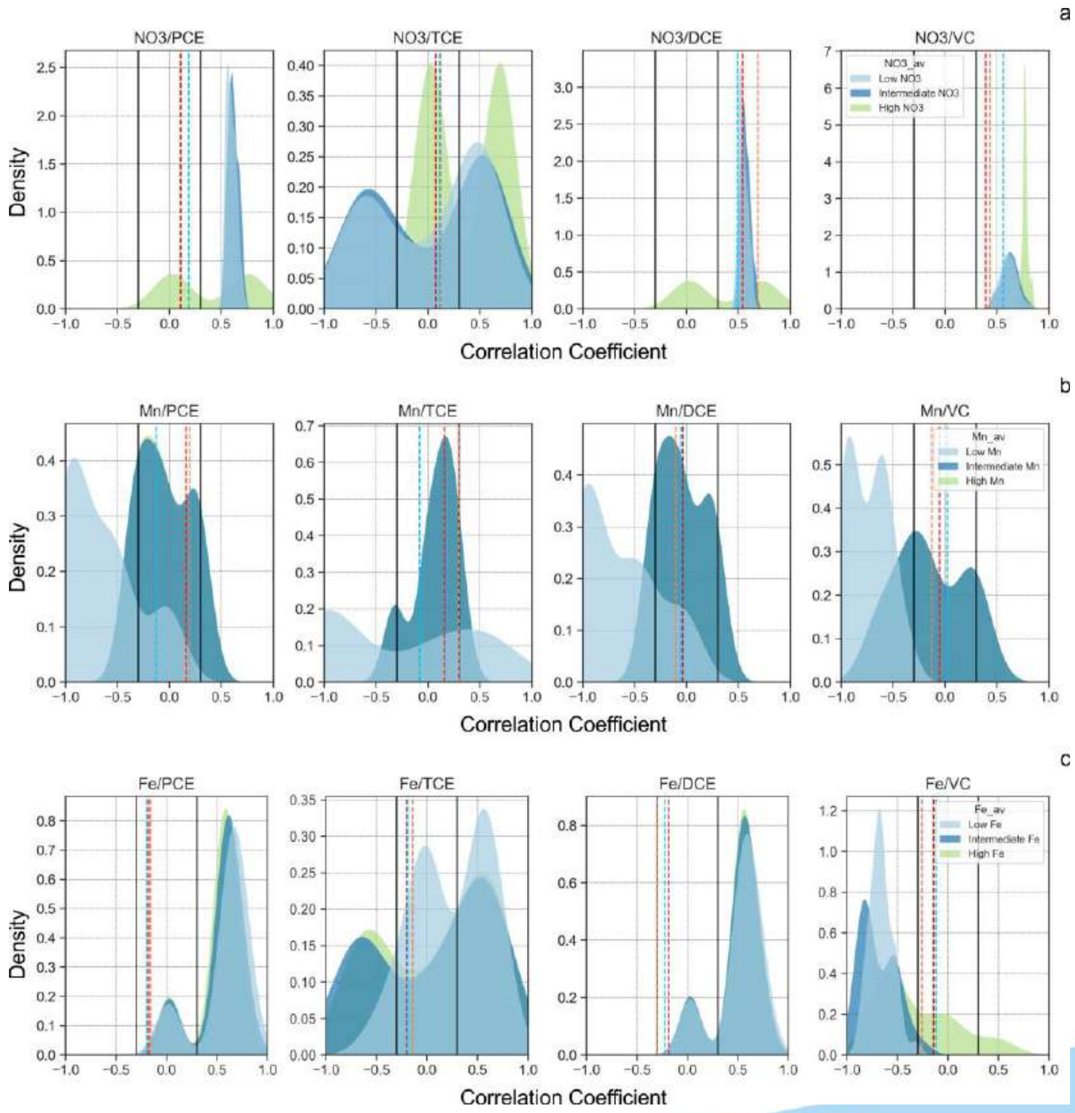


The amount of **chlorinated ethenes did not seem to be so relevant** in conditioning their relationships with inorganic TEAs

⇩

competition for substrate can take place both **at high and low concentrations of chlorinated ethenes**

THE EFFECT OF INORGANIC TEAs AVAILABILITY

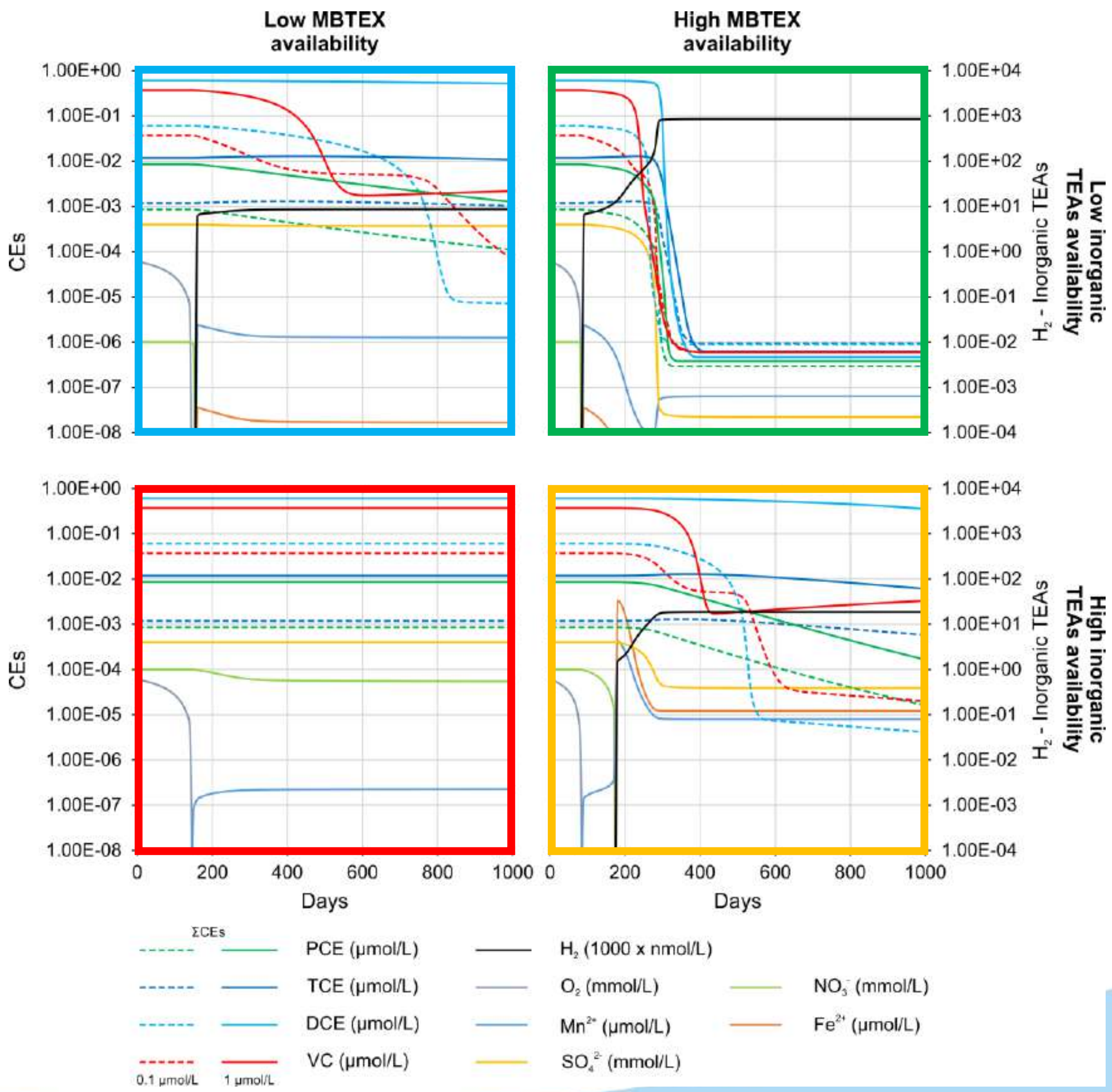


NO_3 vs. CEs match → nitrate inhibits **PCE and TCE** degradation when **highly available**, while **DCEs and VC always**

Mn vs. CEs match → Mn inhibits **CEs** degradation in case of **intermediate and high solubility**

Fe vs. CEs match → Fe shows **unclear results**, suggesting a **negligible effect** of its availability **on RD degradation**

COMPETITION FOR SUBSTRATE WITHIN THE MBTEX PLUME



End-member scenarios:

- **Plume core w/o additional TEAs** → NO competition, **NO RD inhibition**
- **Plume external part w/o additional TEAs** → Intermediate competition, **RD slowed down**
- **Plume core w/ additional TEAs** → Intermediate competition, **RD slowed down**
- **Plume external part w/ additional TEAs** → Strong competition, **RD completely inhibited**

CONCLUSIONS

- The **novel scenario-based numerical approach** was able to **identify and investigate the competition for organic substrate**.
- The **competition for substrate is favored** in conditions of **substrate limitations** and/or in the presence of mostly **nitrate and**, to a lesser extent, intermediate-to-high soluble **Mn(IV) oxi-hydroxides**, which act as competing inorganic TEAs.
- The amount of **chlorinated ethenes as well as the solubility of Fe(III) oxi-hydroxides seem to play an unclear, minor, or negligible role** in the competition process.
- This approach took advantage of **mechanistic process-based knowledge to overcome the issue of spatio-temporally sparse datasets**, **which** often **lead to incorrect and biased interpretations of the processes** occurring in a polluted aquifer.

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THANKS FOR YOUR ATTENTION!

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unesco Intergovernmental Hydrological Programme

AIGA ASSOCIAZIONE ITALIANA GEOLOGIA APPLICATA E AMBIENTALE

ENGEOL IAEG AIGI

IRSA CNR

ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale

Sistema Nazionale per la Protezione dell'Ambiente

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Application of multivariate statistical analysis for the delineation of groundwater bodies: a case study in Campania Region (Southern Italy)

Stefania Stevenazzi[1], Konstantinos Voudouris[2],
Daniela Ducci[1]

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[1] Università degli Studi di Napoli Federico II, Italy
[2] Aristotle University of Thessaloniki, Greece

INTRODUCTION

Groundwater quality in areas characterised by different geological formations, diversified ecosystems, highly developed by human activities and located along the coastline may result in heterogeneous hydrochemical facies distribution. When dealing with large datasets, classical graphical methods (e.g., Stiff, Piper, Schoeller) have some inherent limitations.

The specific objectives of this study are:

- to identify the hydrogeochemical processes
- and to verify the current delineation of four groundwater bodies in Campania Region (DAM, 2021)

Through the application of **hydrogeochemical methods** and **multivariate statistical analyses**.

↓ **hydrogeochemical methods**: Classical and color-coded Piper Diagram

↓ **multivariate statistical analyses**: R-mode Factor Analysis

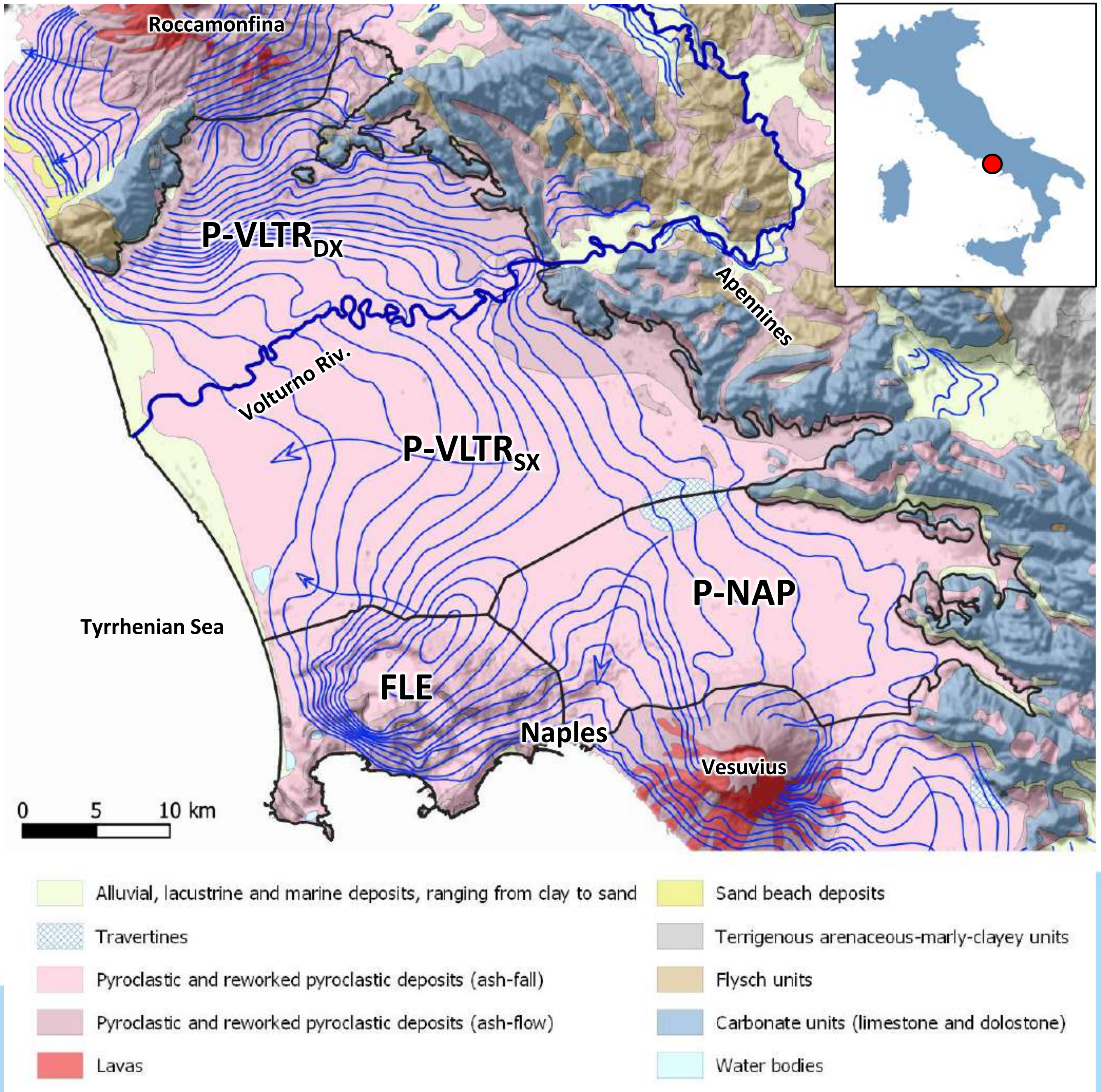
DAM, 2021. Autorità di Bacino Distrettuale dell'Appennino Meridionale. Piano di gestione delle acque ciclo 2021-2027.

STUDY AREA

Groundwater bodies:

- Volturno Plain (P-VLTR$_{DX}$, P-VLTR$_{SX}$) constituted of fluvial, pyroclastic and marine sediments
- Plain of Naples (P-NAP), constituted of fluvial and pyroclastic sediments
- Phlegrean Fields (FLE), an active volcanic area with a series of monogenic volcanic edifices

In the plains, two main porous aquifers are present: a shallow phreatic one and a deep semi-confined (or confined) one separated by a tuff layer of variable thickness



Hydrogeological units: modified from De Vita et al., 2018. J. Maps

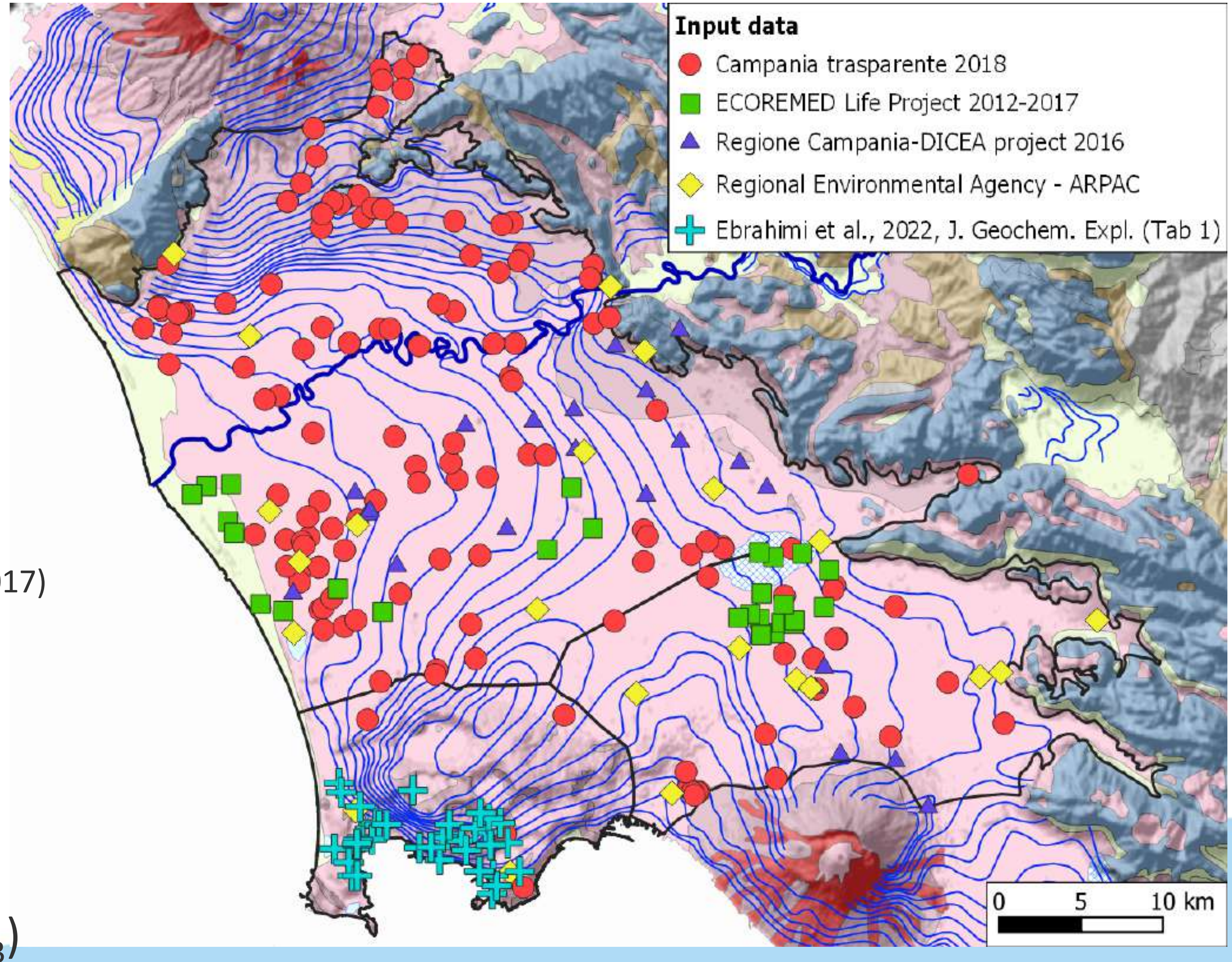
HYDROCHEMICAL DATA

Data from:

A. Campania Trasparente 2018
   (n. 172 sampling points, samples collected in 2016-2017)
B. ECOREMED Life Project 2012-2017
   (n. 27 sampling points, samples collected in 2013)
C. Regione Campania-DICEA project 2016
   (n. 33, sampling points, samples collected in 2016)
D. Regional Environmental Agency - ARPAC
   (n. 31 sampling points, most recent sample collected in 2014-2017)
E. Ebrahimi et al., 2022, J. Geochem. Expl.
   (n. 42 sampling points, samples collected in 2019)

Parameters:

- Electrical conductivity (EC), pH
- Major ions (Ca, Mg, Na, K, HCO_3, Cl, SO_4, NO_3)
- Minor elements (As, Fe, Mn, V, B)



Partially published data: (B) in Ducci et al., 2017, IJERPH; (C) in Ducci et al., 2019, GEAM

HYDRO-CHEMICAL FACIES

Graphical methods for aqueous geochemical data visualisation (e.g., Piper, Schoeller, Stiff diagrams, etc.) help to better understand spatio-temporal evolution and mixing of water in the hydrogeologic systems.

Steps:

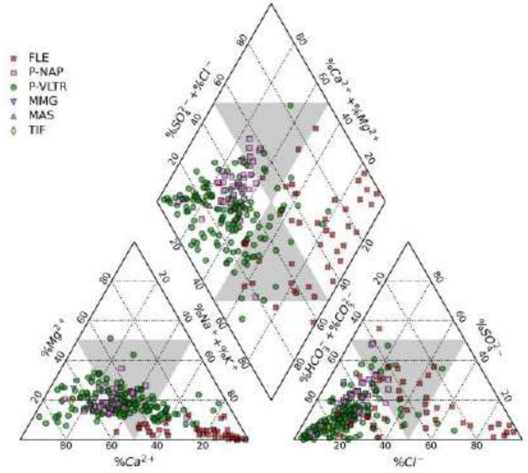
i. Preparation of the dataset(s): check of the ionic balance (error ≤ ± 10%);

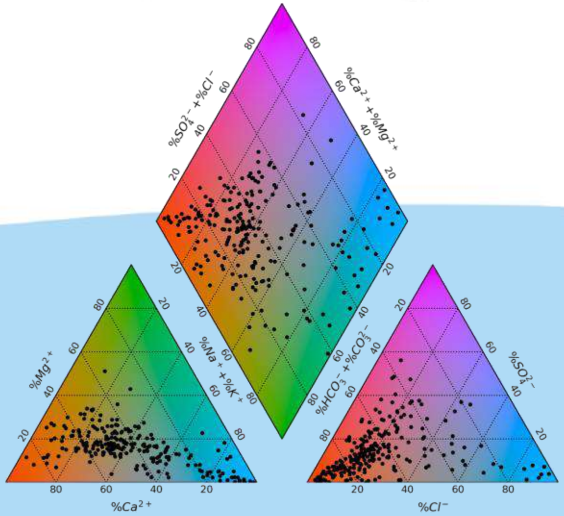
ii. Selection of the software for generating the geochemical diagrams
→ WQChartPy (Yang et al., 2022, Ground Water)

iii. Color coded Piper Diagram (Peeters, 2014, Ground Water): a background color scheme is used to fill the trilinear Piper plot, so that each water sample can be colored with unique RGB values according to its location in the Piper diagram

iv. IDW interpolation is used to map the spatial distribution of RGB values

v. Comparison with previous studies and GWBs delination





MULTIVARIATE STATISTICAL ANALYSIS

Multivariate statistical analysis allows the handling of many geochemical and physical parameters (variables) for grouping water samples showing similarities into homogeneous clusters.

The (hydro)geological interpretation of the factors gives an insight into the main processes which may control the spatial distribution of hydrochemical parameters.

Steps:

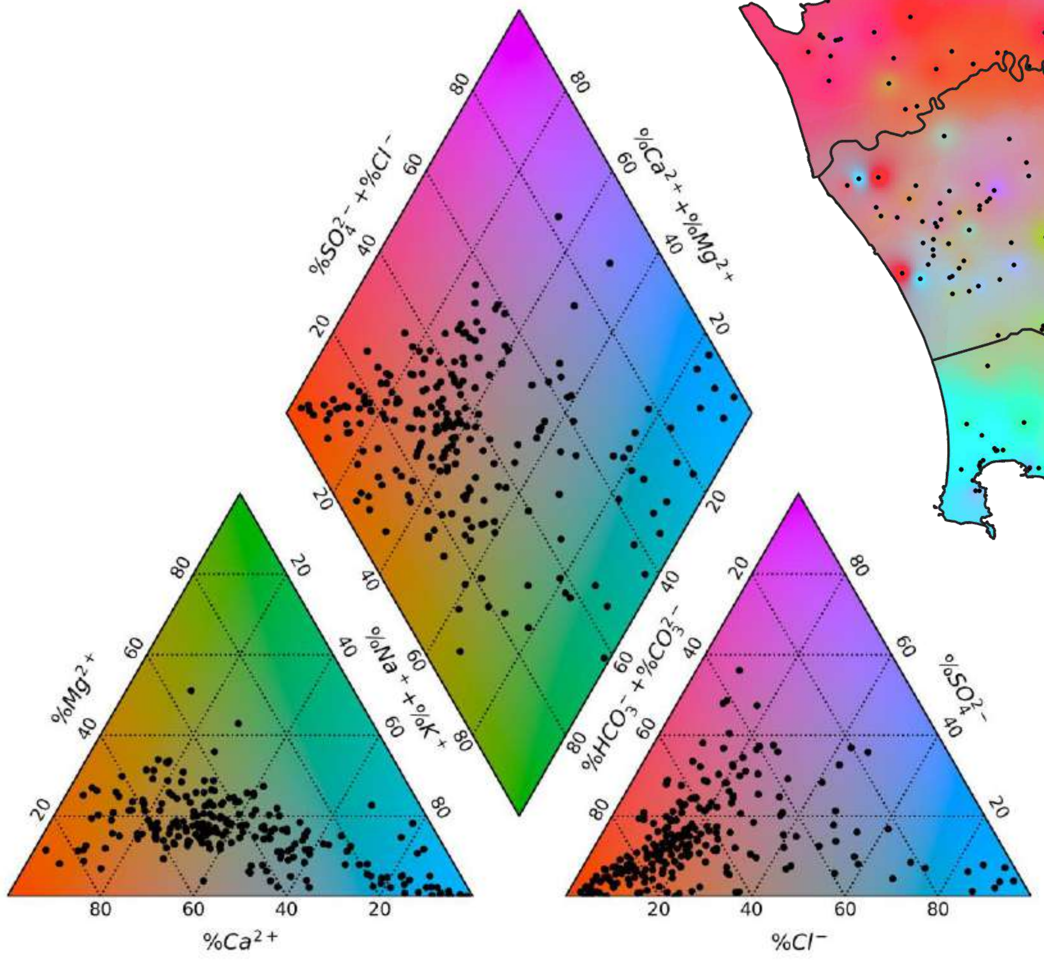
i. Preparation of the dataset(s): check of the ionic balance (error ≤ ± 10%); handling of missing/censored data and outliers; Kolmogorov-Smirnov test on parameters; if necessary, application of a transformation to the values (e.g., log; Box-Cox); standardization of the parameters (z-scores)

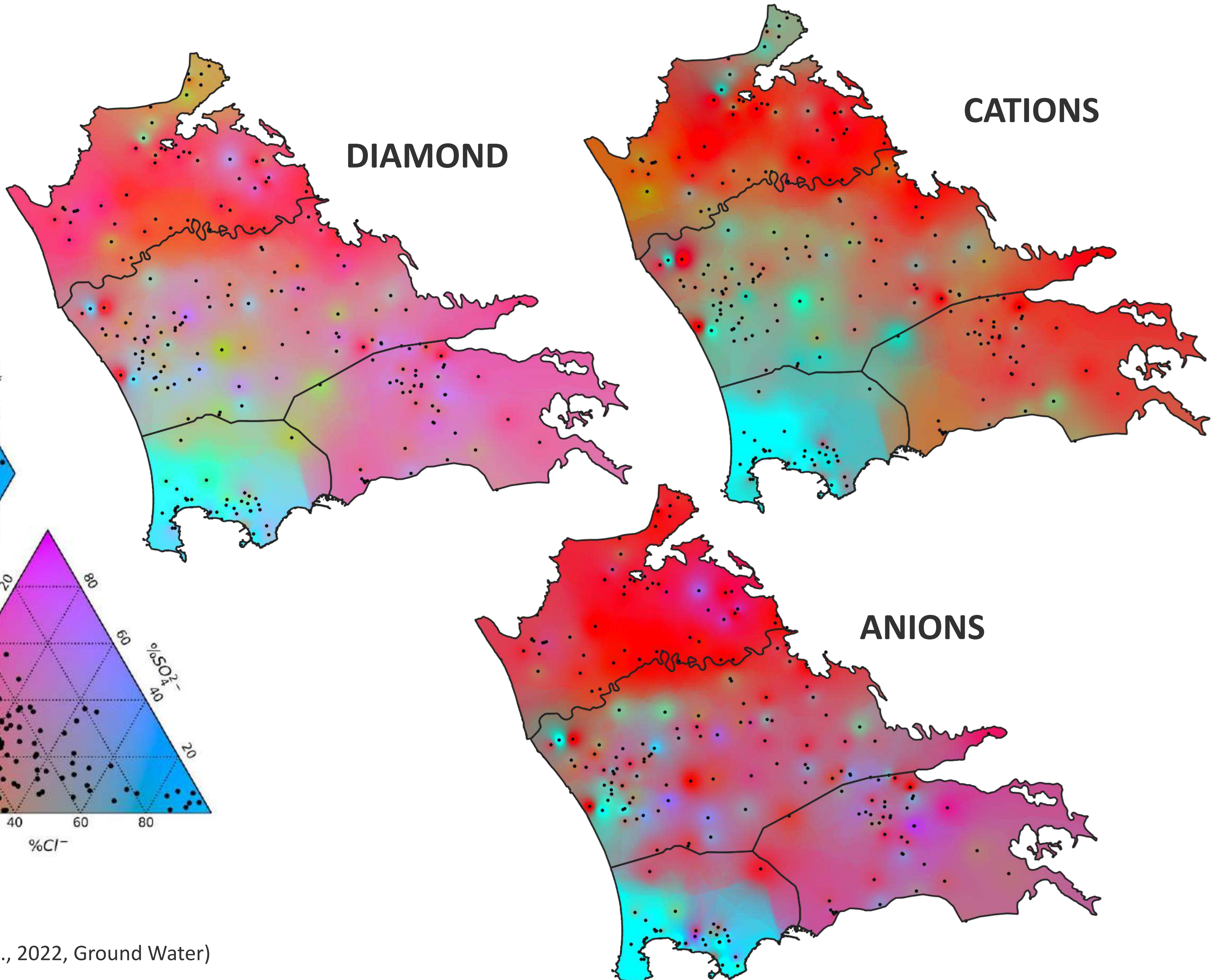
ii. Grouping of the parameters showing similarities based on chemical analyses of water samples (R-mode Factor Analysis)

iii. Mapping of the geographical distribution of the resulting factors

iv. Comparison with previous studies (e.g., Corniello & Ducci 2014, J. Geochem. Expl.; Cuoco et al., 2015, Environ. Monit. Assess.; Busico et al., 2018, Environ. Pollut., etc.) and GWBs delination

RESULTS





Dataset E

Color coded Piper Diagram created w/ WQChartPy (Yang et al., 2022, Ground Water)

IDW interpolation executed w/ ArcGIS 10.8.2

RESULTS

<u>Dataset E:</u> n. samples: 232

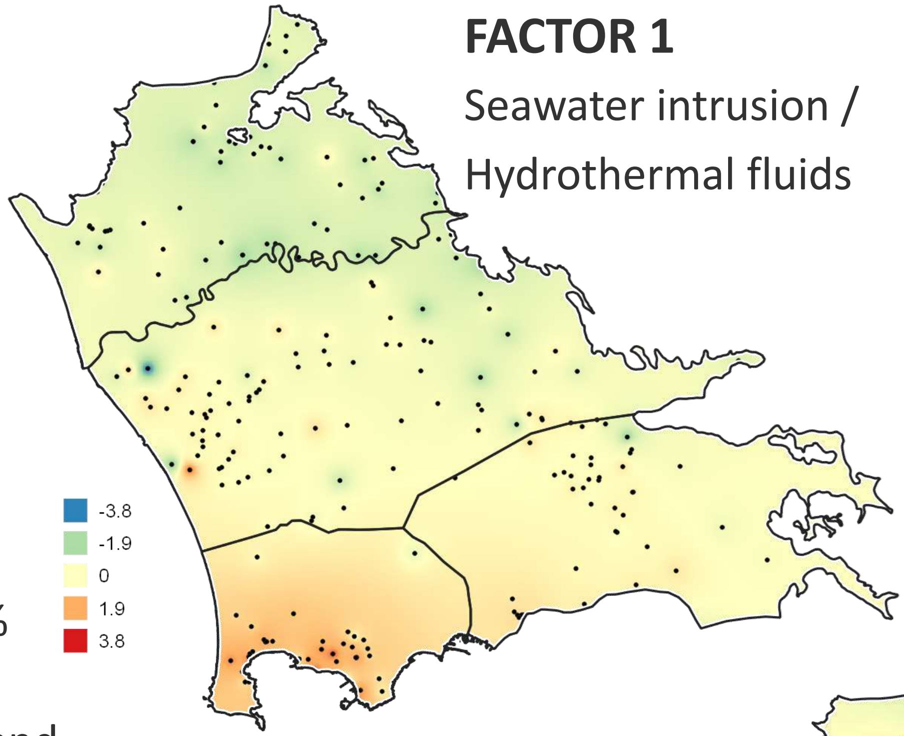
Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy = .738 (>.5)

Total variance explained = 82.5 %

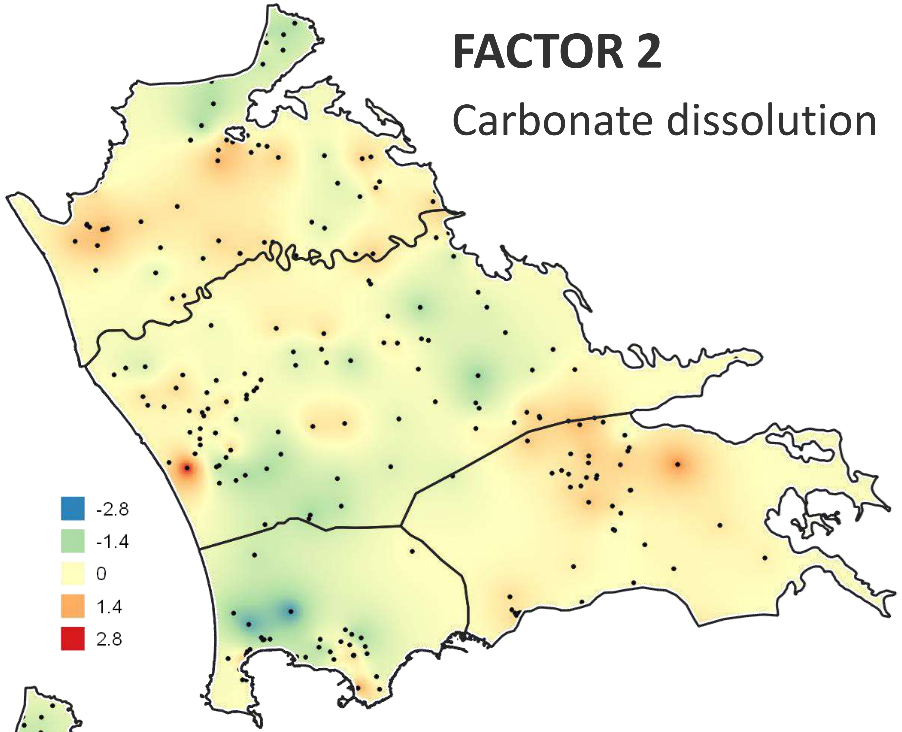
Varimax rotated factor loadings and total variance:

Factor I (44.0%)	Factor II (23.6%)	Factor III (14.9%)
As (.87) Cl (.87) K (.865) SO4 (.70)	HCO_3 (.76) Ca (.92) Mg (.90)	NO_3 (.94) SO_4 (.46)

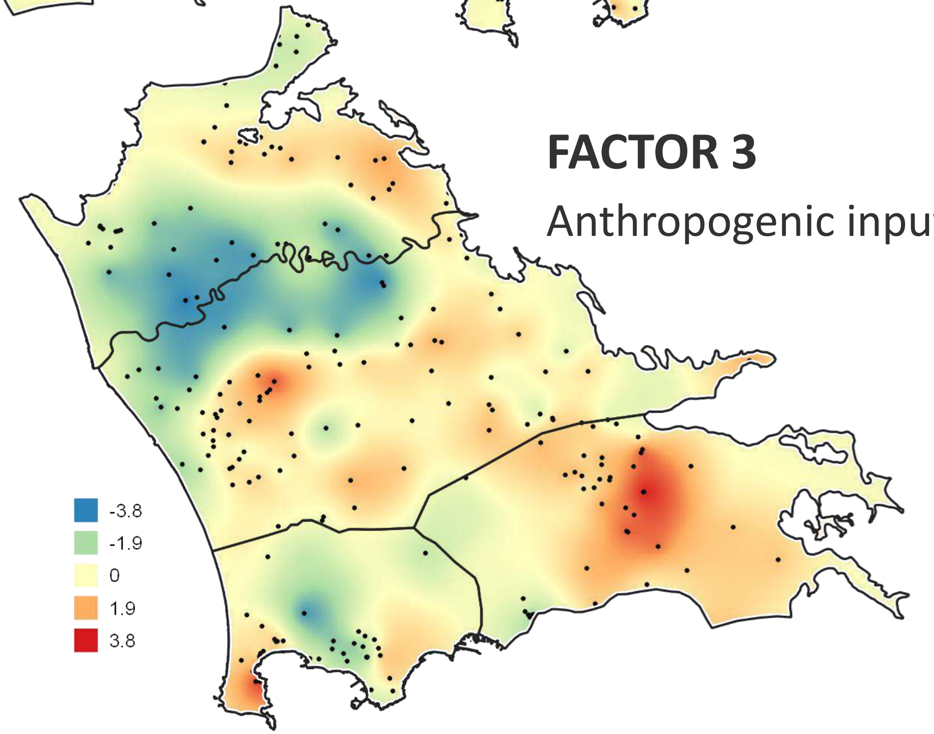
FACTOR 1
Seawater intrusion / Hydrothermal fluids



FACTOR 2
Carbonate dissolution



FACTOR 3
Anthropogenic input



Dataset E. Factor 1: IDW interpolation; Factor 2, 3: kriging interpolation; executed w/ Surfer 11

RESULTS

Dataset H: n. samples: 114

Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy = .546 (>.5)

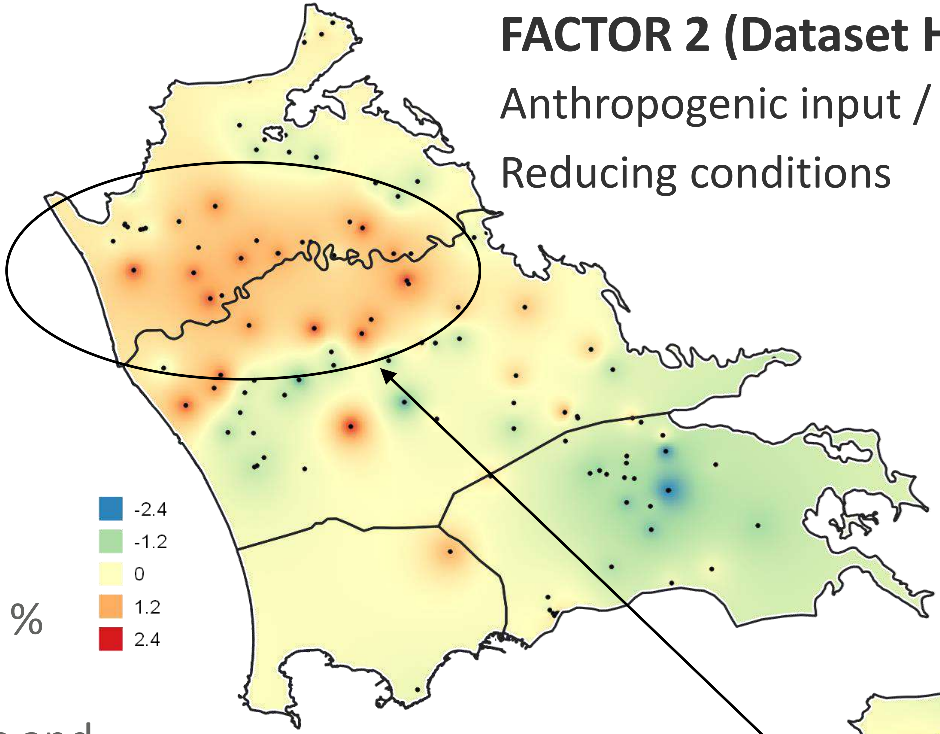
Total variance explained = 72.8 %

Varimax rotated factor loadings and total variance:

Factor I (36.3%)	Factor II (24.2%)	Factor III (12.3%)
HCO_3 (.835)	Fe (.75)	As (.73)
Ca (.91)	Mn (.70)	Cl (.78)
Mg (.83)	NO_3 (-.87)	Na (.75)
	SO_4 (-.73)	K (.70)

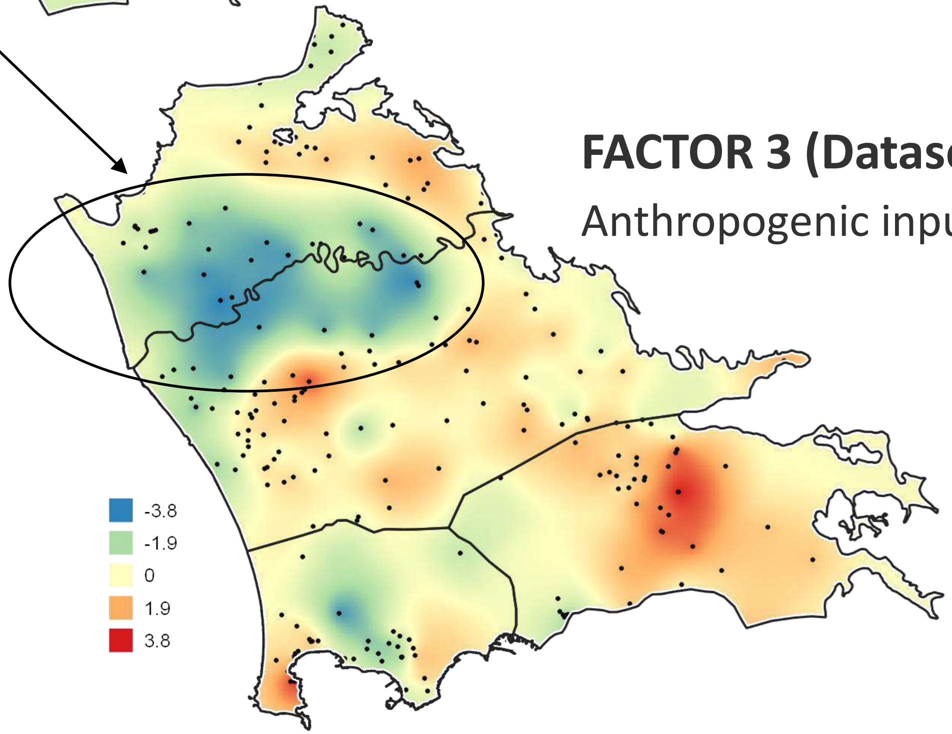
FACTOR 2 (Dataset H)

Anthropogenic input / Reducing conditions



FACTOR 3 (Dataset E)

Anthropogenic input



Dataset H. Factor 2: IDW interpolation; executed w/ Surfer 11

CONCLUSIONS

i. evaluate the consistency and reliability of public available datasets (i.e., source; sampling date; XYZ data; complete information on sampling points, e.g., well screen depth);

ii. highlight the necessity and usefulness of large chemical database to assess multivariate statistical analysis;

iii. identify the hydrogeochemical processes, mostly reflecting known processes (salinization, carbonate rocks dissolution, natural or anthropogenic inputs, redox conditions, volcanic products contribution), but also highlighting the influence of groundwater flowpaths on water chemistry; some processes are peculiar of one GWB, but others are in common between two or more GWBs;

iv. open issues: evaluation of the hydrogeochemical processes differences during wet or dry periods (seasonality); evaluation of the long-term trend evolution of hydrogeochemical processes; improvement of the performance of the interpolation techniques.

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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]Dept. of Earth and Environmental Sciences, University of Milano-Bicocca

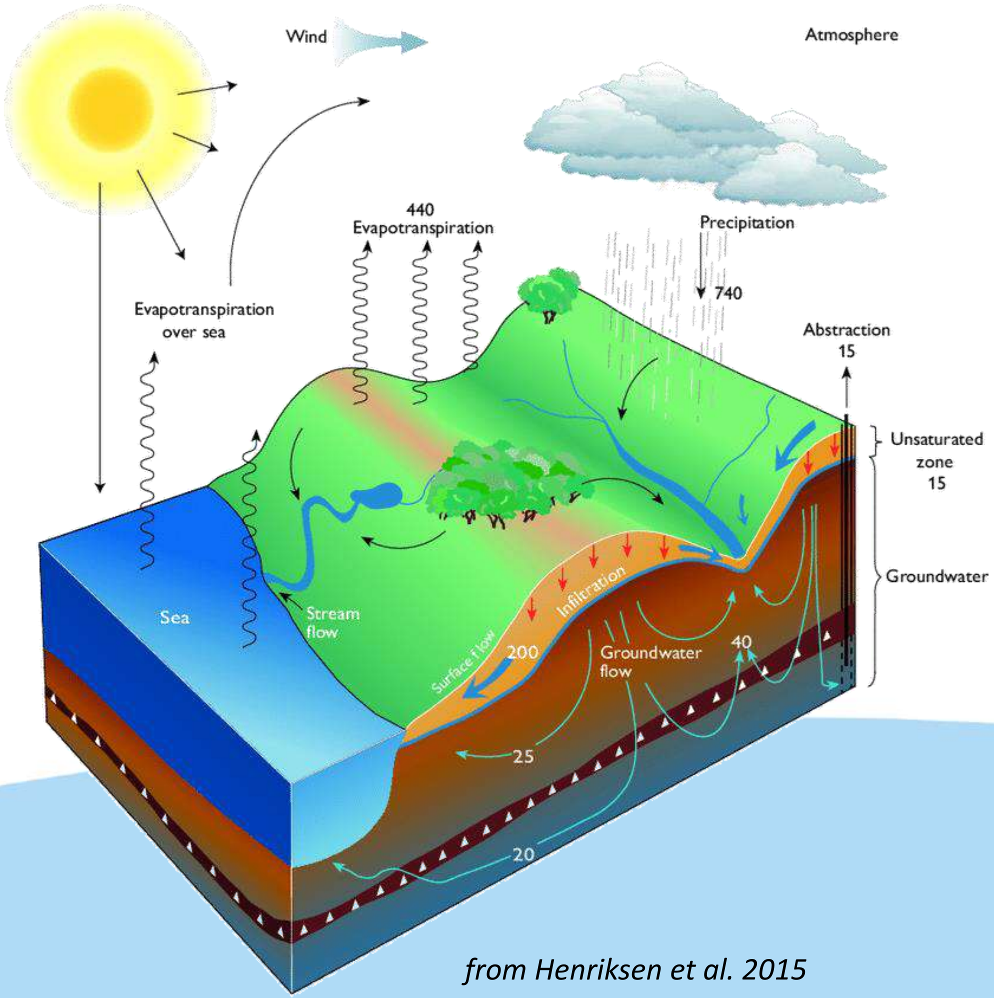
[2]Dept. of Earth and Environmental Sciences, University of Pavia

[3]Regional Agency for Agriculture and Forests of Lombardy

Presentation Outline

Which are the effects of drought on the hydrogeological water balance of shallow Po Plain aquifers in Lombardy region?

1. Main features of Po Plain aquifers.
2. Current main sources of recharge of Po Plain aquifers.
3. How recharge is likely to change (is changing) due to drought.



from Henriksen et al. 2015

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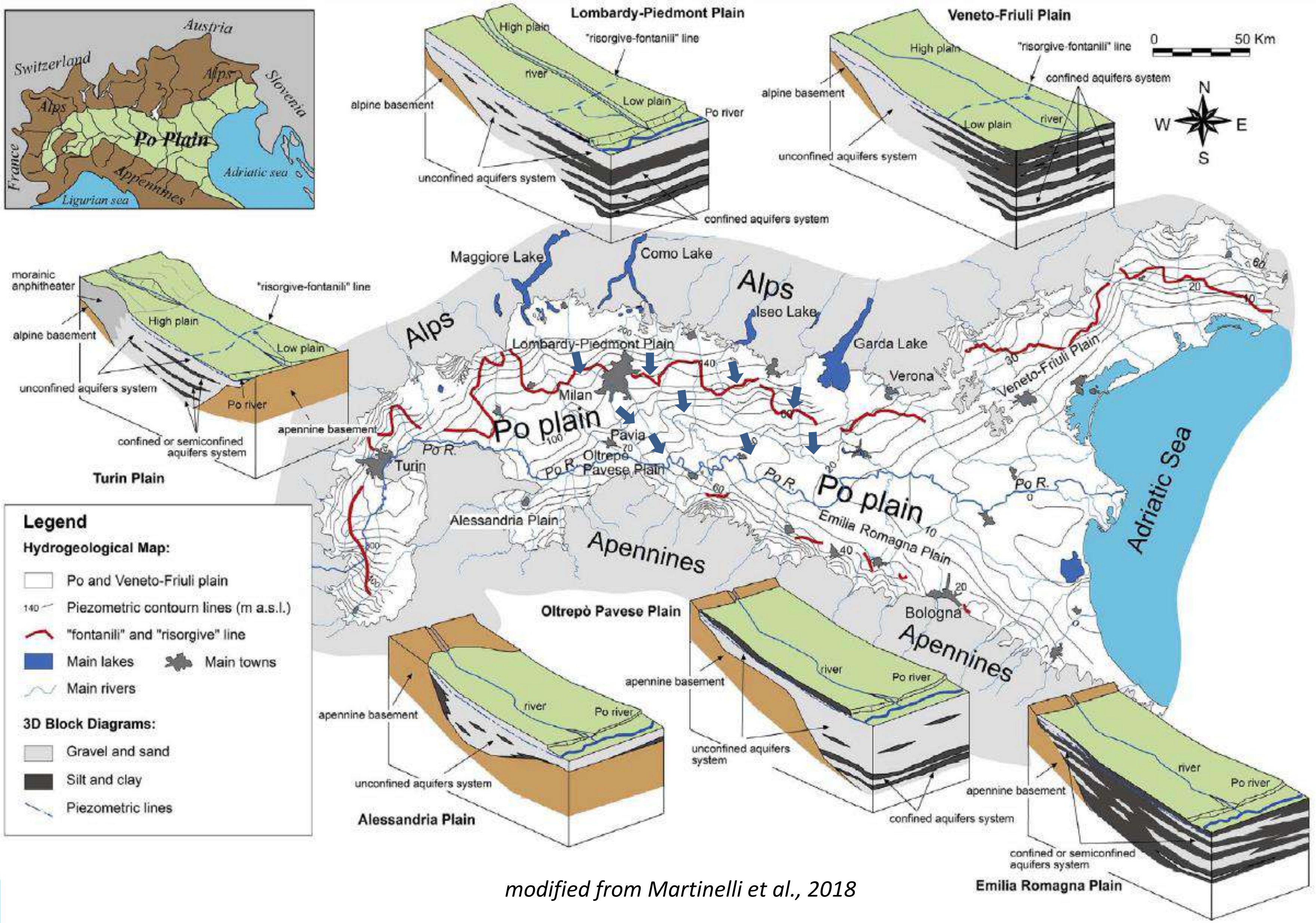
Po Plain Aquifers in Lombardy



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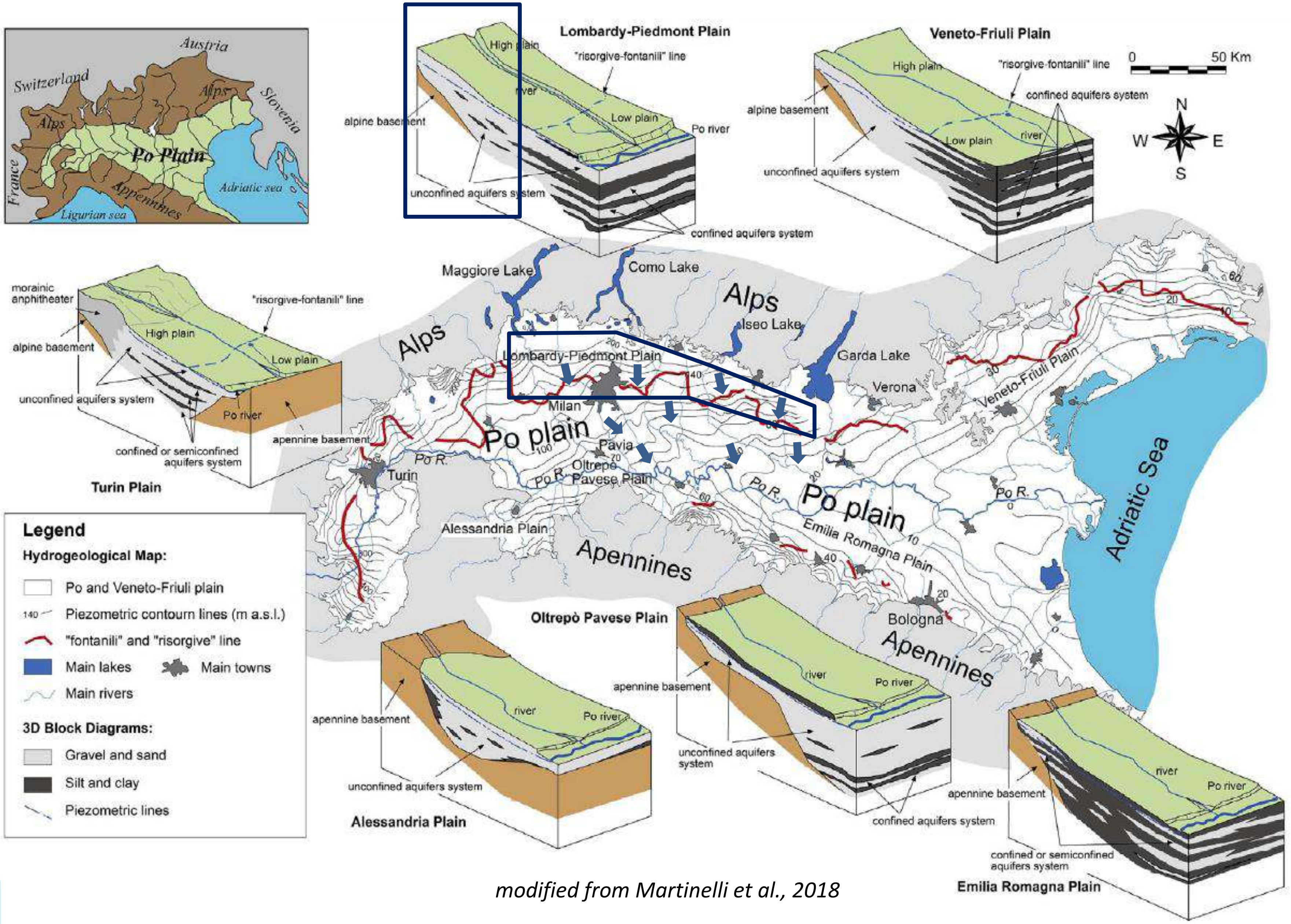
modified from Martinelli et al., 2018

Po Plain Aquifers in Lombardy

Higher Plain:

- Mono-layer unconfined aquifer made of sands and gravels



modified from Martinelli et al., 2018

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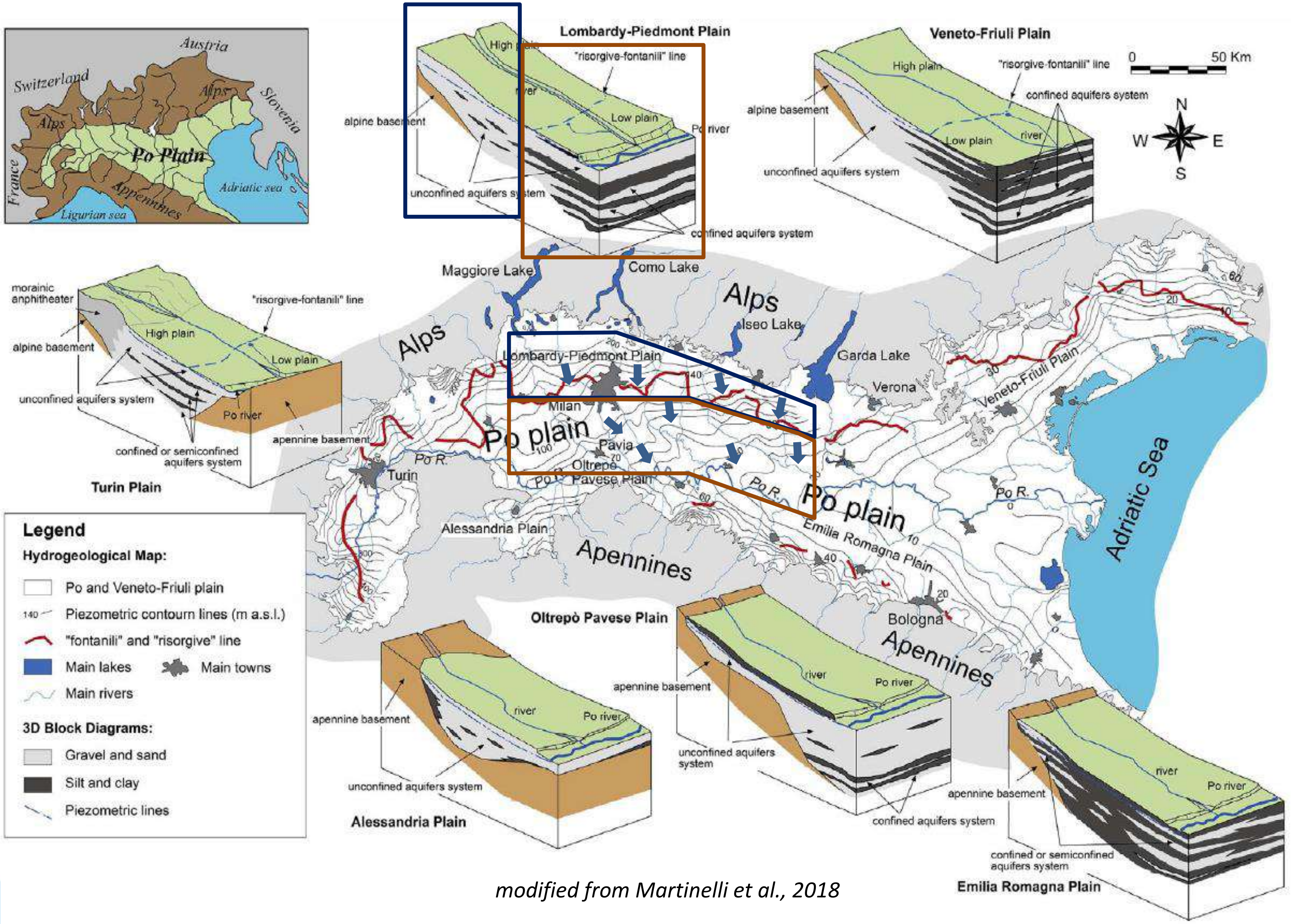
Po Plain Aquifers in Lombardy

Higher Plain:

- Mono-layer unconfined aquifer made of sands and gravels

Lower Plain:

- Multi-layer system made by the alternation of sandy confined aquifers and silty-clay aquitards containing peat



modified from Martinelli et al., 2018

Po Plain Aquifers in Lombardy

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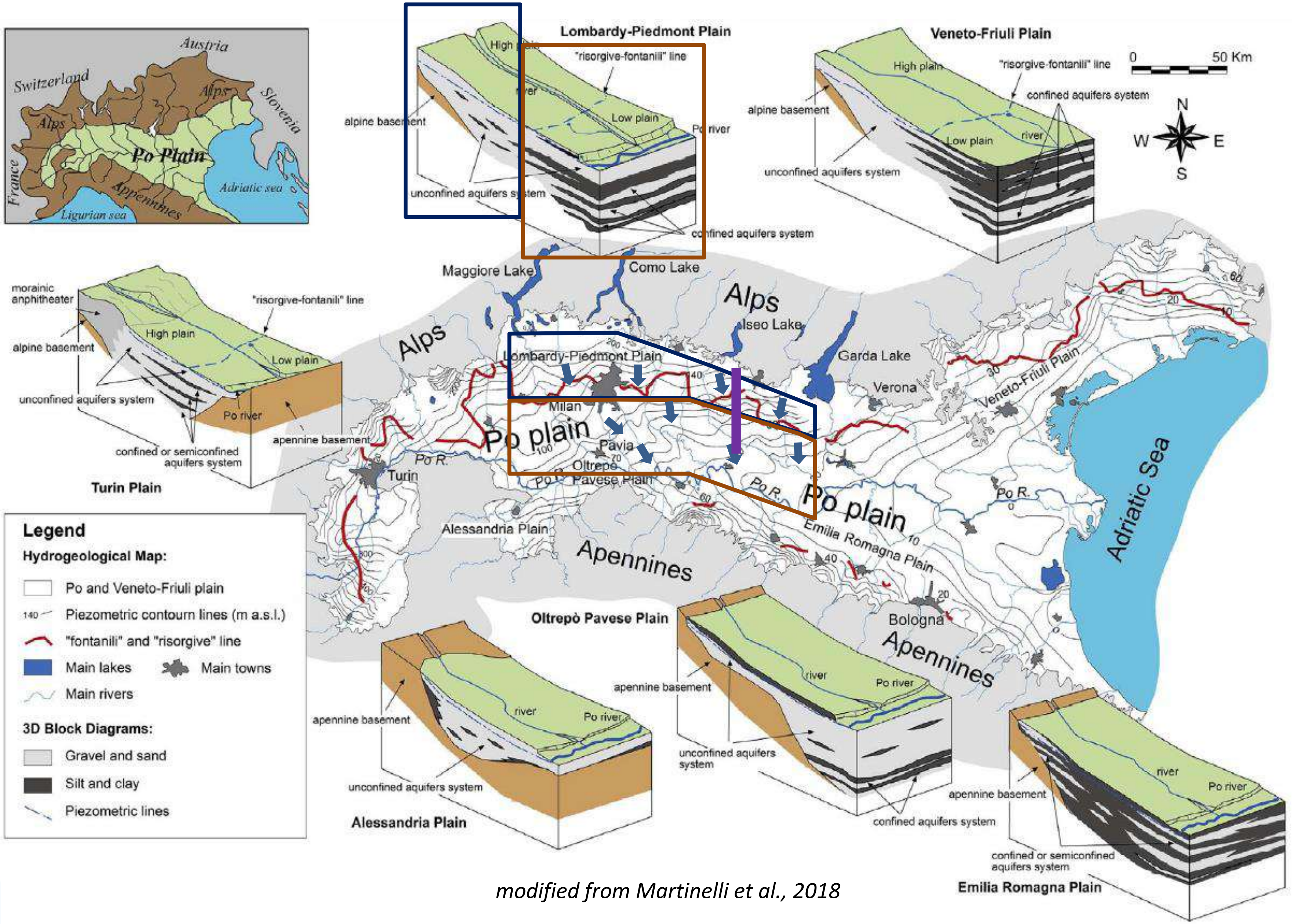
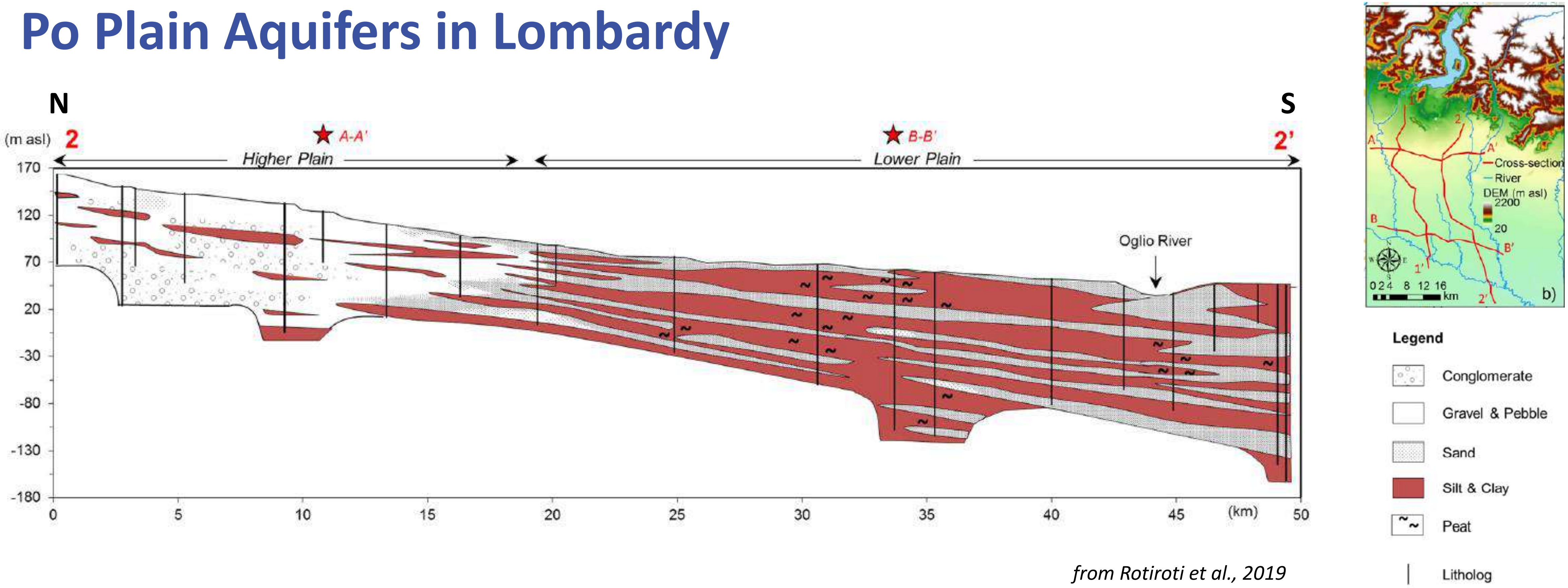


modified from Martinelli et al., 2018

Po Plain Aquifers in Lombardy



from Rotiroti et al., 2019

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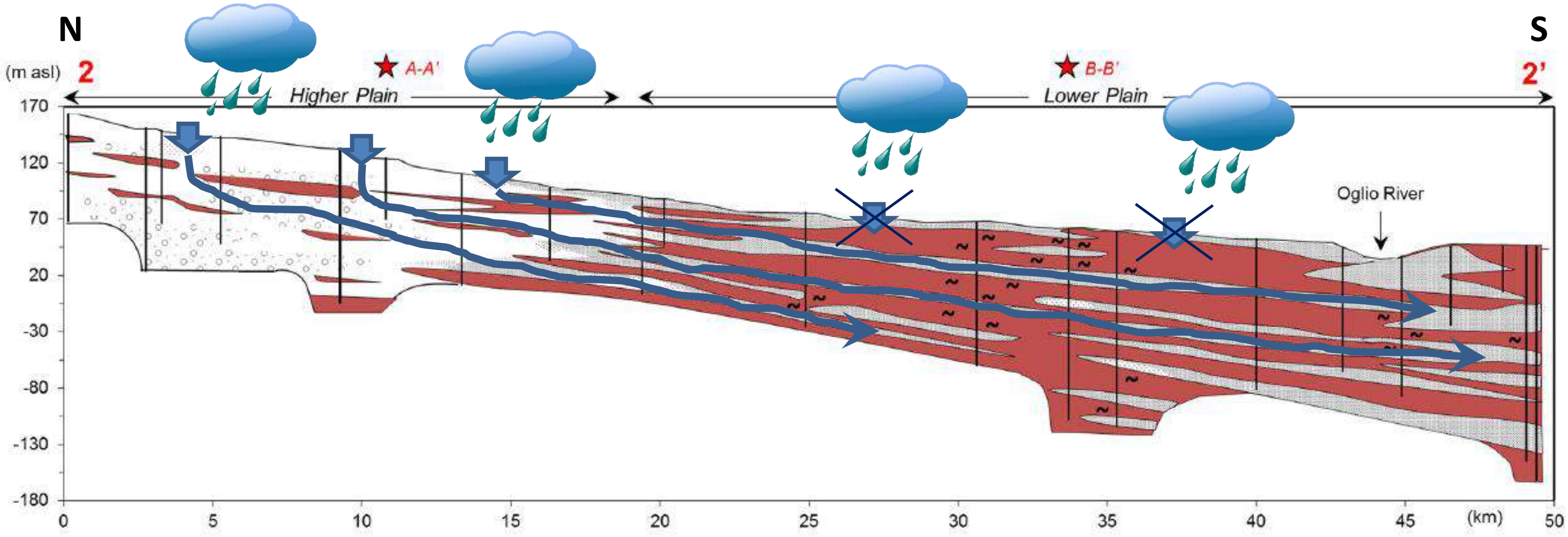
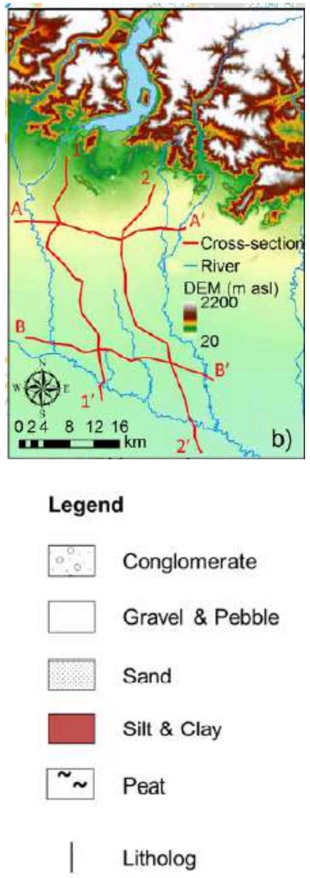
Po Plain Aquifers in Lombardy





from Rotiroti et al., 2019

Lower Plain: None/low recharge from the surface

Higher Plain: High recharge from the surface

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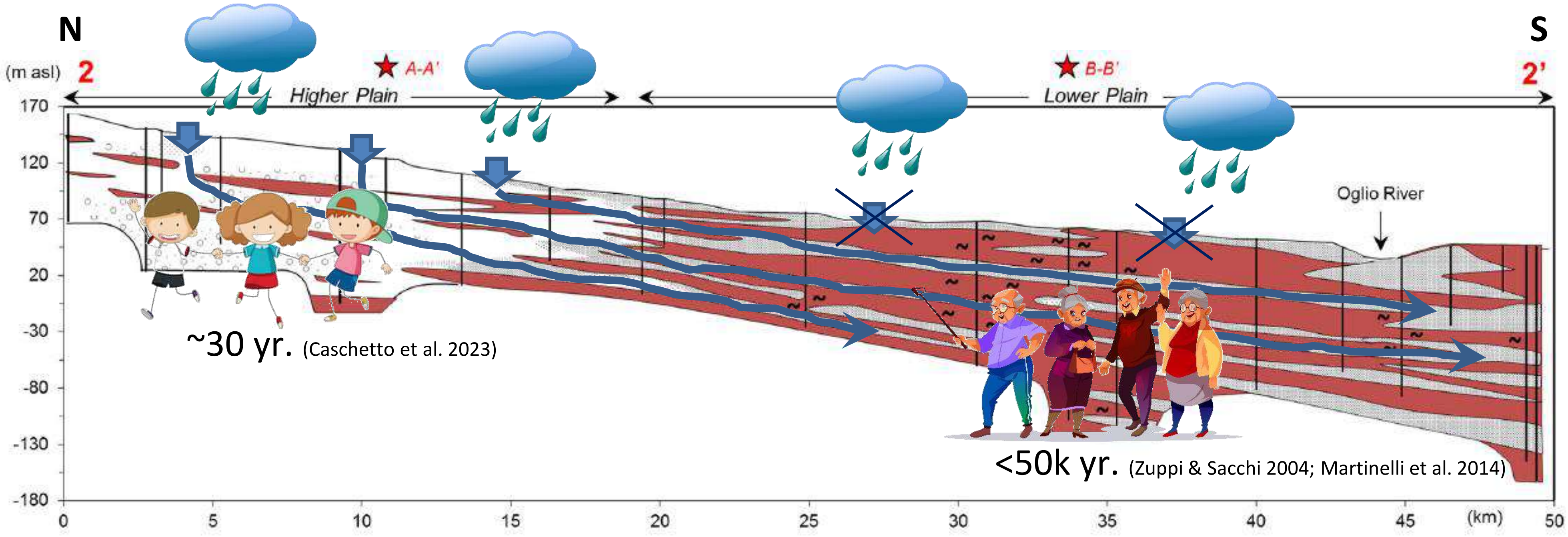
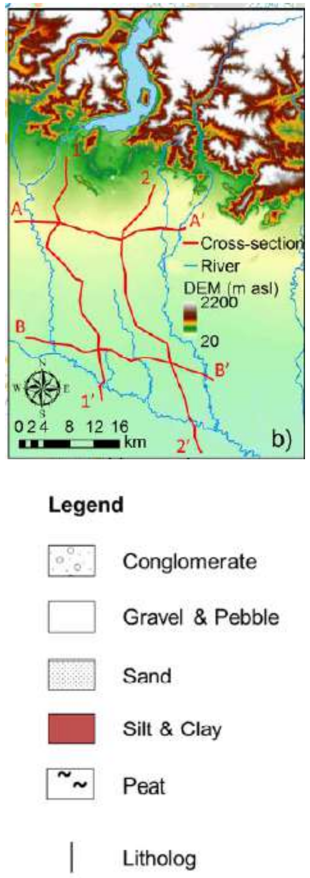
Po Plain Aquifers in Lombardy





from Rotiroti et al., 2019

Lower Plain: None/low recharge from the surface → Long residence times, older ages (hundreds or thousands of years).

Higher Plain: High recharge from the surface → Short residence times, younger ages (tens of years).

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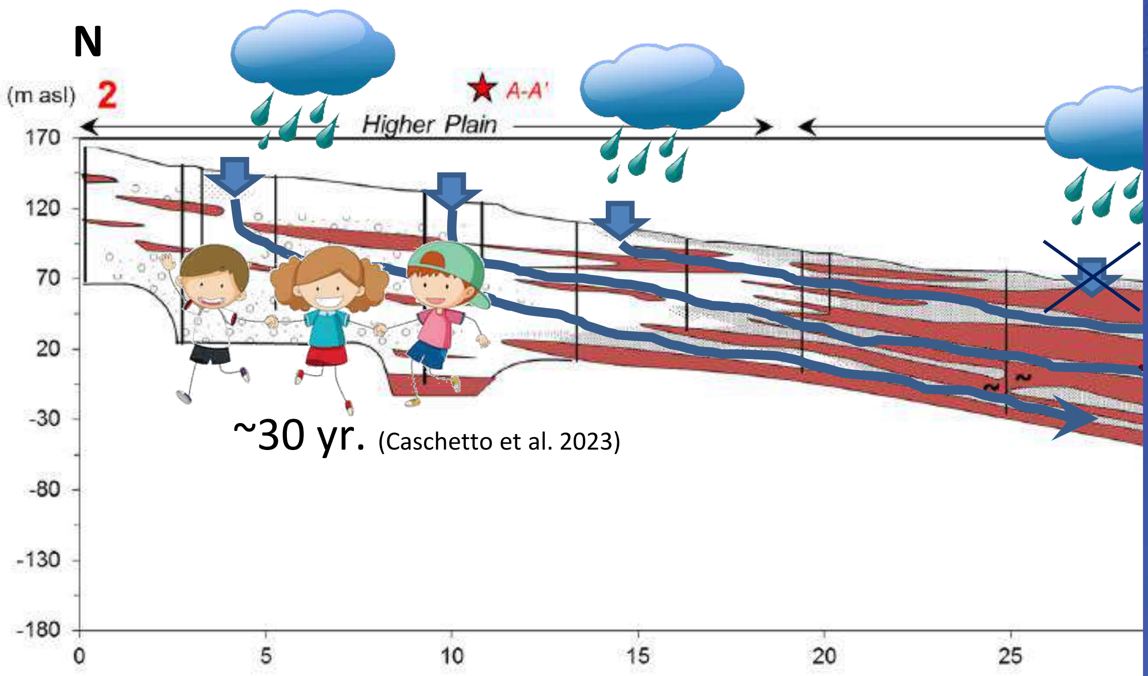
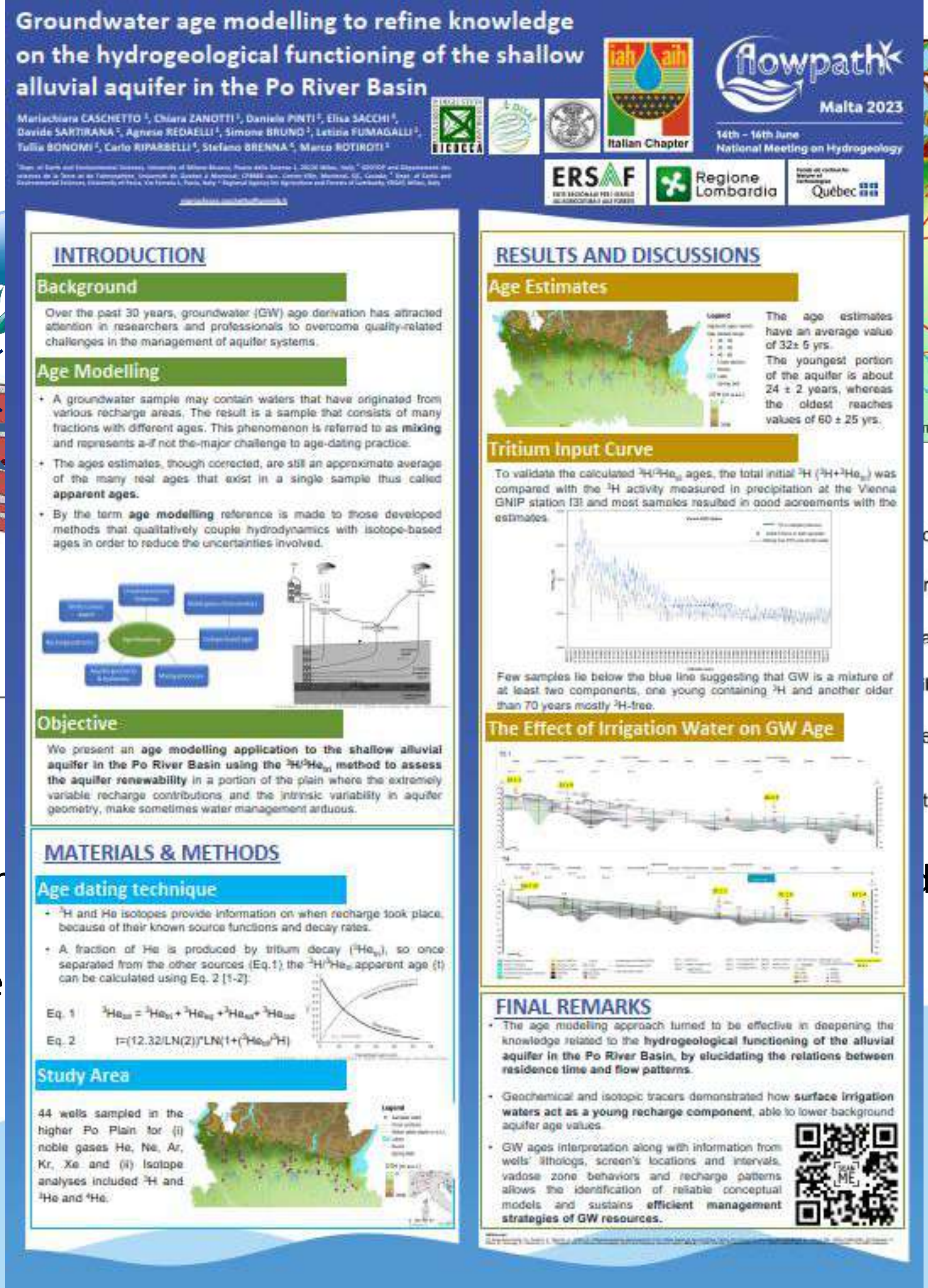
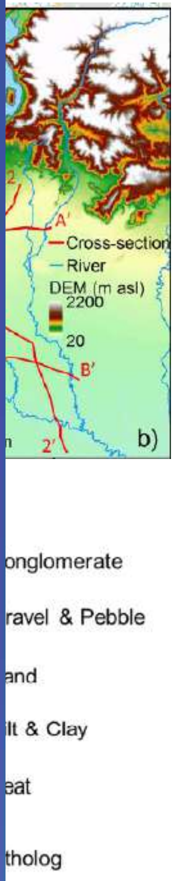
Po Plain Aquifers in Lombardy







Lower Plain: None/low recharge from the surface → Lor ds of years).

Higher Plain: High recharge from the surface → Short re

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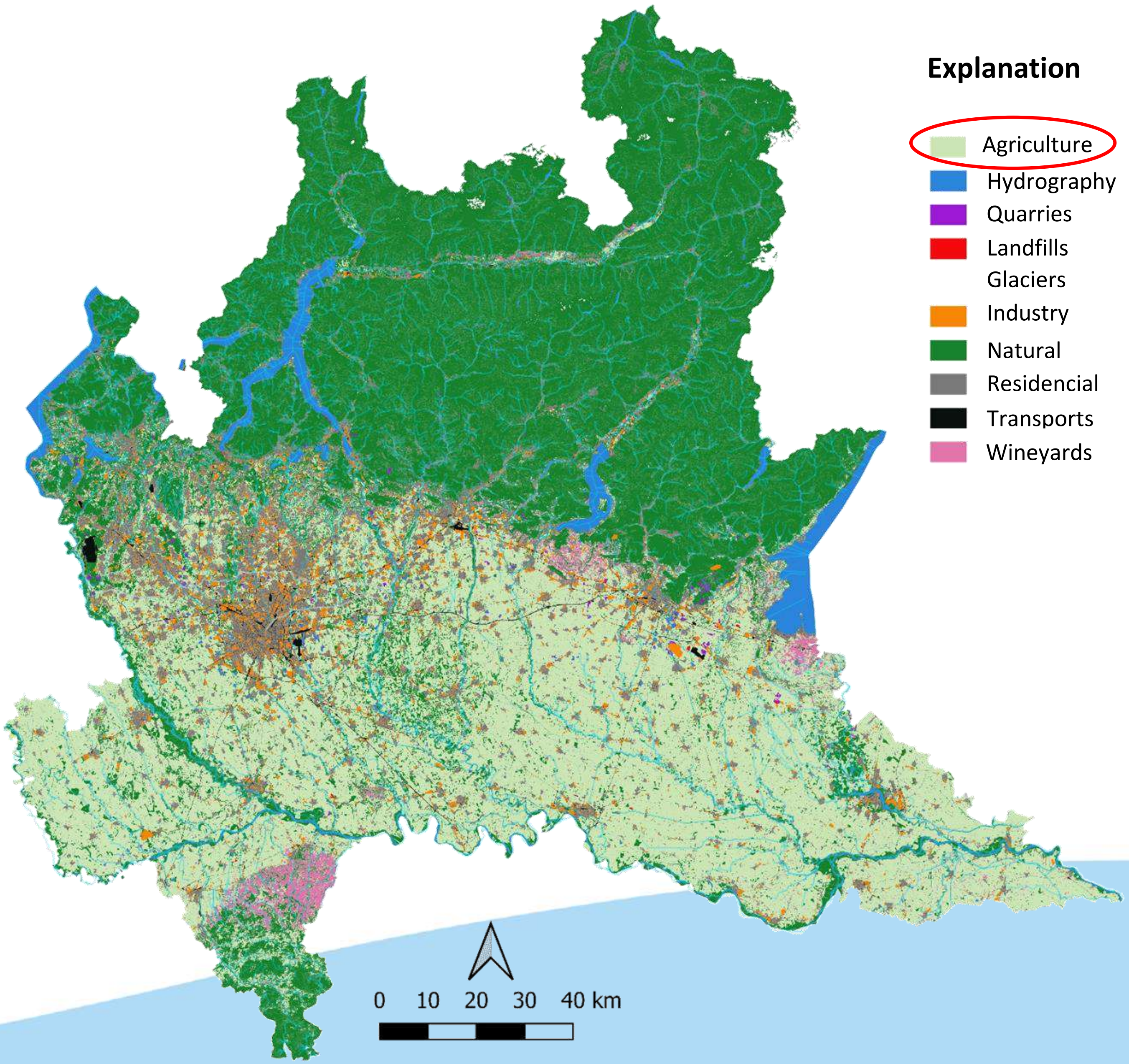
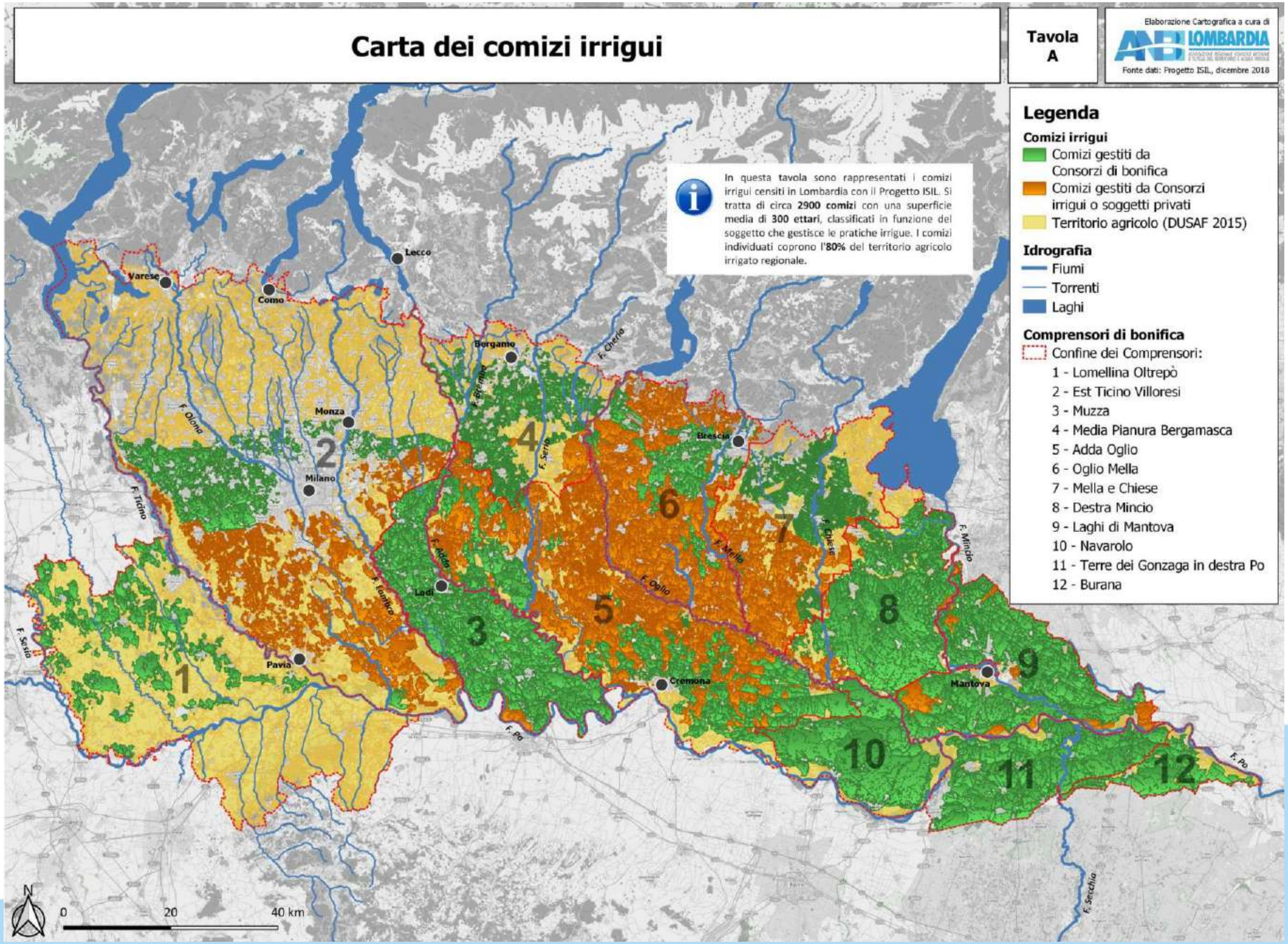
Land Use in Lombardy



Agricultural Irrigation in Lombardy



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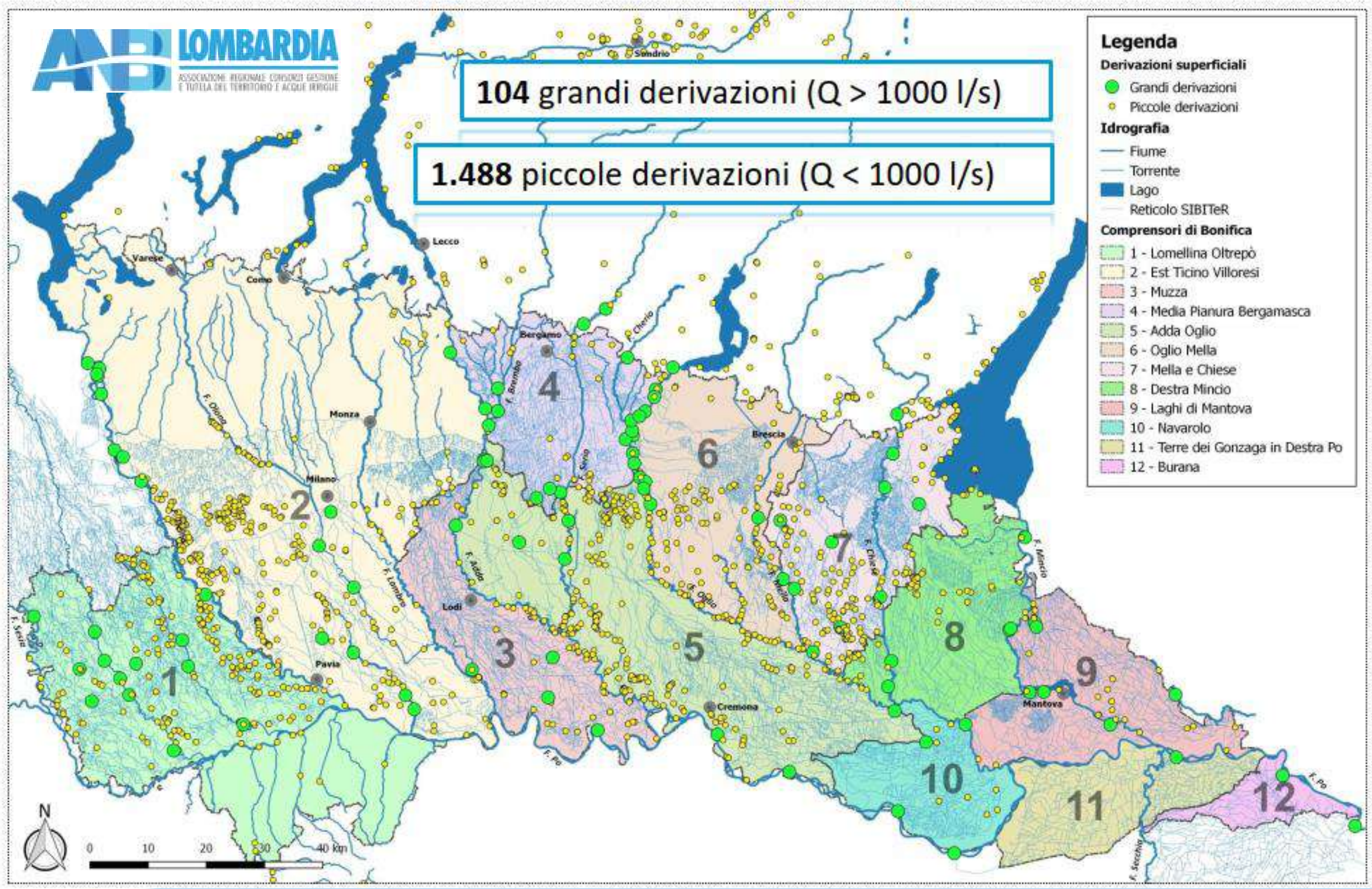
Agricultural Irrigation in Lombardy - Source of Irrigation Water

Main Source of Irrigation Water:

- Water diversion from Subalpine lakes and Alpine rivers to irrigation channel networks.



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Agricultural Irrigation in Lombardy - Irrigation Technique

«Traditional» surface irrigation

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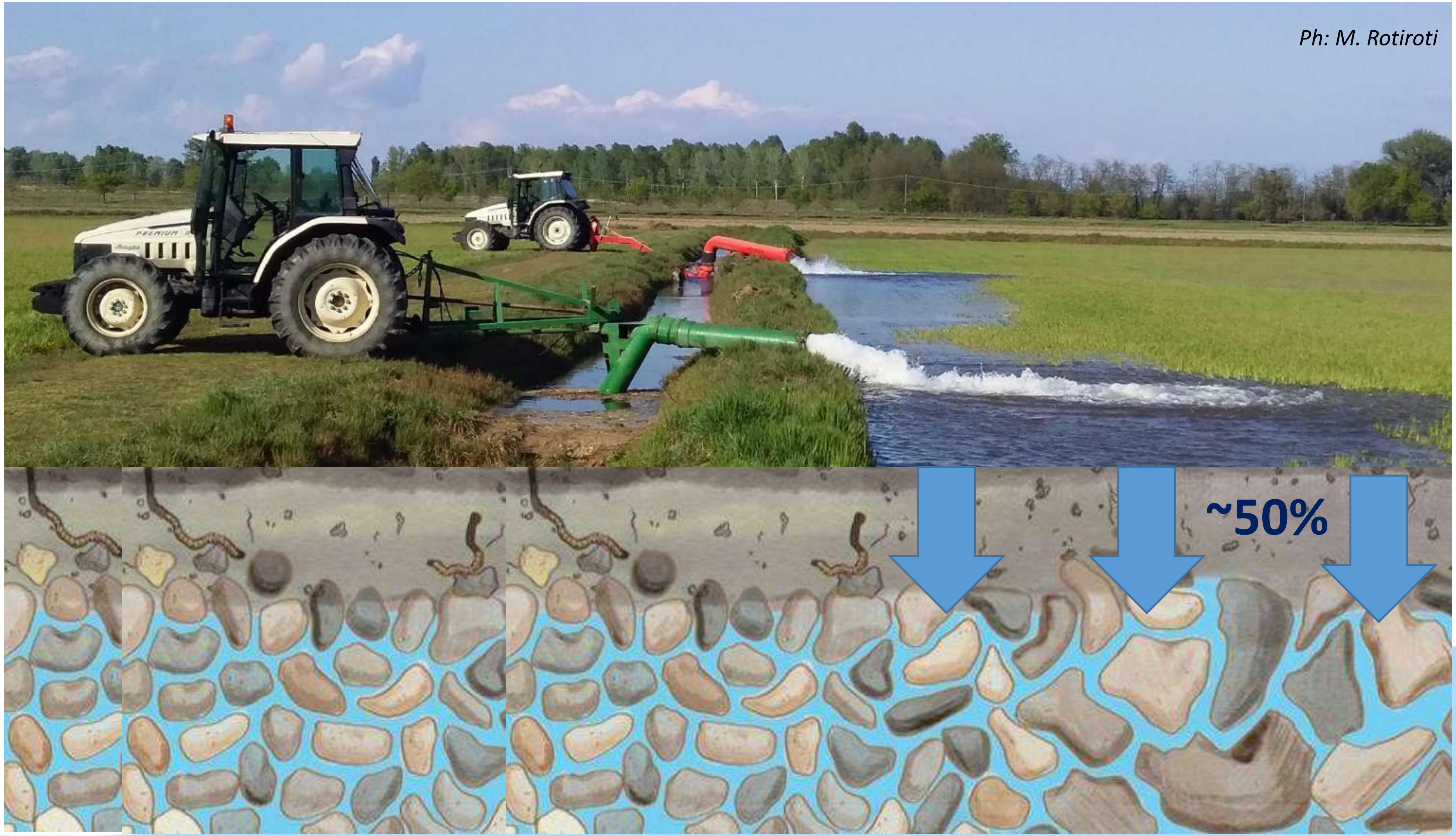
Agricultural Irrigation in Lombardy - Irrigation Technique

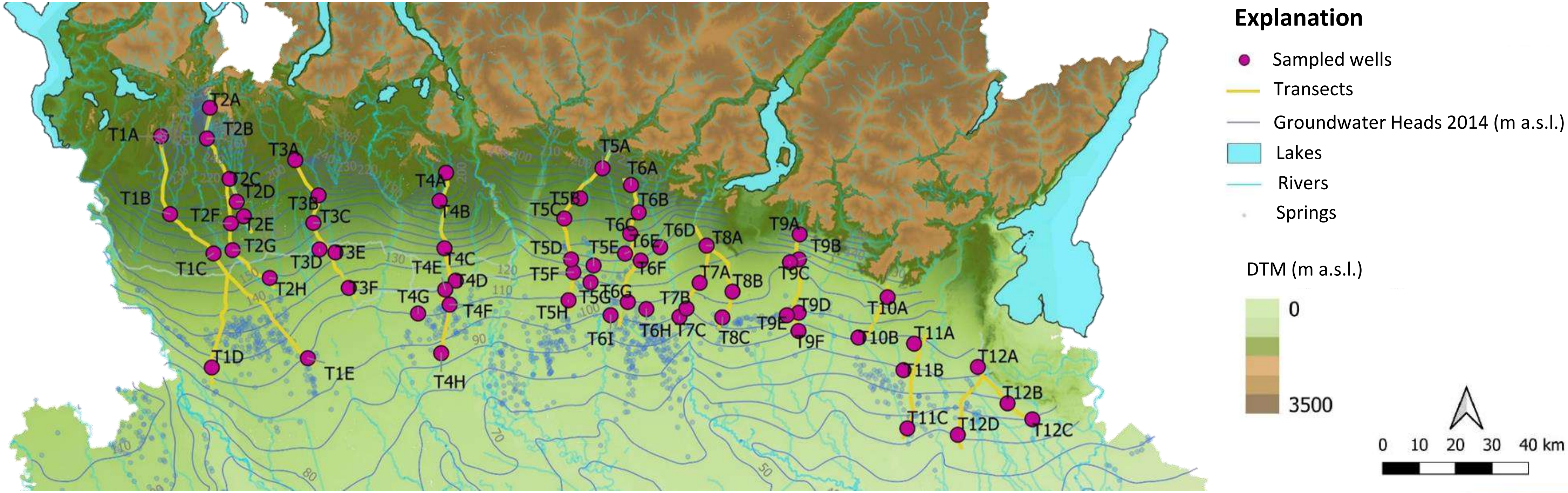
«Traditional» surface irrigation



Return Flow

Tracing Groundwater Recharge in the Higher Plain

Use of **isotope** (δ^2H-H_2O e $\delta^{18}O-H_2O$) & **chemical** (Cl/Br) **tracers**
44 sampled wells arranged **on 15 transects** along groundwater flowpaths, over the entire higher plain



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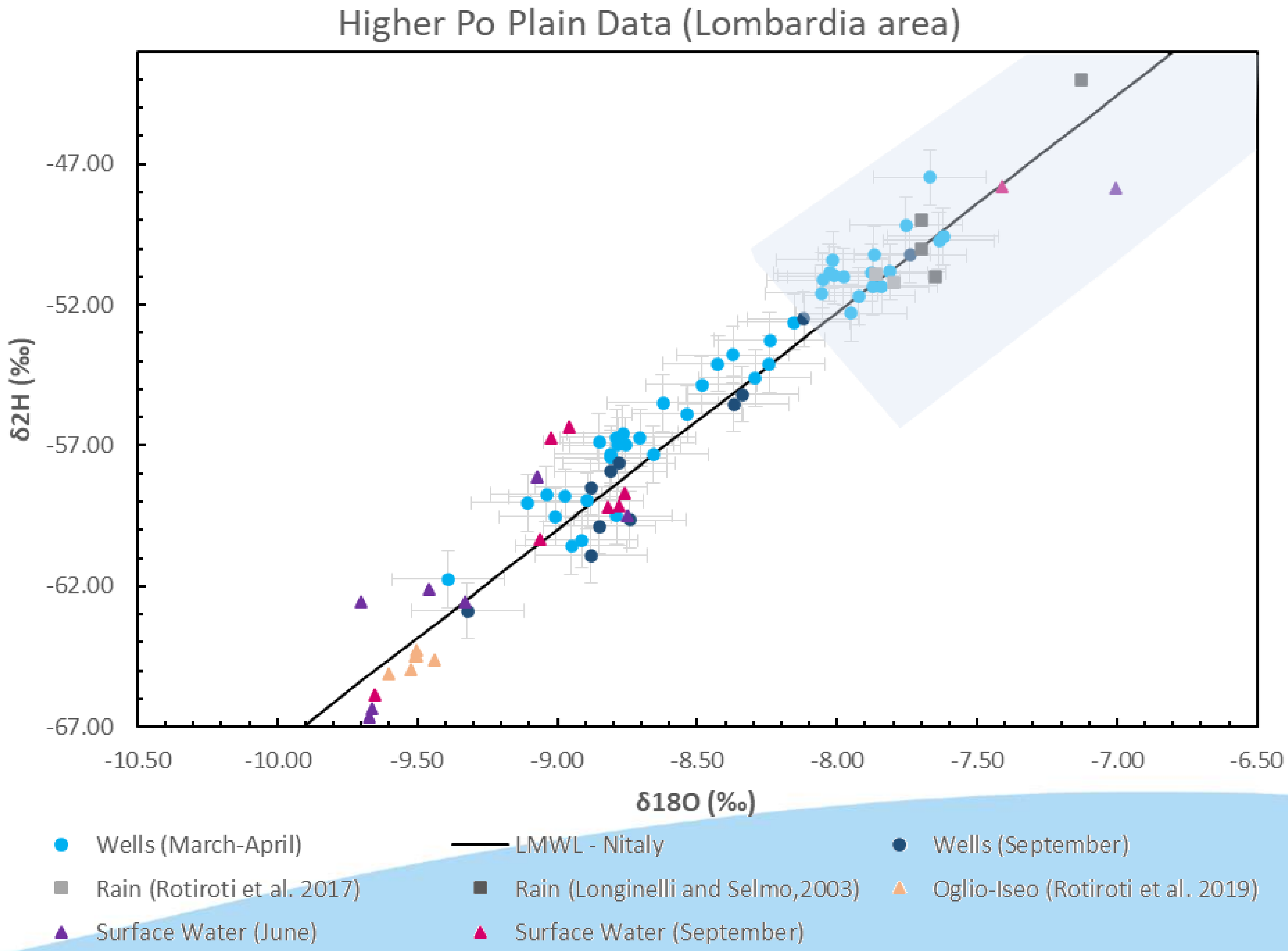
Project: *Studio sulla presenza di nitrati nelle acque sotterranee della Lombardia*

Tracing Groundwater Recharge in the Higher Plain - Water Isotopes



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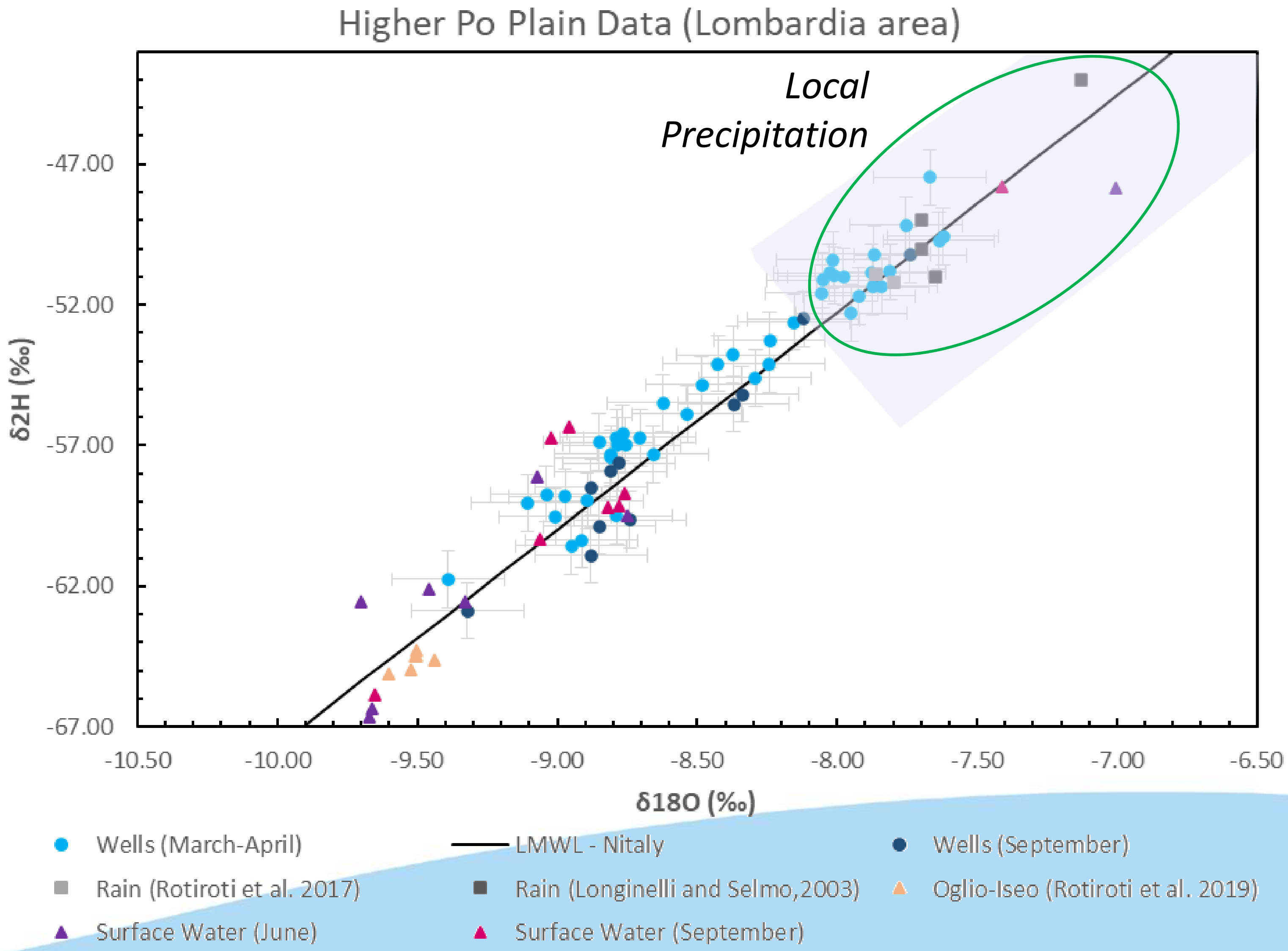
Tracing Groundwater Recharge in the Higher Plain - Water Isotopes



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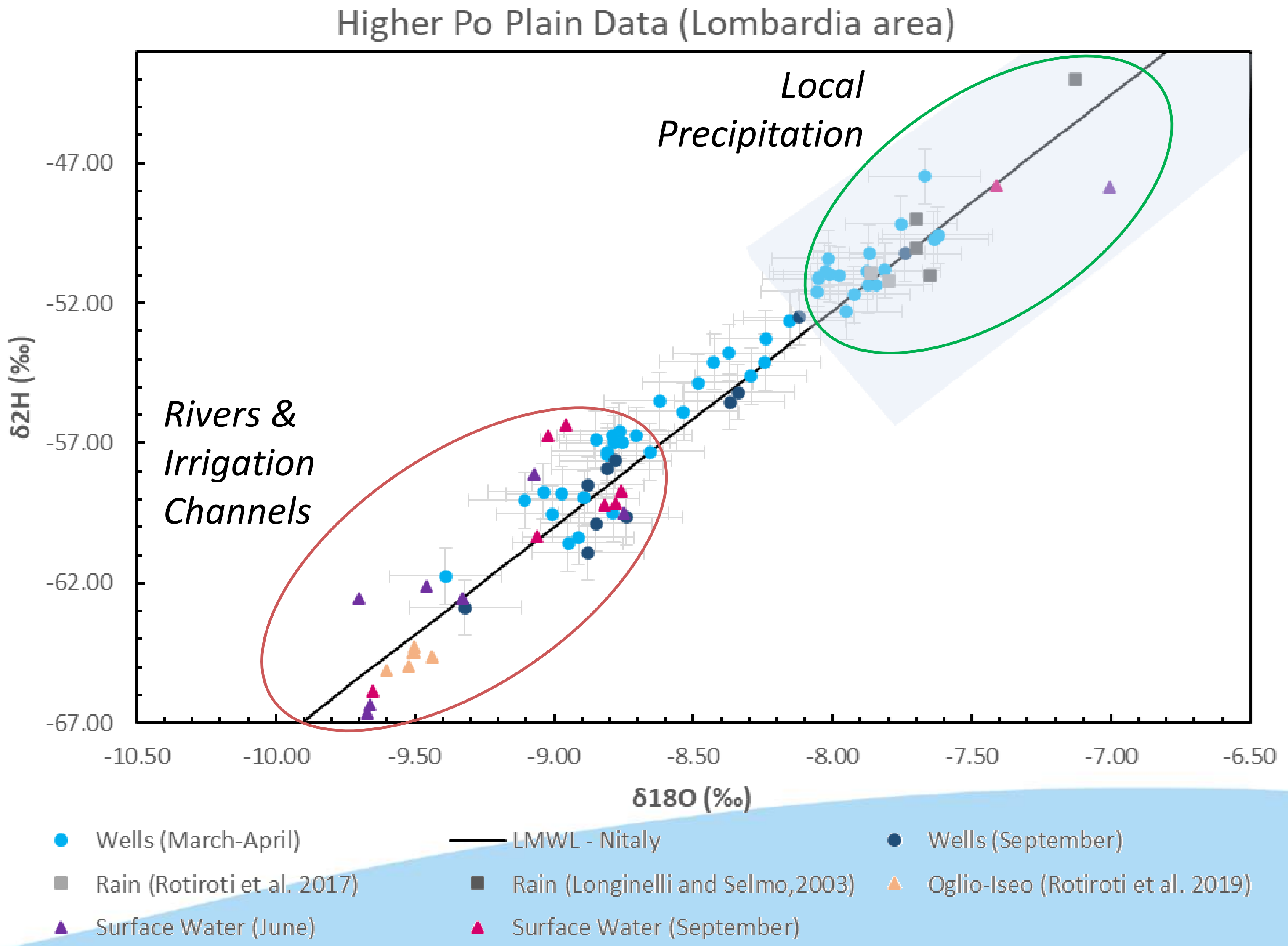
Tracing Groundwater Recharge in the Higher Plain - Water Isotopes

Surface water is the main recharge of the higher plain aquifer



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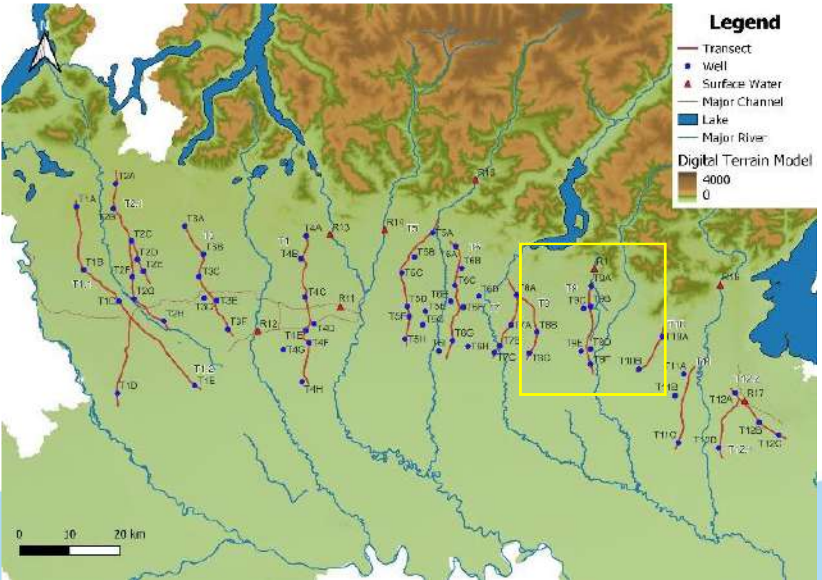
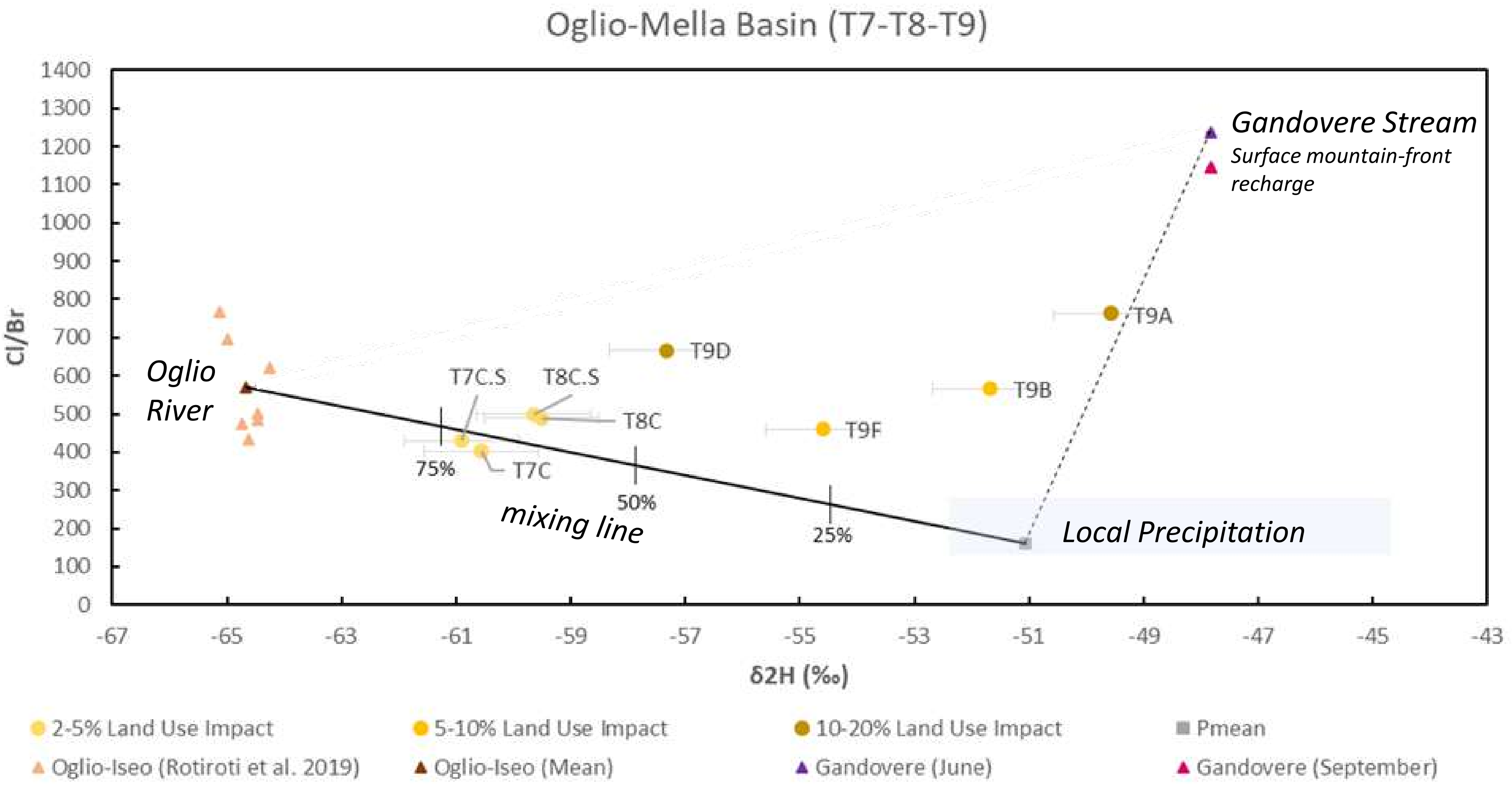
Tracing Groundwater Recharge in the Higher Plain - Mixing Models

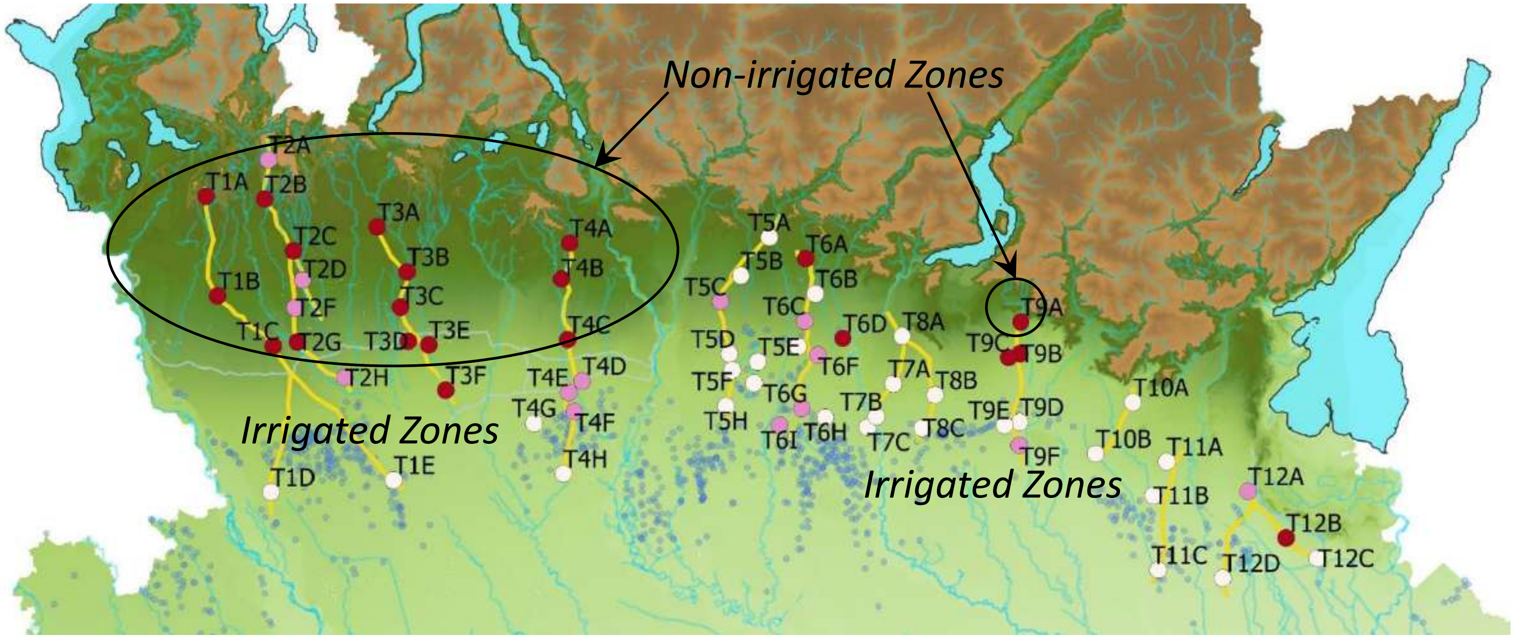
Binary mixing models calculated using δ^2H-H_2O and Cl/Br led to quantify percentage contributions to total recharge

Example of Oglio-Mella Area





Losing Rivers or Irrigation Return Flow?



Explanation

δ2H-H2O (‰)

- -63 - -56 → *Surface Waters*
- -56 - -53
- -53 - -48 → *Local Precipitations*
- Rivers
- Lakes
- Springs

DTM (m a.s.l.)

0

3500

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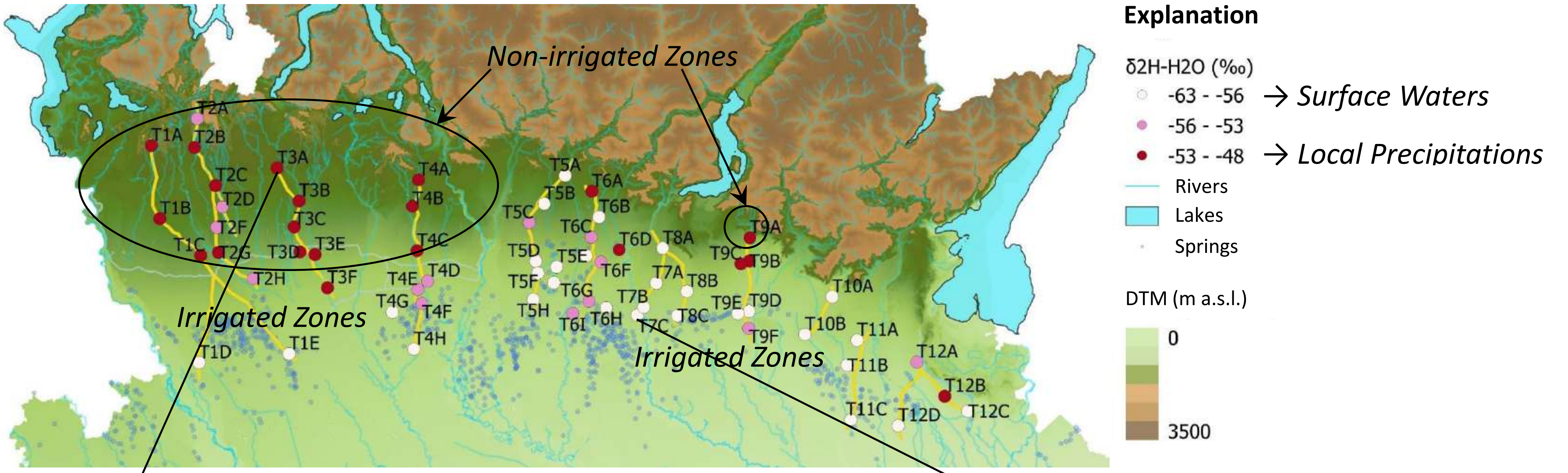
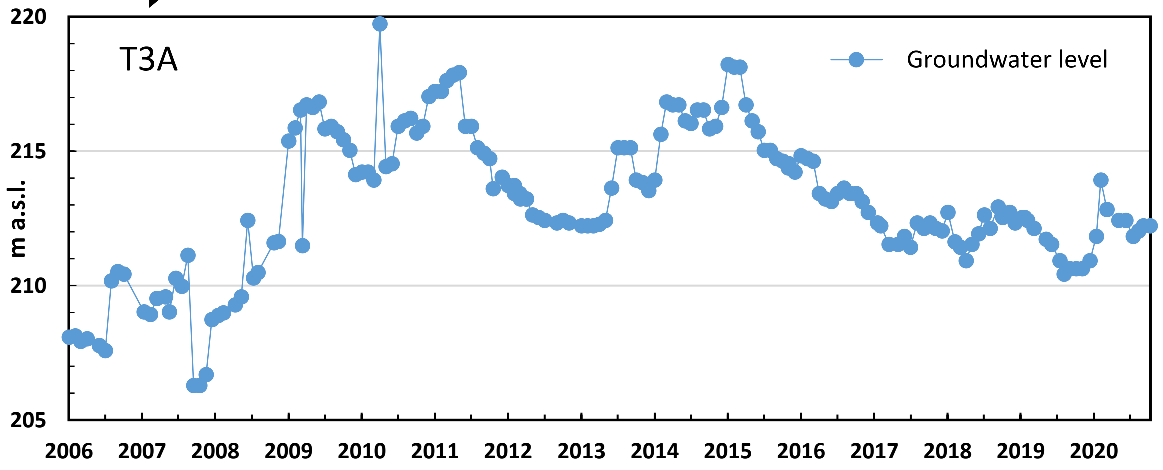
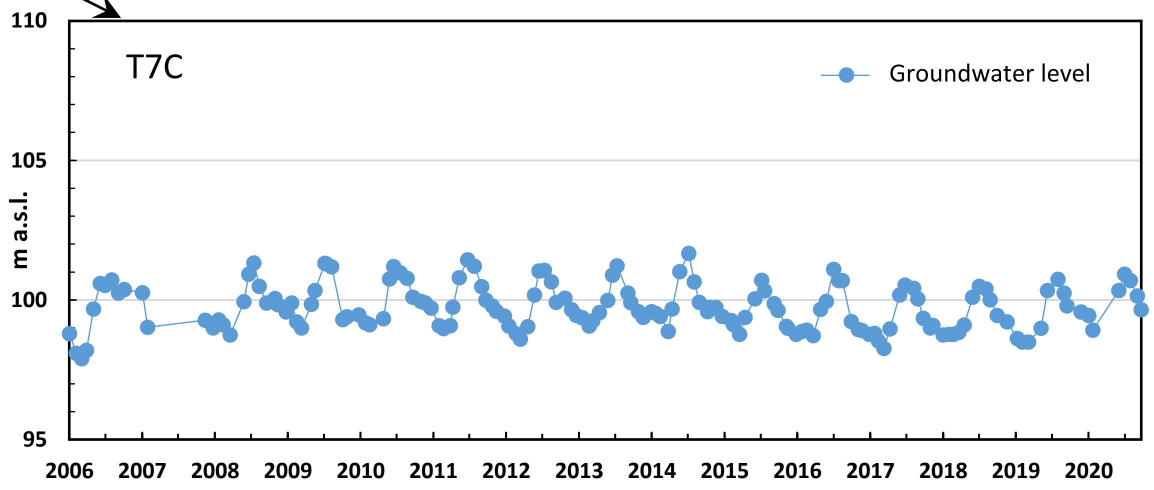
Losing Rivers or Irrigation Return Flow? Return Flow







Tracing Groundwater Recharge - Recap

- **Surface irrigation** fed by surface water bodies, an inefficient method that «looses» large water volumes to the subsurface (around 50%), is the **major source of recharge** (50-75%) in the irrigated areas in the higher plain.

Tracing Groundwater Recharge - Recap

- **Surface irrigation** fed by surface water bodies, an inefficient method that «looses» large water volumes to the subsurface (around 50%), is the **major source of recharge** (50-75%) in the irrigated areas in the higher plain.

- In addition to return flow within the fields, unlined irrigation channels have an important role in recharging the aquifer.

The Effects of Drought

Due to drought, and related surface water shortage during the growing season, the following changes are likely to occur:

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3. from more (corn) to less (sorghum) water-intensive crops

The Effects of Drought on the Hydrogeological Water Balance

Due to drought, and related surface water shortage during the growing season, the following changes are likely to occur:

1. the abandonment of surface-water-irrigation in favor of groundwater-fed irrigation (irrigation wells) → **+ GW Output**

2. the shifting from the inefficient surface irrigation method to more efficient methods (sprinkler/micro/drip irrigation)
↓
3. from more (corn) to less (sorghum) water-intensive crops → **— GW Input**

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The Effects of Drought on the Hydrogeological Water Balance

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↓

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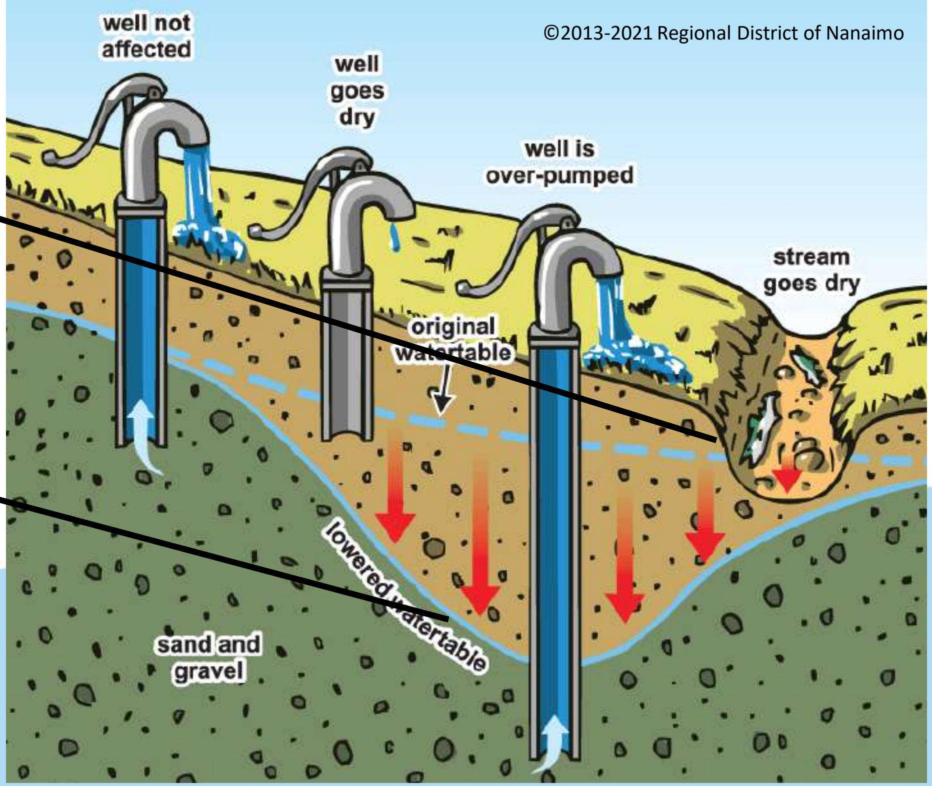
The drying of many typical low-land springs (fontanili)

The depletion of groundwater resources



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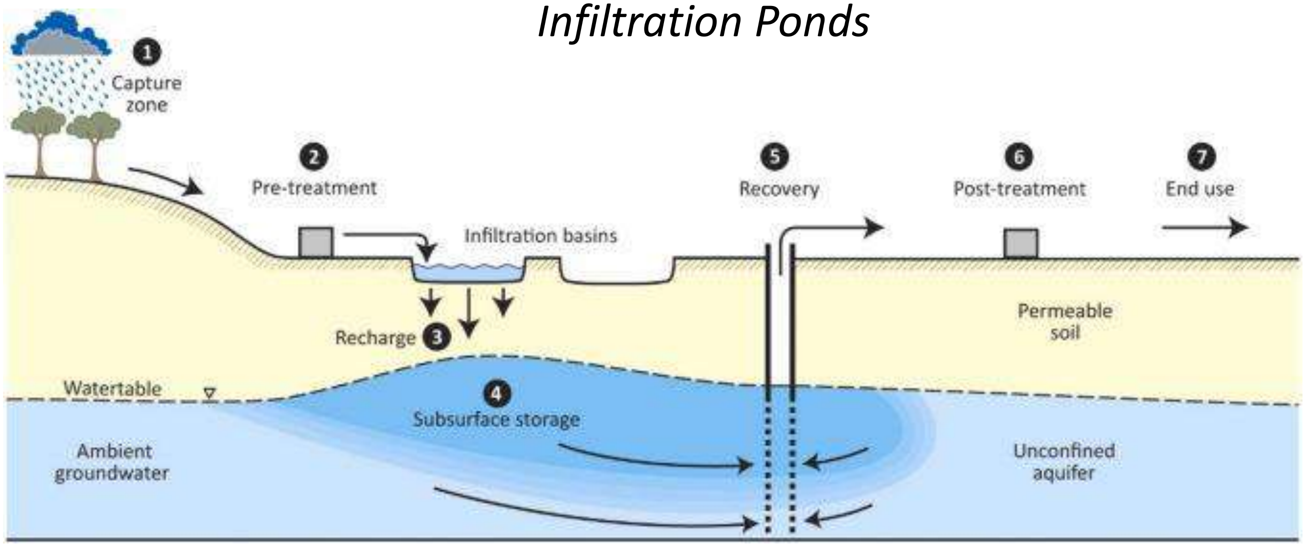
Solutions? Yes, Implementing Managed Aquifer Recharge

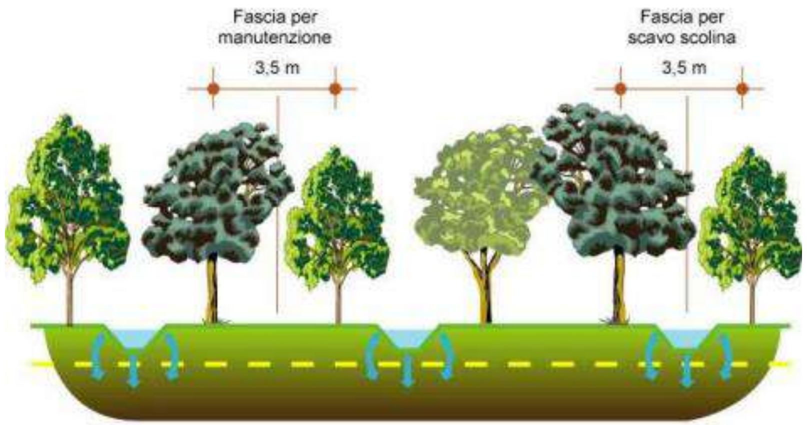
Mitigation actions, such as managed aquifer recharge system, are urgently needed.

Infiltration Ponds



from Vanderzalm et al. 2022

Forested Infiltration Areas



from Mezzalira 2017

Italian Examples:
Val di Cornia
Conoide del Marecchia

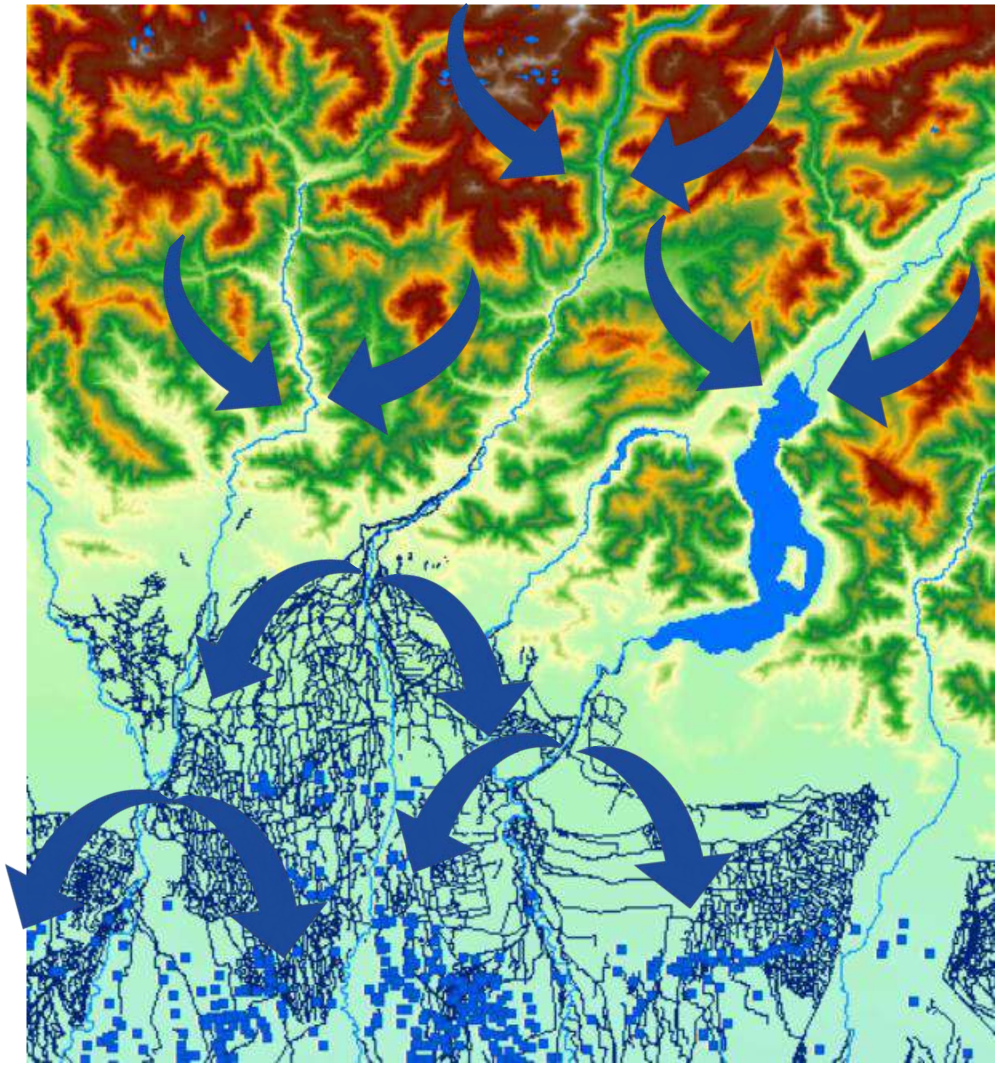
Developed in Veneto

Take-Home Message

Surface irrigation in the higher plain, fed by Alpine surface water bodies, can be considered the largest “unintentional” MAR system of Italy, allowing the infiltration of Alpine rain and meltwater into the Po Plain aquifers.

Adaptation to climate change is erasing this unintentional MAR system.

New actions are urgently needed to counteract the expected groundwater depletion.



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flowpath Malta 2023

14th – 16th June
National Meeting on Hydrogeology

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Thank You !!!

JUNE 14-16, 2023

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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] Department of Biological, Geological and Environmental Sciences (BiGeA), Alma Mater Studiorum – University of Bologna

[2] Emilia Romagna Region - Geological, Seismic and Soil Survey

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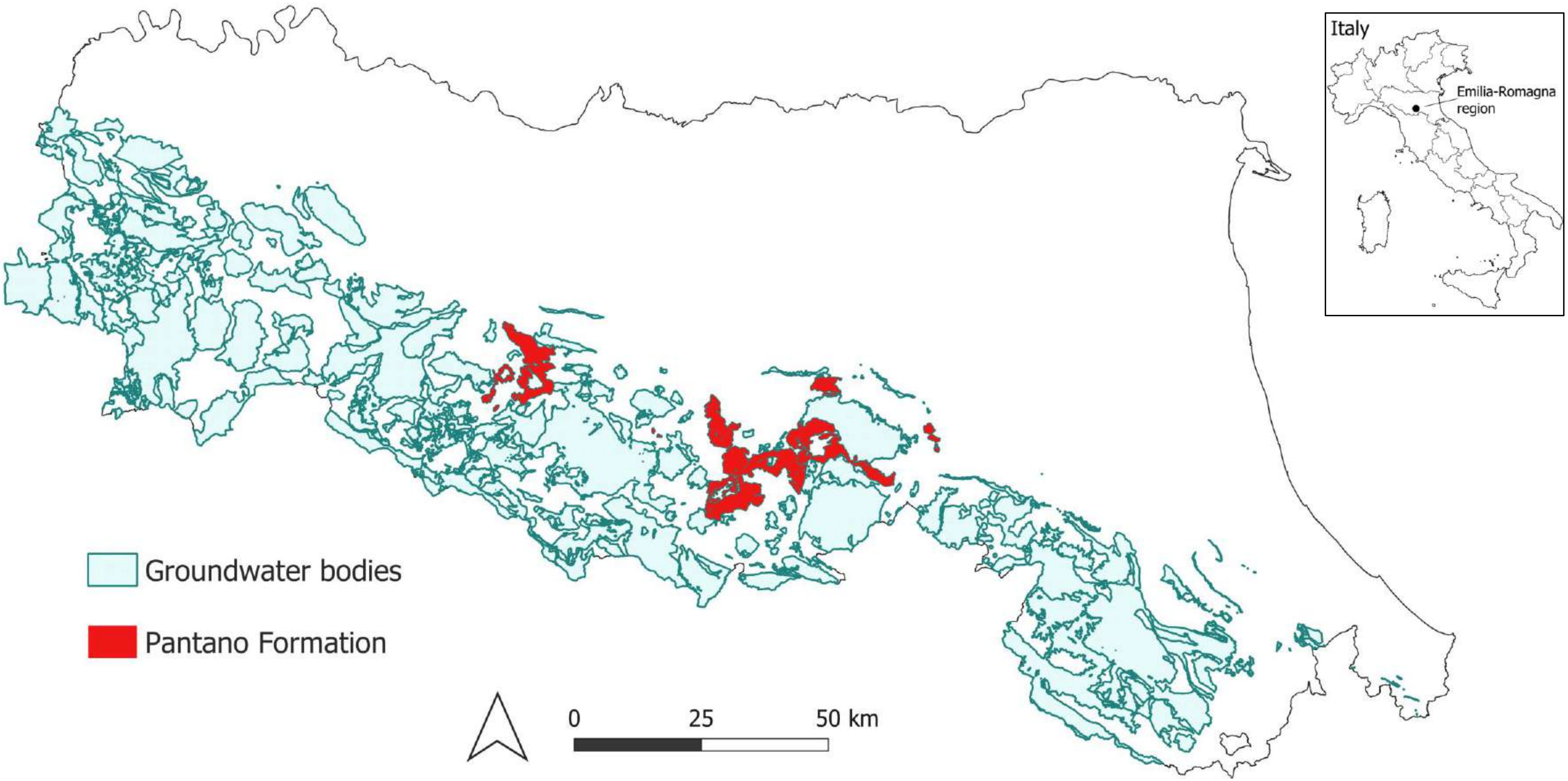
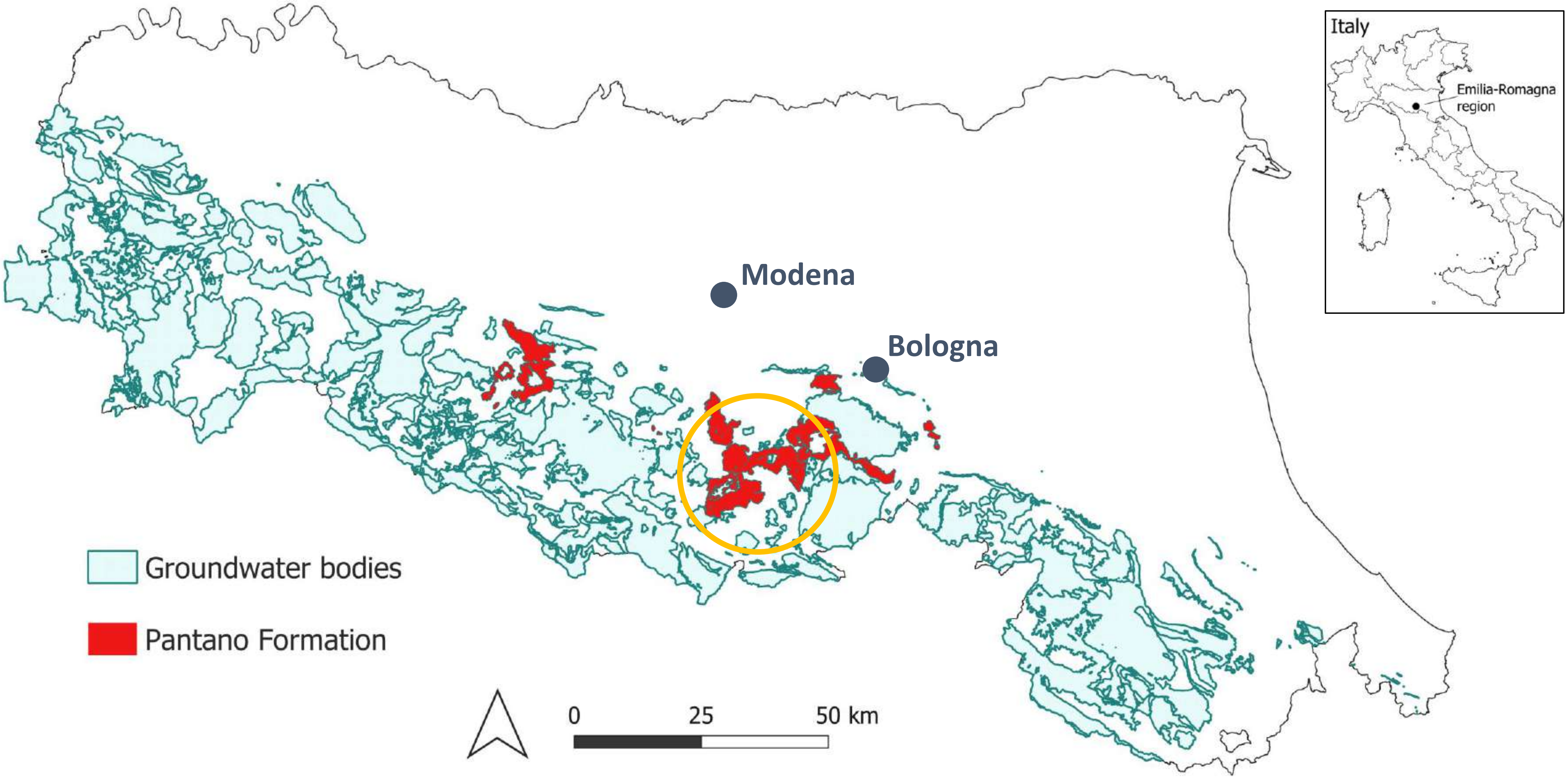
GEOLOGICAL SURVEY
EMILIA-ROMAGNA REGION

Study financed by *GruppoHERA Spa*

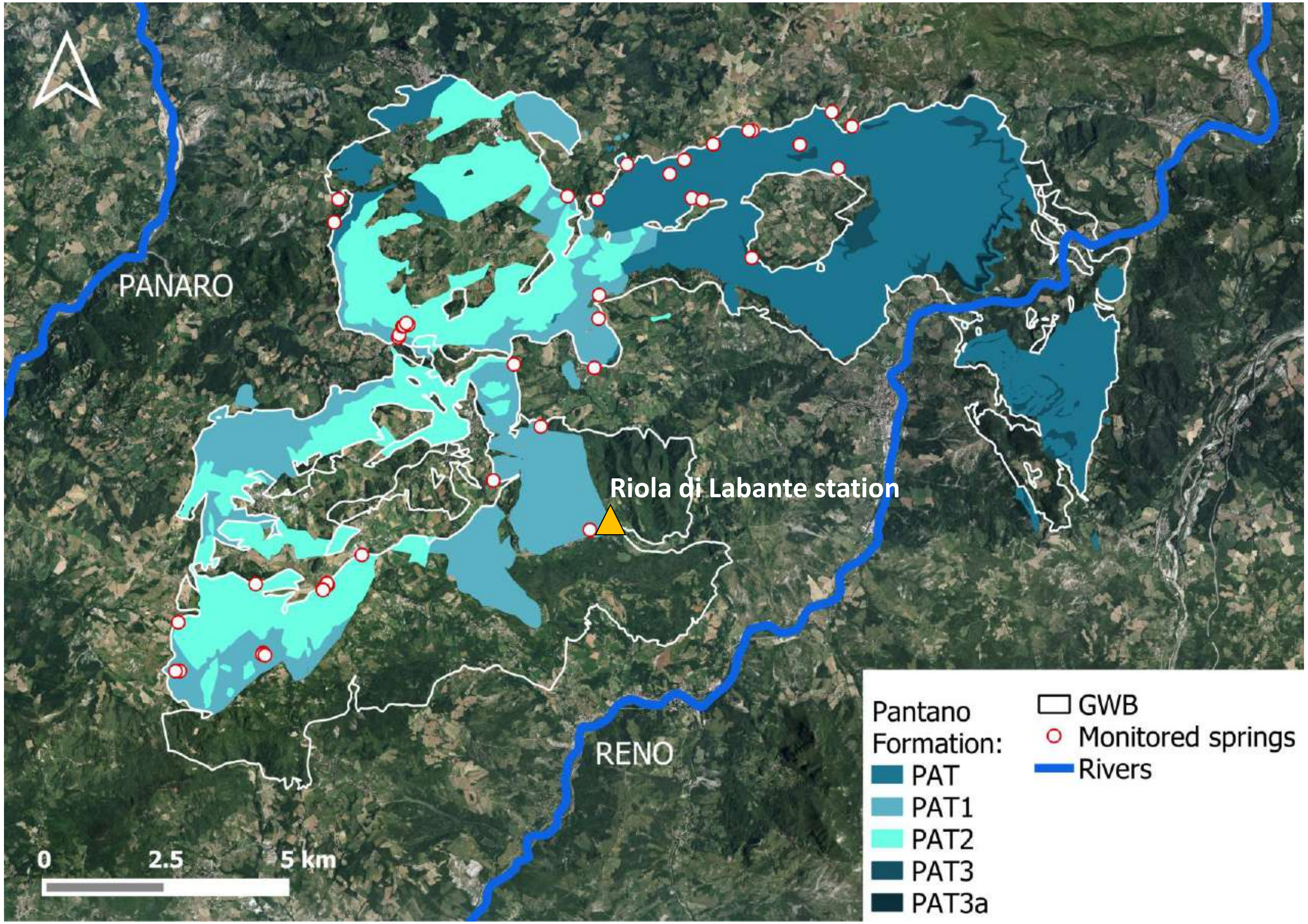
THE NORTHERN APENNINES AQUIFERS



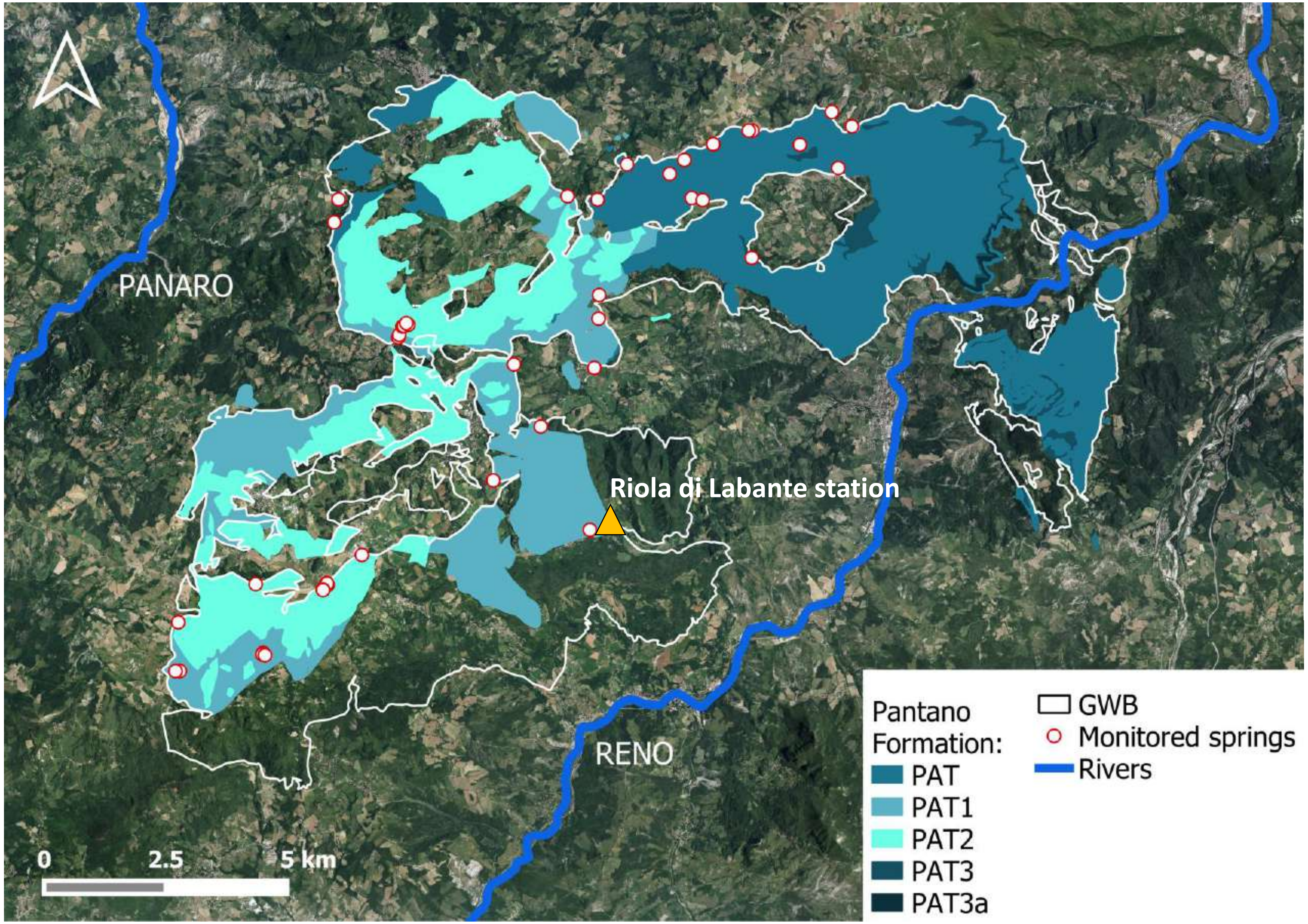
THE NORTHERN APENNINES AQUIFERS



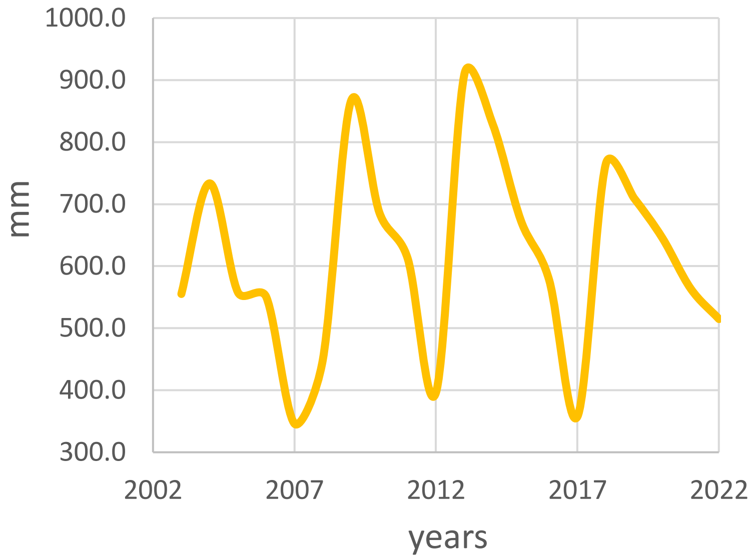
STUDY AREA


PANARO
RENO
Riola di Labante station
Pantano Formation:
PAT
PAT1
PAT2
PAT3
PAT3a
GWB
Monitored springs
Rivers
0
2.5
5 km

STUDY AREA



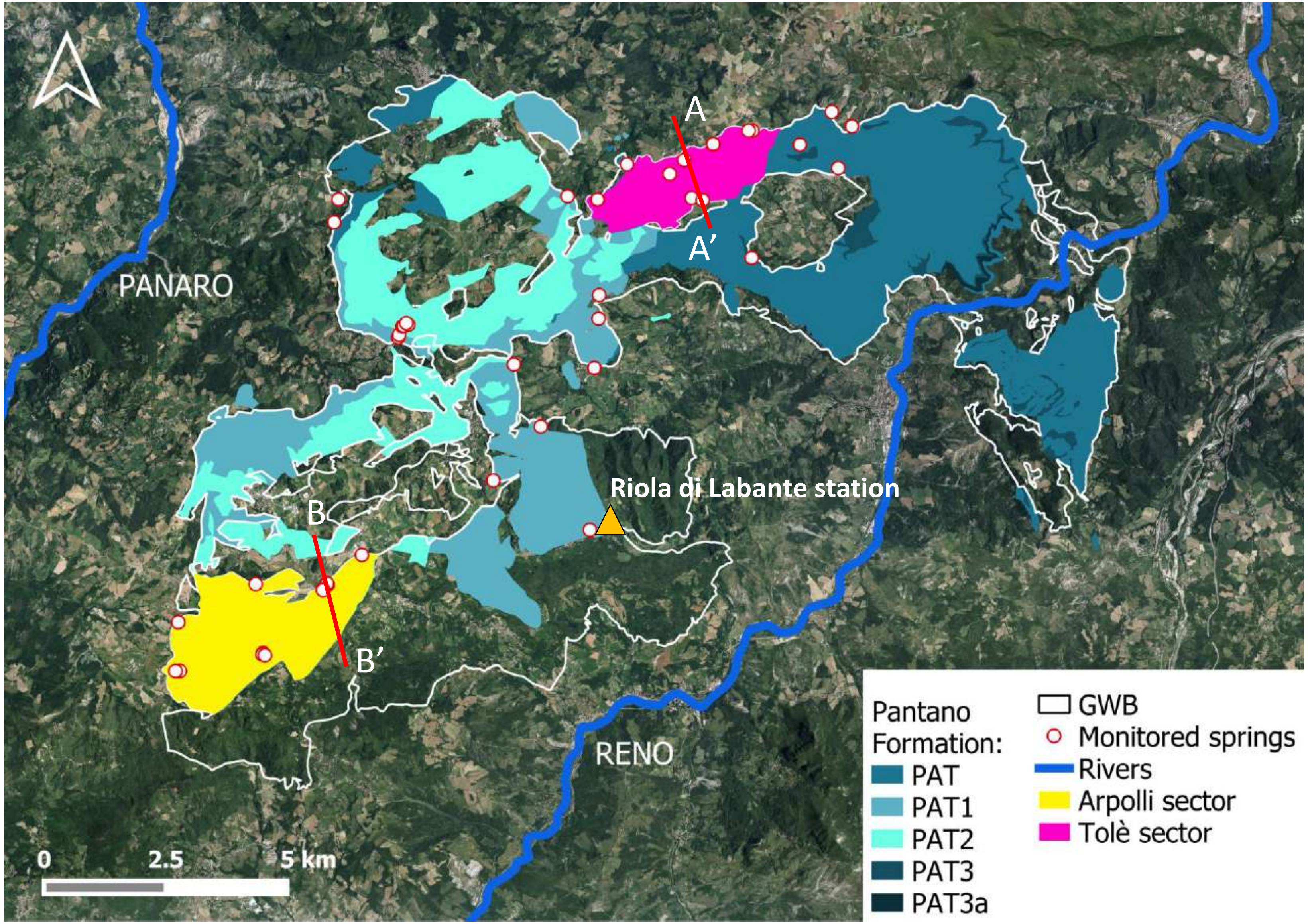
Accumulated precipitation during recharge period (nov-may) at pluviometric station of Riola di Labante



Periodic climatic crisis

5 years oscillation

STUDY AREA


A
A'
B
B'
PANARO
RENO
Riola di Labante station
0
2.5
5 km
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PAT
PAT1
PAT2
PAT3
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Monitored springs
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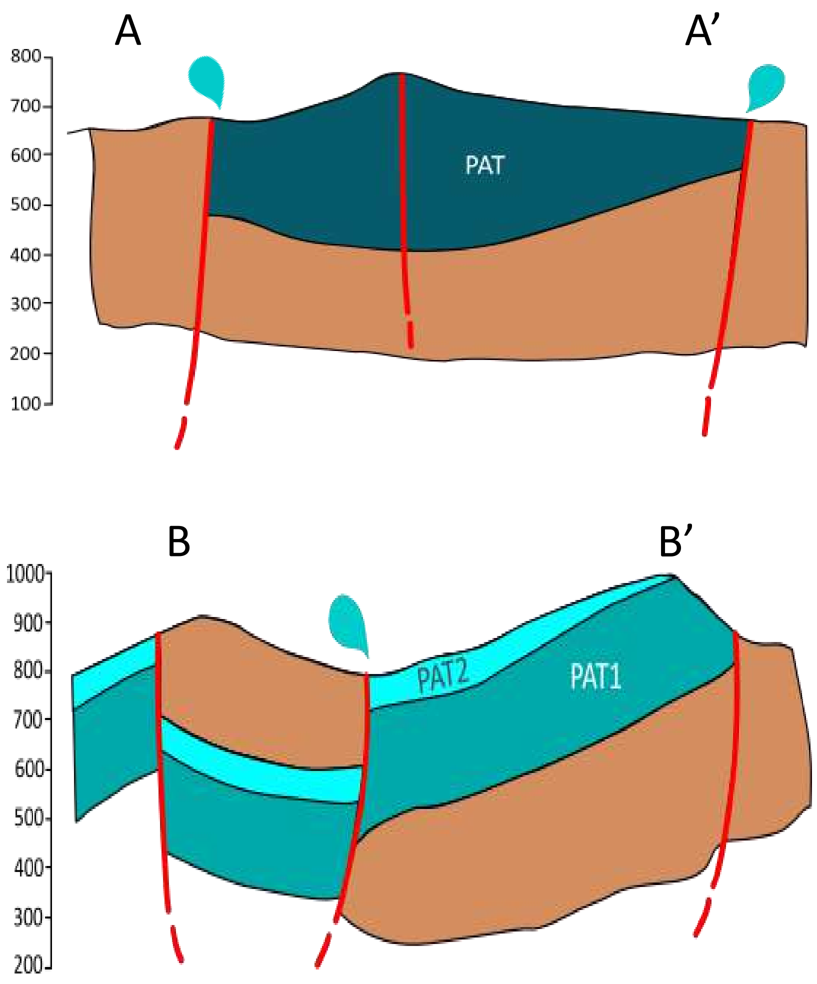
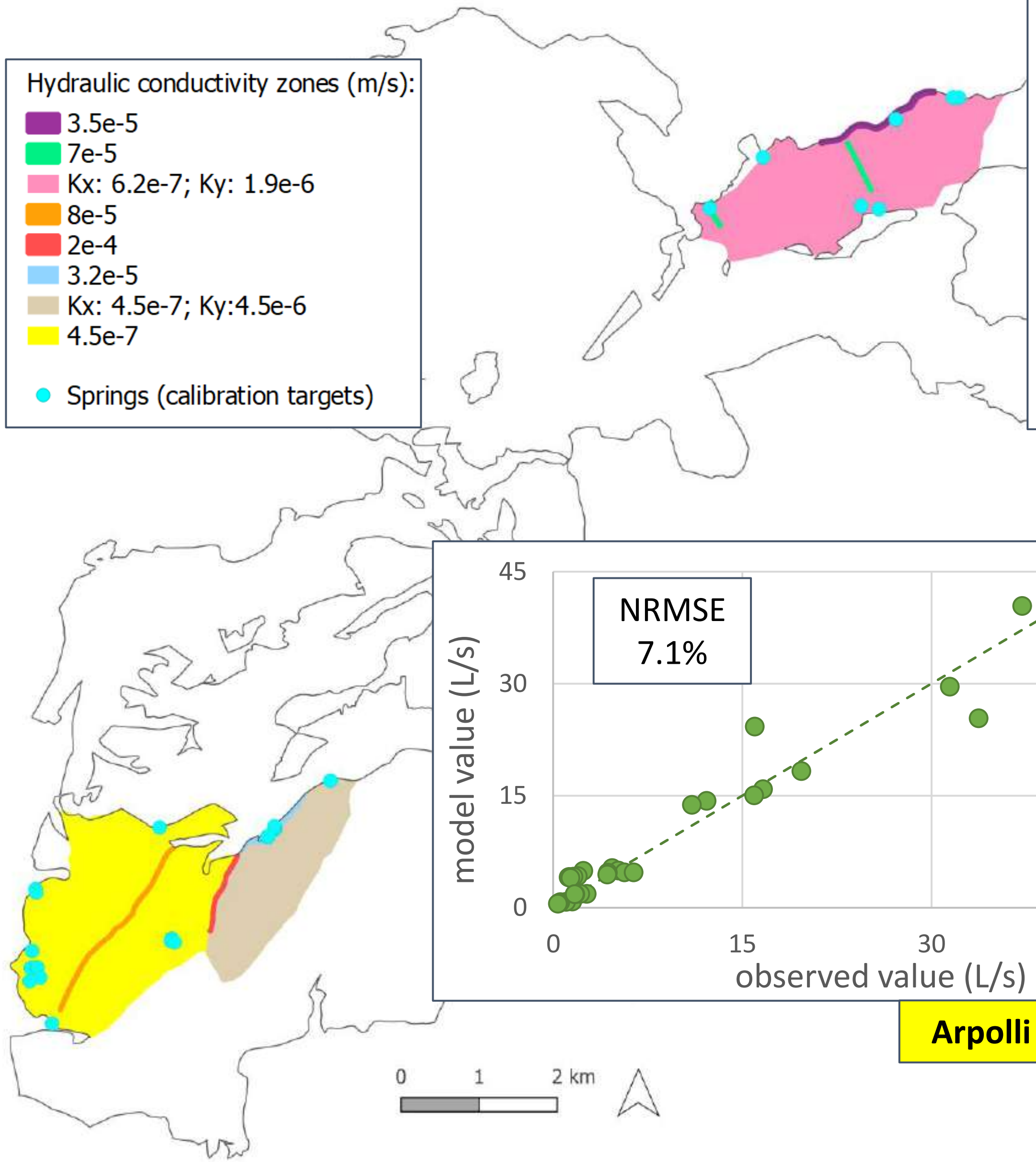
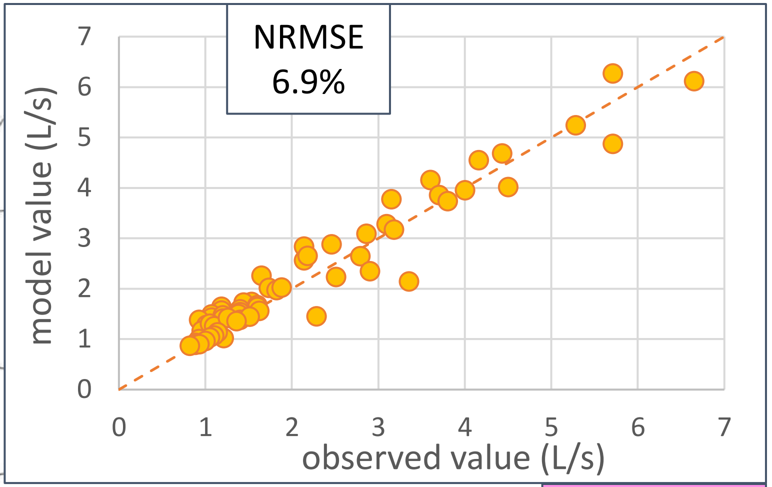
Arpolli sector
Tolè sector


A
A'
800
700
600
500
400
300
200
100
PAT
B
B'
1000
900
800
700
600
500
400
300
200
PAT2
PAT1

MODEL FEATURES



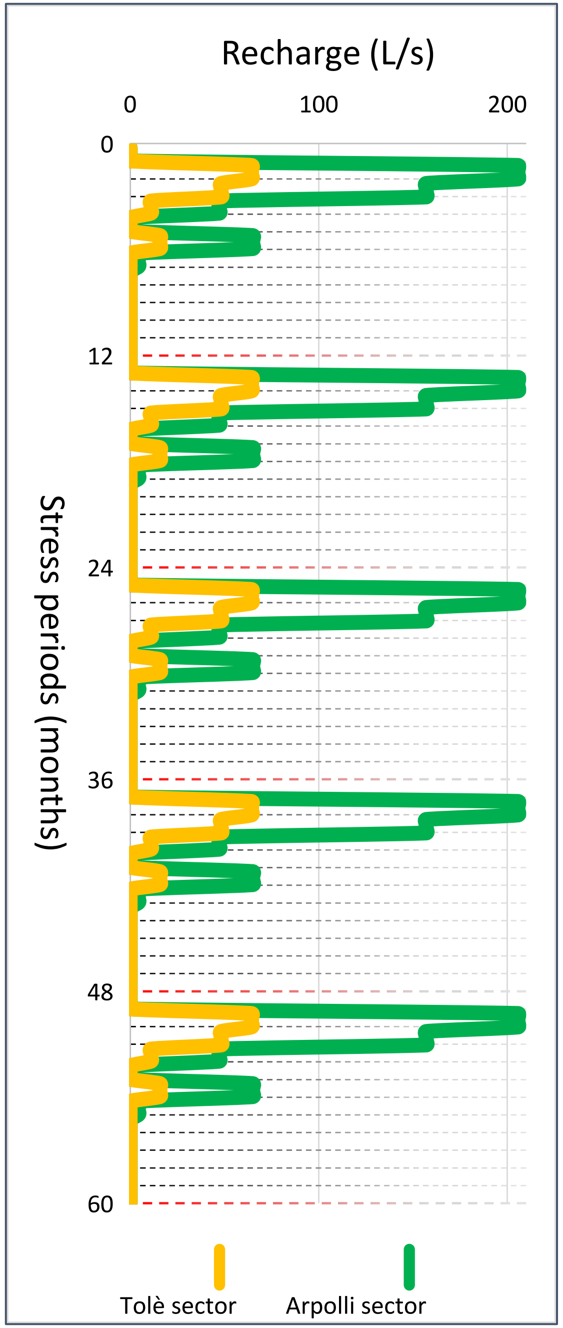
Arpolli sector



Tolè sector

Code: MODFLOW2005

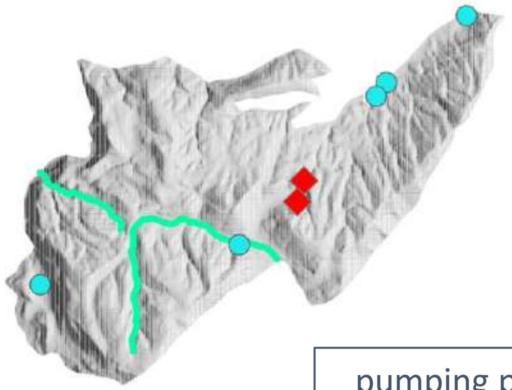
Equivalent porous medium (EPM) approach

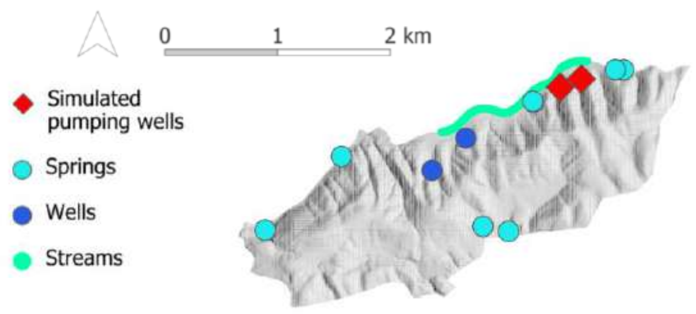


RESULTS AND PROPOSED SOLUTIONS

CALIBRATION YEAR (2020-2021)

Arpolli sector		
Scenario	Pumping rate	Net pumping rate
A1	**5 L/s**	**3.2 L/s**
A2	**8 L/s**	**5.1 L/s**



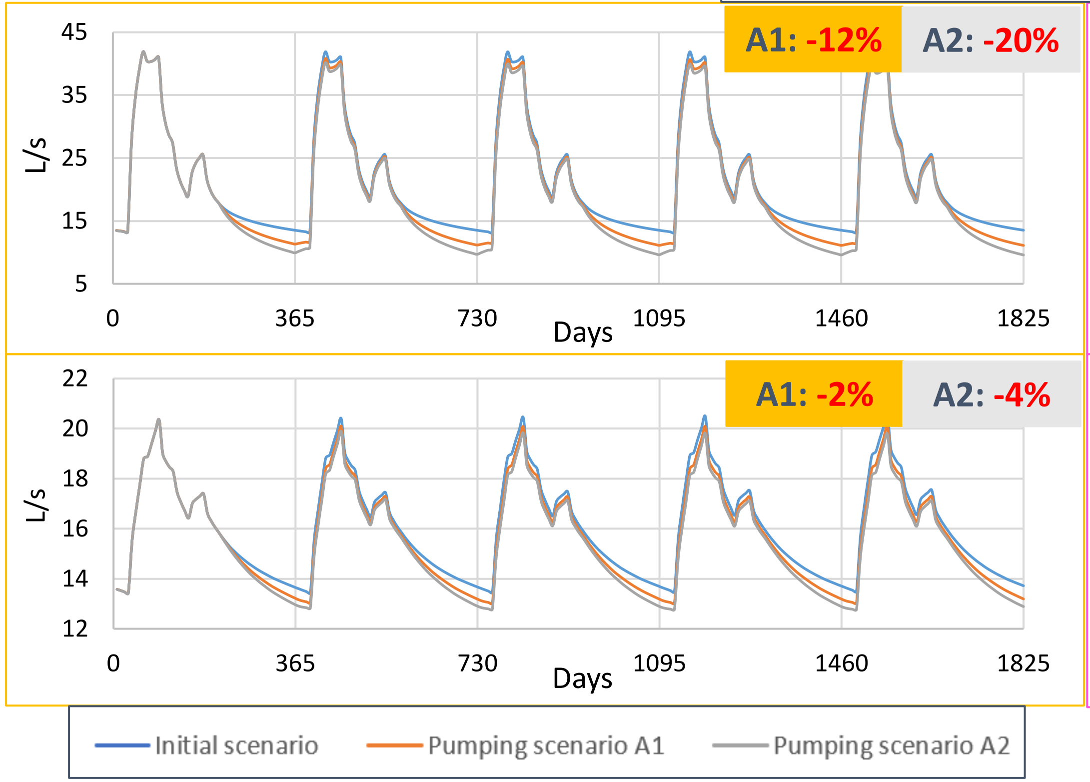


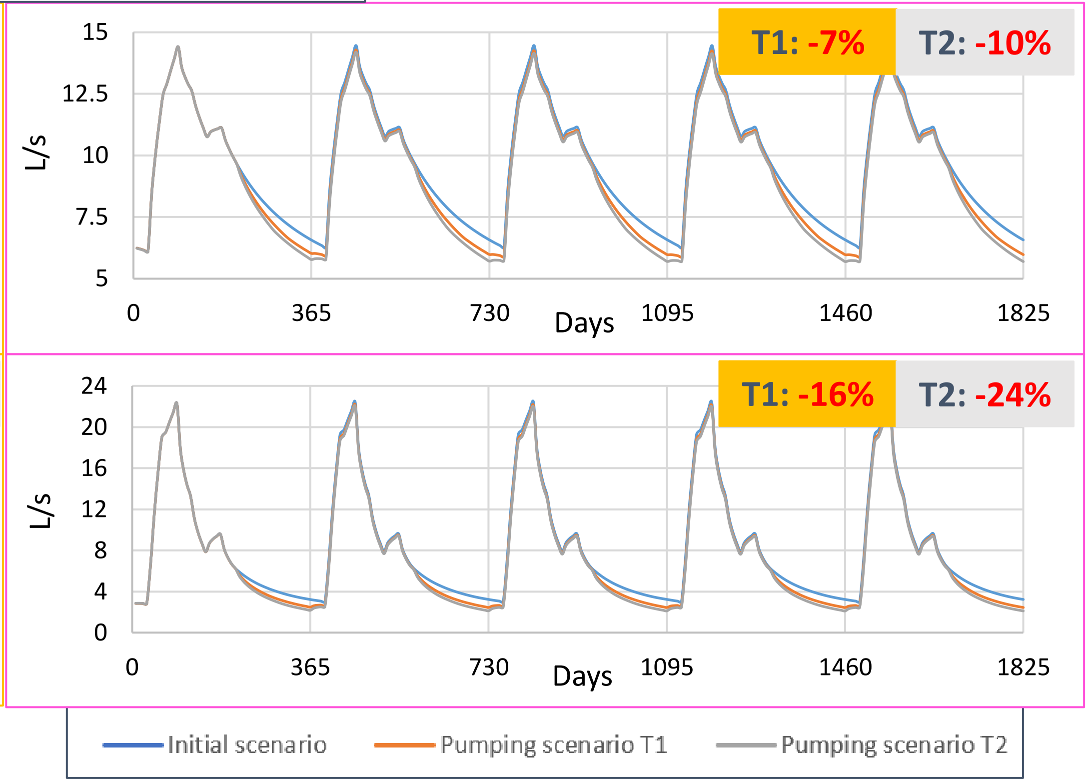
Tolè sector		
Scenario	Pumping rate	Net pumping rate
T1	**2 L/s**	**1.5 L/s**
T2	**3 L/s**	**2.2 L/s**

pumping period: 5 months during summer

Effects on **springs**

Effects on **streams**



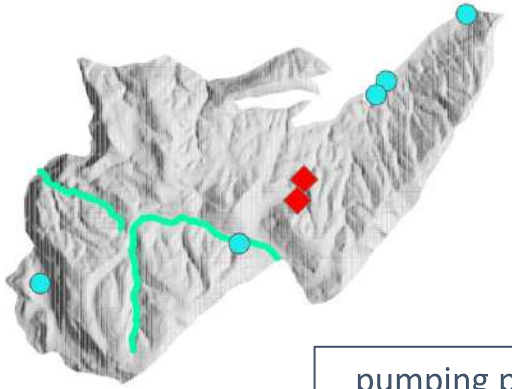


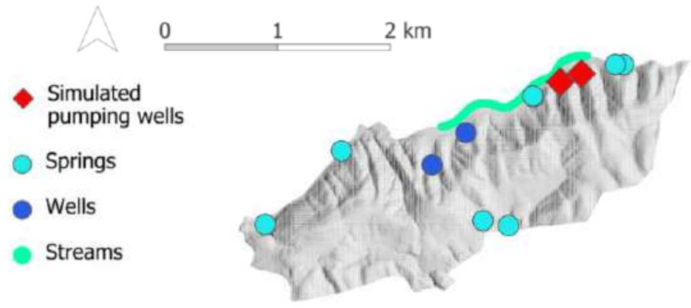
RESULTS AND PROPOSED SOLUTIONS

STRESSFUL CLIMATIC YEAR (2021-2022)

Arpolli sector

Scenario	Pumping rate	Net pumping rate
A1	**5 L/s**	**3 L/s**
A2	**8 L/s**	**4.9 L/s**





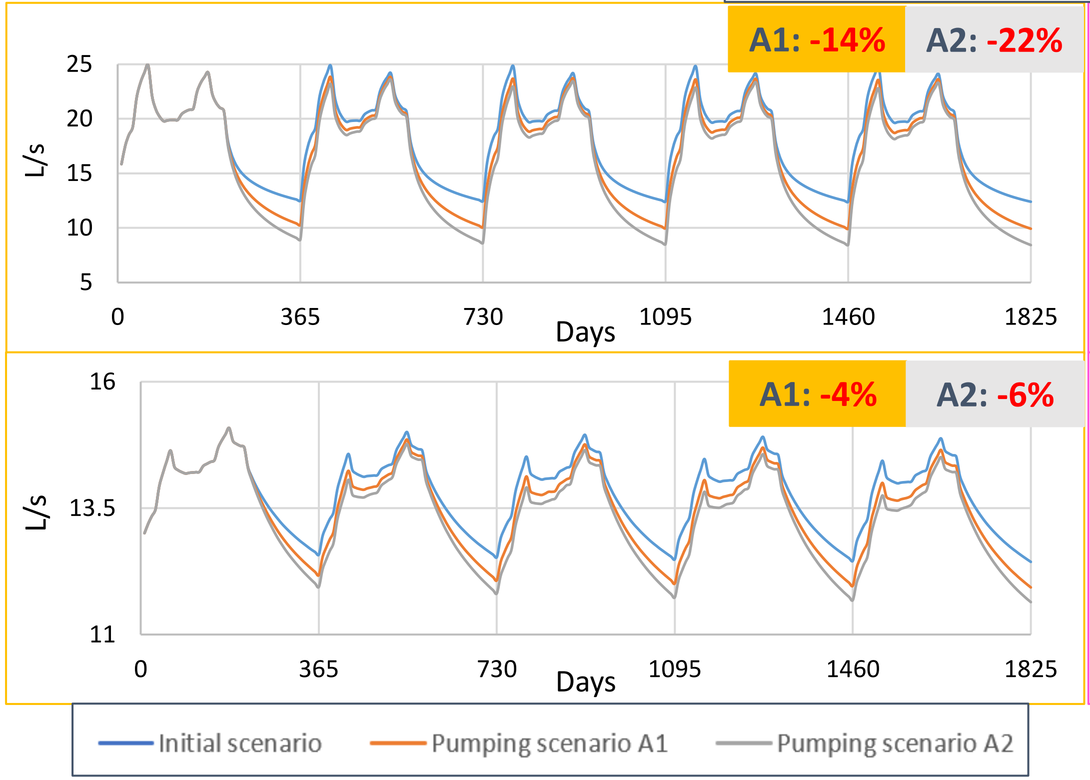
Tolè sector

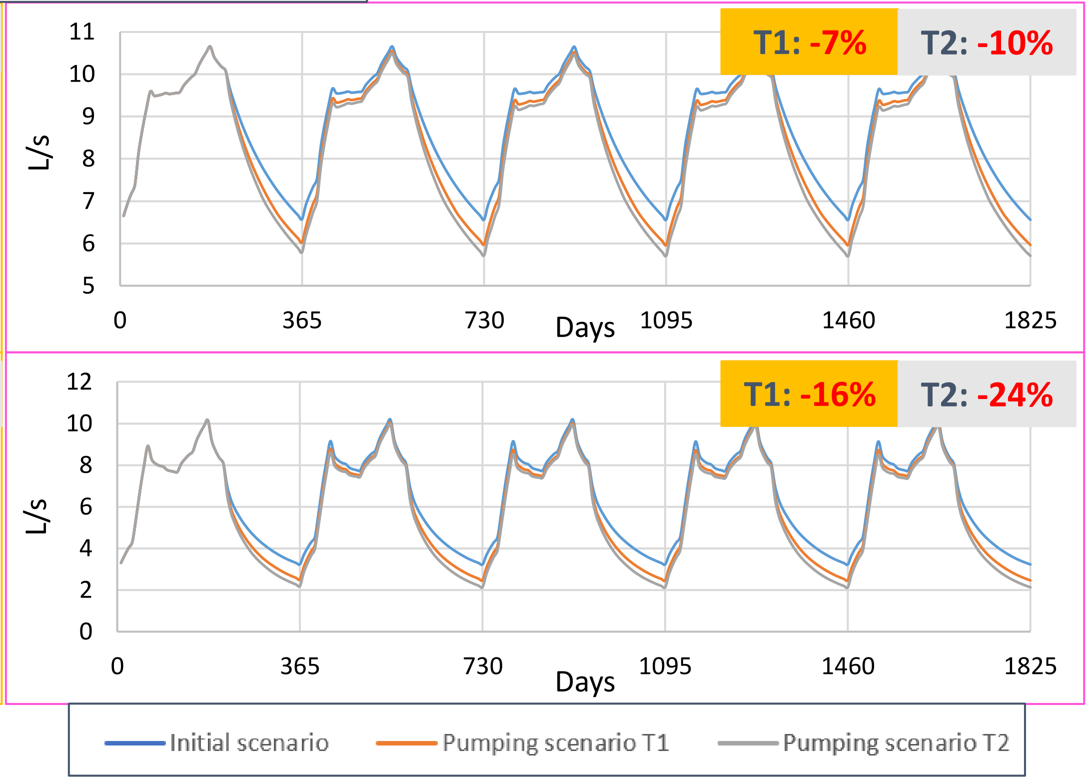
Scenario	Pumping rate	Net pumping rate
T1	**2 L/s**	**1.4 L/s**
T2	**3 L/s**	**2.2 L/s**

pumping period: 5 months during summer

Effects on **springs**

Effects on **streams**





CONCLUSIONS

	Arpolli	*Tolè*
Water supplied by **tanker trips** in 2022	**1999 m^3**	**6870 m^3**
Water potentially supplied by **proposed solutions**	**>40’000 m^3**	**>19’000 m^3**

Emergency water supply
that can be exploited during critical period

Models allowed to define an optimal pumping schedule as **management strategy**, according to:

- Hydrogeological **setting**
- **Impact** on spring discharge and environmental flow
- **Sustainability** during stressful climatic conditions

Observed favorable hydrogeological properties and hydro-structures deserve **site-specific studies** to define sustainable management strategies in sight of **future climatic crisis**, especially in **vulnerable areas** such as mountainous aquifers

GOVERNMENT OF MALTA

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GROUNDWATER FLOW MODELING FOR THE SUSTAINABLE EXPLOITATION OF THE MONTE CASTELLO AQUIFER

Pietro RAI[1], Luca ZINI[1], Claudia CHERUBINI[2]

[1] Università degli Studi di Trieste

[2] Università degli Studi di Ferrara

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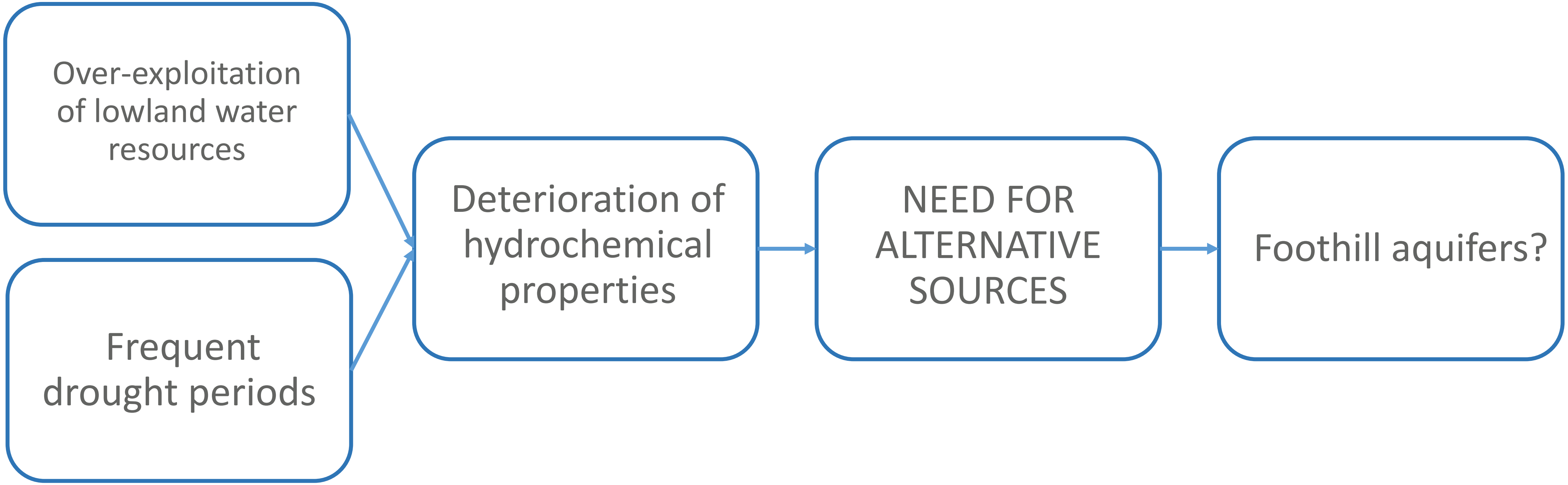
Session 3 - Emerging Challenges to Groundwater Quantity and Quality

30035

PROBLEM SETTING:

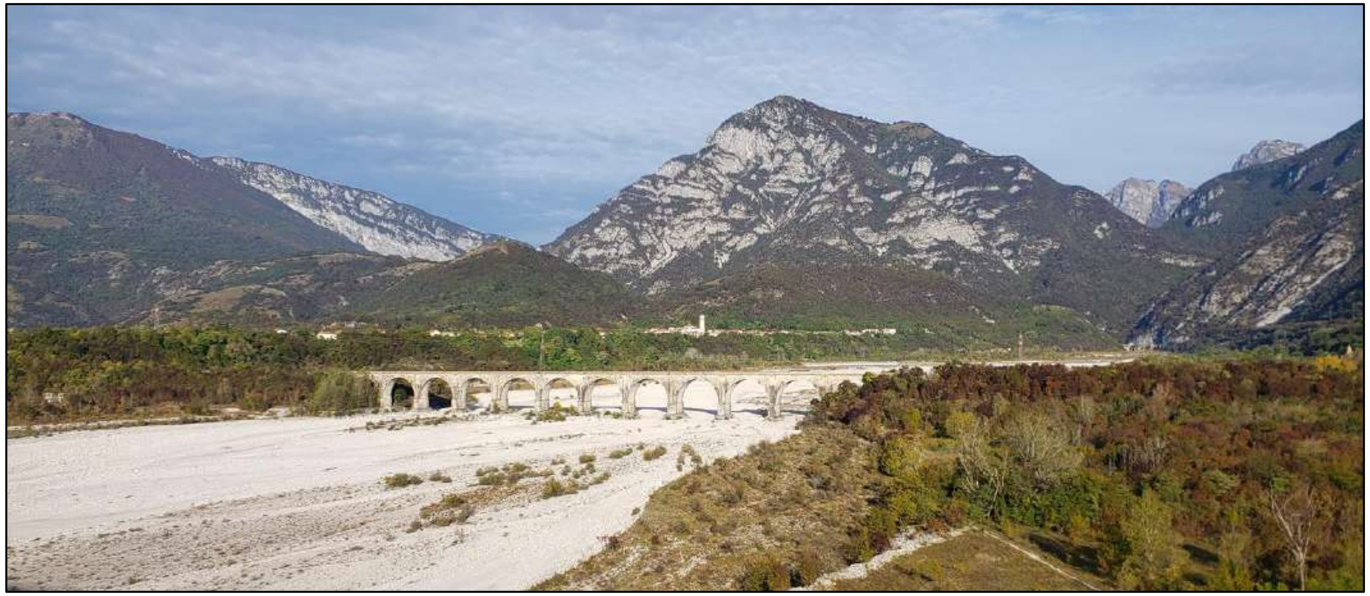


TARGETS:

- To study the hydrogeological features of Monte Castello site (interactions with Ravedis reservoir)

- To implement a hydrogeological flow model in order to assess:

    - Reservoir's leakage
    - The effects of drilling a pumping well



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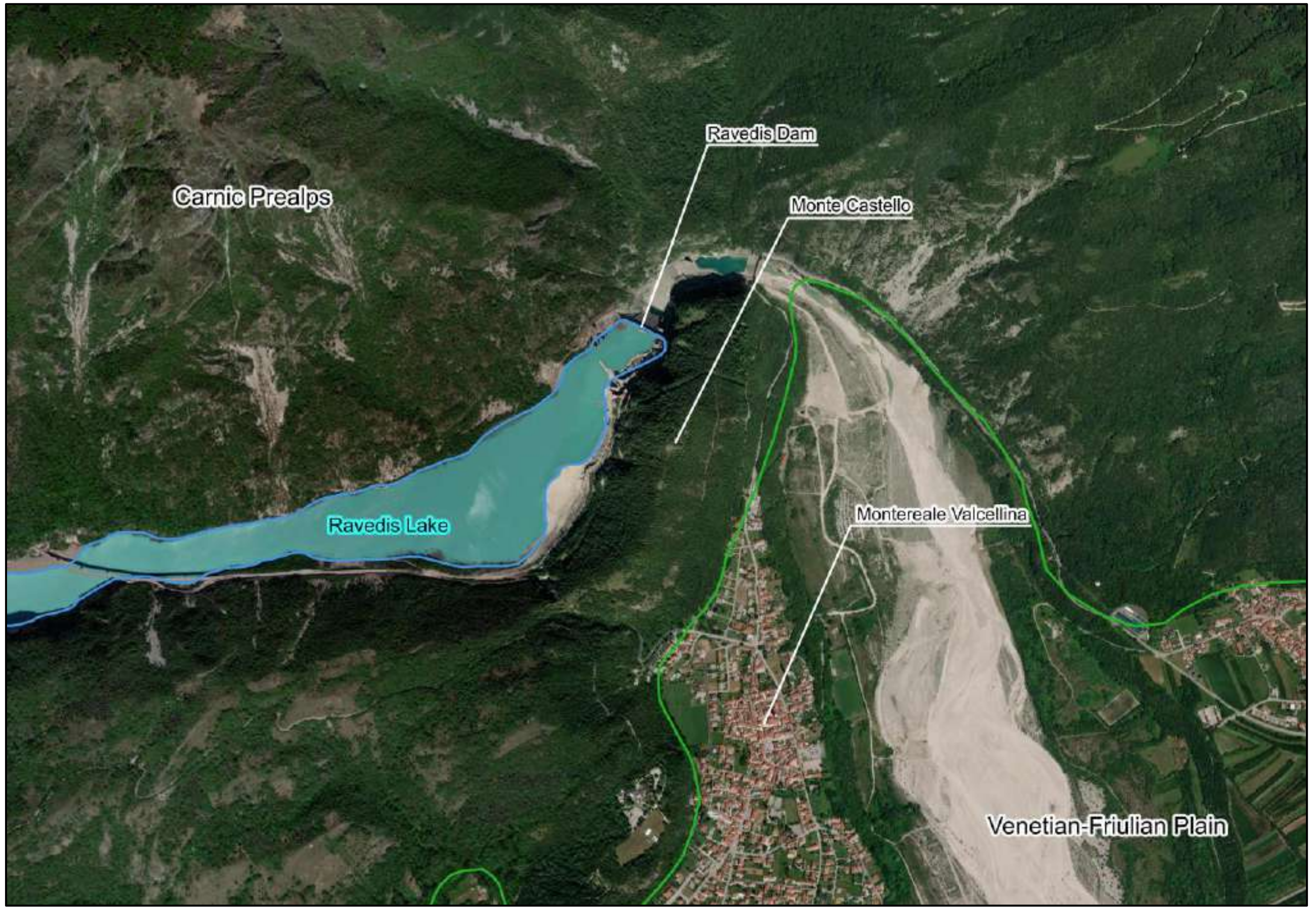
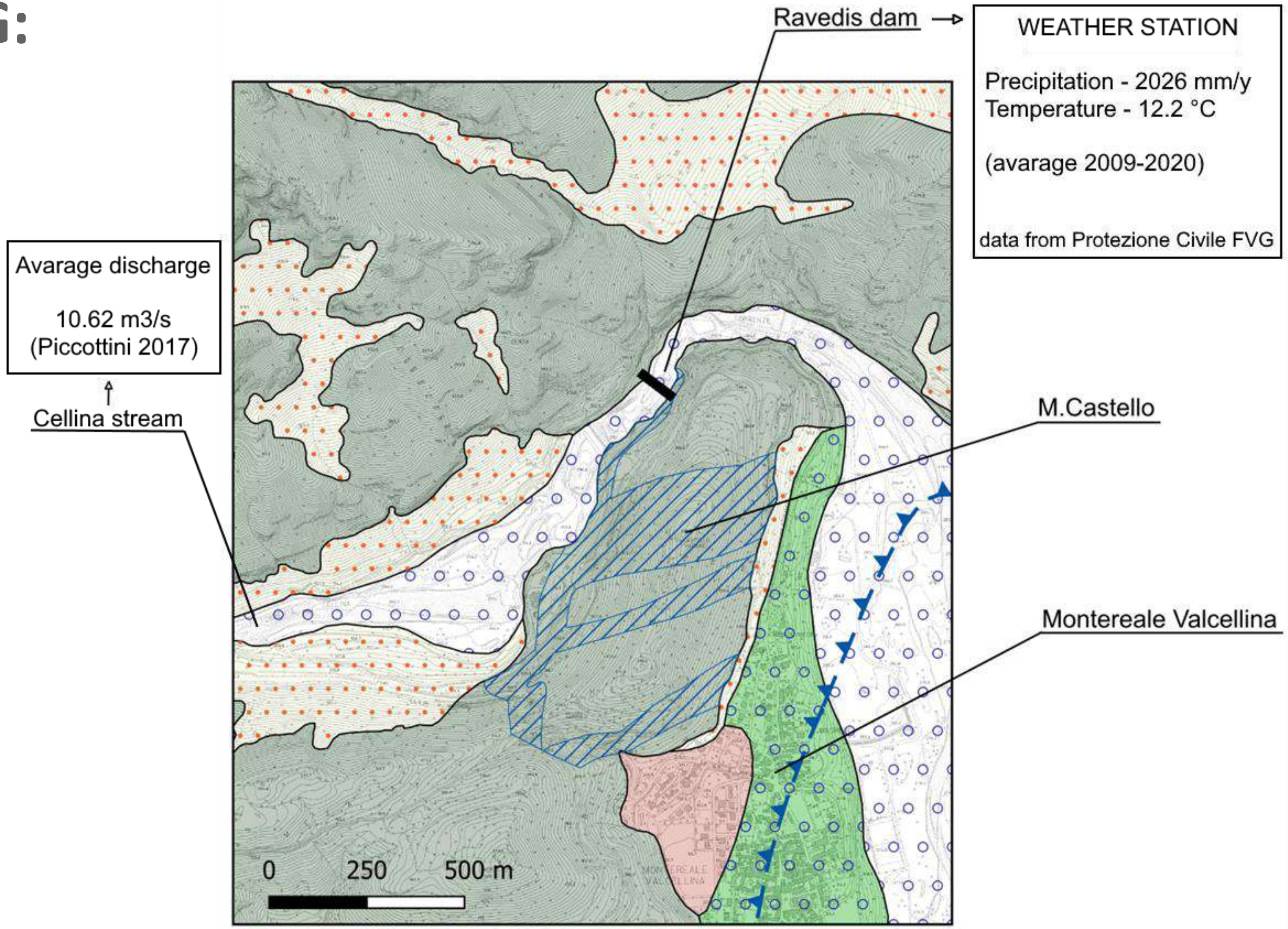
GEOGRAPHICAL SETTING:



1:25.000

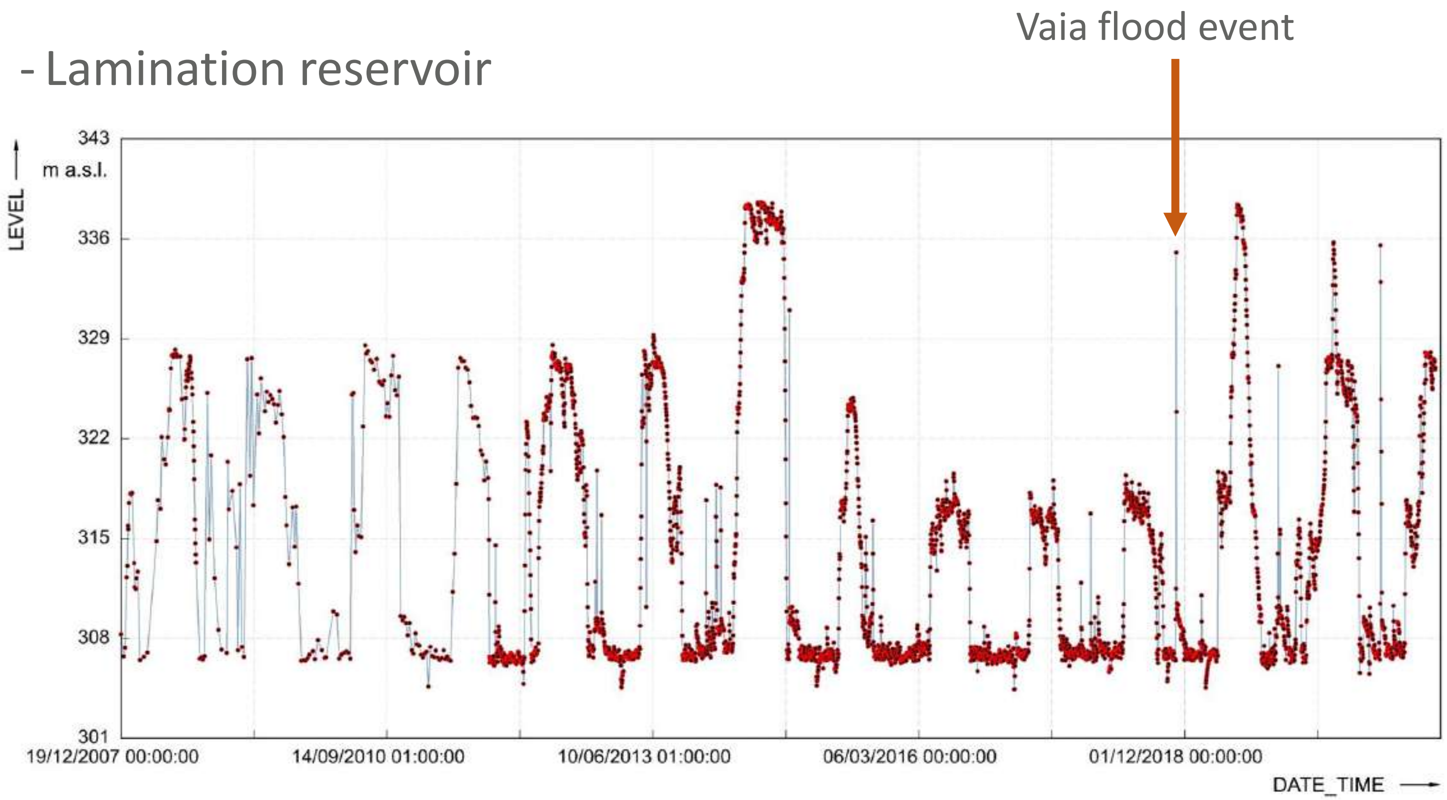
(HYDRO)GEOLOGICAL SETTING:

"Polcenigo-Maniago Thrust"
Colluvial talus
Gravel of Cellina Stream
Alluvial fan
Sandy gravel of Cellina alluvial fan
"Cellina Limestone"
Highly fractured areas in M.Castello (Perello 2001)



RAVEDIS DAM:

- Lamination reservoir



- Water reservoir for agricultural use and hydropower production

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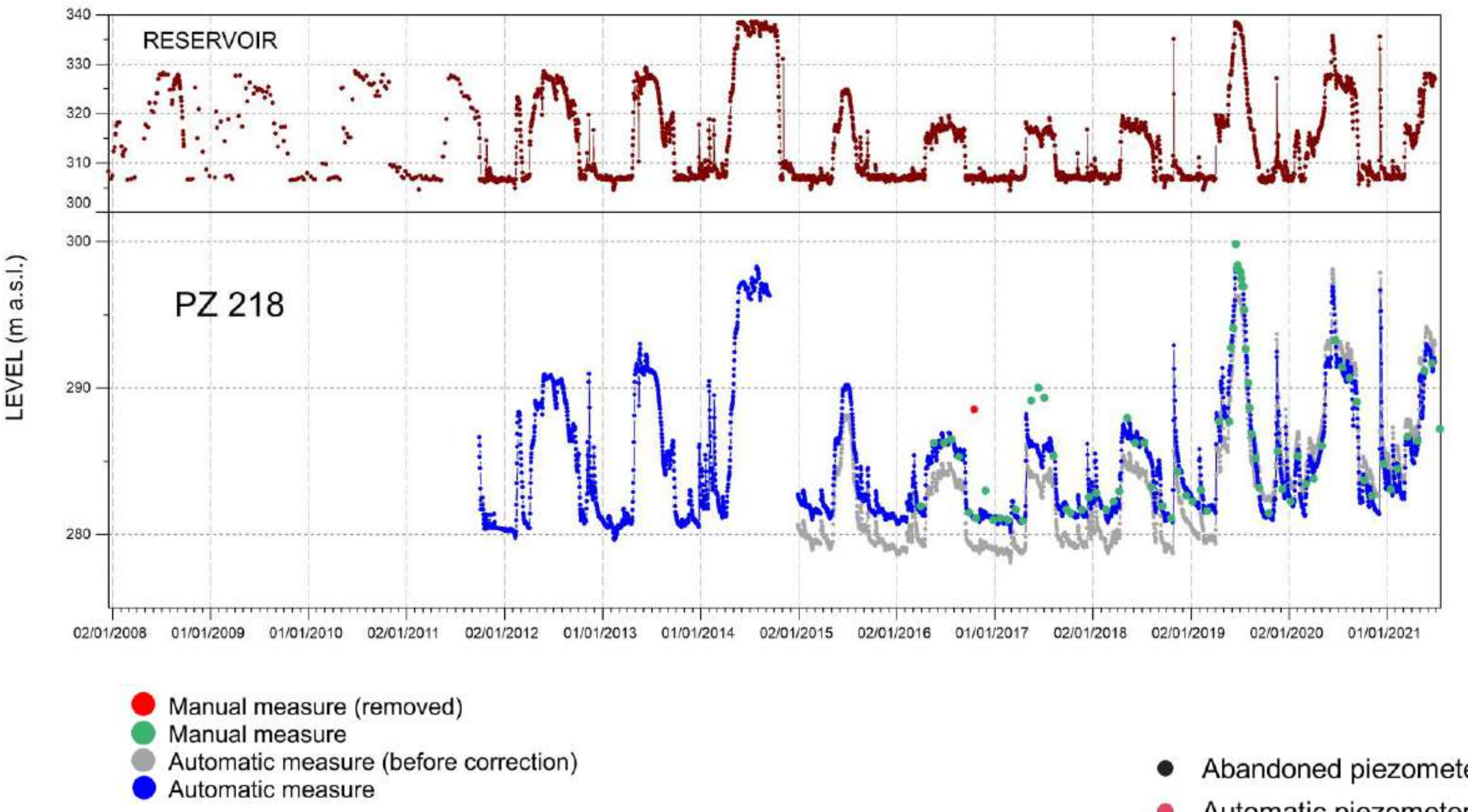
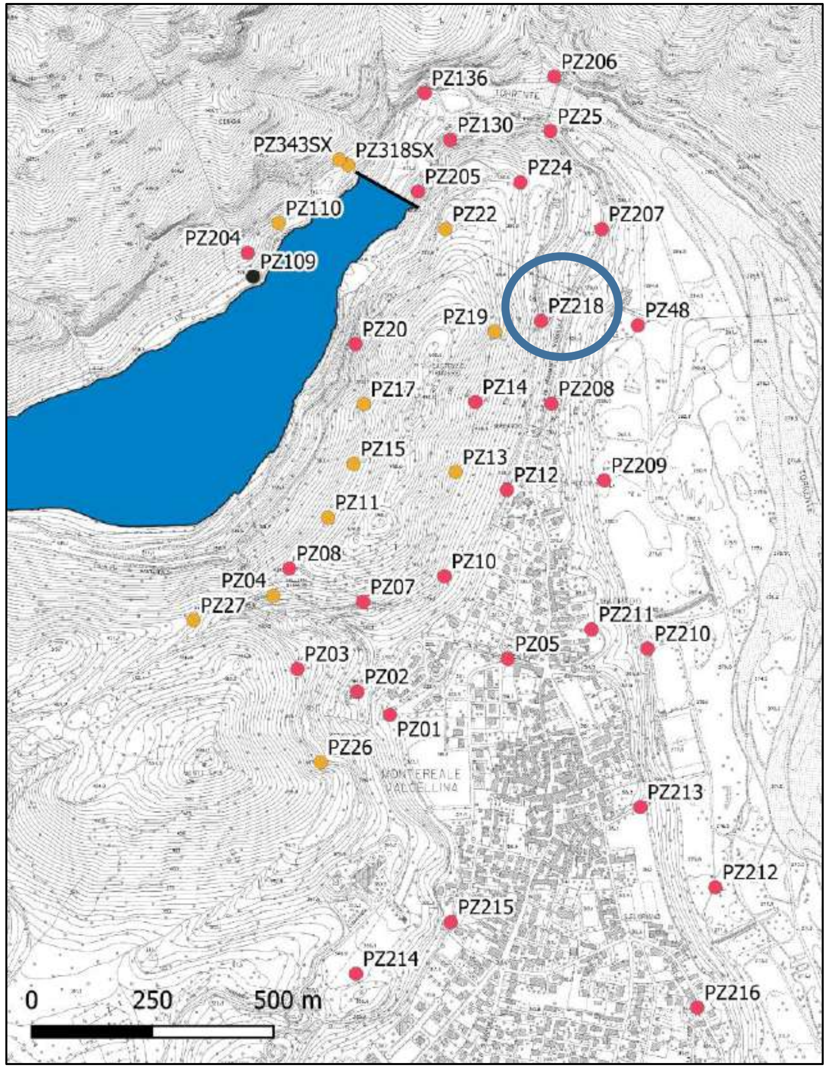
PIEZOMETRIC MONITORING SYSTEM:





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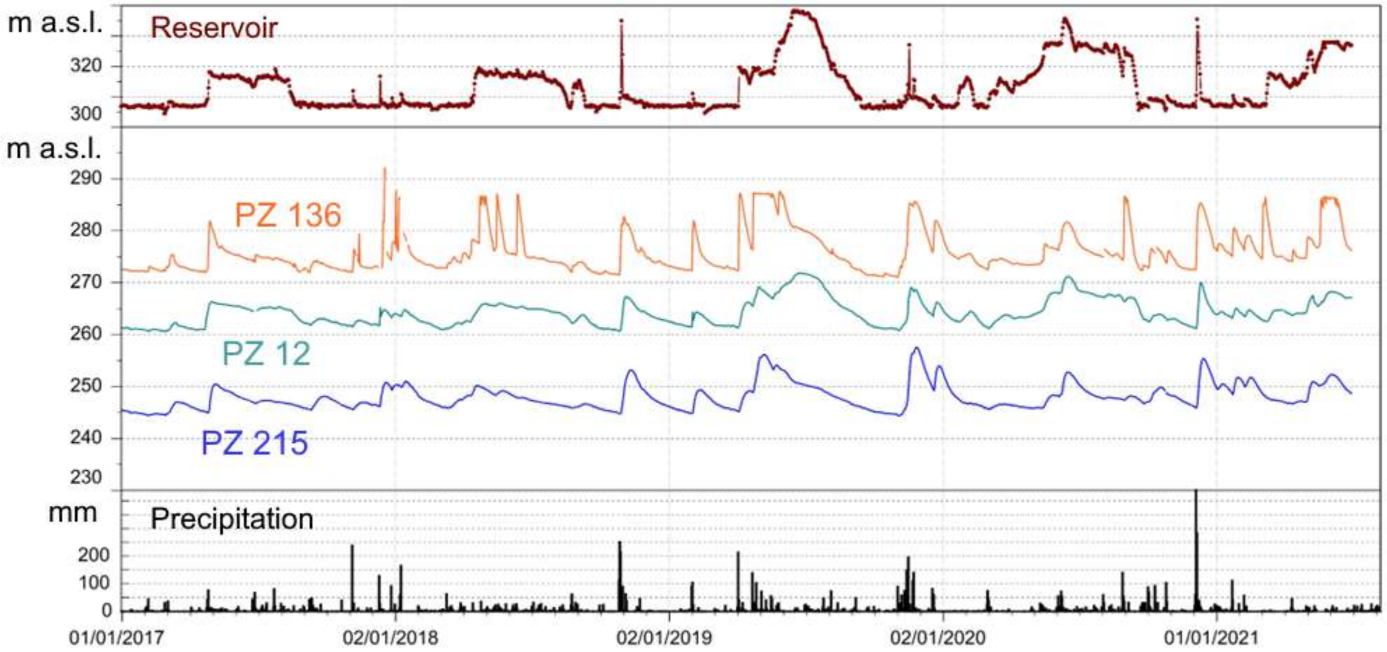
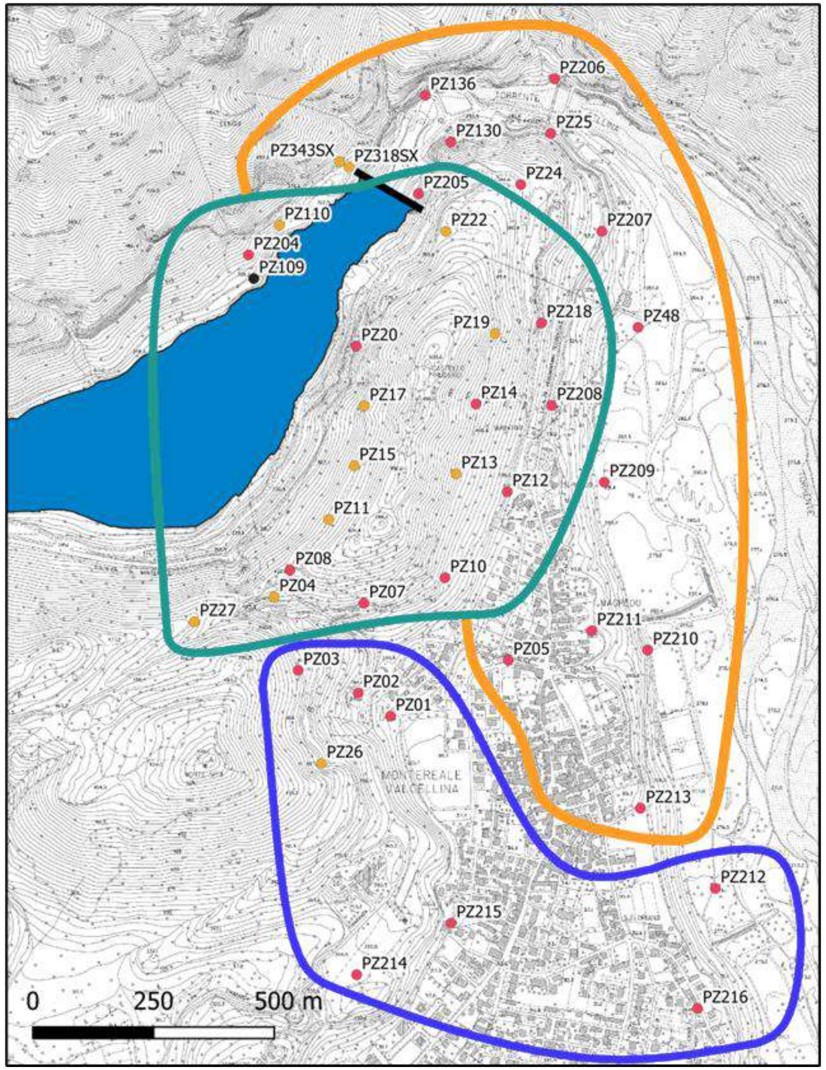
PIEZOMETRIC MONITORING SYSTEM:





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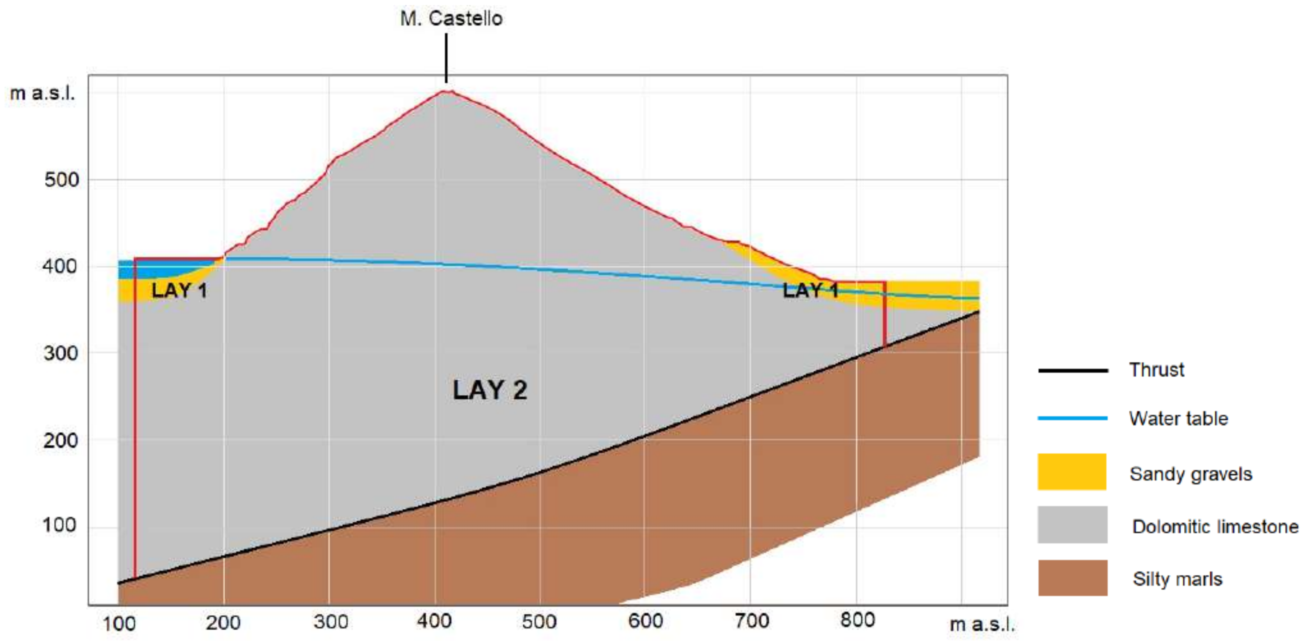
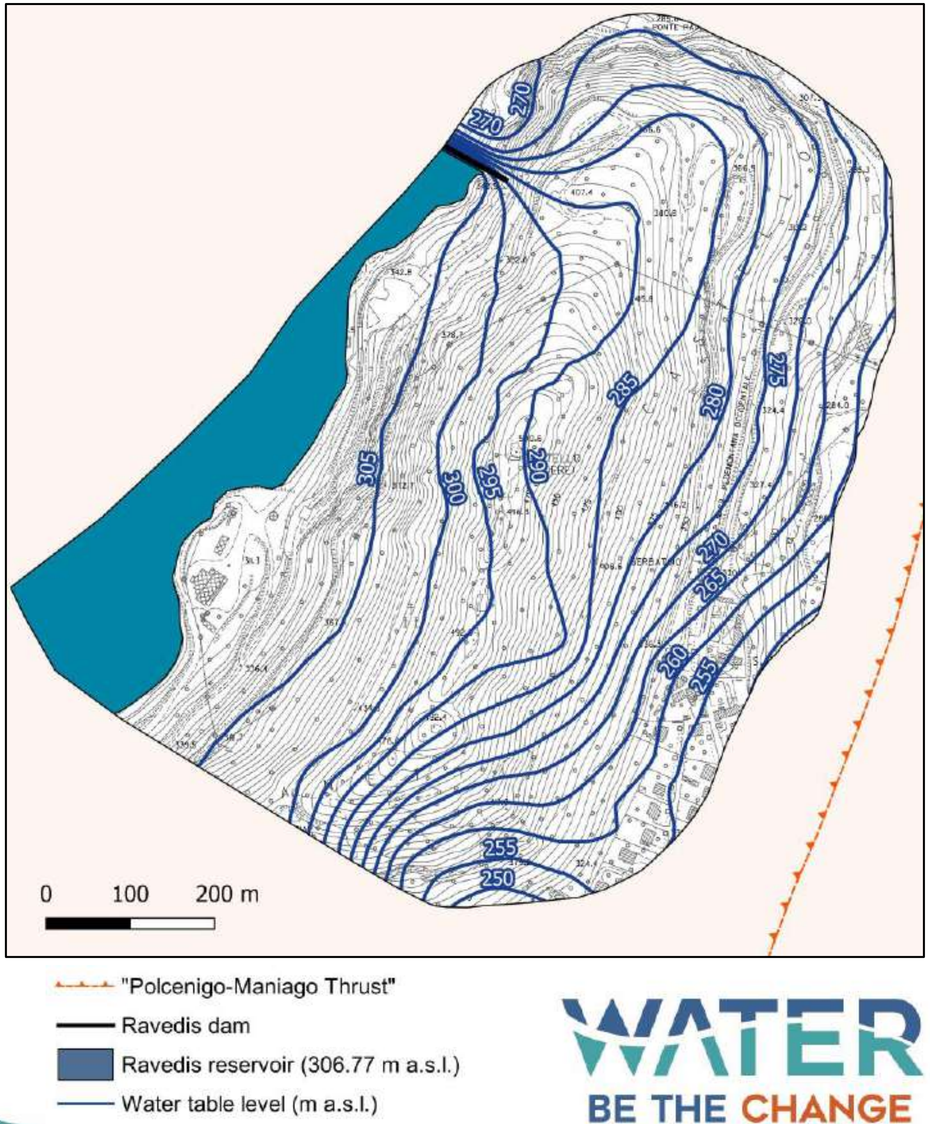
IMPLEMENTATION OF A GROUNDWATER FLOW MODEL:

- Two datasets:
  - May-June 2018
  - January-February 2019





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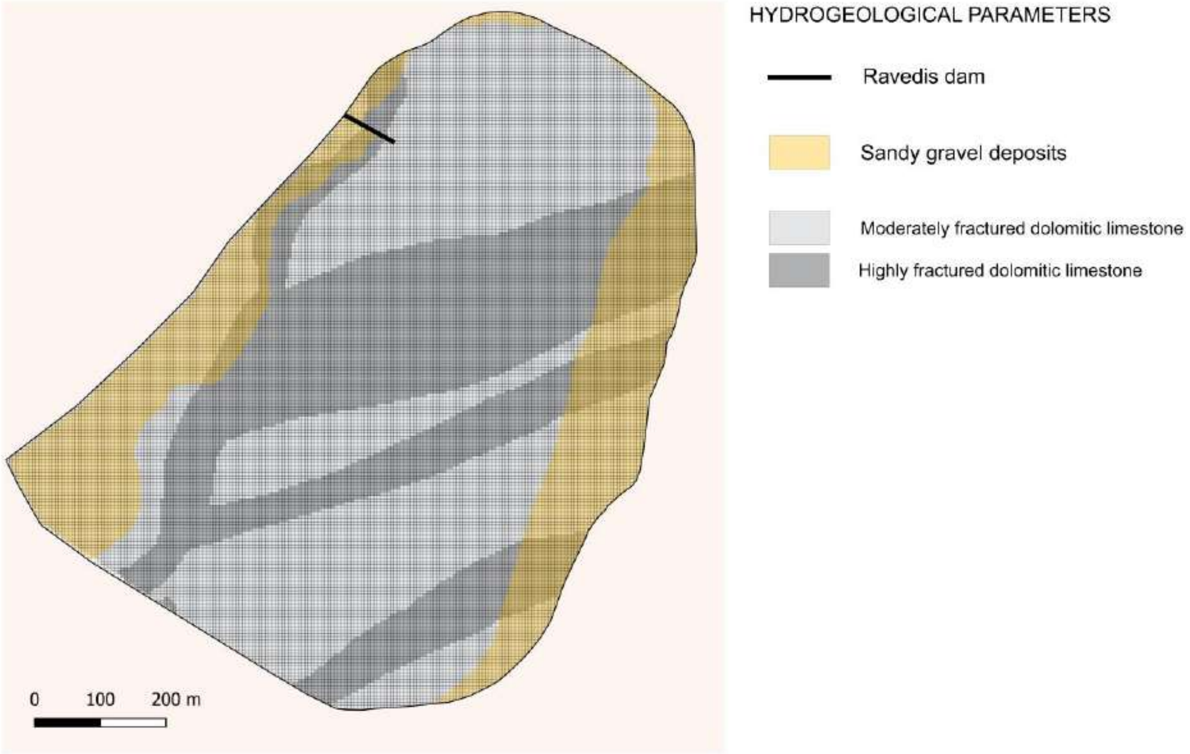
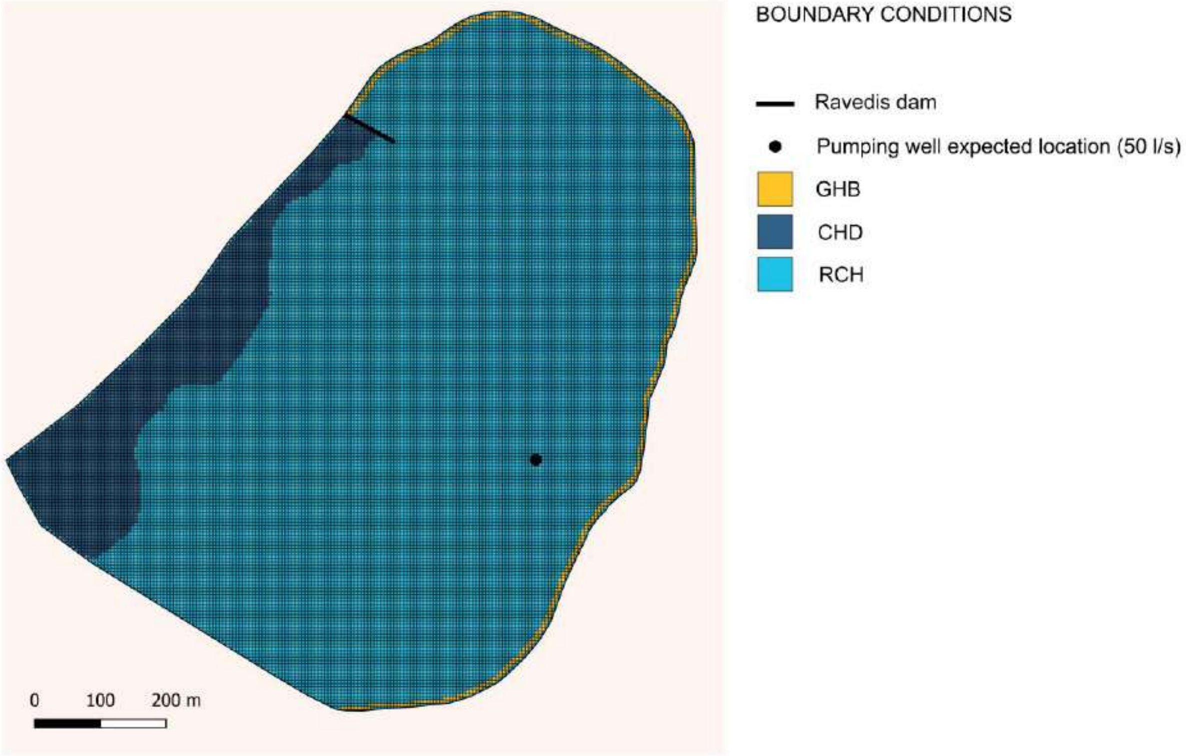
IMPLEMENTATION OF A GROUNDWATER FLOW MODEL:

MODFLOW-2005 code – FREEWAT platform (Rossetto *et al.* 2018)





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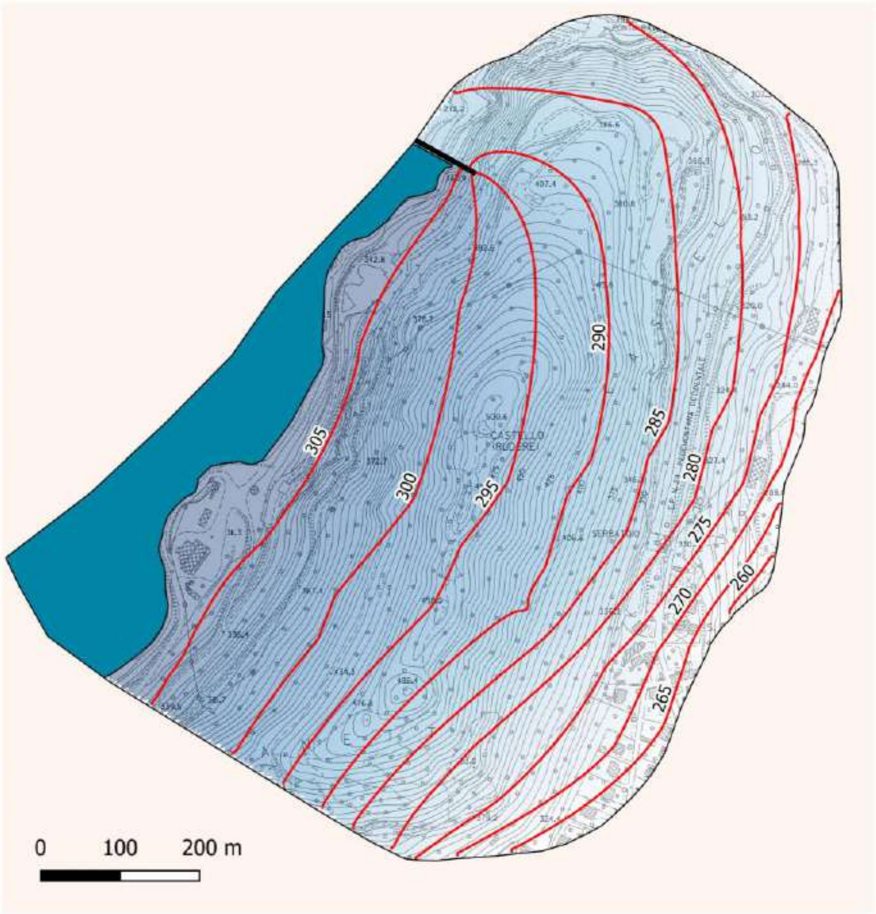
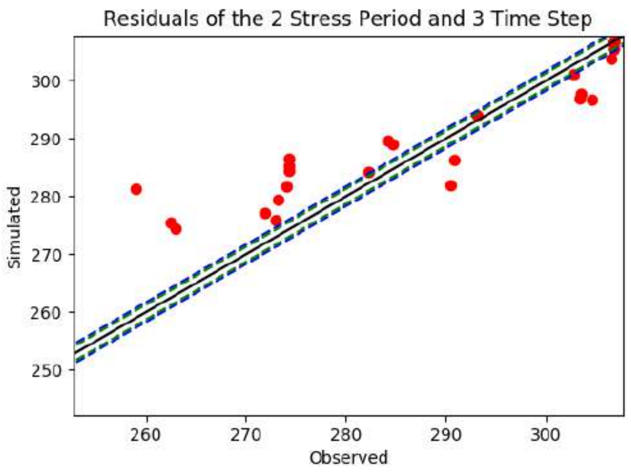
MODELING RESULTS:



Ravedis dam

Water table level (m a.s.l.)



Normalized RMS = 0.964

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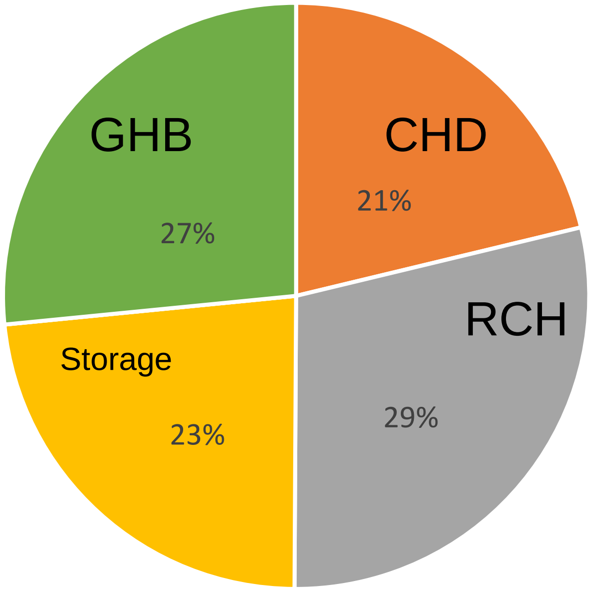
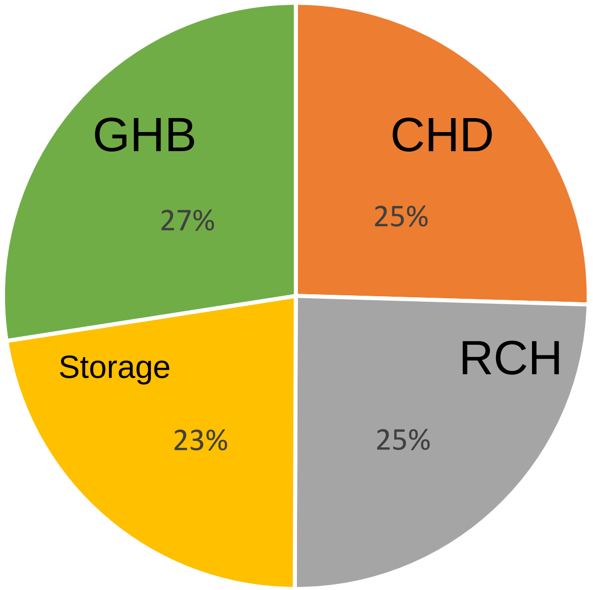
MODELING RESULTS:

```
 HEAD WILL BE SAVED ON UNIT   51 AT END OF TIME STEP    3, STRESS PERIOD    2
1
  VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP    3, STRESS PERIOD   2
  ------------------------------------------------------------------------------

     CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
     ------------------                 ------------------------

           IN:                                   IN:
           ---                                   ---
             STORAGE =          7.4642             STORAGE =      2.0466E-02
       CONSTANT HEAD =      73873.0469       CONSTANT HEAD =       2239.6494
     HEAD DEP BOUNDS =          0.0000     HEAD DEP BOUNDS =          0.0000
            RECHARGE =     100335.1875            RECHARGE =       3344.5063

            TOTAL IN =     174215.7031            TOTAL IN =       5584.1763

          OUT:                                  OUT:
          ----                                  ----
             STORAGE =      81222.9062             STORAGE =       2496.0154
       CONSTANT HEAD =          2.1978       CONSTANT HEAD =      8.3149E-02
     HEAD DEP BOUNDS =      92386.0312     HEAD DEP BOUNDS =       3071.3020
            RECHARGE =          0.0000            RECHARGE =          0.0000

           TOTAL OUT =     173611.1250           TOTAL OUT =       5567.4004

            IN - OUT =        604.5781            IN - OUT =         16.7759

 PERCENT DISCREPANCY =           0.35     PERCENT DISCREPANCY =           0.30
```

Winter conditions volumetric budget - 1 month (m3)



Summer conditions volumetric budget - 1 month (m3)



Reservoir's leakages: 2240 m3/day 2932 m3/day

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CONCLUSIONS:

- Hydrogeological characterization of the area showed a close link between Ravedis reservoir and Monte Castello aquifer

- Modeling of the aquifer is greatly affected by the lack of information on hydrogeological parameterization

- The previous point influenced in particular the attempt to evaluate the effects of the construction of a pumping well

- The model created allowed to obtain a preliminary estimate of the reservoir's leakages

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References:

Perello, P., 2001: Serbatoio di Ravedis sul Torrente Cellina ad uso regolazione piene, utilizzazione irrigua ed idroelettrica - Analisi geologico-idrogeologica sulla spalla destra in prossimità dello sbarramento (M. Castello).- Consorzio di Bonifica Cellina-Meduna

Piccottini, M., 2017: Impianto idroelettrico «Briglia Cellina» - Studio Impatto Ambientale - Sintesi Non Tecnica.- En Celinia srl

Rossetto, R., De Filippis, G., Borsi, I., Foglia, L., Cannata, M., Criollo, R., Vázquez-Suñé, E., 2018. Integrating free and open source tools and distributed modelling codes in GIS environment for data-based groundwater management, Environmental Modelling & Software, 107:210-230

Acknowledgements:

Sincere thanks to *Consorzio di Bonifica Cellina Meduna* for providing the piezometric dataset and an important number of technical reports concerning the studied area.

Many thanks also to *HydroGEA SpA* for partially funding this study.

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Enhanced Thermal Response Test interpretation through MODFLOW-USG and PEST_HP

POLITECNICO MILANO 1863

Sara Barbieri
Matteo Antelmi
Pietro Mazzon
Luca Alberti

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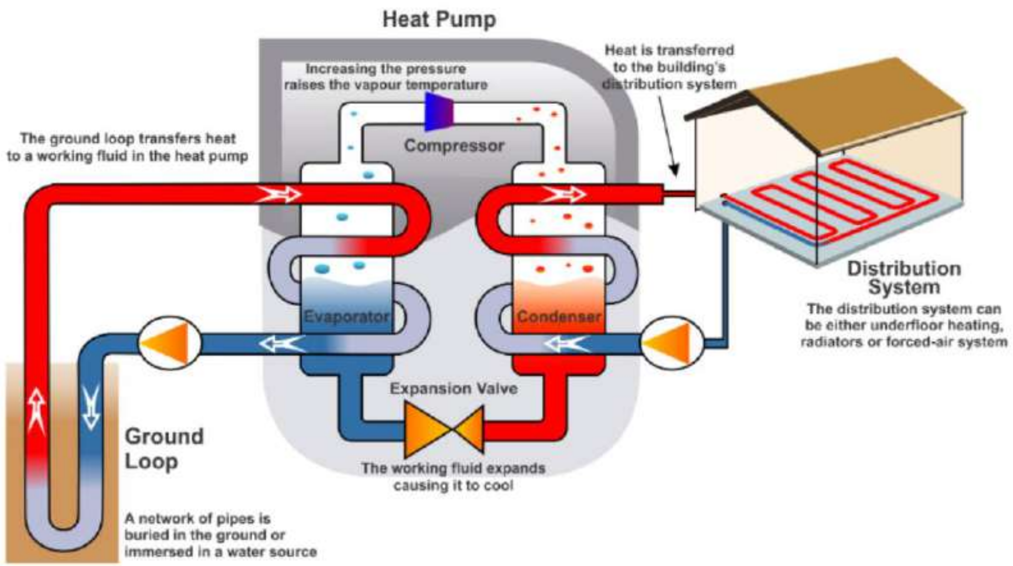
GEOTHERMAL ENERGY

SHALLOW CLOSED LOOP SYSTEMS

Energy systems coupled to the ground by means of a closed-loop vertical/horizontal U-shaped pipe (Borehole Heat Exchangers (BHE))



Source: http://www.nzgeothermal.org.nz

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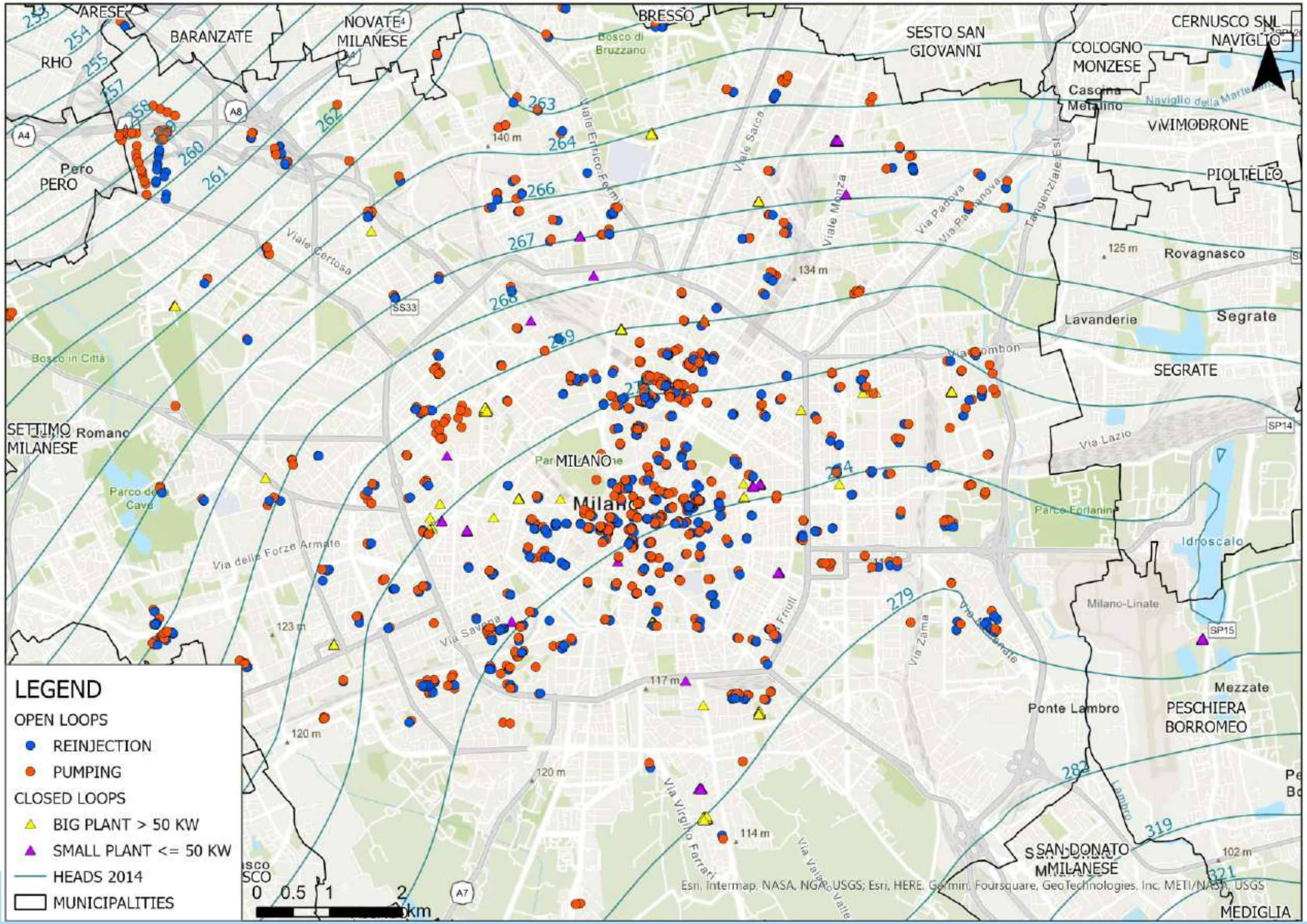
MILAN MUNICIPALITY – GEOTHERMAL PLANTS

OPEN LOOPS:

- 791 PUMPING WELLS
- 653 REINJECTION WELLS

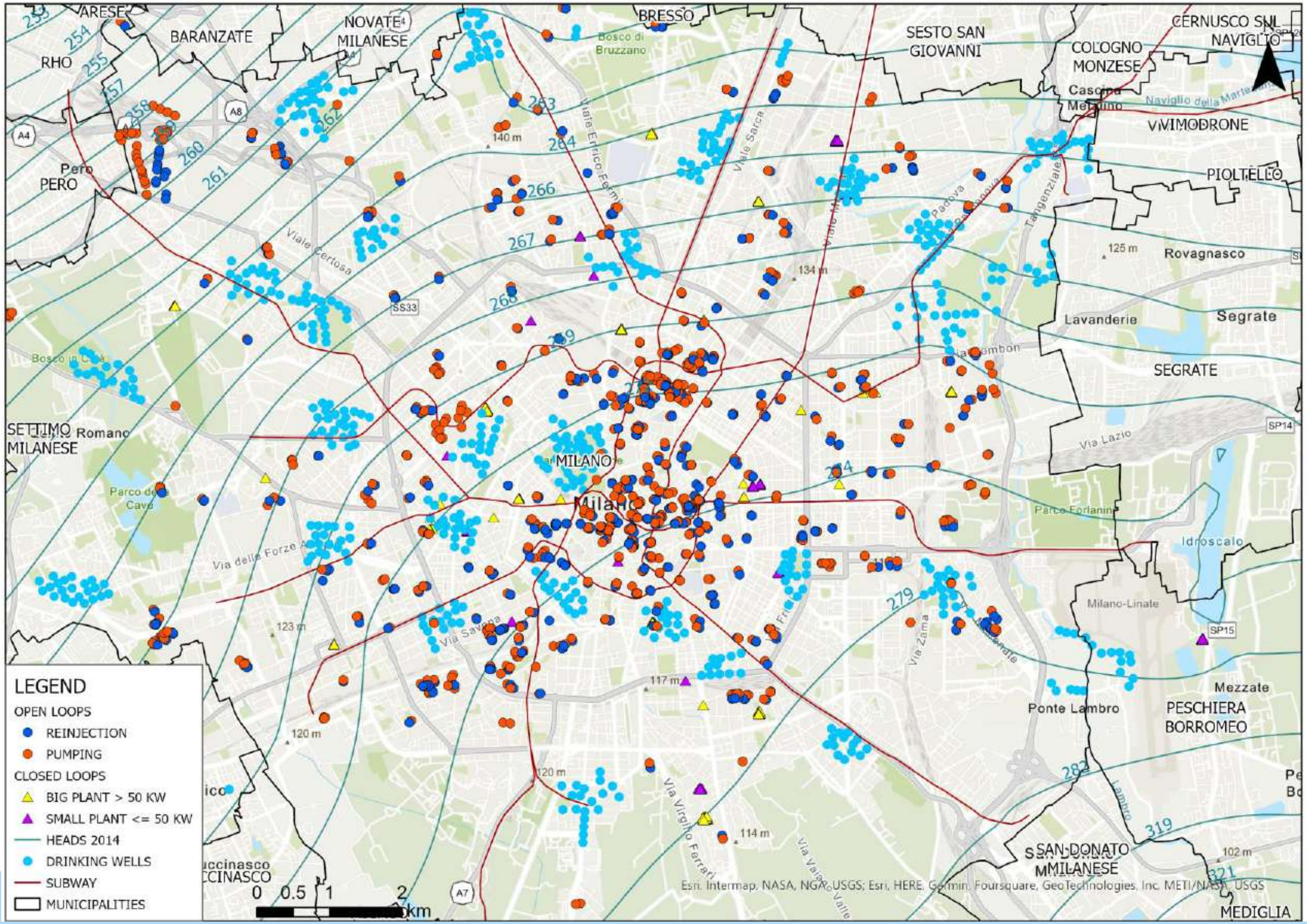
CLOSED LOOPS:

- 605 BOREHOLE HEAT EXCHANGERS



MILAN MUNICIPALITY – GEOTHERMAL PLANTS

- High risk of mutual interference
- Geo-exchange system efficiency decrease
- Interference with other underground infrastructures (drinking wells, subways, etc.)



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SHALLOW CLOSED LOOP SYSTEMS DESIGN

- **Legislation requirements in Italy → Decree 30 sept 2022:**
  - Underground thermal parameters estimation from literature for installations < 50 kW
  - Thermal Response Test for installations with thermal power > 50 kW
  - UNI technical standards for materials selection, environmental requirements and installation

- **Underground heat exchange efficiency:**
  - Underground thermal and hydrogeological properties knowledge
  - Existence of other geothermal plants or adjacent underground utilities

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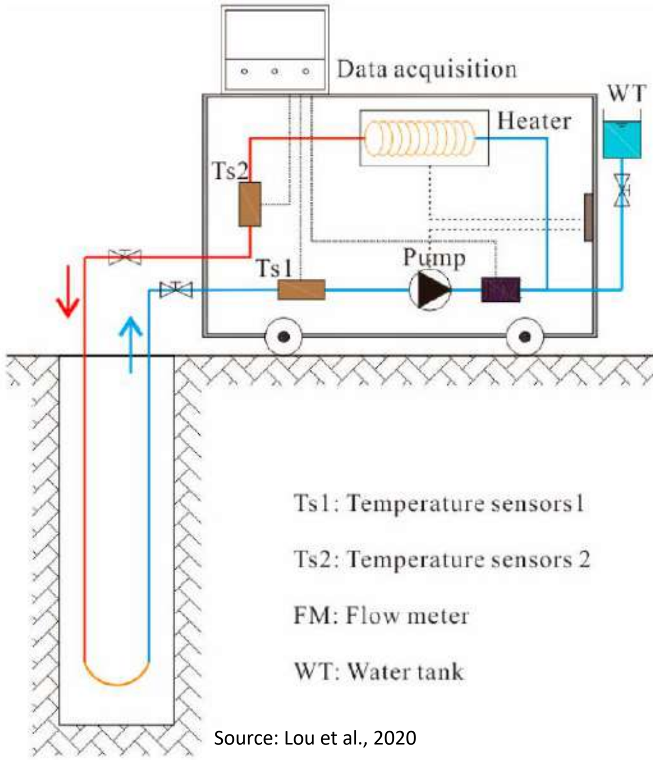
THERMAL RESPONSE TEST

THERMAL RESPONSE TEST (TRT)

- Injection of constant heat rate to the ground
- Inlet/outlet borehole temperatures monitoring
- Underground thermal properties estimation, borehole thermal resistance and unperturbed aquifer temperature



Source: Lou et al., 2020

TRTs produce temperature data over time to be interpreted through analytical solutions

↓

One averaged thermal conductivity value of subsoil along the depth

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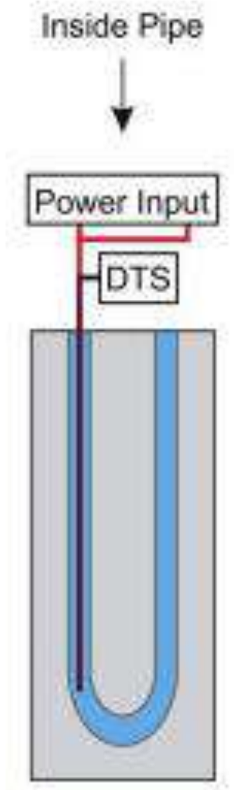
ENHANCED THERMAL RESPONSE TEST

- Constant heat rate injection through a heating cable in the inlet branch of the borehole heat exchanger
- No circulation of the heat carrier fluid inside U-shape pipe
- Temperatures measurment along the depth through temperature detectors at different time intervals



ETRTs produce temperature data over time and depth to be interpreted with analytical solutions

↓

Punctual thermal conductivity values of subsoil over the depth

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ENHANCED THERMAL RESPONSE TEST

Do we really need thermal properties along the depth?

- These data allow us to identify those layers with higher thermal conductivity and thermal borehole resistance, thus supporting the design of the probes
- Furthermore, by interpreting the data with 3D numerical models, it is possible to estimate the water table velocity, if present

↓

Knowledge of soil and aquifer properties along the vertical helps at the system design stage to increase its efficiency and investigate any interference with other underground structures

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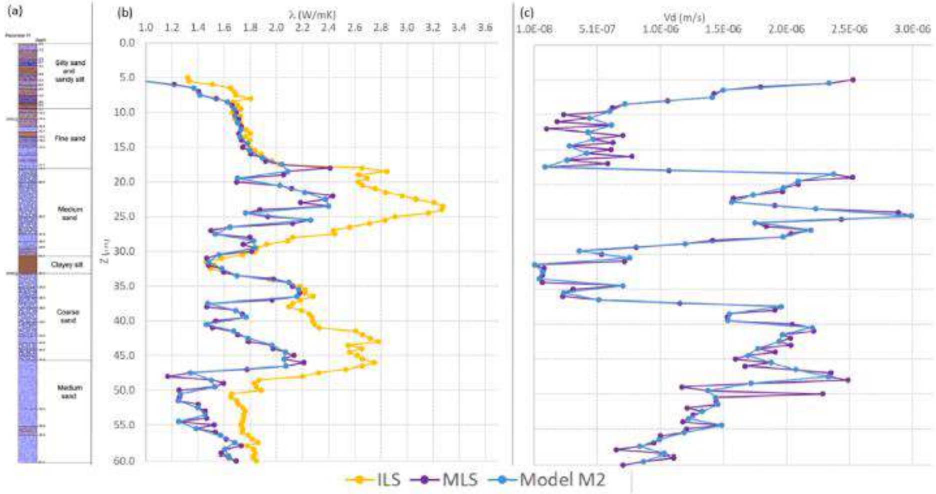
TRT & ETRT NUMERICAL SIMULATION

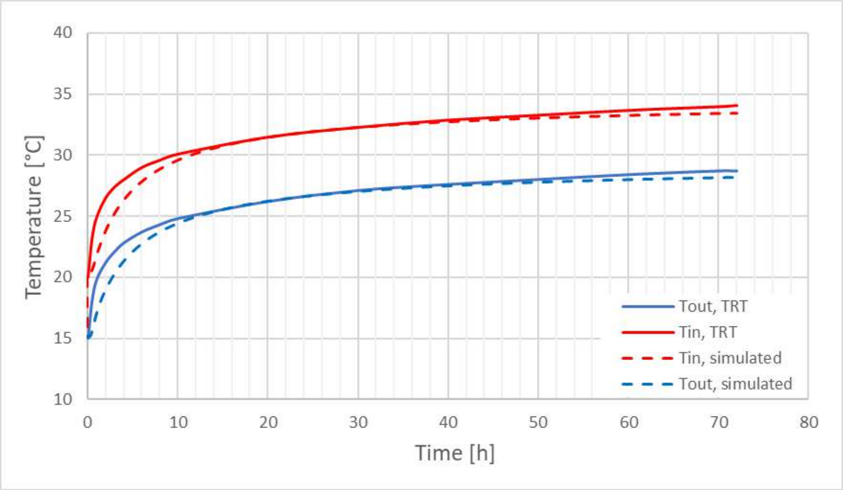
Simulated through MODFLOW numerical code so far by our research group:

- ITYPE option through MODFLOW coupled to MT3DMS for ETRT simulation, **Antelmi et al., 2020;**
- CLN and DRT packages from MODFLOW USG for TRT simulation, **Barbieri et al., 2022.**

ETRT



TRT



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ETRT SIMULATION

The CLN-DRT packages were validated for TRTs, now this is a preliminary validation for ETRTs

- Simulated as a TRT → CLN and DRT packages from MODFLOW USG:

q	W/m
BHE length	m
Q	W

$$Q = m_{water} \cdot c_{p,water} \cdot \Delta T$$

cp	4186	J/kg/°C
m_{water}	0.13	kg/s
ΔT	**X**	**°C**

- Assisted calibration with PEST_HP → temperature target at 4 time instants along the depth

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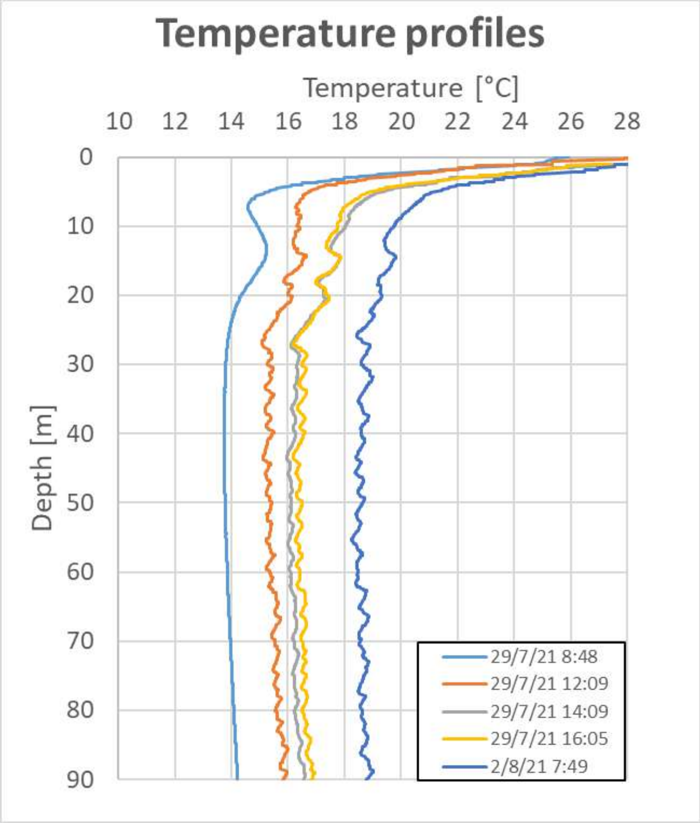
CASE STUDY N.1 - NEGLIGIBLE FLOW

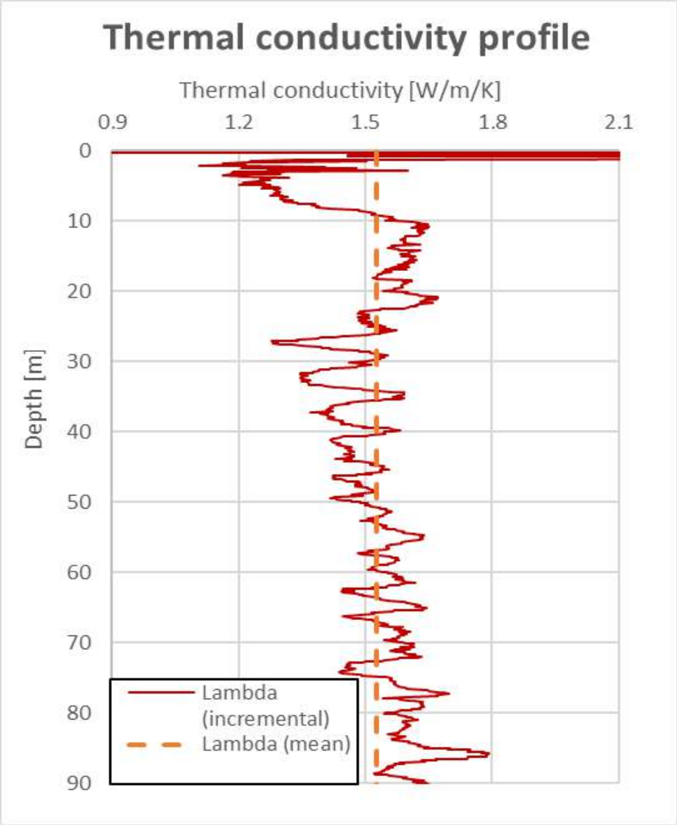
- Input data:

q	15.6	W/m
BHE length	95.8	m
Q	1494.48	W

→ $Q = m_{water} \cdot c_{p,water} \cdot \Delta T$ →

cp	4186	J/kg/°C
m_{water}	0.13	kg/s
ΔT	**2.75**	**°C**





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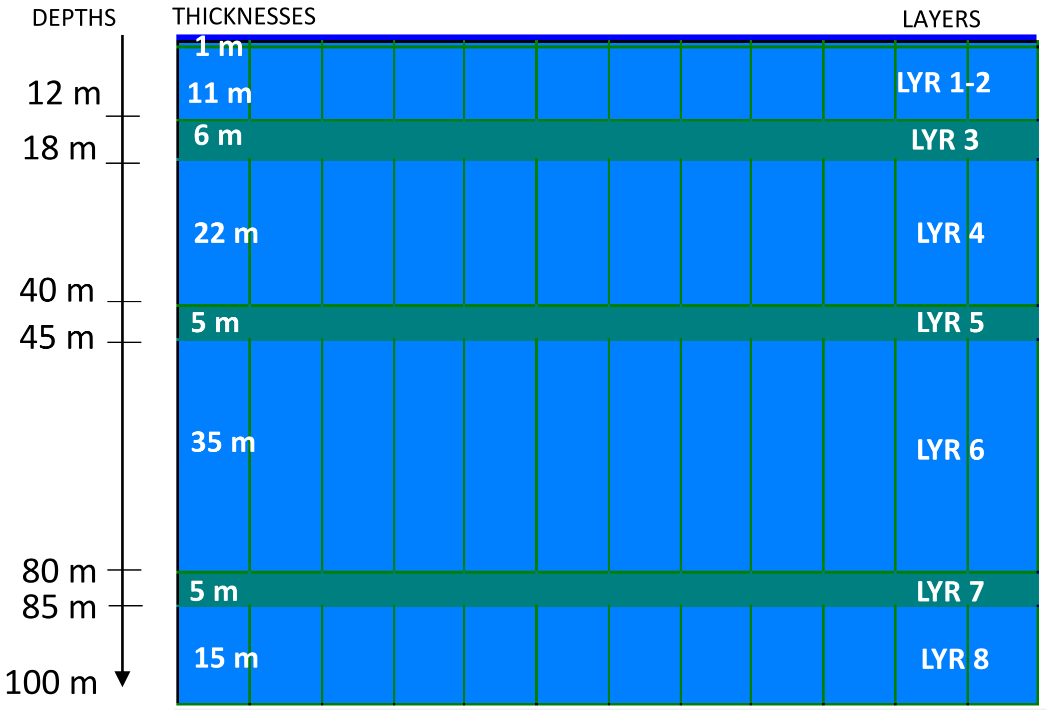
CASE STUDY N.1 – PROPERTIES

VERTICAL DISCRETIZATION:



PEST input range of k [m/s]	Bulk density [kg/m³]	Heat capacity [J/kg/K]	PEST input range of thermal conductivity [W/m/K]	Initial T [°C]
1E-08 - 1E-06	1800	833	0.6 – 1.8	25.24/16.24
1E-06 - 1E-04	2100	1143	1.4 - 2	15.07
1E-07 - 1E-04	2000	1100	1.3 – 1.8	13.93
1E-06 - 1E-04	2100	1143	1.4 - 2	13.75
1E-06 - 1E-05	2000	1100	1.4 – 1.8	13.89
1E-06 - 1E-04	2100	1143	1.4 - 2	14.12
1E-08 - 1E-06	2000	1100	0.6 – 1.8	14.23

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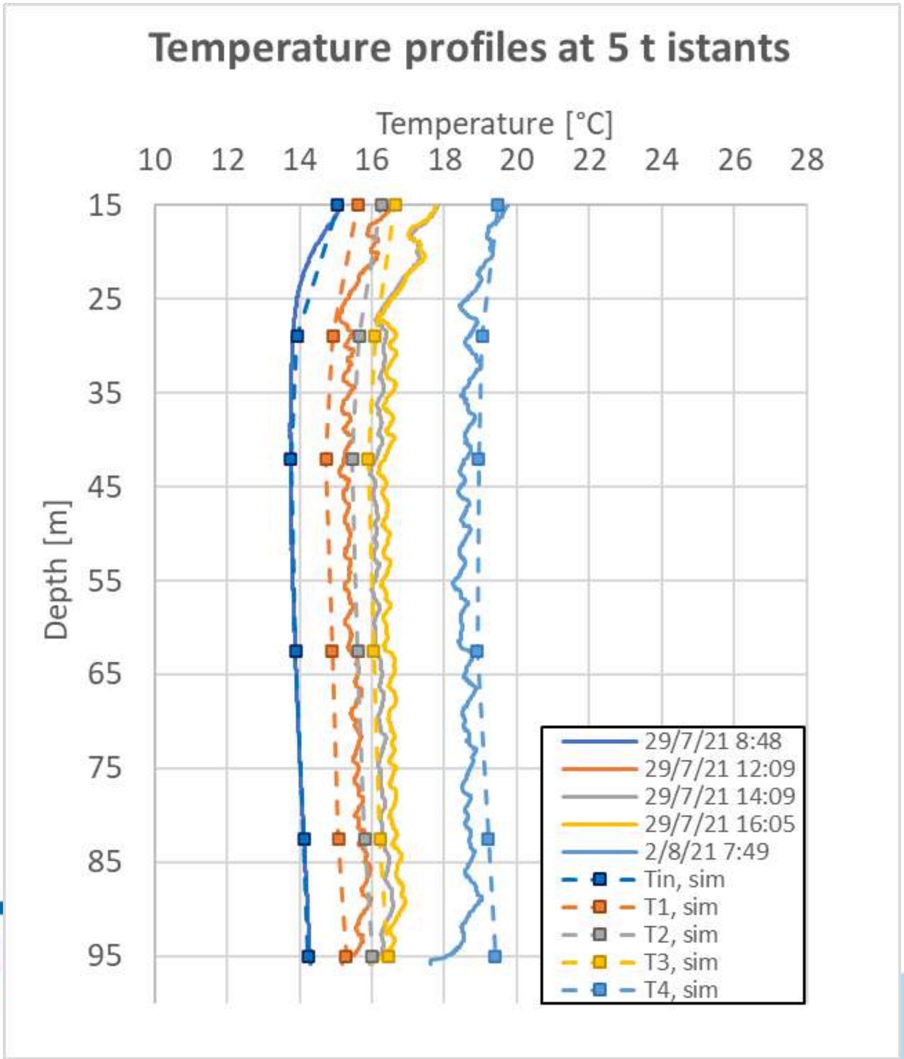
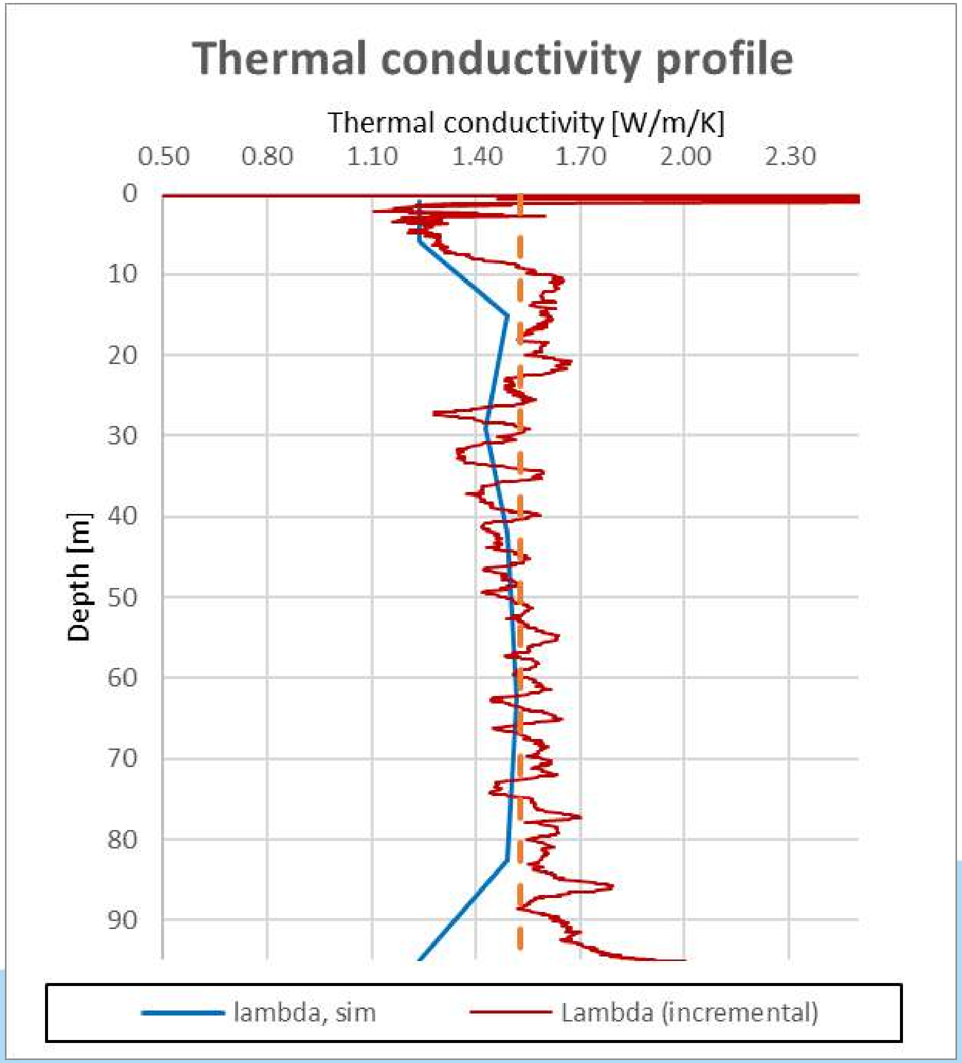
CASE STUDY N.1 – RESULTS





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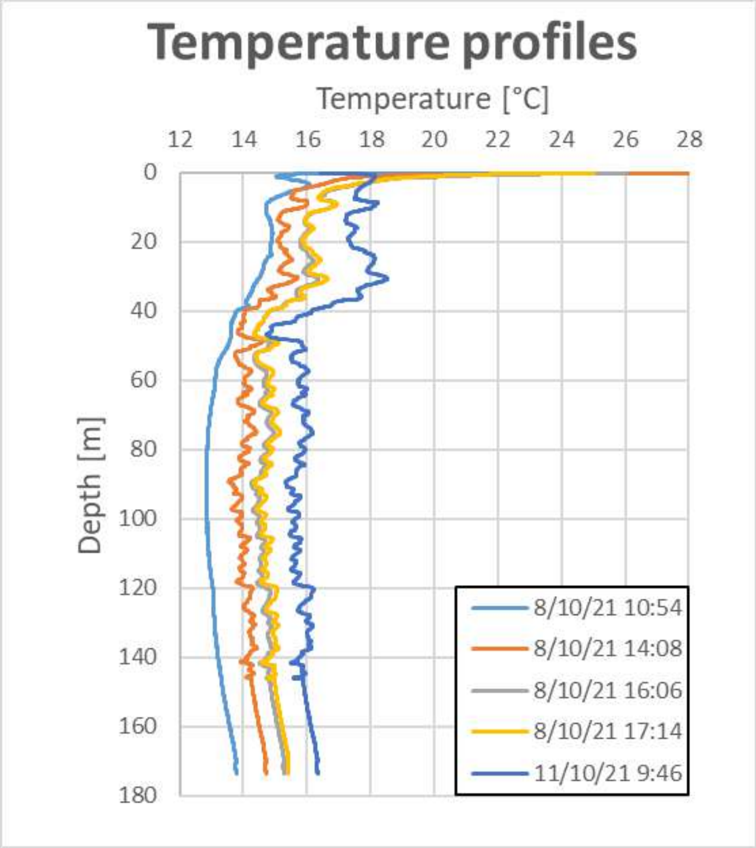
CASE STUDY N.2 – NOT NEGLIGIBLE FLOW

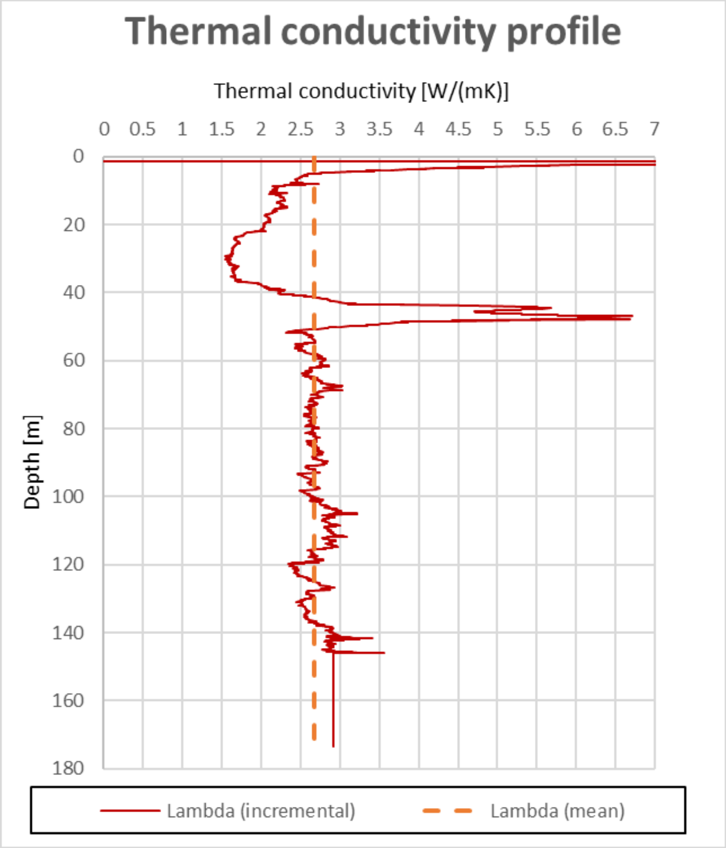
- Input data:

q	15.6	W/m
BHE length	173.6	m
Q	2708.16	W

→ $Q = m_{water} \cdot c_{p,water} \cdot \Delta T$ →

cp	4186	J/kg/°C
m_{water}	0.13	kg/s
ΔT	**4.98**	**°C**





WATER BE THE CHANGE

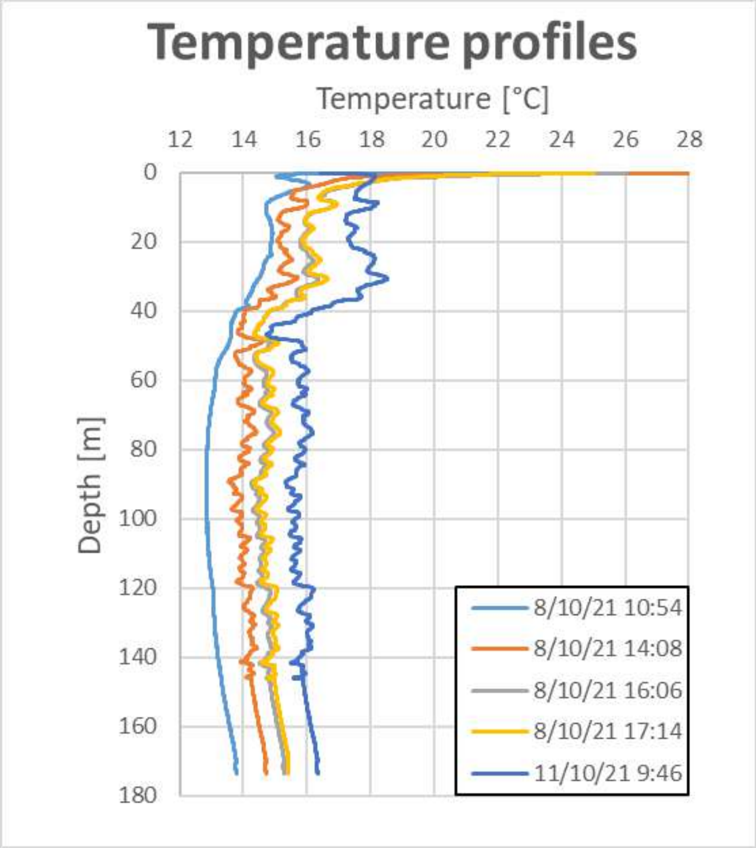
CASE STUDY N.2 – NOT NEGLIGIBLE FLOW

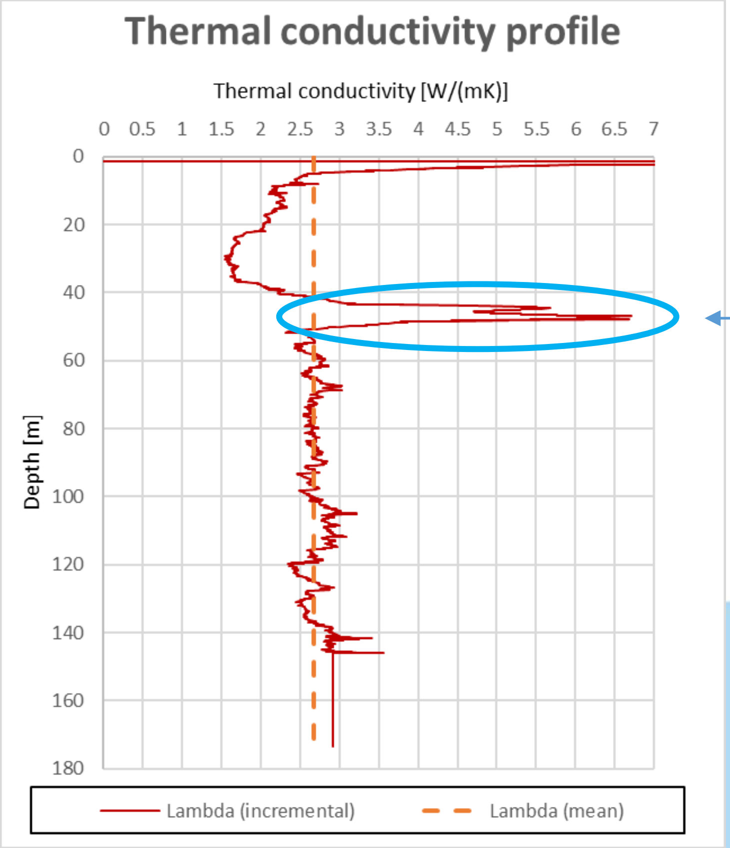
- Input data:

q	15.6	W/m
BHE length	173.6	m
Q	2708.16	W

→ $Q = m_{water} \cdot c_{p,water} \cdot \Delta T$ →

cp	4186	J/kg/°C
m_{water}	0.13	kg/s
ΔT	**4.98**	**°C**





INFINITE LINE SOURCE SOLUTION DOES NOT CONSIDER GROUNDWATER FLOW

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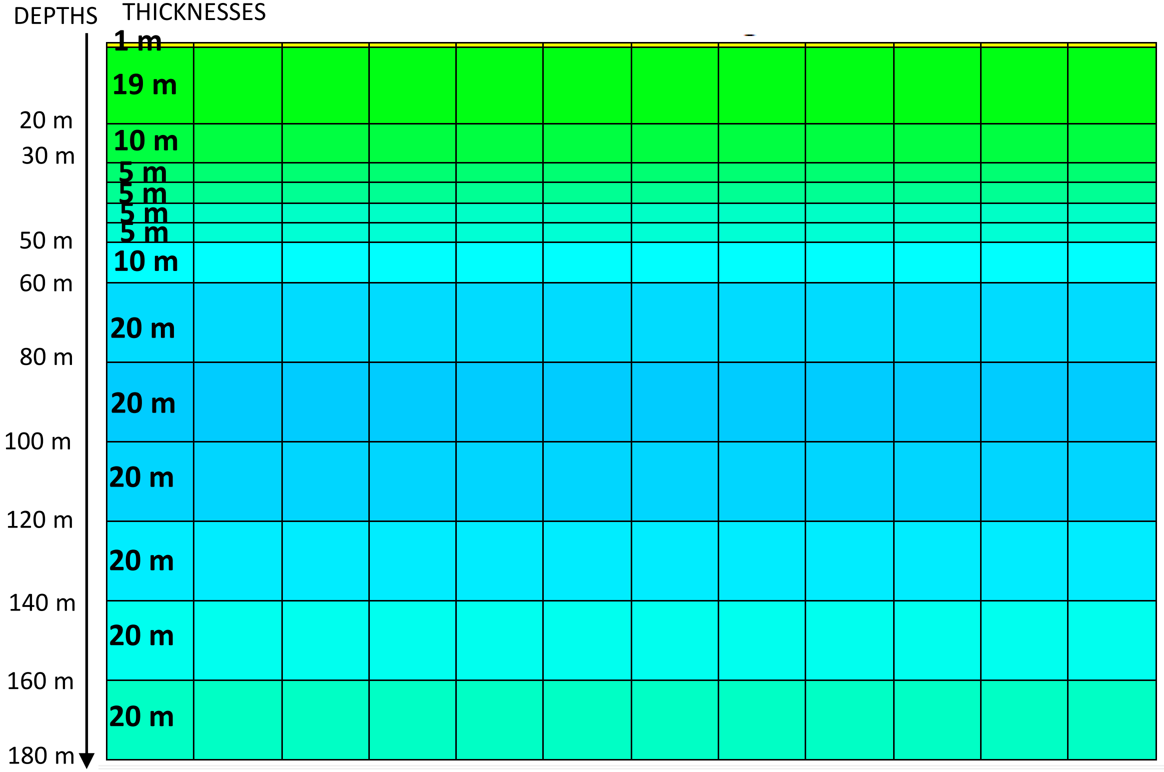
CASE STUDY N.2 – PROPERTIES

VERTICAL DISCRETIZATION:



k [m/s]	Bulk density [kg/m^3]	Heat capacity [J/kg/K]	Thermal conductivity [W/m/K]	Initial T [°C]
1E-06	1900	1105	2	17.13/15.09
1E-06	1900	1105	2.1	14.74
1E-06	1900	1105	2.1	14.36
1E-02	2100	1095	2.4	13.69
1E-02	2100	1095	2.4	13.26
1E-06	2550	823	2.7	12.98
1E-06	2550	823	2.7	12.85
1E-06	2550	823	2.7	12.93
1E-06	2550	823	2.7	13.11
1E-06	2550	823	2.7	13.38
1E-06	2550	823	2.7	13.71

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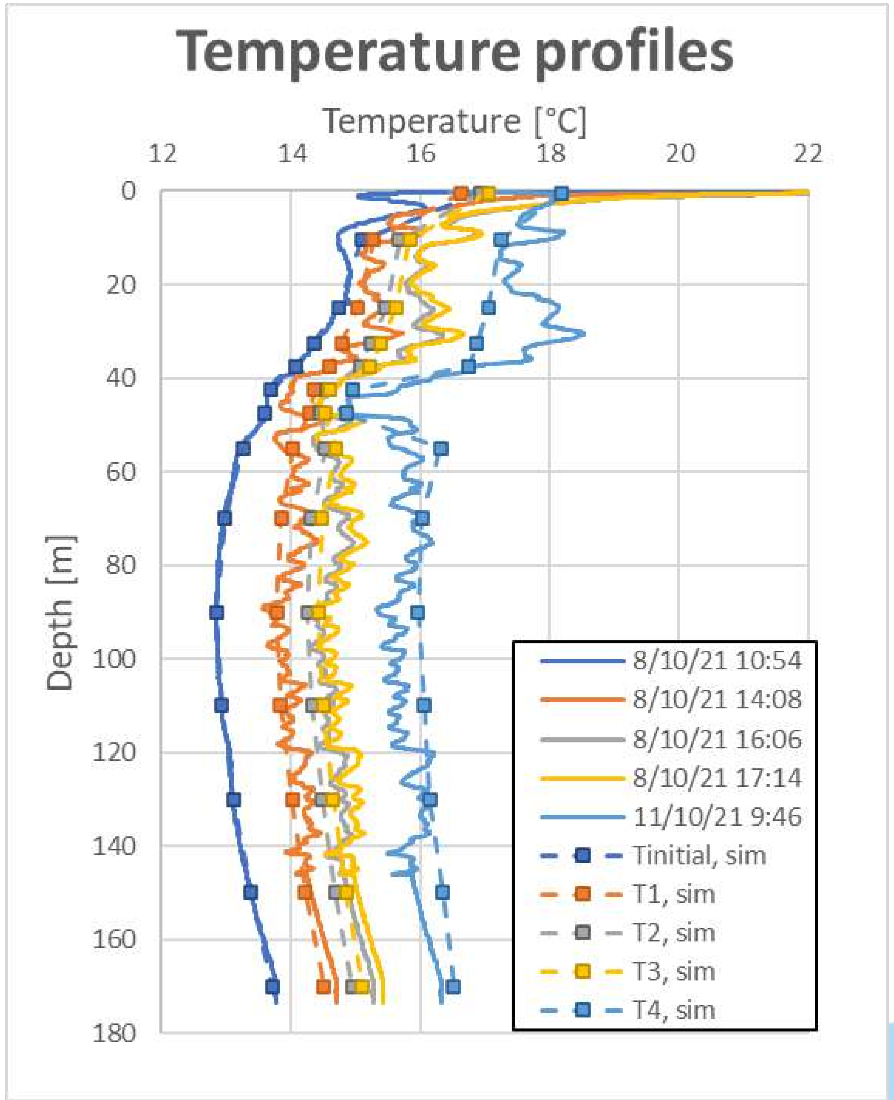
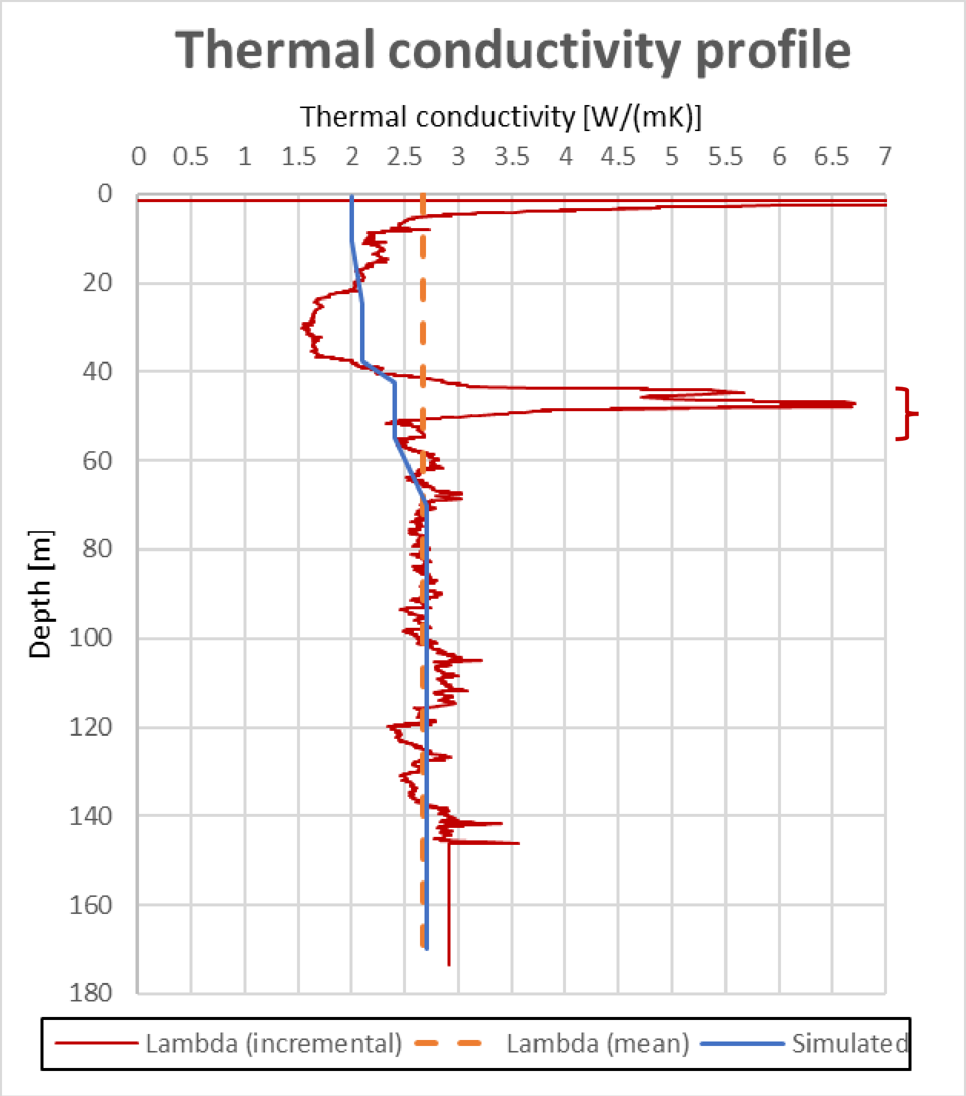
CASE STUDY N.2 – RESULTS





Estimated flow velocity 5E-05 m/s

CONCLUSIONS

- Relevance of vertical distributed thermal and hydrogeological properties
- Importance of training for technicians/engineers to consider the presence of any underground structures in the surrounding area
- Strongly recommended numerical modeling for groundwater flow velocity estimation
- To avoid the waste of the geothermal resource, a strong regulation that aims to avoid interference between installations and implementation of a public database of existing plants are needed

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IMPACT OF DROUGHT ON THE PIEDMONT PLAIN (NW, ITALY) WATER RESOURCES: CURRENT STATUS AND PREDICTIONS IN THE CONTEXT OF CLIMATE CHANGE

Susanna Mancini, Manuela Lasagna, Domenico Antonio De Luca

Università di Torino, Dipartimento di Scienze della Terra

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AIMS OF THE STUDY

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.

A spatiotemporal analysis of the impacts of the drought of recent years (2021-2022) on water resources in the Piedmont plain is presented.

METEOROLOGICAL DATA

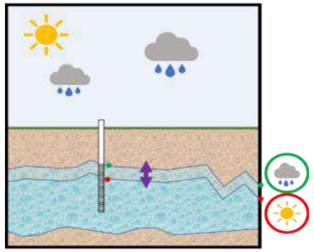
- RAINFALL (R)
- AIR TEMPERATURES (AT)

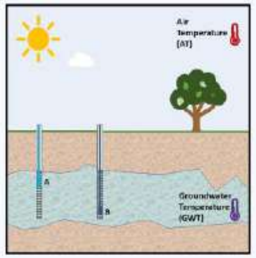
RIVERS DATA

- DISCHARGE (Q)
- WATER TEMPERATURES (WT)

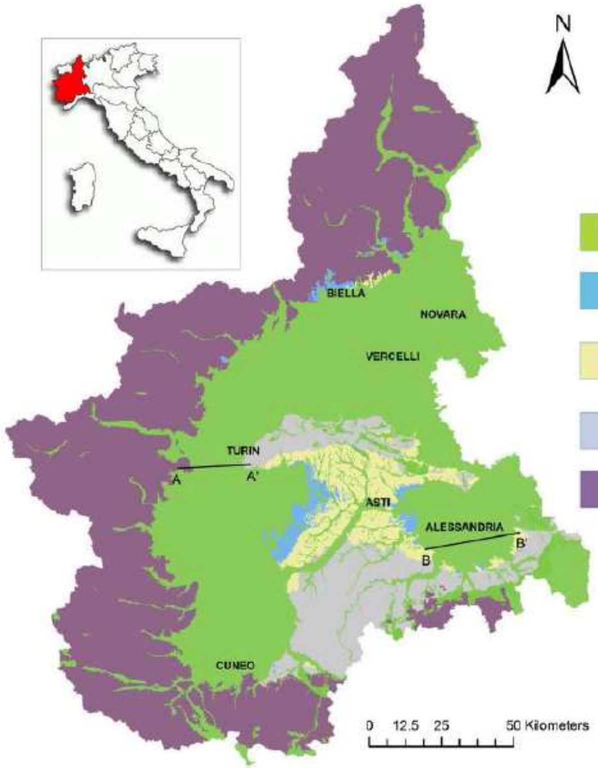
GROUNDWATER DATA

- GROUNDWATER LEVELS (GWL)
- GROUNDWATER TEMPERATURES (GWT)





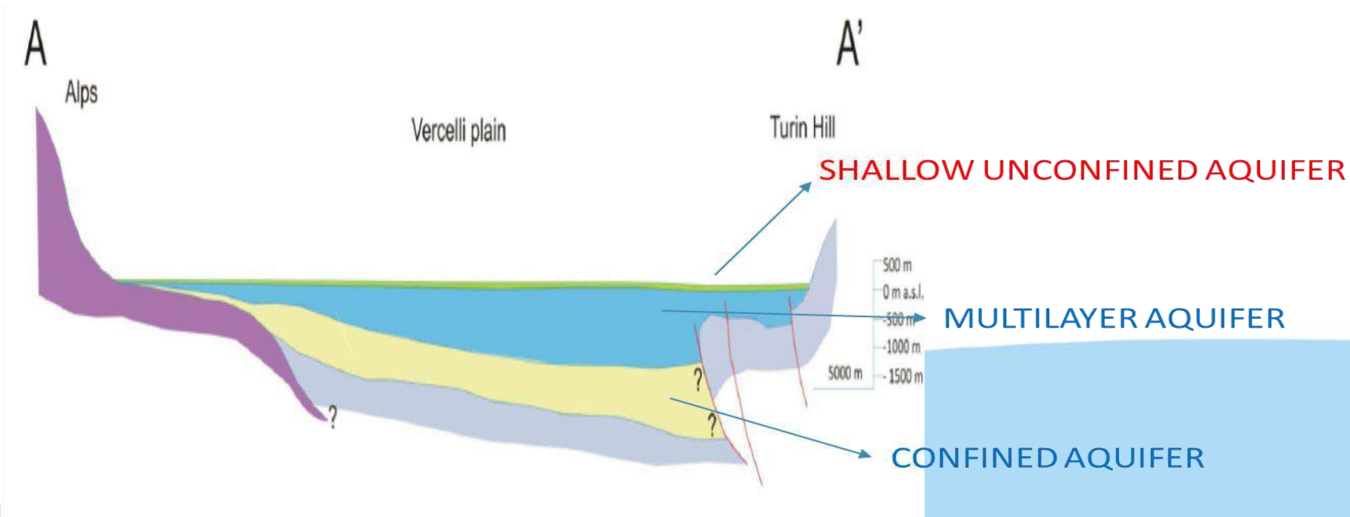
HYDROGEOLOGICAL SETTING OF PIEDMONT PLAIN



Lasagna et al. (2018). Environ Earth Sci 77:277

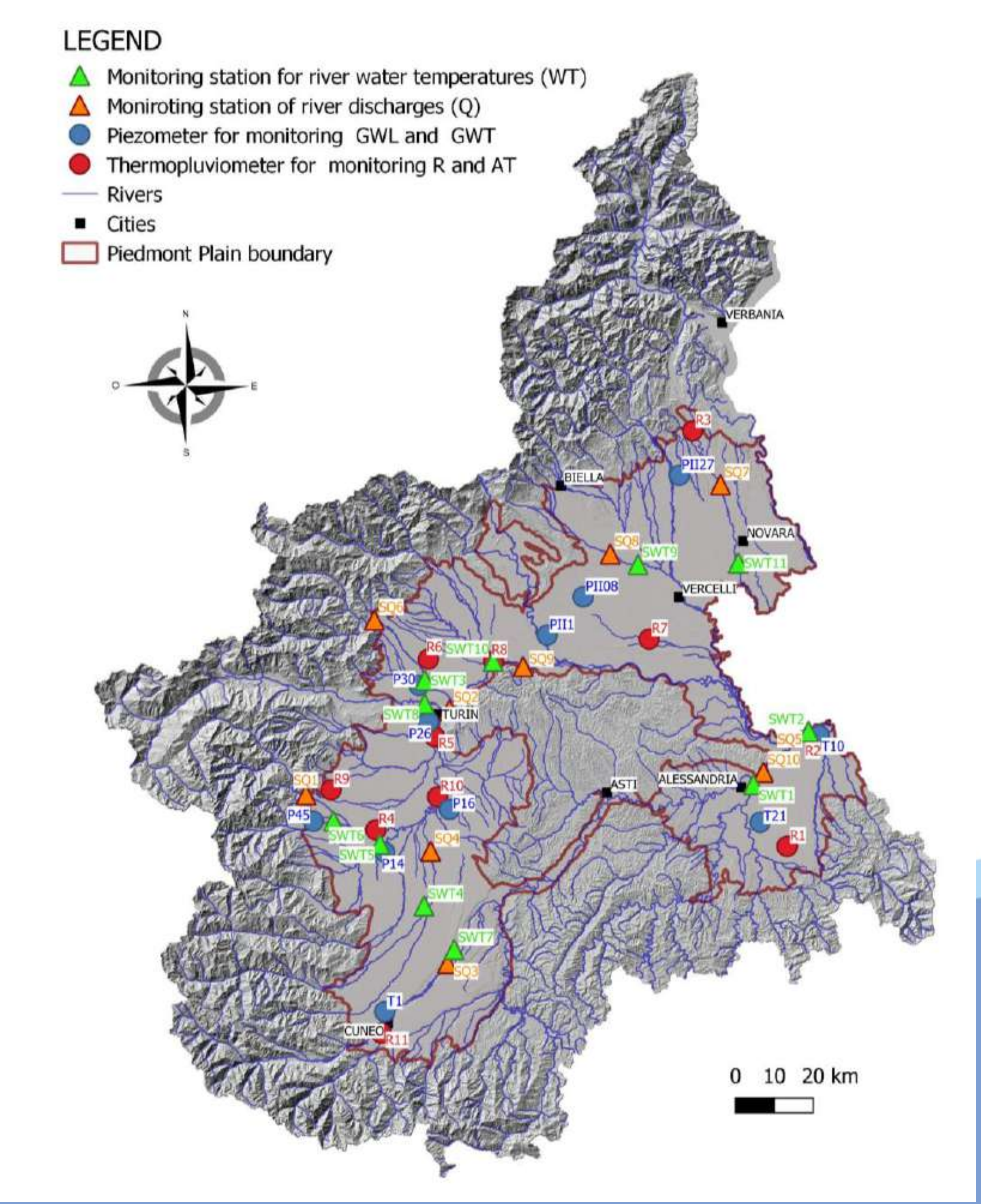
From top to bottom

- ALLUVIAL DEPOSITS COMPLEX → SHALLOW UNCONFINED AQUIFER
- VILLAFRANCHIAN COMPLEX → MULTILAYER AQUIFER
- PLIOCENE MARINE COMPLEX → CONFINED AQUIFER
- OLIGO-MIOCENE MARINE SUCCESSION
- ALPINE BASAMENT UNIT



The **Piedmont Plain** is the western most part of the Po Plain, cover the **27%** of the regional territory and is the largest and most important GW reservoir in the region.

DATASET



MONITORING WELLS:

10 GWL time-series

10 GWT time-series

WEATHER STATIONS:

10 R time-series

10 AT time-series

RIVER STATIONS:

10 Q time-series

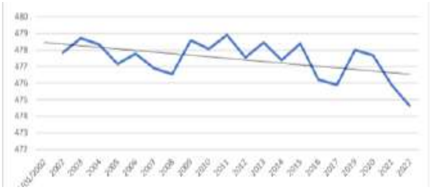
10 WT time series

METHODS: ANALYSIS PERFORMED

Various statistical analyses were carried out on monitoring data of the automatic regional networks.
Period of analysis 2002-2022, annual and monthly average data

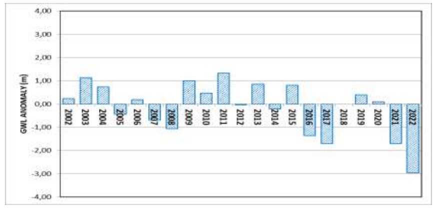
TREND ANALYSIS

Evolution in time
Mann Kendall test
P-value = 0.05



ANOMALIES

Deviation of annual (monthly) data from the value of the reference period (average 2002-2020)

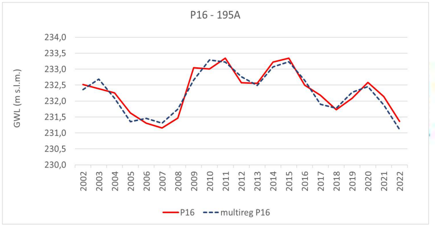


BOX PLOTS

25th-75th percentiles (band of Natural Fluctuation)
Values below the 25th percentile of the GWL may indicate a criticality.
Analysis of 2021 and 2022

COMPARISON

Correlations and multiregression analysis between R and GWL



RESULTS : RAINFALL

No statistical trend in all R time series

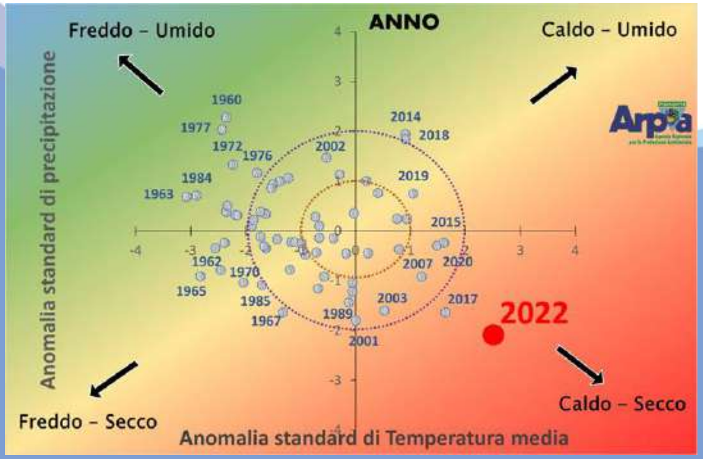
However, R in 2021 (in green) and in 2022 (in red) showed a high decrease compared to the average rainfall (in grey) of the analysed period.

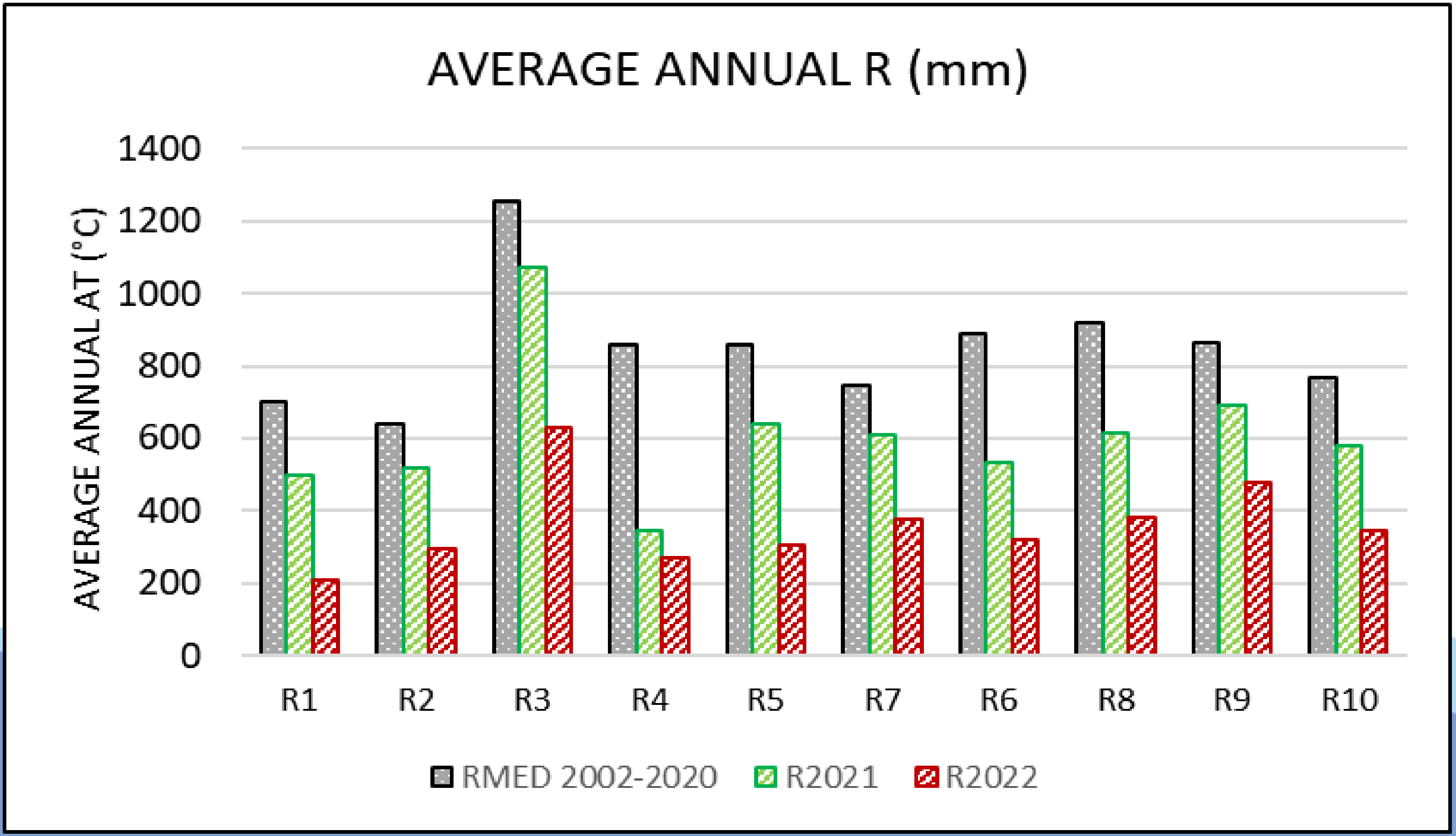
Annual R deficits ranged:

from -19% to -60% (in 2021)

from -45% to -71% (in 2022)

The 2021 was a dry year.
The year 2022 was one of the driest observed in the past 65 years.





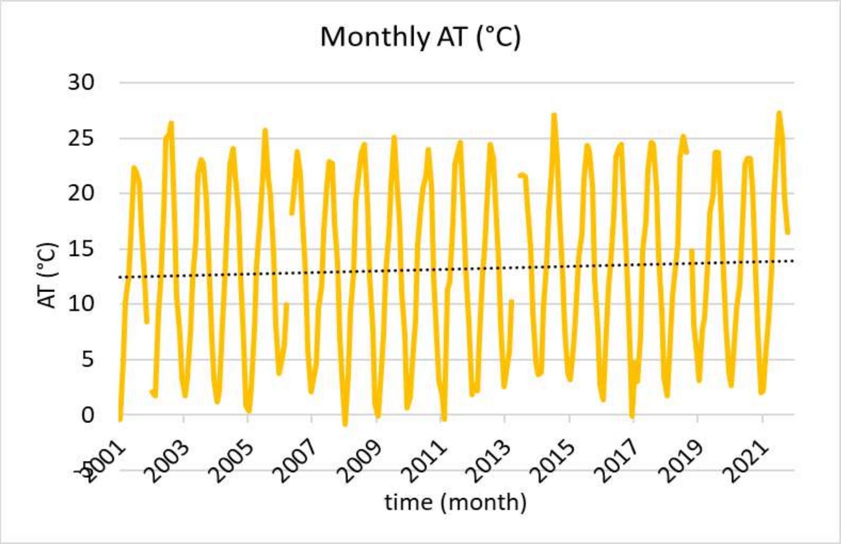
RESULTS : AIR TEMPERATURES

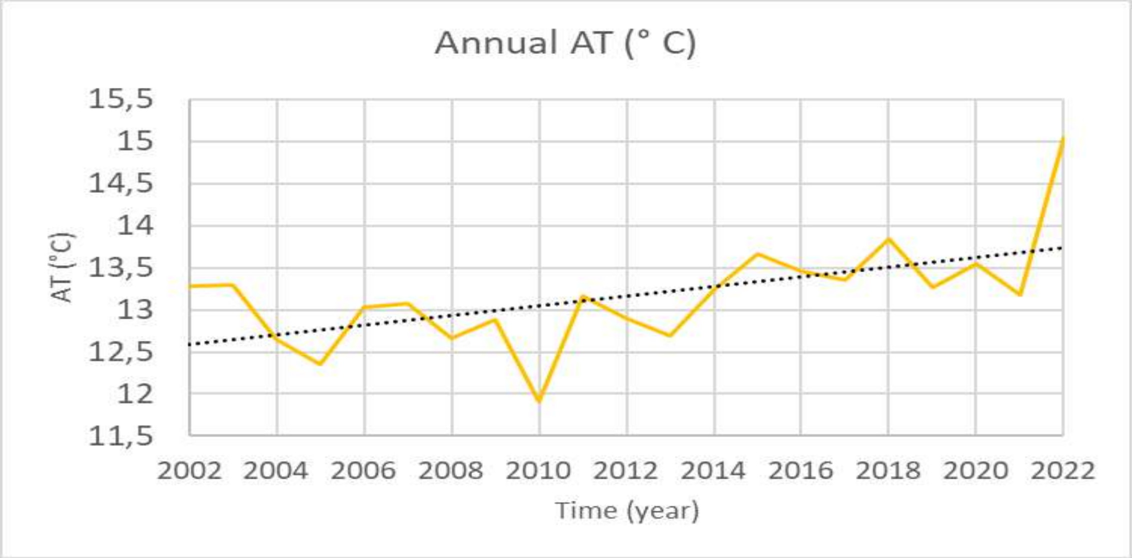
AT showed an increasing trends.

AIR TEMPERATURES

Increasing trend in all AT time series

(AT= 0.4 to 1.5 °C in 10 years)





These climatic conditions have created the preconditions for a severe drought in Europe and in Italy. The worst in 500 years.

WATER BE THE CHANGE

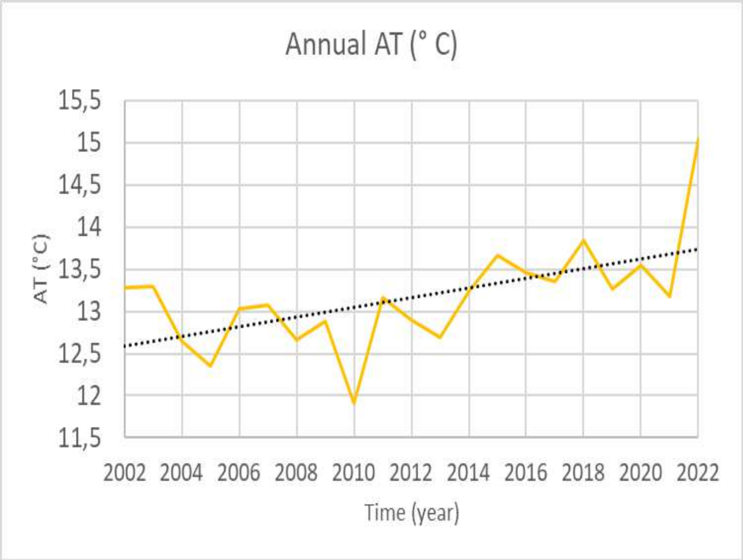
What are the consequences on the water resources?

WATER TEMPERATURES

GWT and WT showed an increasing trends.

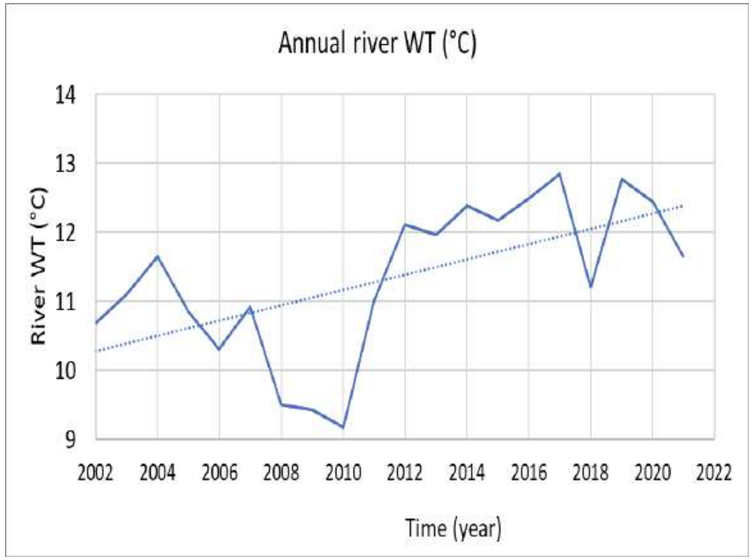
AIR TEMPERATURES

Increasing trend in all AT time series (AT= 0,4 to 1,5 °C in 10 years)



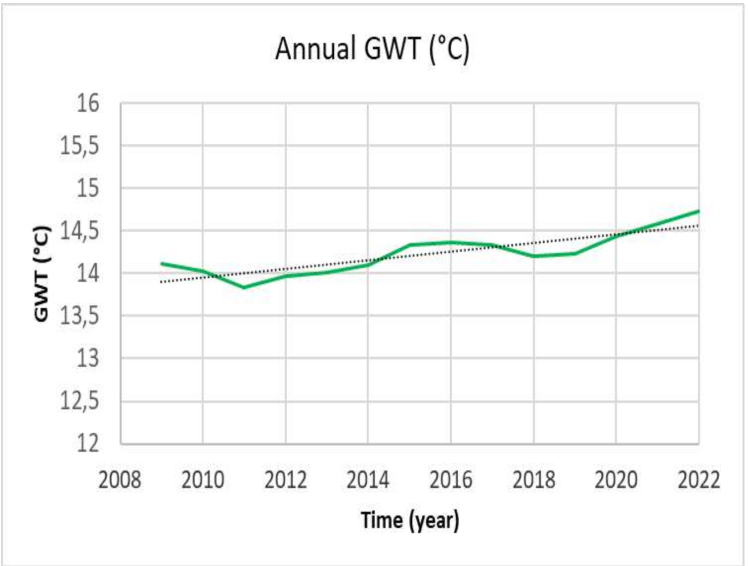
RIVER WATER TEMPERATURES

Increasing trend in all WT time series (AT= 0,6 to 1,4 °C in 10 years)



GW TEMPERATURES

Increasing trend in 90% of GWL time series (T= 0,2 -0,7 °C in 10 years)



WATER BE THE CHANGE

Groundwater is more resilient than air and surface water to climate change

RIVER DISCHARGES

No statistical Q trends

However, due to the deficit of Rainfall, the Qs in 2021 and in 2022 were criticals.

In 2022 rivers discharges deficit ranged from -55% up to -100%

Dora Riparia Feb. 2022

Fiume Po Jan. 2022

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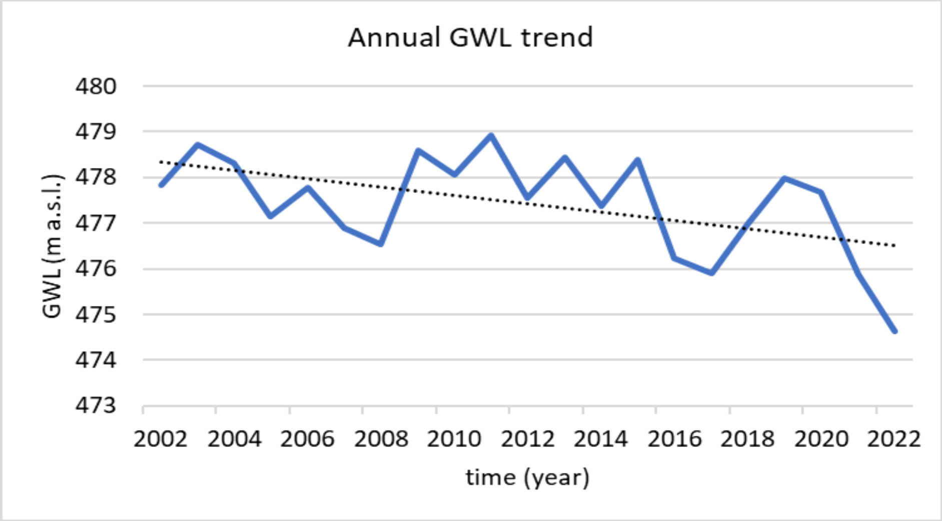
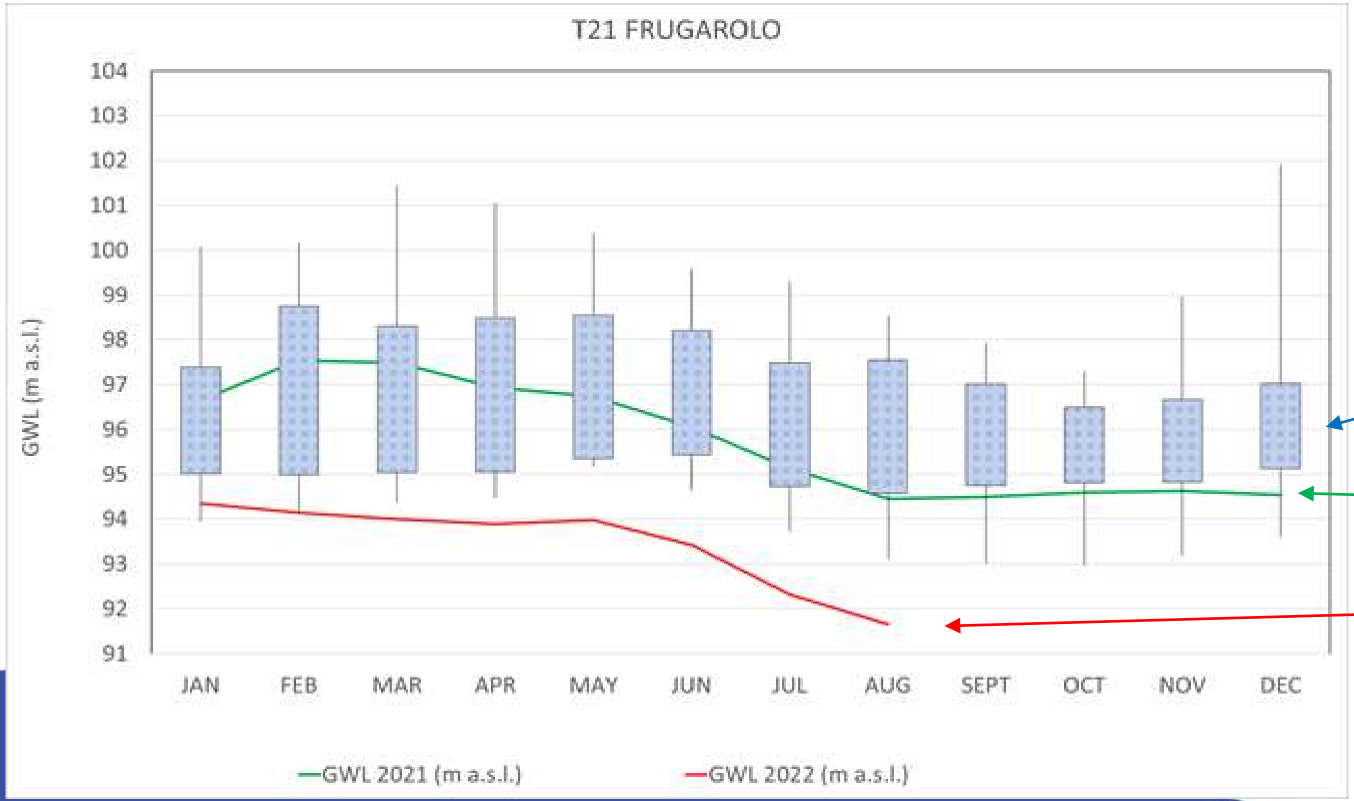
GROUNDWATER LEVELS

Decreasing trend in 80% of GWL time series (GWL= from -0,2 to -1,3 m in 10 years)

GWL of 2022 was the lowest of the whole study period





monthly average GWL fluctuation in the 2002-2020 period

monthly GWL of 2021

monthly GWL of 2022

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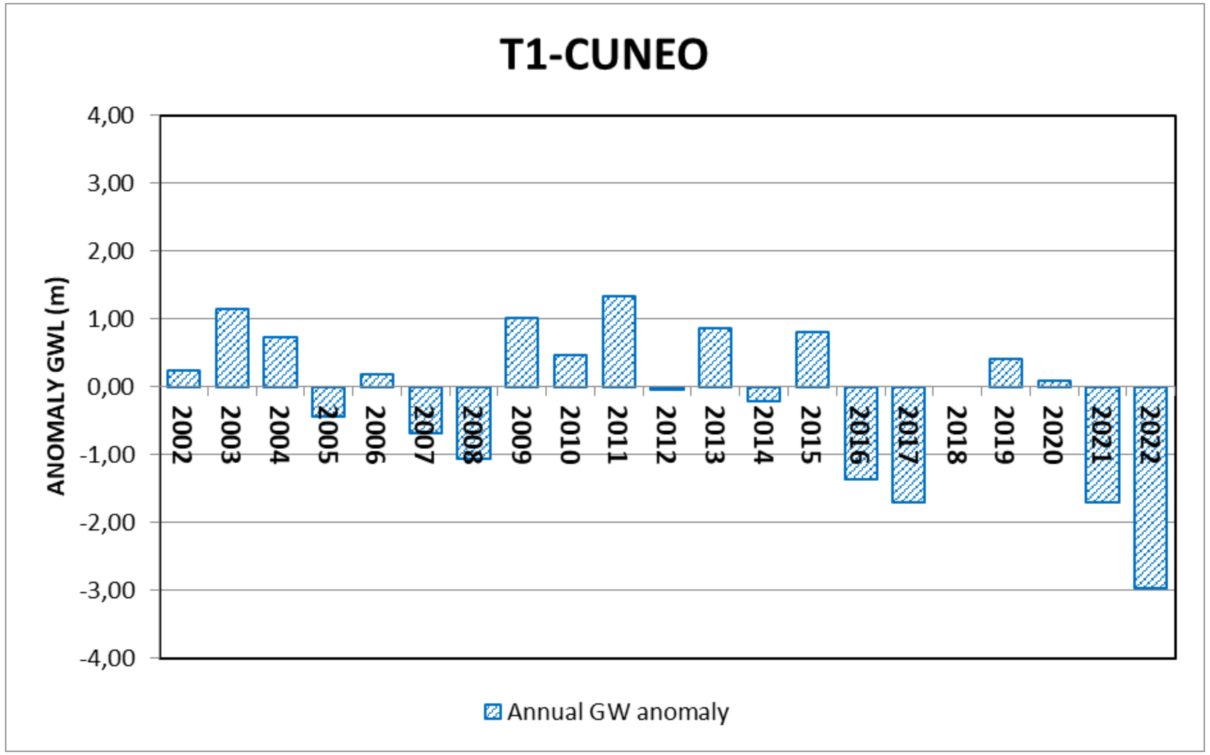
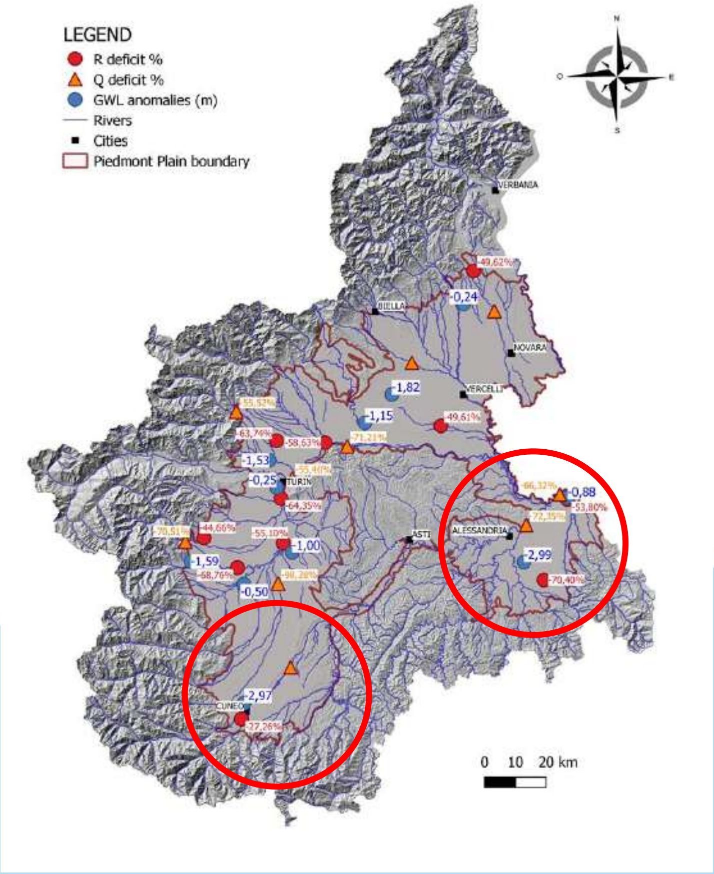
GROUNDWATER LEVELS

In 2022 a negative annual anomaly was observed in almost all the monitoring wells



Anomaly analysis highlighted the highest deviation of GWL from the reference value up to -3 m for yearly data, and more than -6 m for monthly data.



The analyses allow us to detect the most critical areas for GW in Piedmont Plain (Cuneo and Alessandria plains) in 2022

Critical areas

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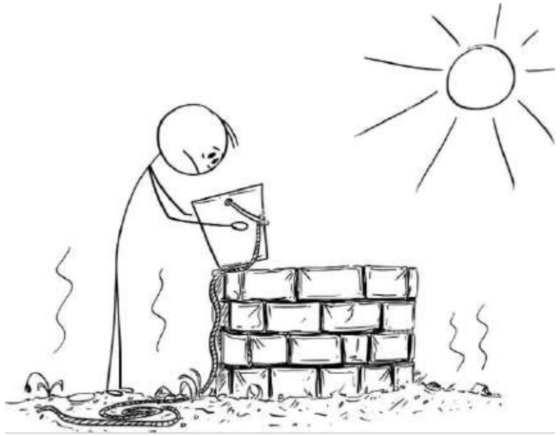
CONSEQUENCES



Some shallow wells became dry

Po spring – summer 2022

Depletion of springs discharge in alpine areas

Alterations in the discharge of fontanili (plain springs, typical of Po Plain, an oasis of biodiversity and an important resource for the area).

Fontanile Ulè (Vigone - Turin Plain)

July 2017

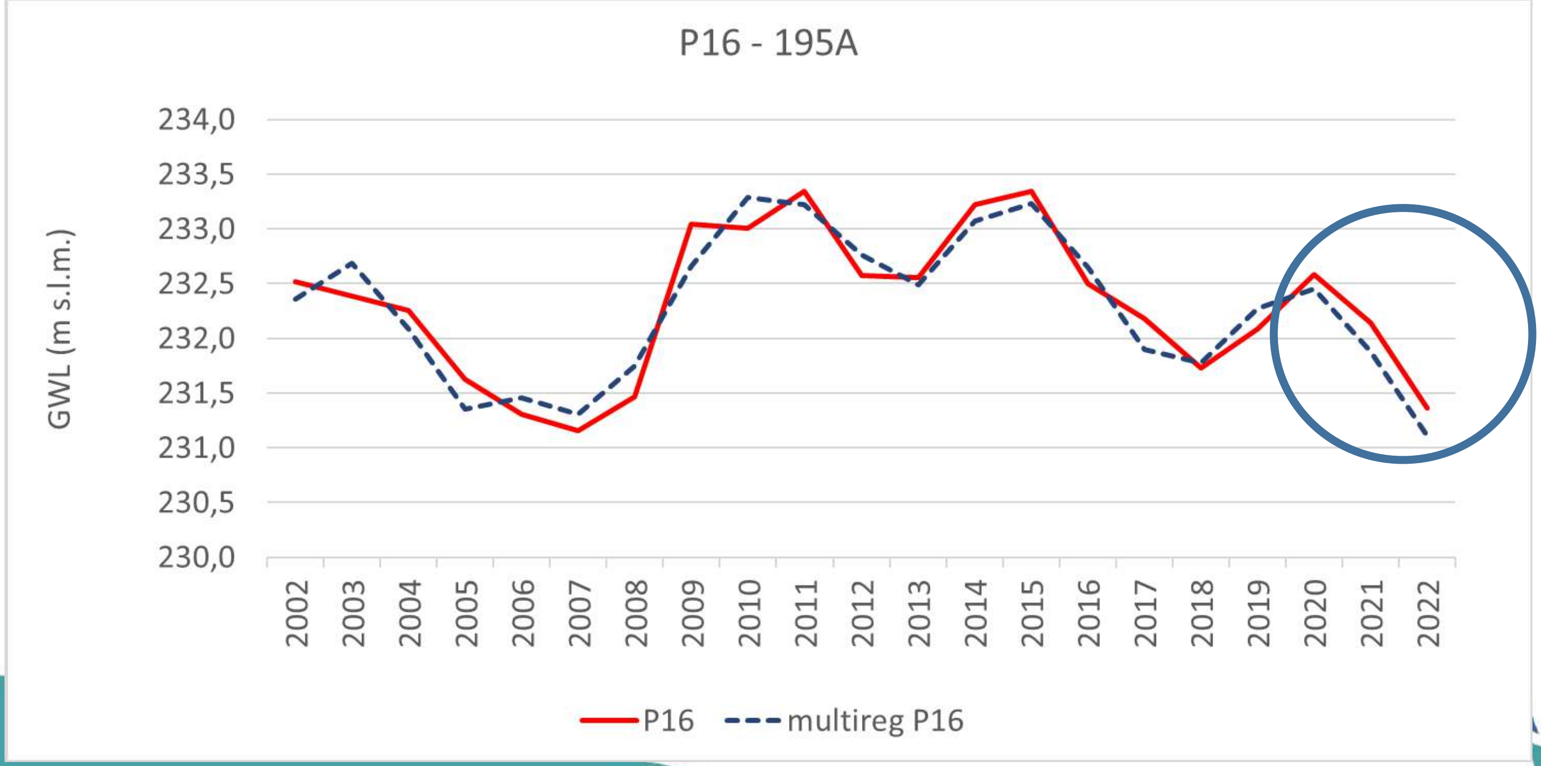
May 2022

MULTIPLE REGRESSION MODEL BETWEEN R and GWL

After the analyses of the correlation between R and GWL, we observed a good correlation at 0, 1 or 2 years. Consequently we tried to analyse the consequences of the current situation of draught for the next years.

measured

modeled



Intercept	228,2972
a	0,001494
a-1	0,002512
a-2	0,001335

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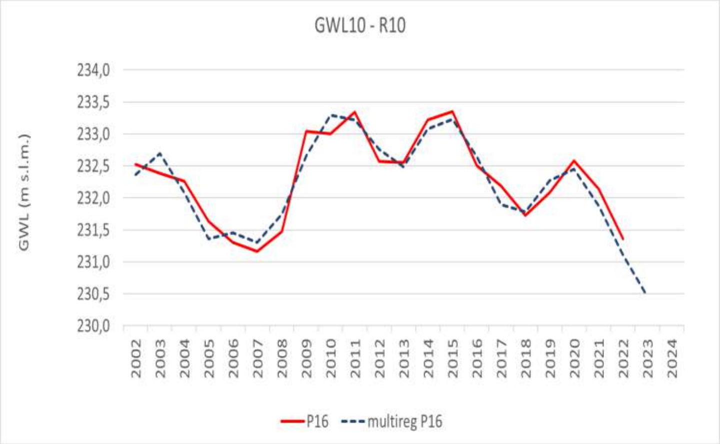
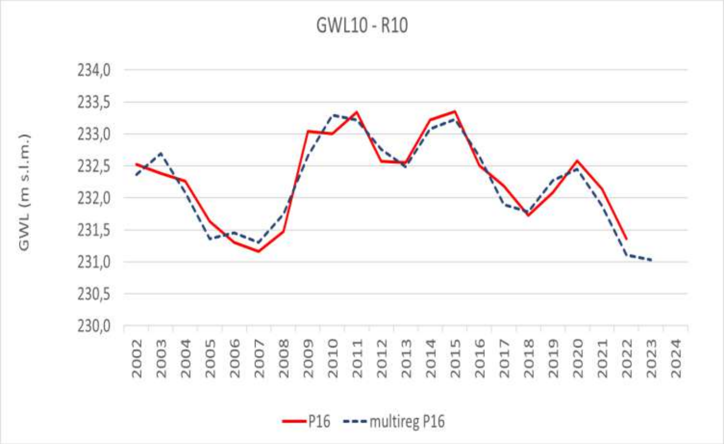
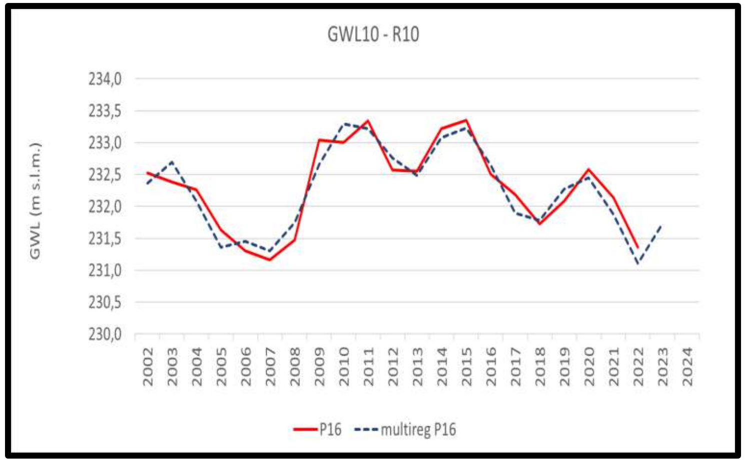
MULTIPLE REGRESSION MODEL BETWEEN R and GWL

Attempting a forecast for 2023 is possible by assuming three different precipitation scenarios

SCENARIO 1 LOW RAINFALLS	SCENARIO 2 AVERAGE RAINFALLS	SCENARIO 3 HIGH RAINFALLS
345 mm	740 mm	1200 mm







If the precipitation for 2023 will be like 2022, GWL will decrease about 1 m;
If the precipitation for 2023 will return about the average precipitation, GWL will remain quite constant to 2022 value.
If the precipitation for 2023 will increase up to 1200 mm/year, GWL will finally increase about 0.5 m.

CONCLUSIONS

GW temperatures and levels have been highly impacted by the 21-22 drought.
However GW showed to be more resilient than air and surface water.
The impacts on surface water are clearly visible.
GW impacts are not directly observable, only the analyses of continuous monitoring data allow us to detect variation on quantity and quality of GW.

CHALLENGES

To work with stakeholders and Agencies to implement GW monitoring network not only for shallow aquifers but also for confined and semiconfined aquifers (the most important for drinking water purposes in Piedmont).

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Associazione ACQUE SOTTERRANEE

SOCIETÀ GEOLOGICA ITALIANA 1881 MENTE ET MALLEO

IGAG Istituto di Geologia Ambientale e Geoingegneria

unesco Intergovernmental Hydrological Programme

AIGA ASSOCIAZIONE ITALIANA GEOLOGIA APPLICATA E AMBIENTALE

ENGEOL IAEG AIGI

IRSA CNR

ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale

Sistema Nazionale per la Protezione dell'Ambiente

EUROPEAN UNION
European Regional Development Fund

VisitMalta

water services corporation

iah aih Italian Chapter

THE ENERGY & WATER AGENCY

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flowpath

Malta 2023

14th – 16th June
National Meeting on Hydrogeology

JUNE 14-16, 2023

WATER.ORG.MT

Estimation of transit time along the unsaturated zone in the protection of groundwater resources

UNICA-DSCG

Lobina F.[1], Stumpp C.[2], Coppola A.[1], Vacca A.[1], Arras C.[1], Biddau R.[1], Piscedda A.F.[1], Porru M.C[1], Vacca S.[1], Da Pelo S.[1]

[1]Department of Chemical and Geological Sciences, University of Cagliari
[2]University of Natural Resources and Life Sciences, Institute of Soil Physics and Rural Water Management, Vienna 1190, Austria

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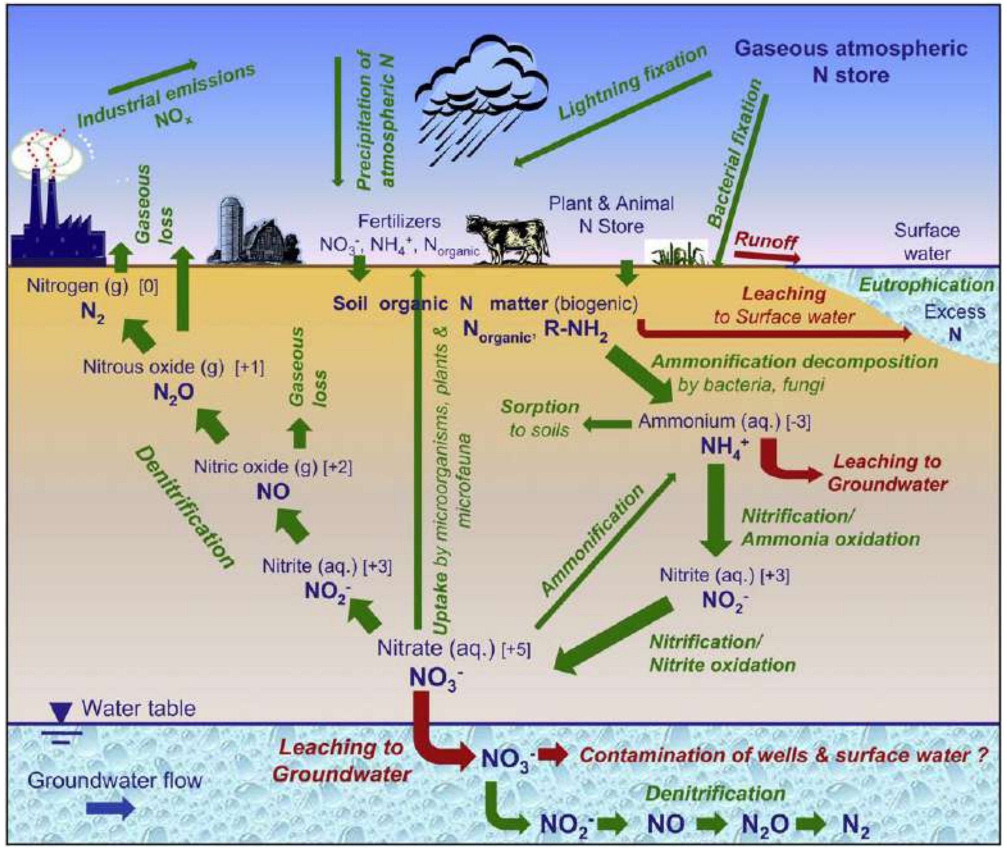
REGIONE AUTÒNOMA DE SARDIGNA
REGIONE AUTONOMA DELLA SARDEGNA
AUTORITÀ DI BACINO

FSC Fondo per lo Sviluppo e la Coesione

BOKU SoPhy Institut für Bodenphysik und landeskulturelle Wasserwirtschaft

PON RICERCA E INNOVAZIONE 2014 - 2020

Nitrogen Pollution



(Rivett et al., 2008)

- Development of agricultural activities
- Overuse of fertilizers
- Nitrate contamination of groundwater

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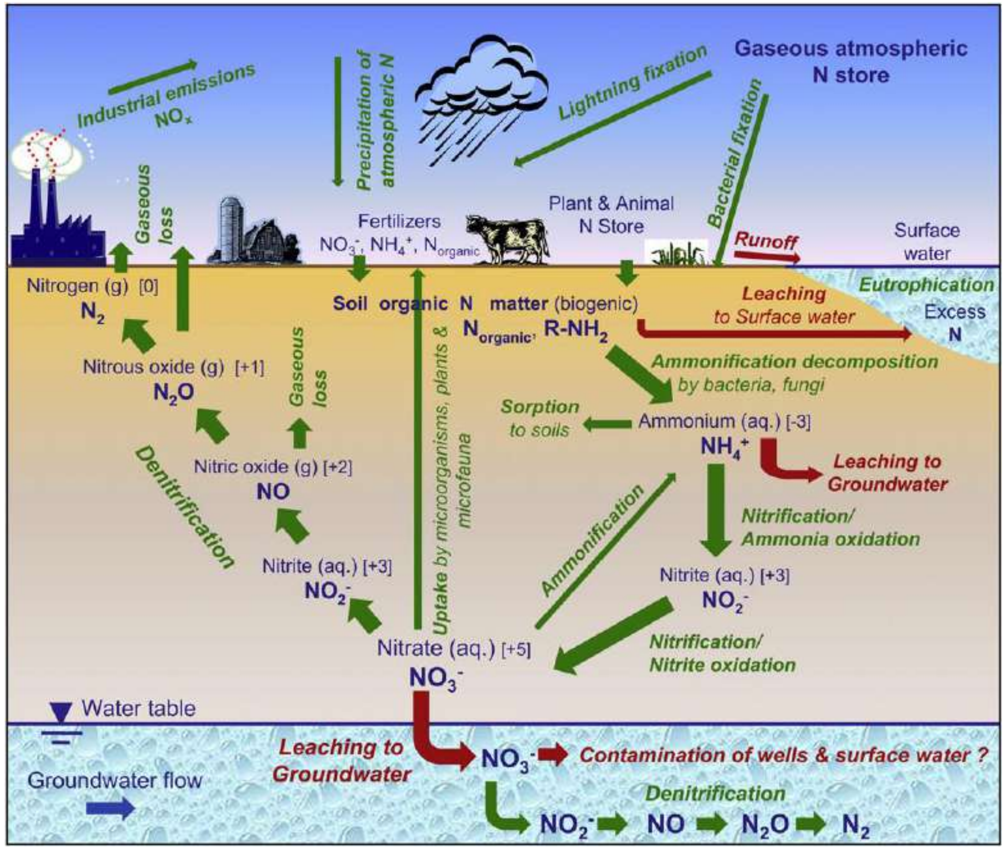
Nitrogen Pollution



(Rivett et al., 2008)

Development of agricultural activities

Overuse of fertilizers

Nitrate contamination of groundwater

91/676/CEE

2000/60/CE

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Research Gap

Has there
been any
improvement?

No!

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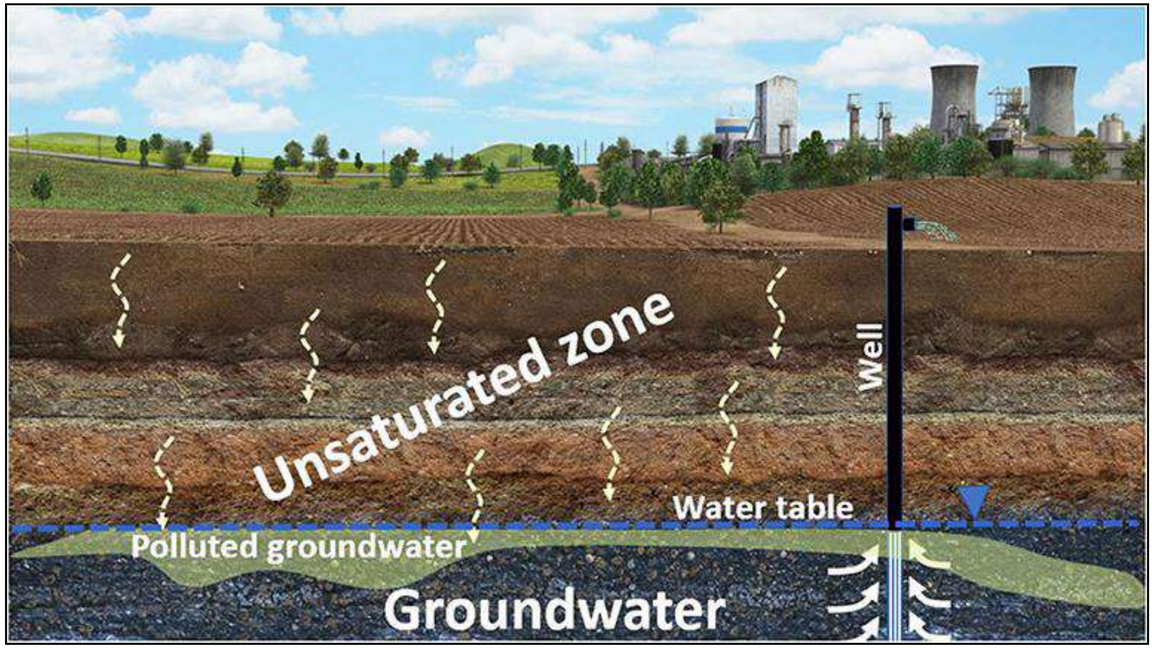
Research Gap

Has there been any improvement?

No!



Dahan (2020)

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The unsaturated zone is the main factor controlling water movement and pollutant leaching, but it is often neglected

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

Purpose of the research

Estimate the timing and the rate of groundwater recharge using stable water isotope profiles in the vadose zone at the two sites by comparing the physical properties of the soils.

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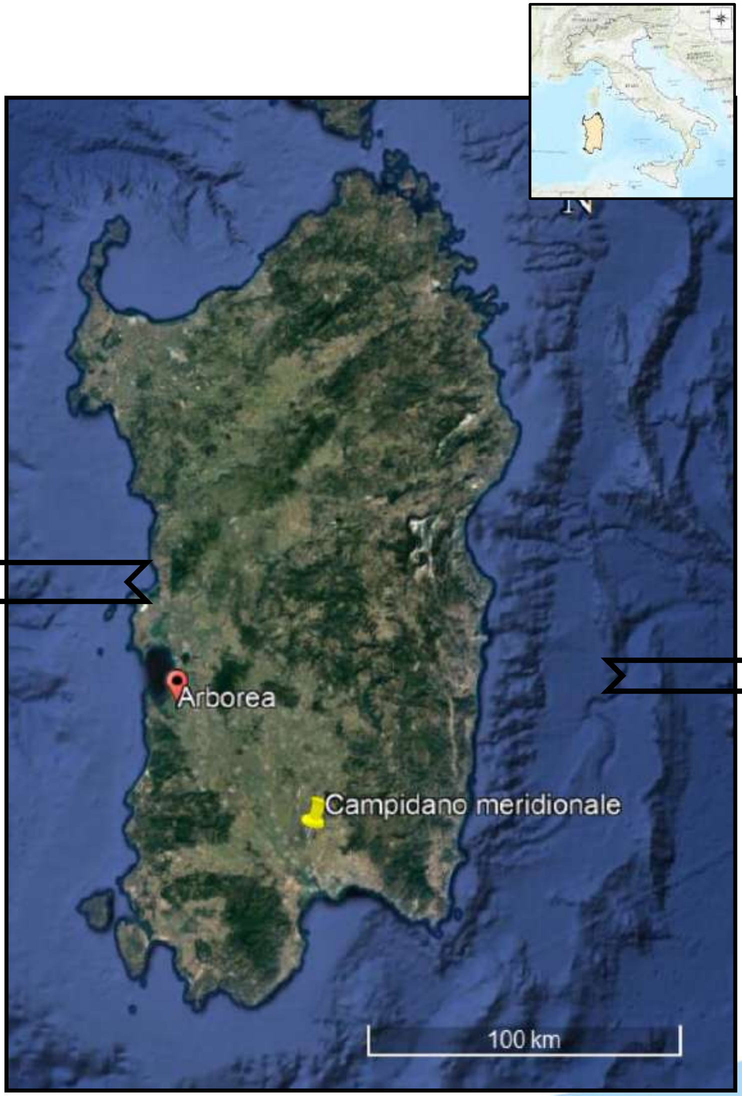
Study Areas

Arborea



Campidano

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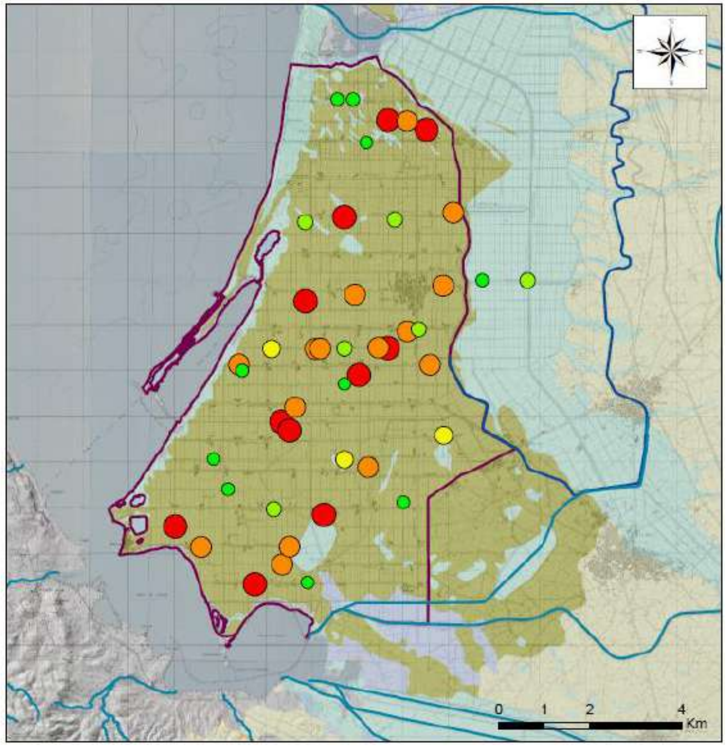
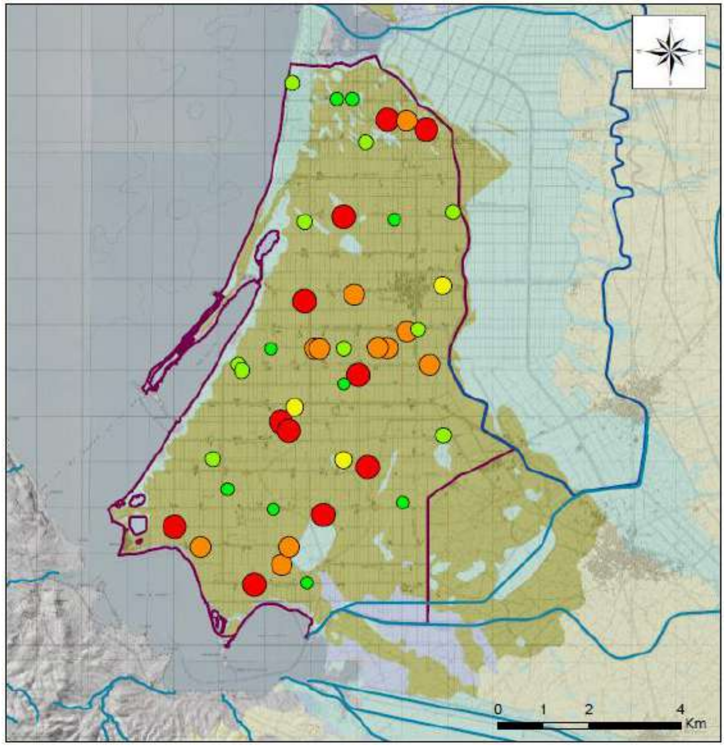
Arborea Site

Maps of nitrate concentrations in groundwater

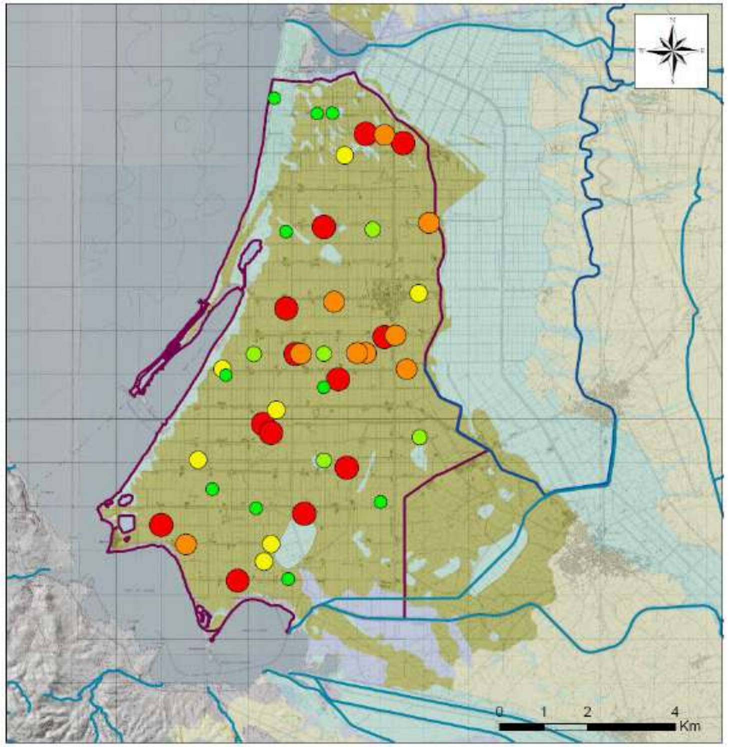
Average data from 2007 to 2011



Average data from 2011 to 2015



Average data from 2016 to 2021



Legend

Nitrate (mg/l)

- < 10
- 10 - 37.5
- 37.5 - 50
- 50 - 100
- > 100

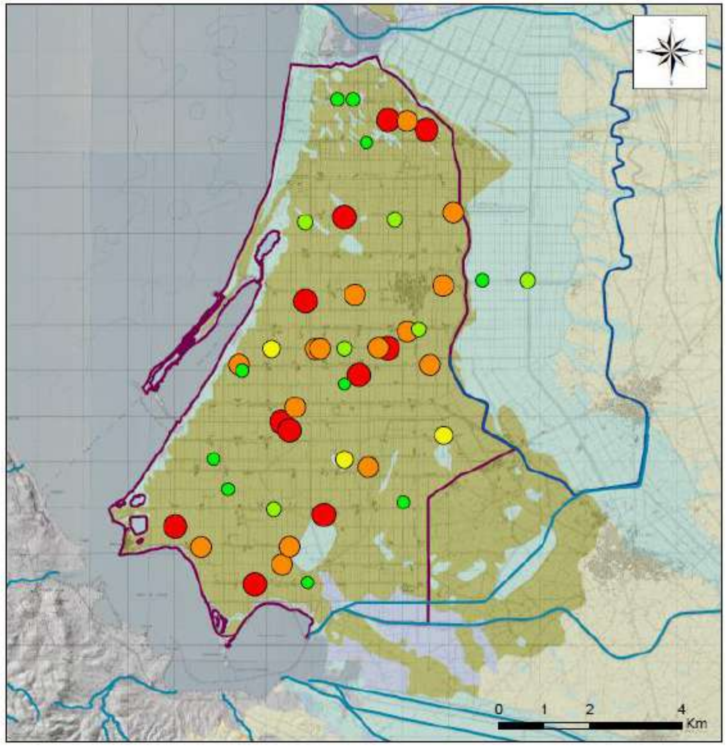
Geology

- Alluvial (silty-clay) and marsh deposits (Holocene)
- Alluvial (gravel and clayey sands) deposits (Holocene)
- Ancient marine sand deposits (Upper Pleistocene - Holocene)
- Surface water
- Artificial Canals
- ZVN Arborea

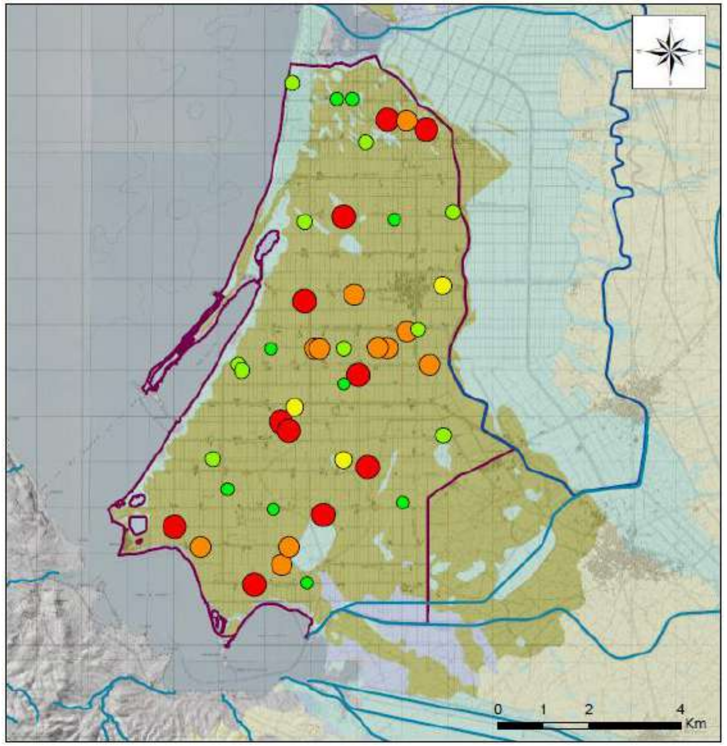
Arborea Site

Distribution maps of nitrate concentrations in groundwater

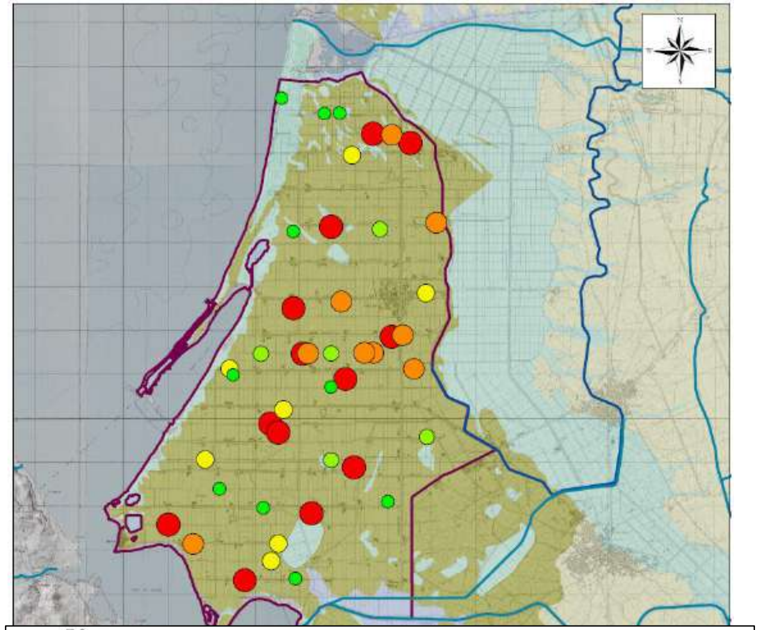
Average data from 2007 to 2011



Average data from 2011 to 2015



Average data from 2016 to 2021



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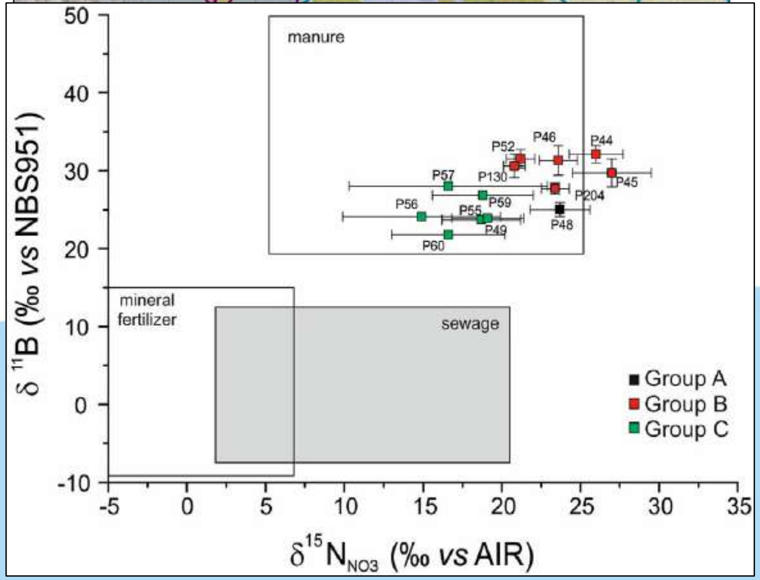
- Ancient marine sand deposits (Upper Pleistocene - Holocene)
- Surface water
- Artificial Canals
- ZVN Arborea

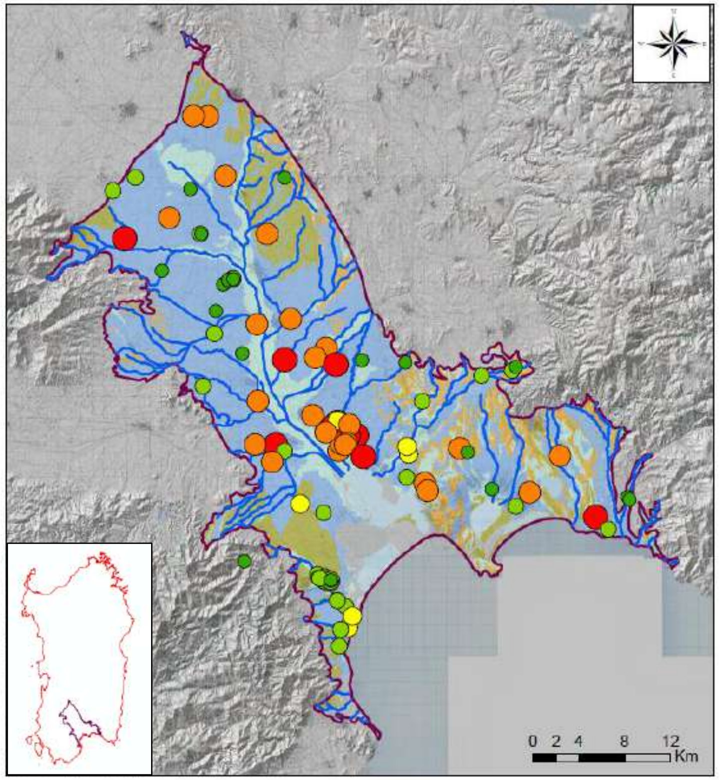
The predominant source of nitrate is manure application *(Biddau et al., 2019)*



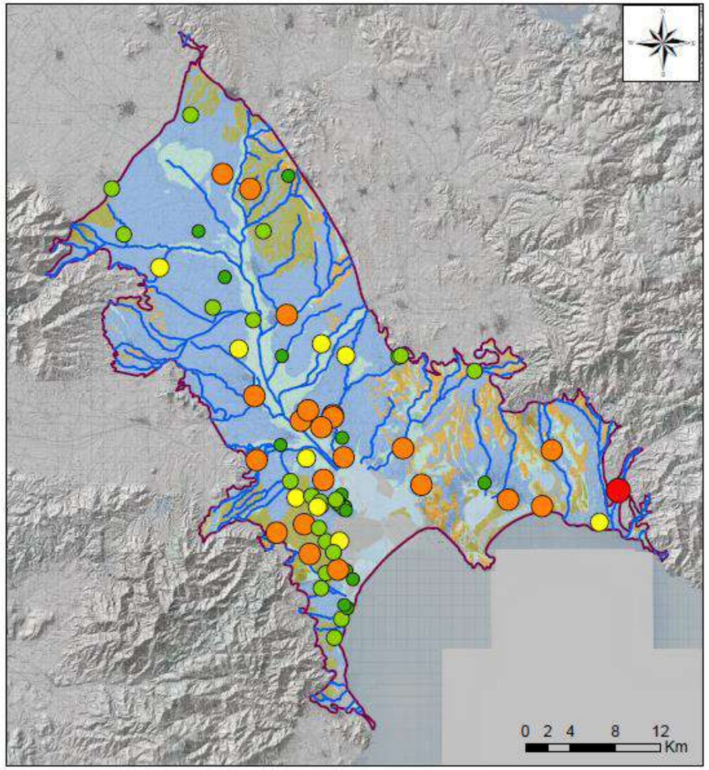
Southern Campidano

Maps of nitrate concentrations in groundwater

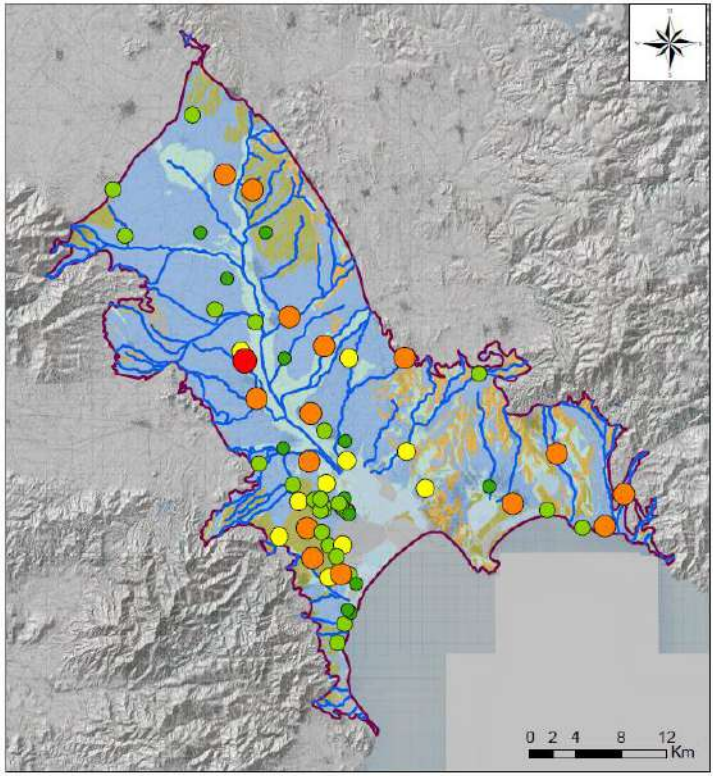
Data until 2009



Average data from 2011 to 2015



Average data from 2016 to 2021



Legend

Nitrate (mg/l)

- < 10
- 10 - 37.5
- 37.5 - 50
- 50 - 100
- > 100
- Surface water
- Artificial Canals
- Campidano boundaries

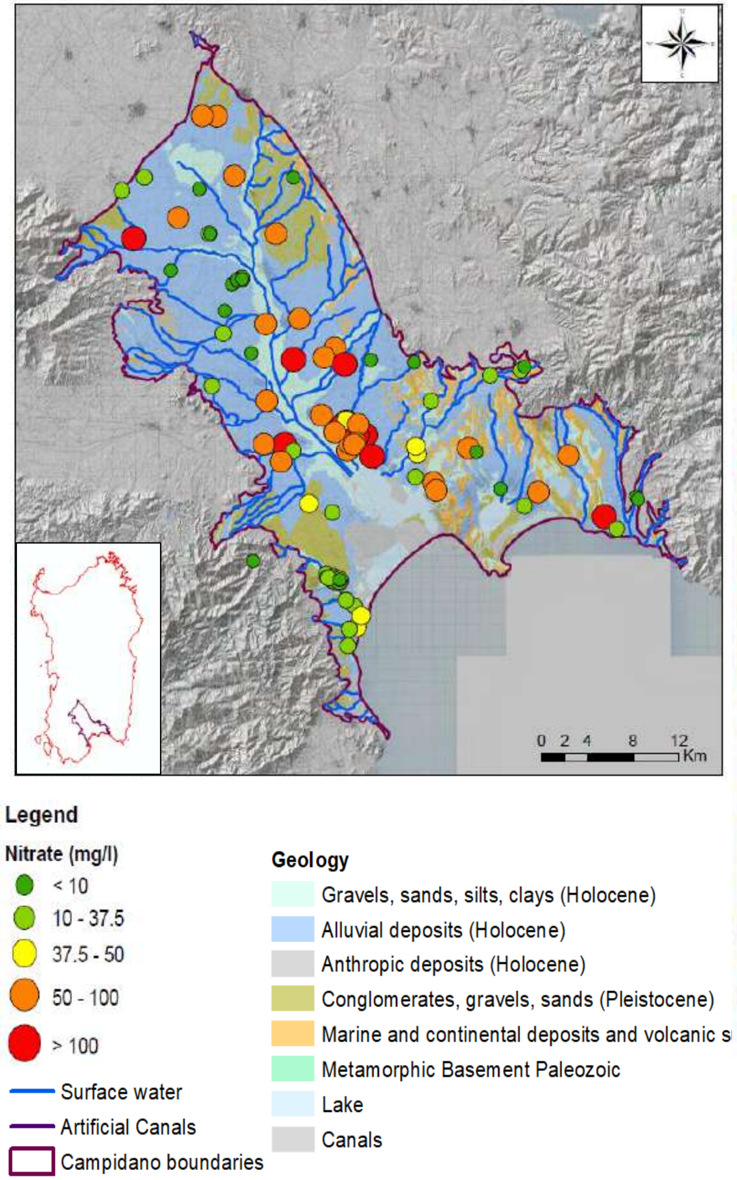
Geology

- Gravels, sands, silts, clays (Holocene)
- Alluvial deposits (Holocene)
- Anthropic deposits (Holocene)
- Conglomerates, gravels, sands (Pleistocene)
- Marine and continental deposits and volcanic successions Oligo-Miocene
- Metamorphic Basement Paleozoic
- Lake
- Canals

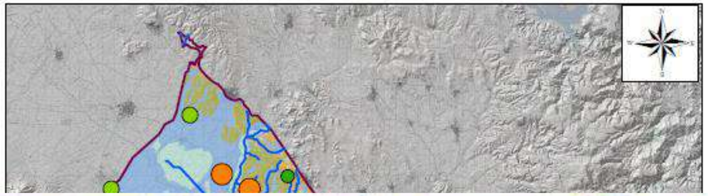
Southern Campidano

Distribution maps of nitrate concentrations in groundwater

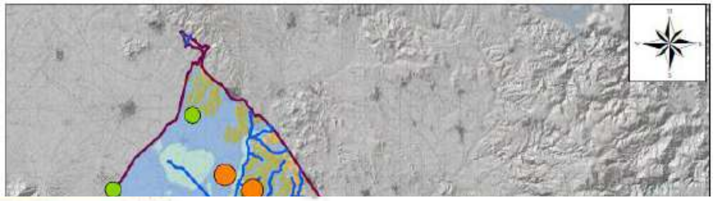
Data until 2009

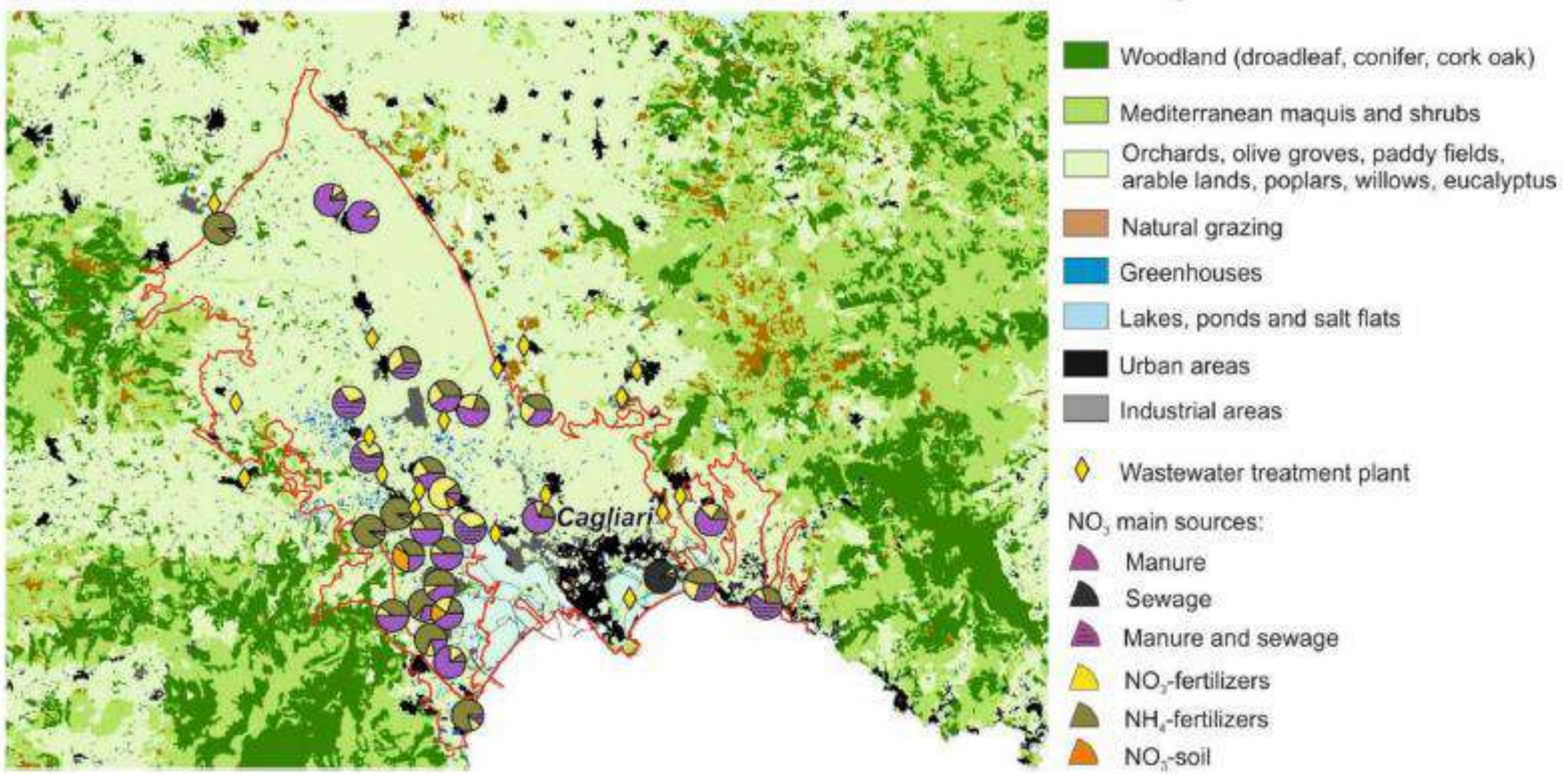


Average data from 2011 to 2015



Average data from 2016 to 2021

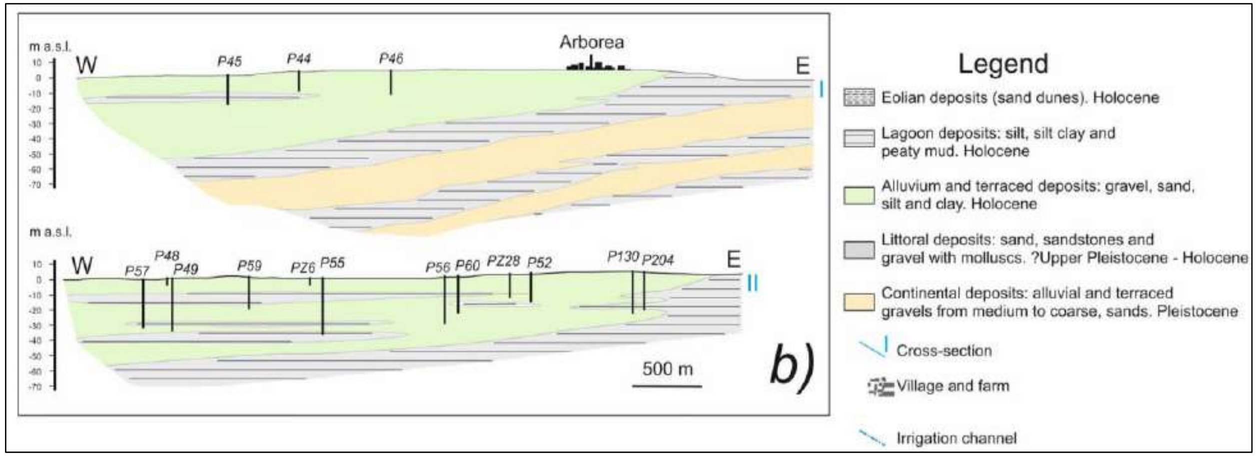




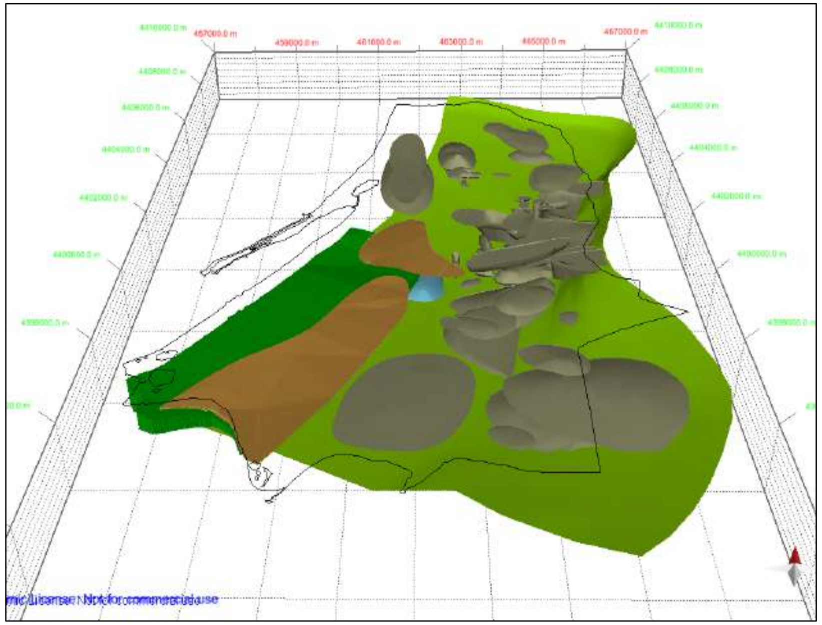
Spatial distribution of the potential NO_3^- sources estimated by isotopic analyses and the SIAR model *(Biddau et al., 2023)*

Hydrogeological framework

Arborea

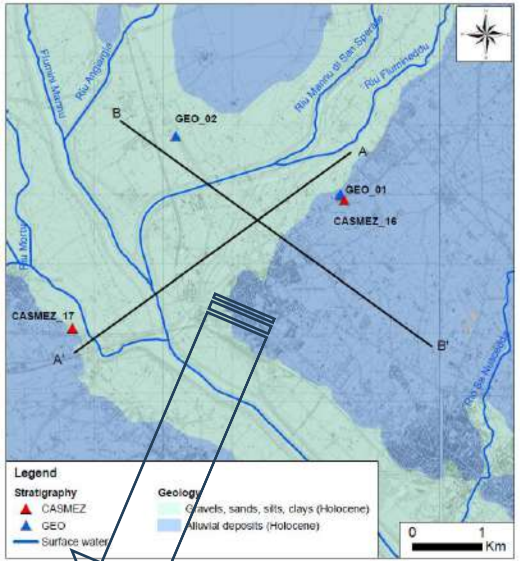


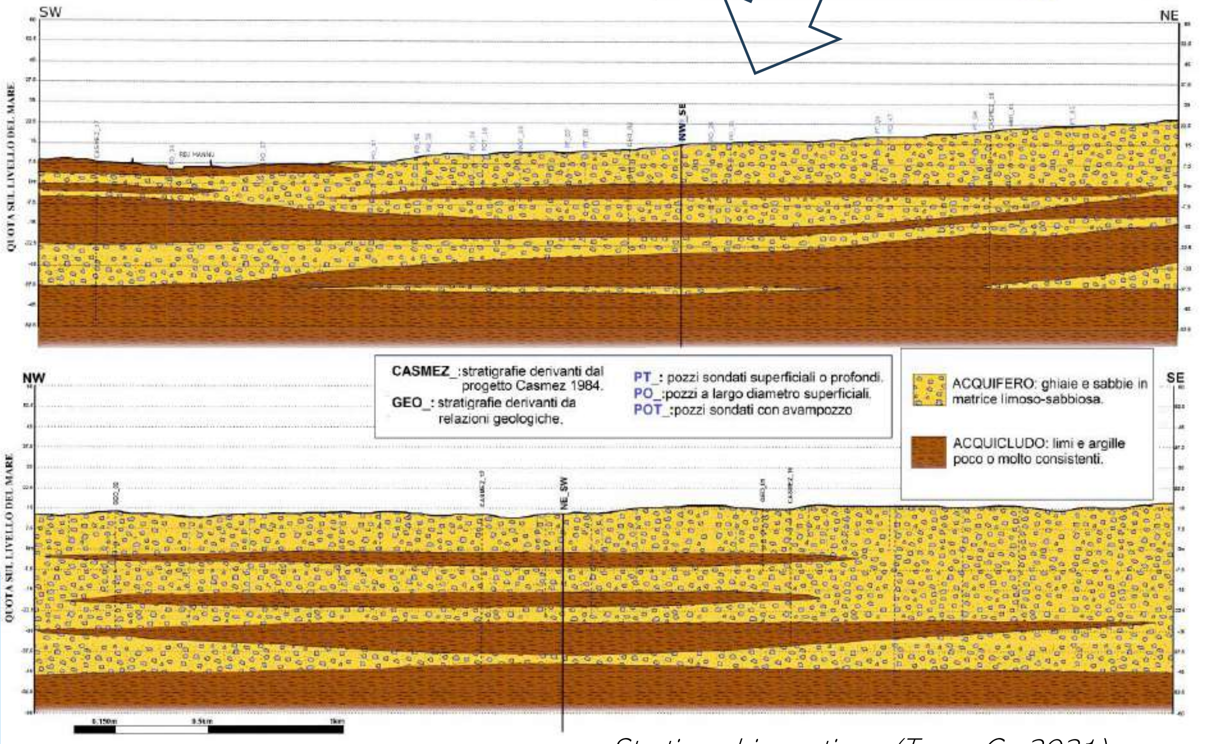
(Biddau et al., 2019)



Project AS-STGRI, unpublished data

Campidano





Stratigraphic sections (Tocco G., 2021)

Methodology

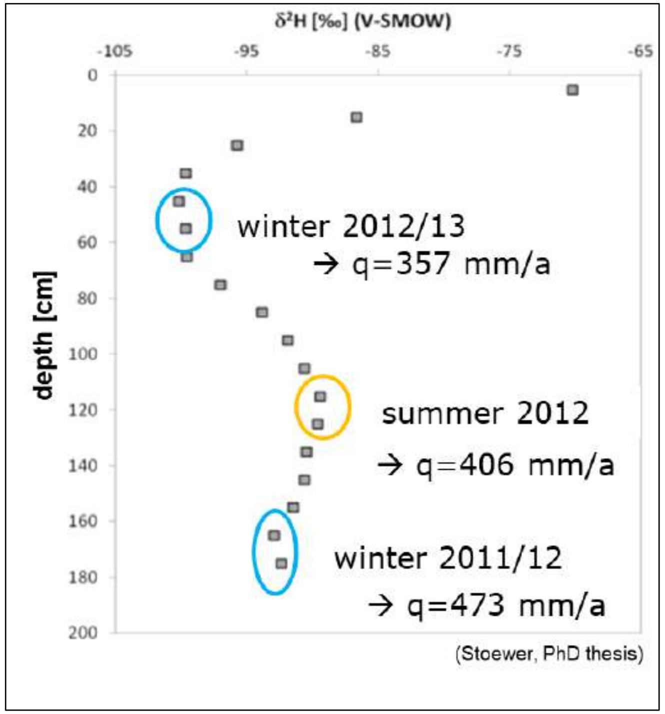
Piston flow concept

The "peak-shift" method

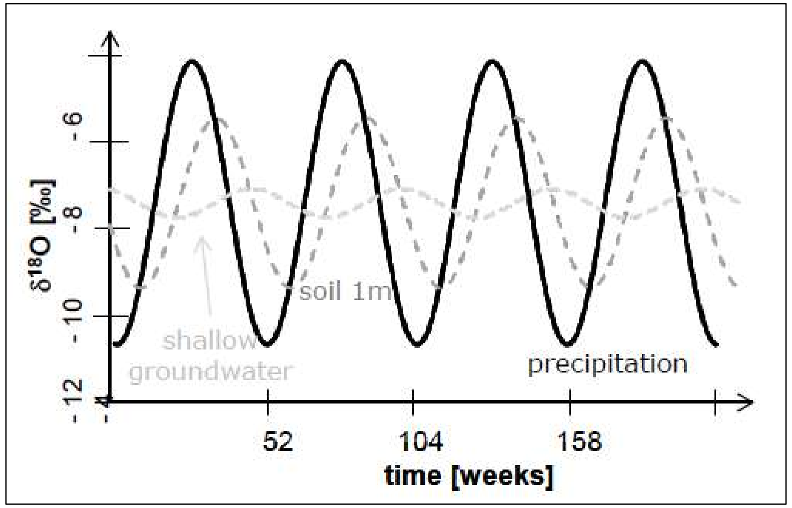
Calculation of recharge

$$R_T = \frac{1}{T} \int_{i=0}^{m} (\theta_{zi} - \theta_r) \cdot (z_{i+1} - z_i)$$

Chesnaux and Stumpp (2018)



(Stumpp, 2019)

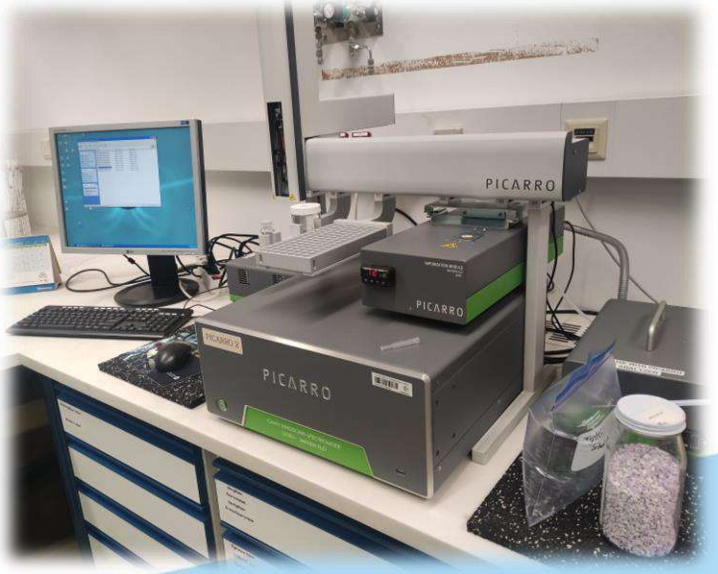


(Stumpp, 2019)

- ➢ water fluxes and transit times for transport processes
- ➢ quantification of average recharge rates
- ➢ identification of infiltration events

Methodology

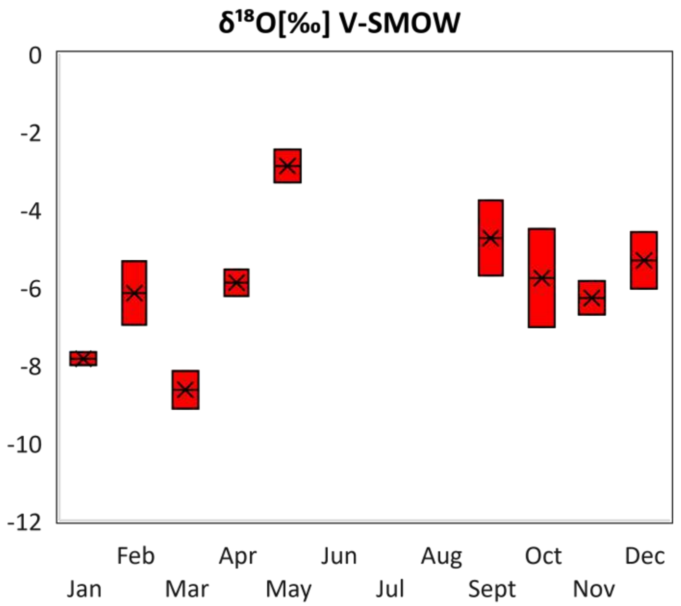
- Analysis of isotope ($\delta^{18}O$ and $\delta^{2}H$) in rainwater every months.
- Collection of soil samples every 10 cm along a vertical profile with a hand auger or a core drill machine.
- Determination of soil physical properties: water content, grain size distribution, and volumetric water content.

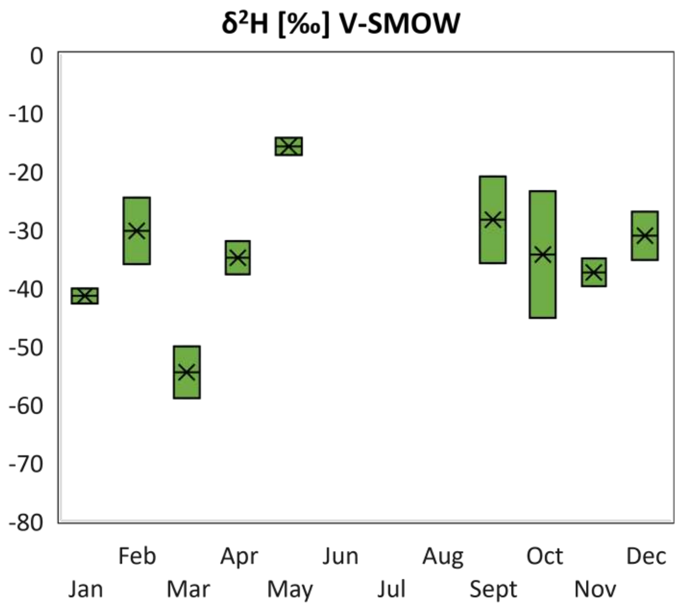


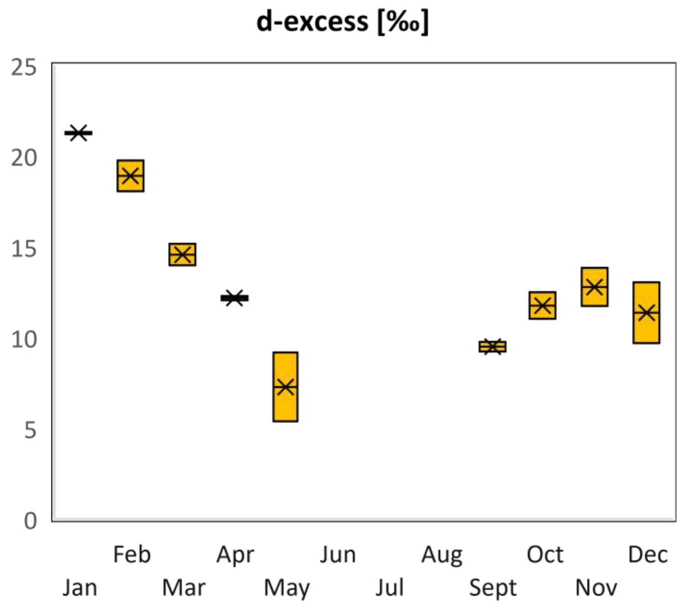
- Analysis of the water stable isotopes ($\delta^{2}H$ and $\delta^{18}O$) in the soil samples using direct H_2O(liquid)–H_2O(vapor) porewater equilibration methods (Wassenaar et al, 2008) were measured at the Institute for Soil Physics and Rural Water Management (Vienna, Austria).

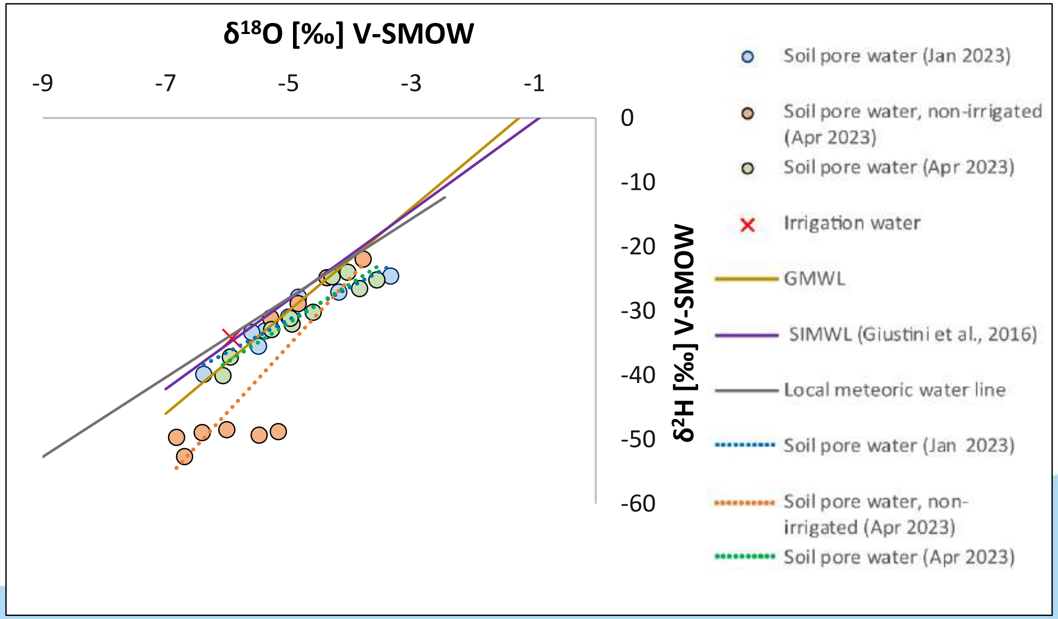
Results: Arborea Site

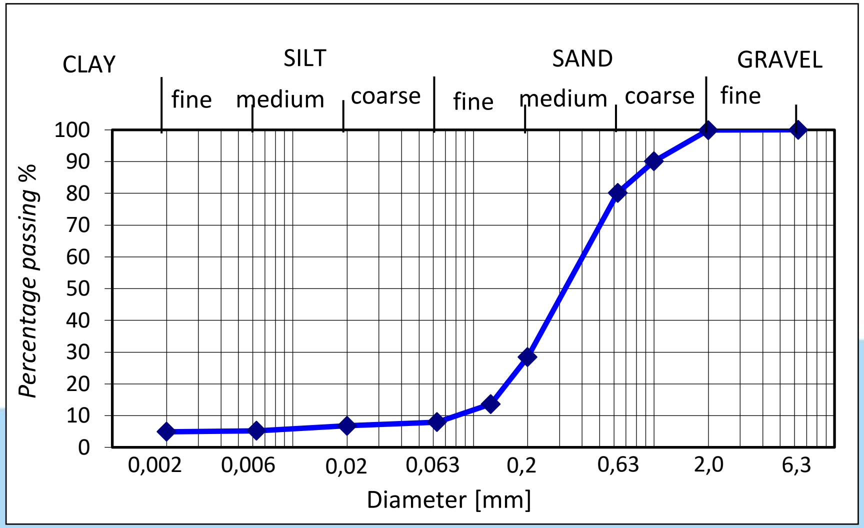
Rainwater



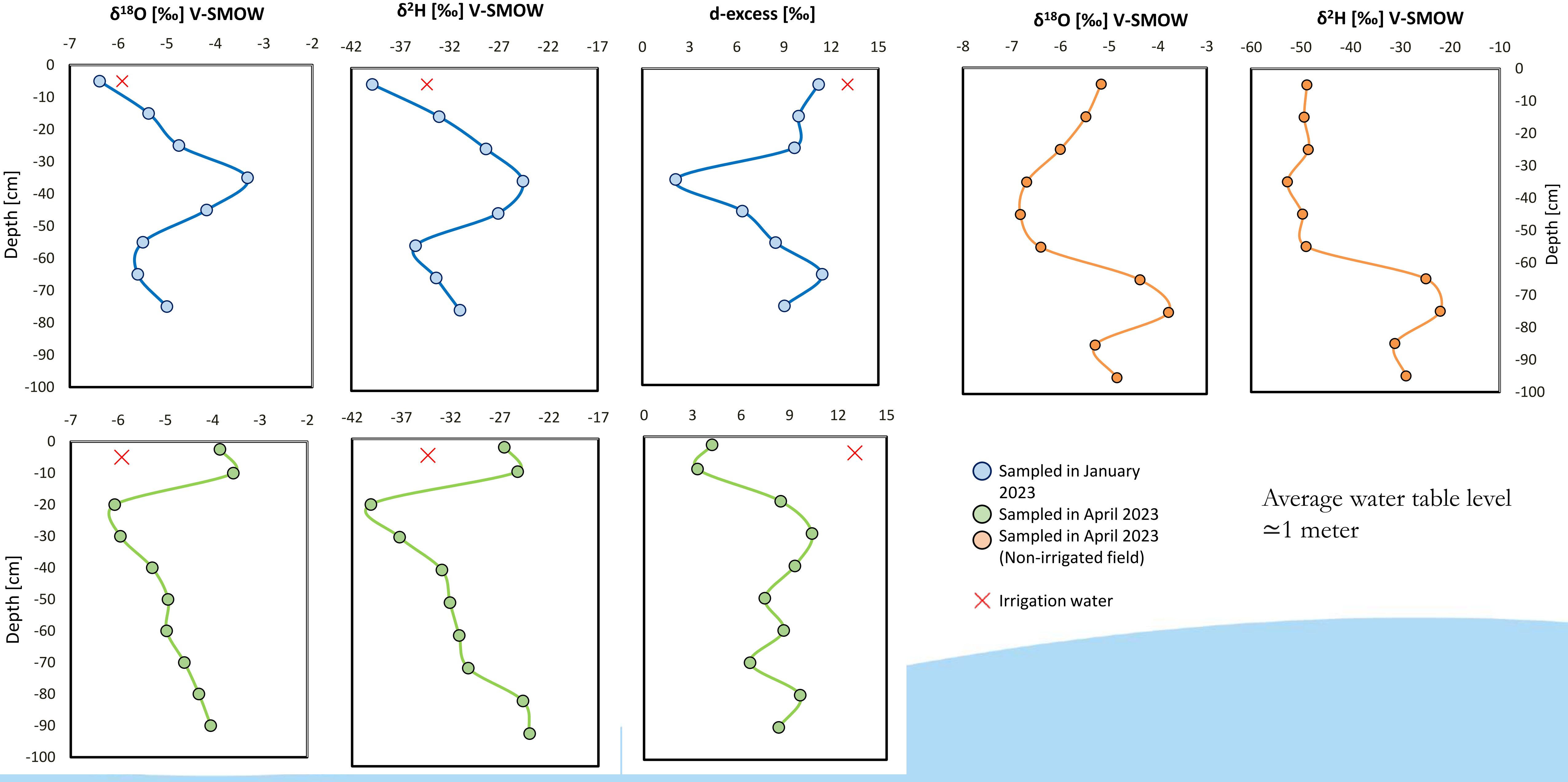








Results: Arborea Site

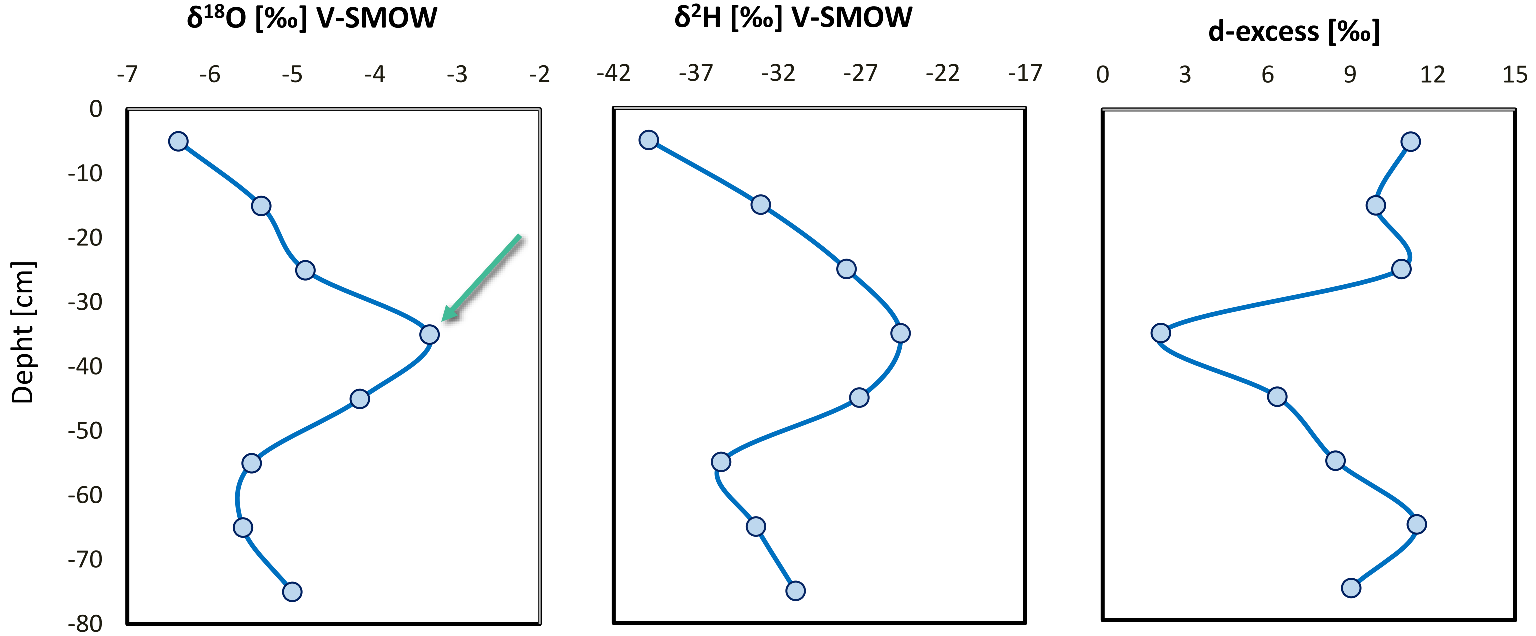


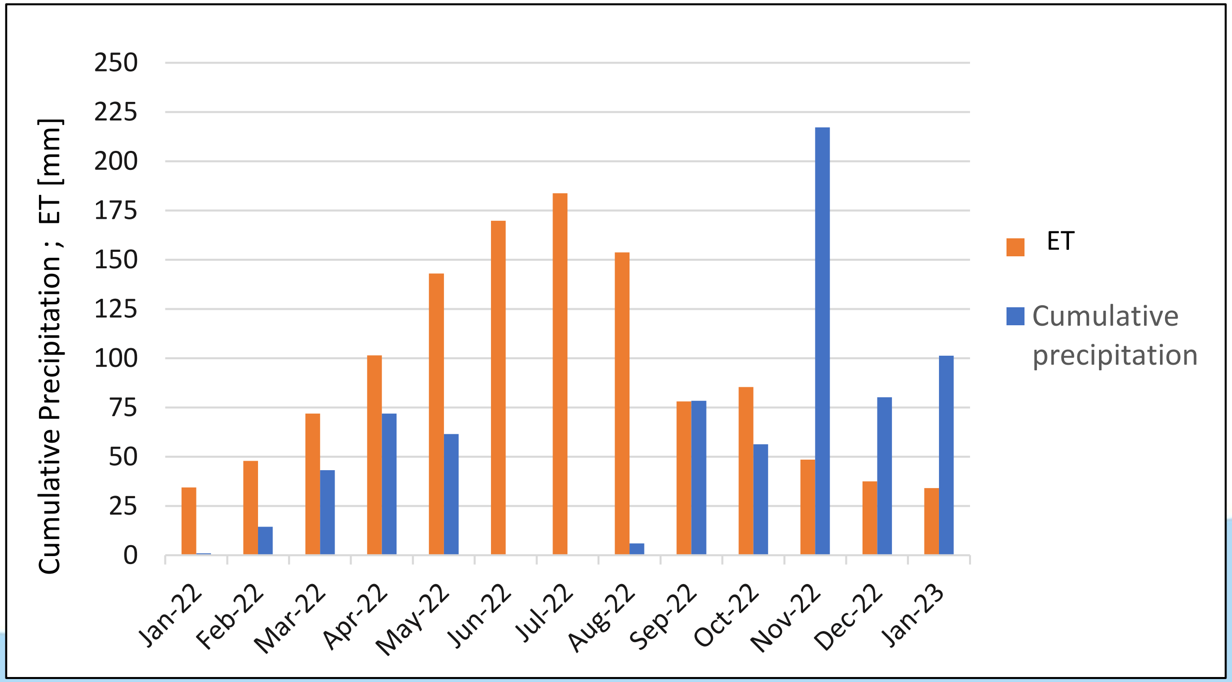
Average water table level ≃1 meter

Results: Arborea Site

If we assume that the -3.34‰ can be the spring peak (≃ April/May 2022)

- - 35 cm in profile from April/May 2022 to January 2023
- 9/10 months to reach -35 cm
- Average water flow velocity 0.12 cm/day or 0.0012 m/day





Evapotranspiration calculated using the Hargreaves method for the last year

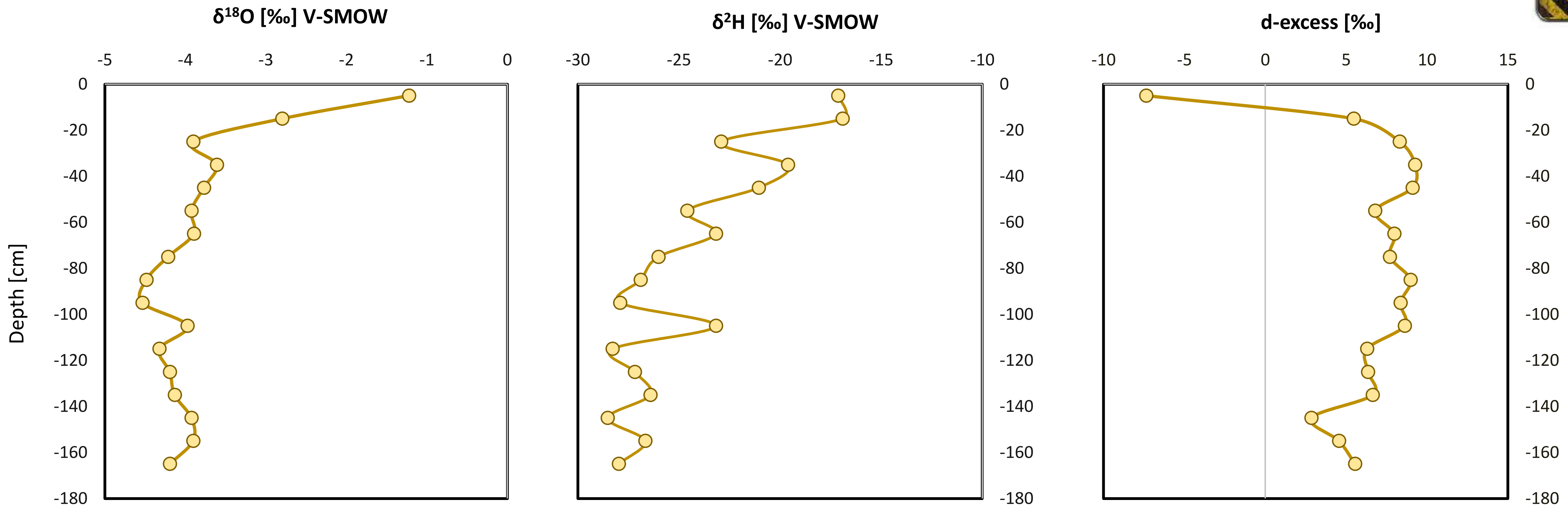
Calculation of possible groundwater recharge

$$R_T = \frac{1}{T} \int_{i=0}^{m} (\theta_{zi} - \theta_r) \cdot (z_{i+1} - z_i)$$

Rt = 80.39 mm in 9 months

According to the calculation of the 673 mm of rainfall, only **12%** goes to recharge the aquifer (80 mm) in 9 months.

Results: Campidano site



- Evaporation front in the first centimeters
- There could be many seasonal cycles
- It seems that the flow is slower, the texture is clayey
- Influence from irrigation

Conclusion

- ❖ The pronounced seasonal differences observed in the isotopic signatures of rainwater makes possible to apply the "peak-shift" method.
- ❖ Estimation of recharge rate is in the expected order of magnitude; however, discrepancies can be related to irrigation.
- ❖ Further analyses in both the study areas are required to better interpret the collected data; they include
  - Definition of soil water retention curve (to determine the precise value of θr)
  - Evaluation of soil hydraulic conductivity values
  - Isotope analysis of irrigation water at different time
- ❖ A site-specific estimation of nitrate leaching can be obtained by measuring nitrate concentrations in soil water below the root zone with suction cups (it is an ongoing work).

Thanks for your attention!

francesca.lobina@unica.it

Work partially founded by Agreement POA FSC 2014-2020 Servizio Tutela e Gestione delle Risorse Idriche, Vigilanza sui Servizi Idrici e Gestione delle Siccità - Direzione generale Agenzia Regionale del distretto Idrografico della Sardegna.

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Malta 2023

14th – 16th June
National Meeting on Hydrogeology

JUNE 14-16, 2023

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The role of faults on groundwater circulation: the case study of Monte Marine fault (Central Apennines, Italy)

Petrella E., Ferragonio M.R., Polimeno M., Pizzati M., Balsamo F.

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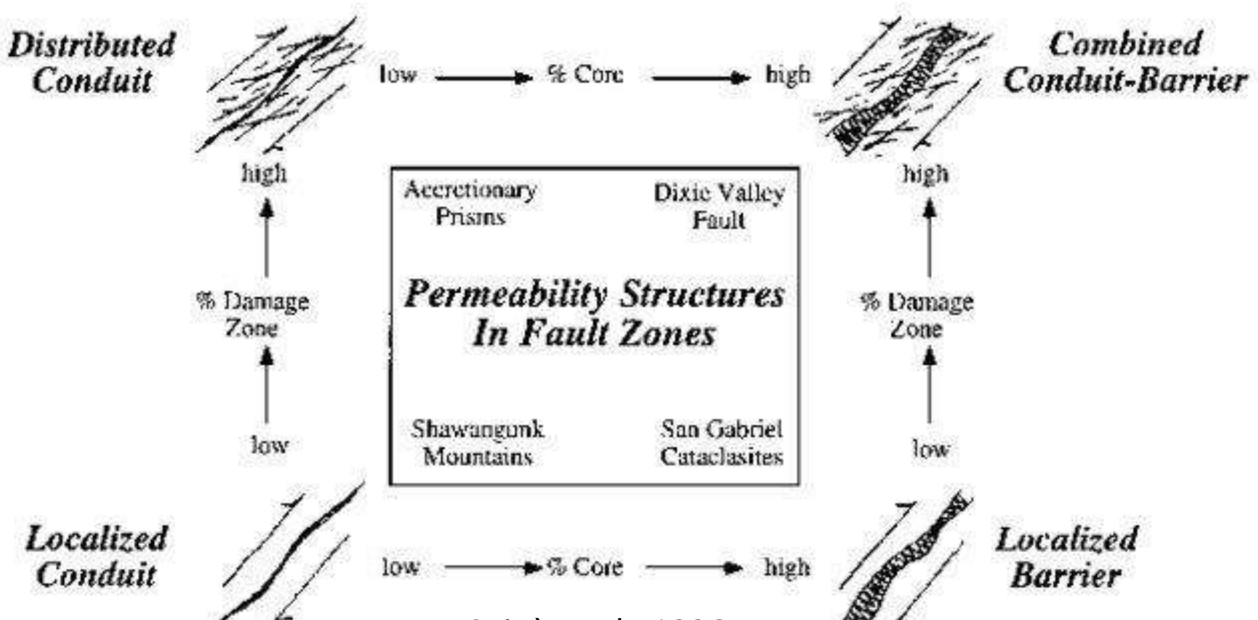
Framework

- In Central Italy many of the urban settlements are placed in intermontane basin nearby active faults.
- Deformation along faults introduces permeability heterogeneity and anisotropy of the media.
- Fault zones may act as a conduit for flow, a barrier to flow or as a complex conduit/barrier.



Cainè et al., 1996

AIM

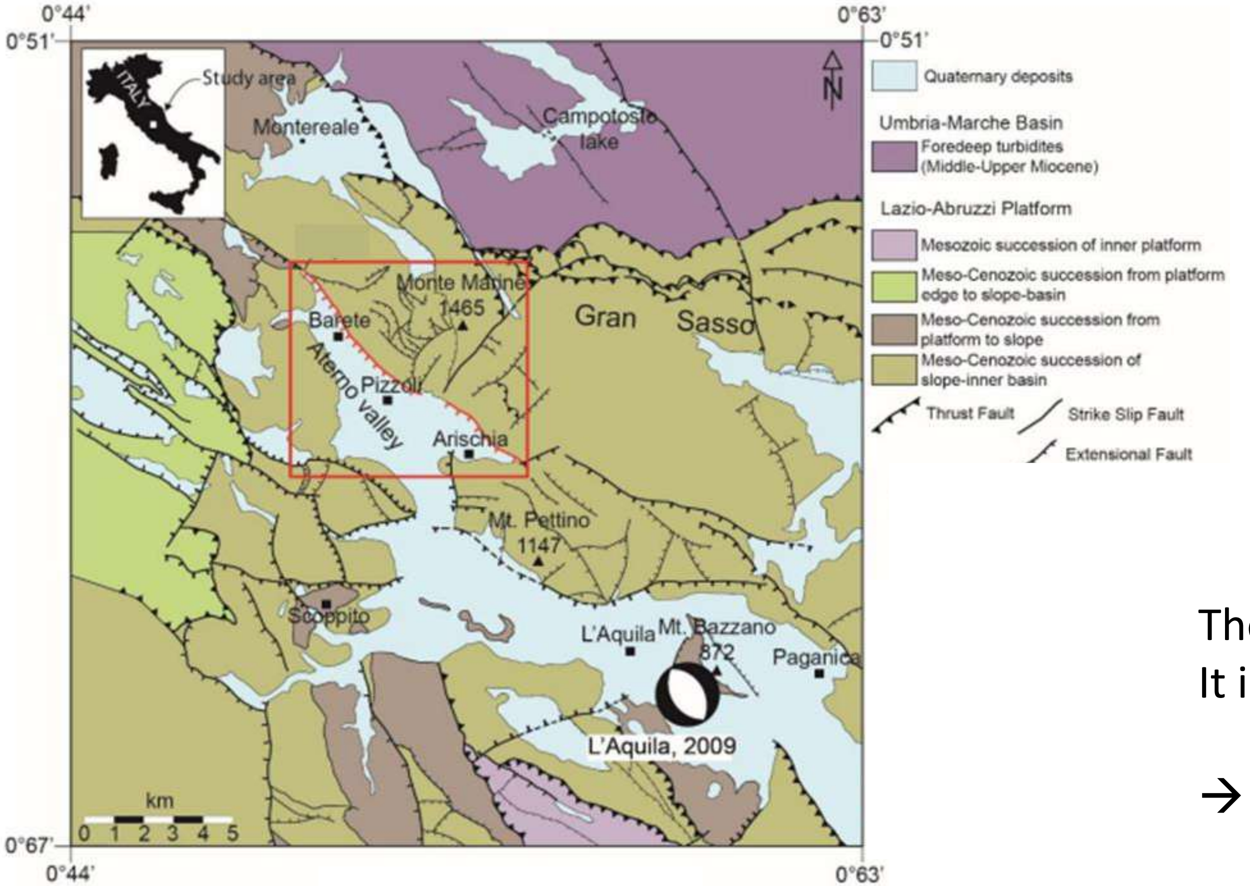
Understand the hydrogeological role of a complex fault zone

QUESTIONS:

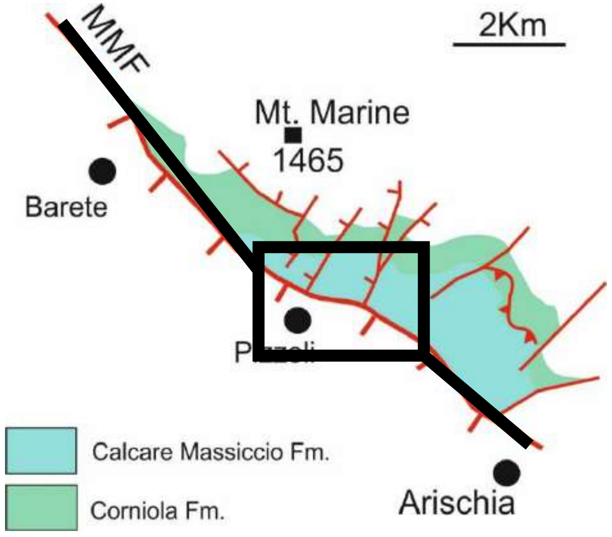
→ Act they as barrier, drain, or conduit-barrier with respect to groundwater flow?

→ Is their role constant along the entire length?

Monte Marine Fault (Pizzoli, AQ)



Cortinovis *et al.*, 2019



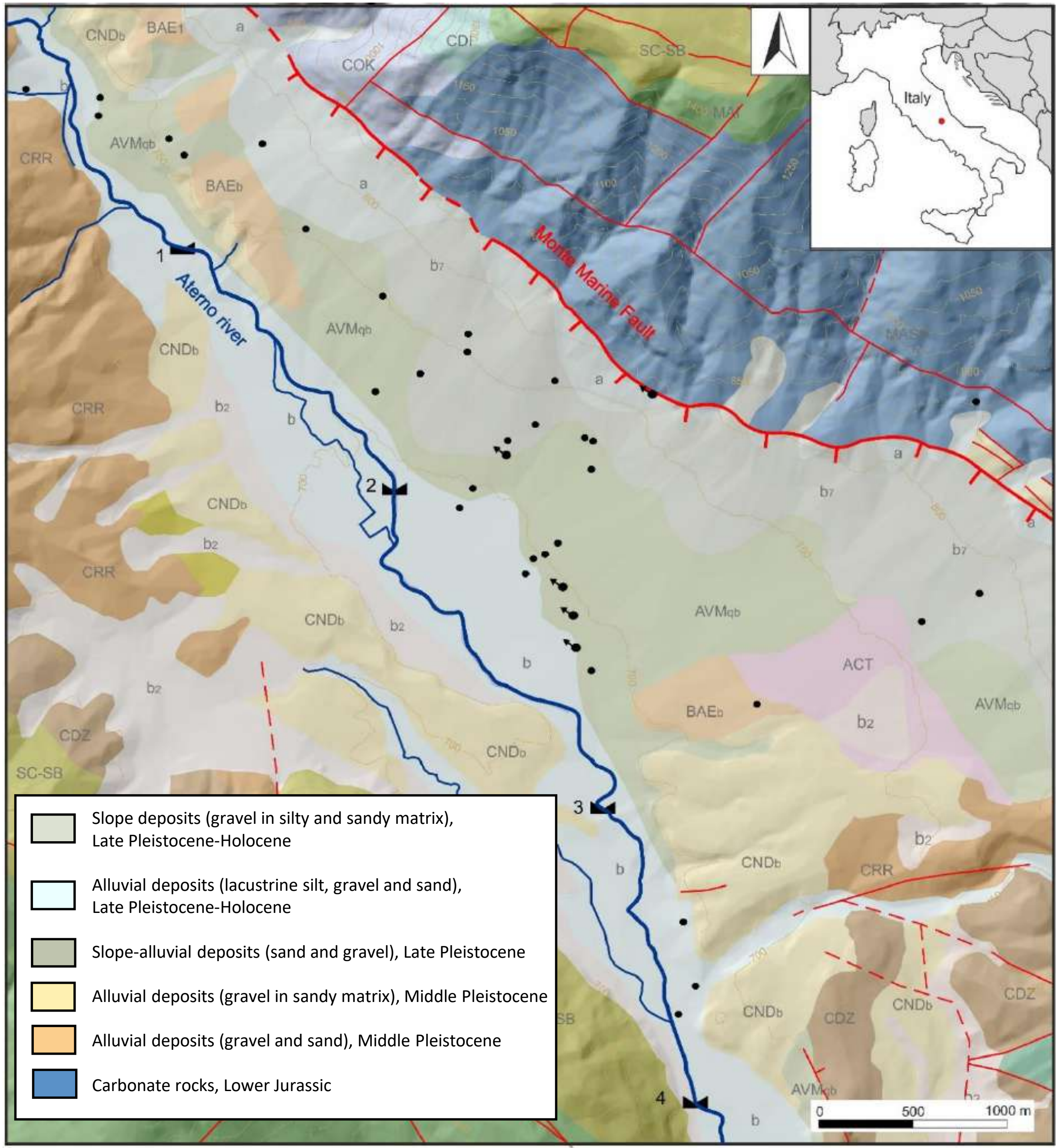
- → Central Apennines
- → Western part of the Gran Sasso carbonate aquifer
- → MMF is a NW-SE-trending active extensional fault
- → It develops in a partially dolomitized carbonate rocks

The structural architecture varies significantly along strike.
It is composed of (Cortinovis et al., 2019):

- → two near-parallel major fault strands characterized by a master fault surface with normal kinematics
- → hard-linked step-over zone characterized by E-W trending faults where anomalous amounts of shattered rocks form characteristic bad-land morphologies

It crops out continuously for ~8 Km.

Monitoring Plan



Aterno Valley basin is a NW-SE trending tectonic depression (half graben)

It is composed of almost 200 m of quaternary alluvial deposits (Santo et al., 2013)

Hydrogeological investigations

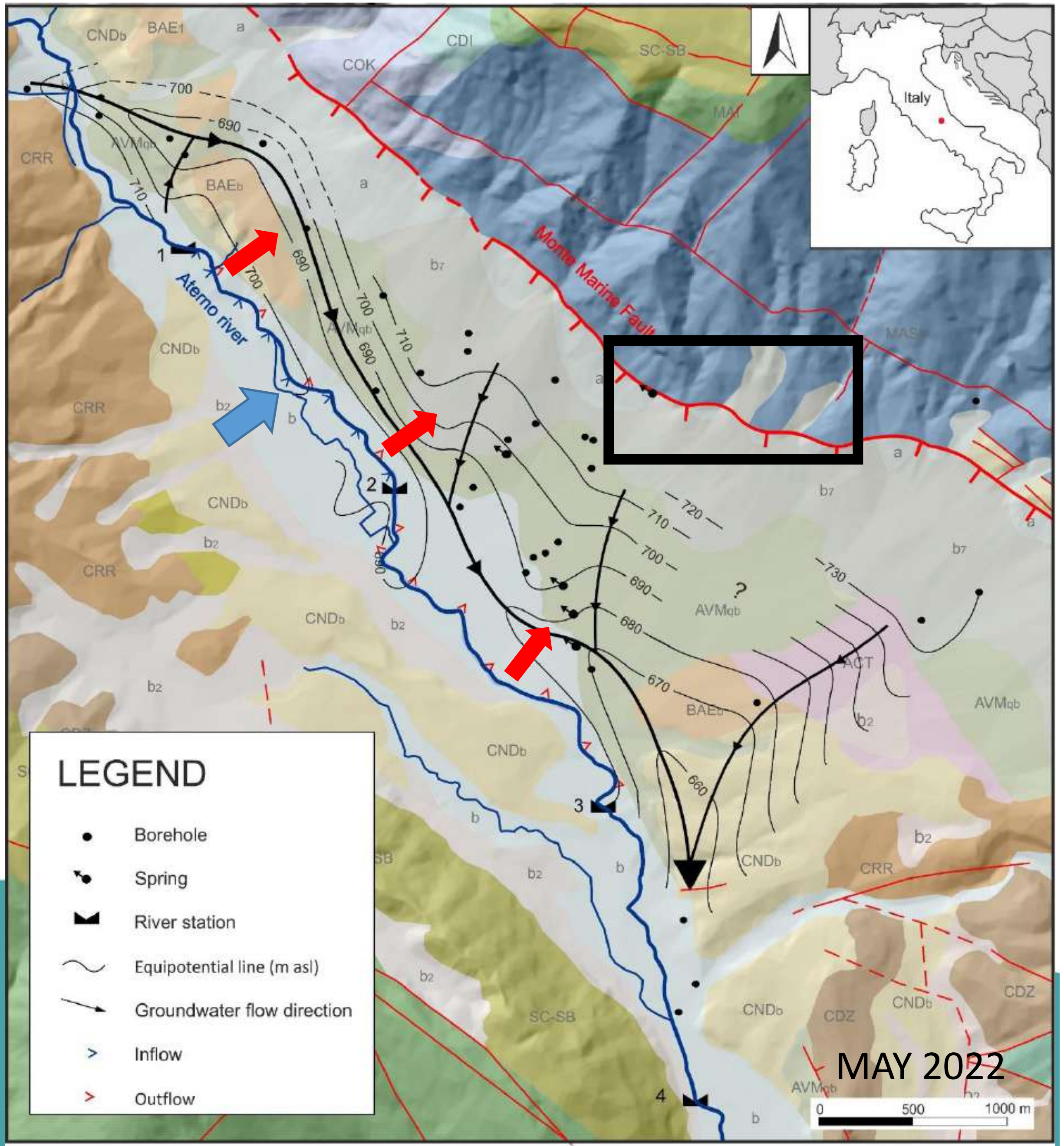
- Groundwater level (n.38)
- River discharge (n. 4)
- Springs discharge (n. 6)

Geochemical and isotopic investigations

- Physico-chemical parameters (EC, T, pH)
- Isotopic investigation ($\delta^{18}O$; $\delta^{2}H$)

Timing: Every three-months (may 2021- may 2022)

Results



GROUNDWATER

- Main groundwater flow direction parallel to the river (NW-SE)
- Secondary underground drainage axes (NE-SW) coming from carbonate massif toward the alluvial plain
- The groundwater flow scheme did not change over time
- The Aterno river has a mixed interaction with the alluvial plain both in time and in space, but it mainly feeds the groundwater on the left riverside.

Groundwater flow scheme is influenced by:

1. Flow-through from carbonate aquifer along all fault length?
2. Local infiltration into the basin?
3. Combination of the previous two hypotheses?

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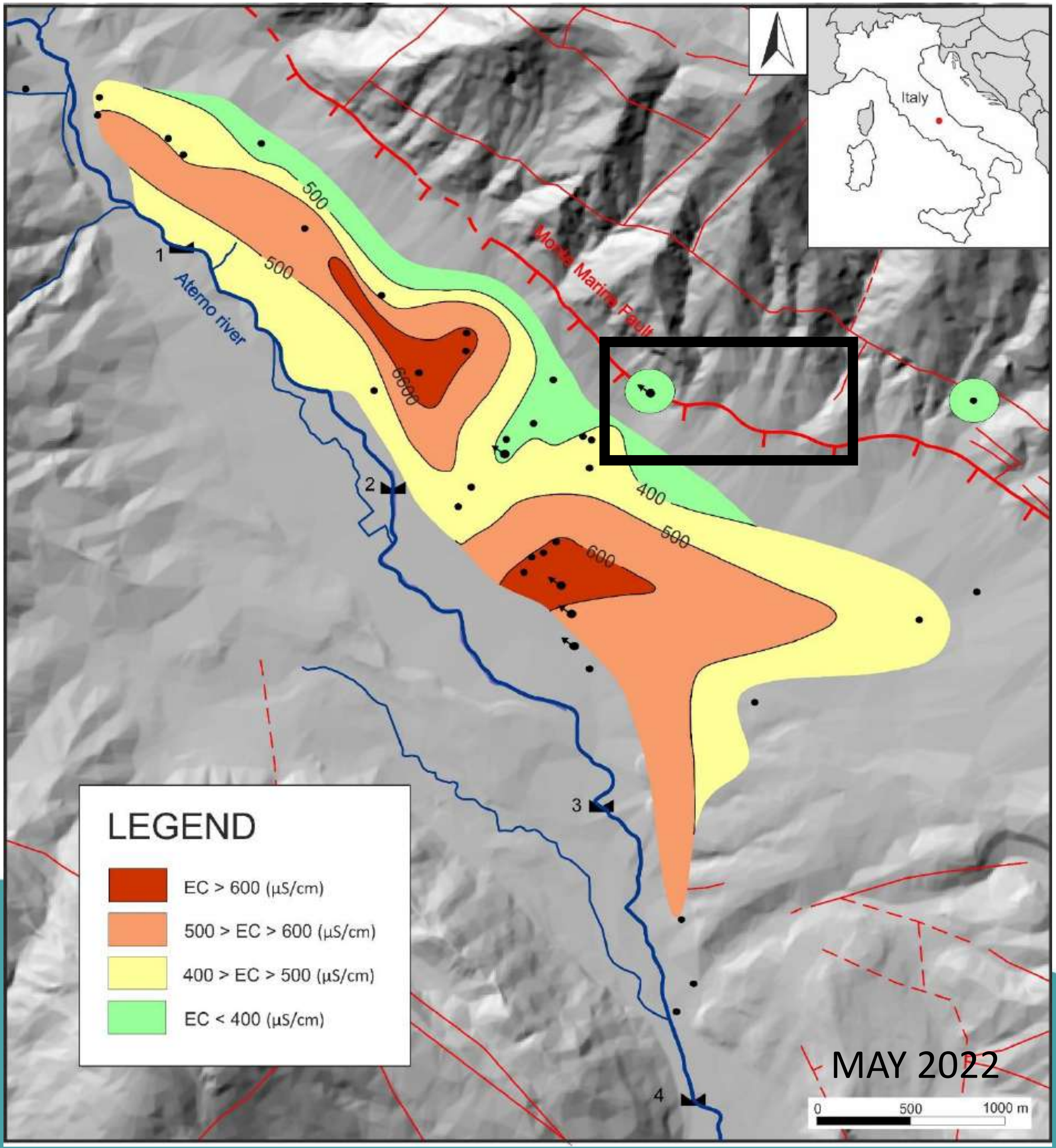
Results



ELECTRICAL CONDUCTIVITY

- The distribution of the EC values is not homogeneous in the Aterno Plain
- The lowest values are found all along the entire length of MMF and in the central part of the plain
- The low EC values found in alluvial aquifer are in the range of the values of water points sampled in the carbonate aquifer

The EC values suggest the existence of a flow-through all along the fault

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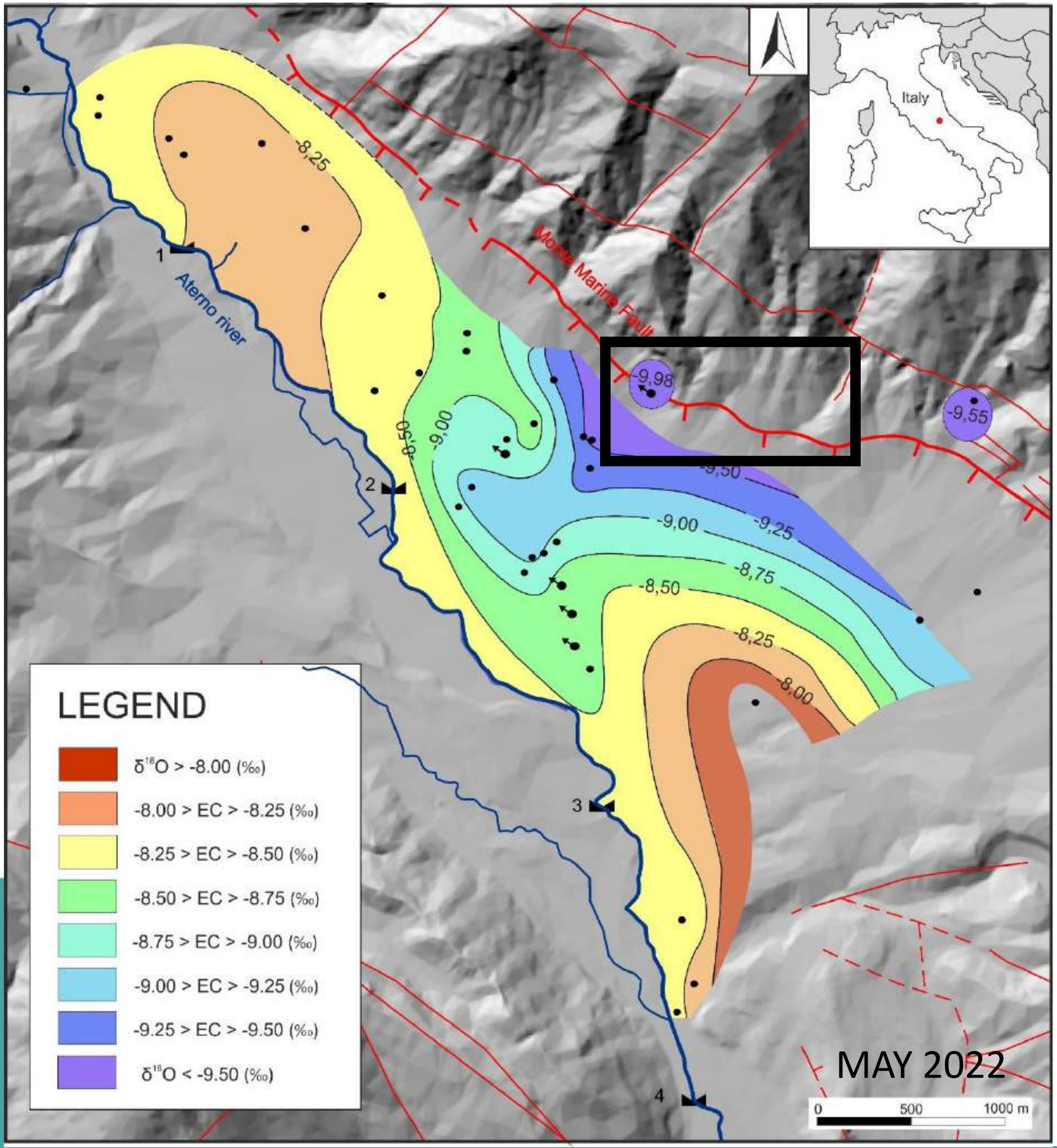
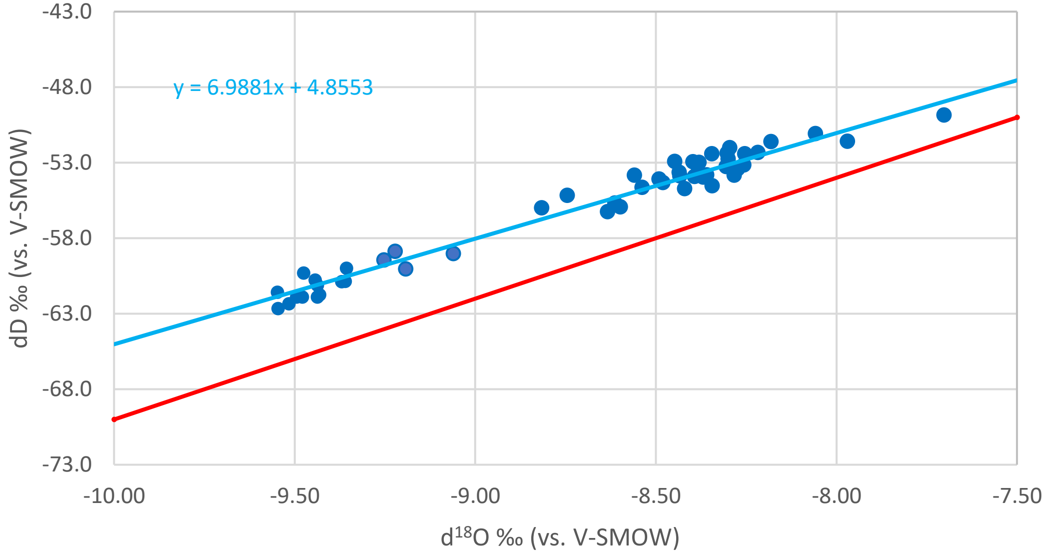
Results



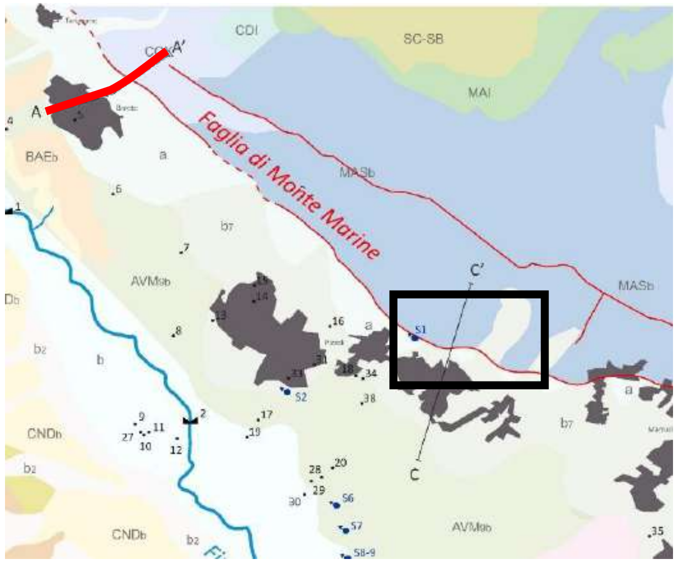
STABLE ISOTOPE CONTENT



- Strong isotopic variation in groundwater
- Lighter isotopic signature were found in correspondence of the step-over zone
- The lighter isotopic content ($\delta^{18}O$< -9,50‰) suggests high recharge area (~ 1300 m als), not compatible with the altitude of the Aterno Basin (~700 m asl)

The stable isotopes identify a local and significant flow-through from the carbonate aquifer

Hydrogeological role of faults

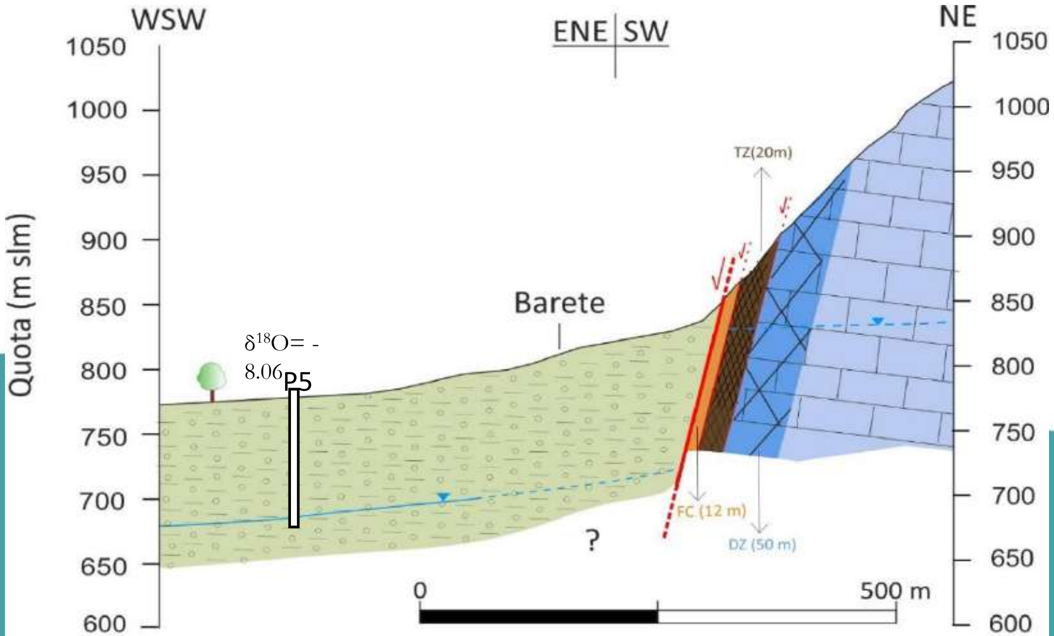


1. Fault core: 12 m
→ Ultracataclasite (Low permeability)

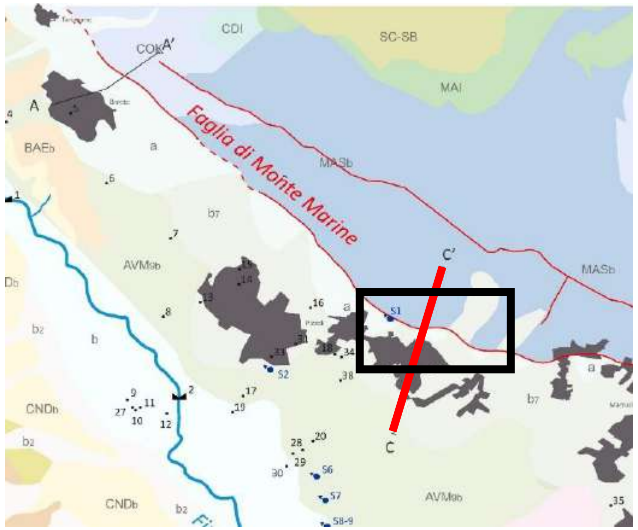
2. Transition zone: 20 m
→ Fault breccias (Very high permeability)

3. Damage zone: 50m
→ Fractured limestone (High permeability)

THE MAIN FAULT STRANDS ACT AS A BARRIER



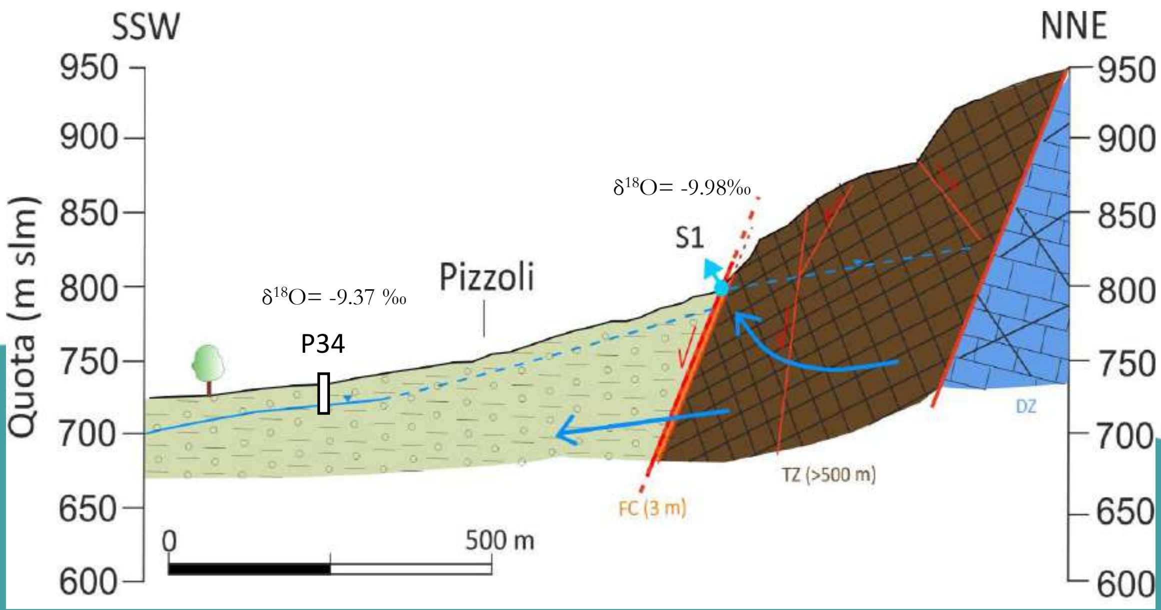
Hydrogeological role of faults



1. Fault core: 3 m
→ Ultracataclasites (Low permeability)

2. Transition zone: >500 m
→ Fault breccias (Very high permeability)

3. Damage zone: >50m
→ Fractured limestone (High permeability)



THE STEP-OVER ZONE ACT MAINLY AS A DRAIN

Main conclusions

The experimental data show that:

- The MMF does not have a unique hydrogeological behavior
- It is an impermeable barrier where the thickness of the damage zone is in the order of a few tens of meters.
- A significant flow-through is permitted in the step-over area, where the local permeability is enhanced due to the presence of 100’s of meters of loose fractured materials (breccias).
- This peculiar structural complexity controls the occurrence of the along-fault spring and permits a significant flow-through from carbonate aquifer toward the alluvial plain

Thanks for your attention

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National Meeting on Hydrogeology

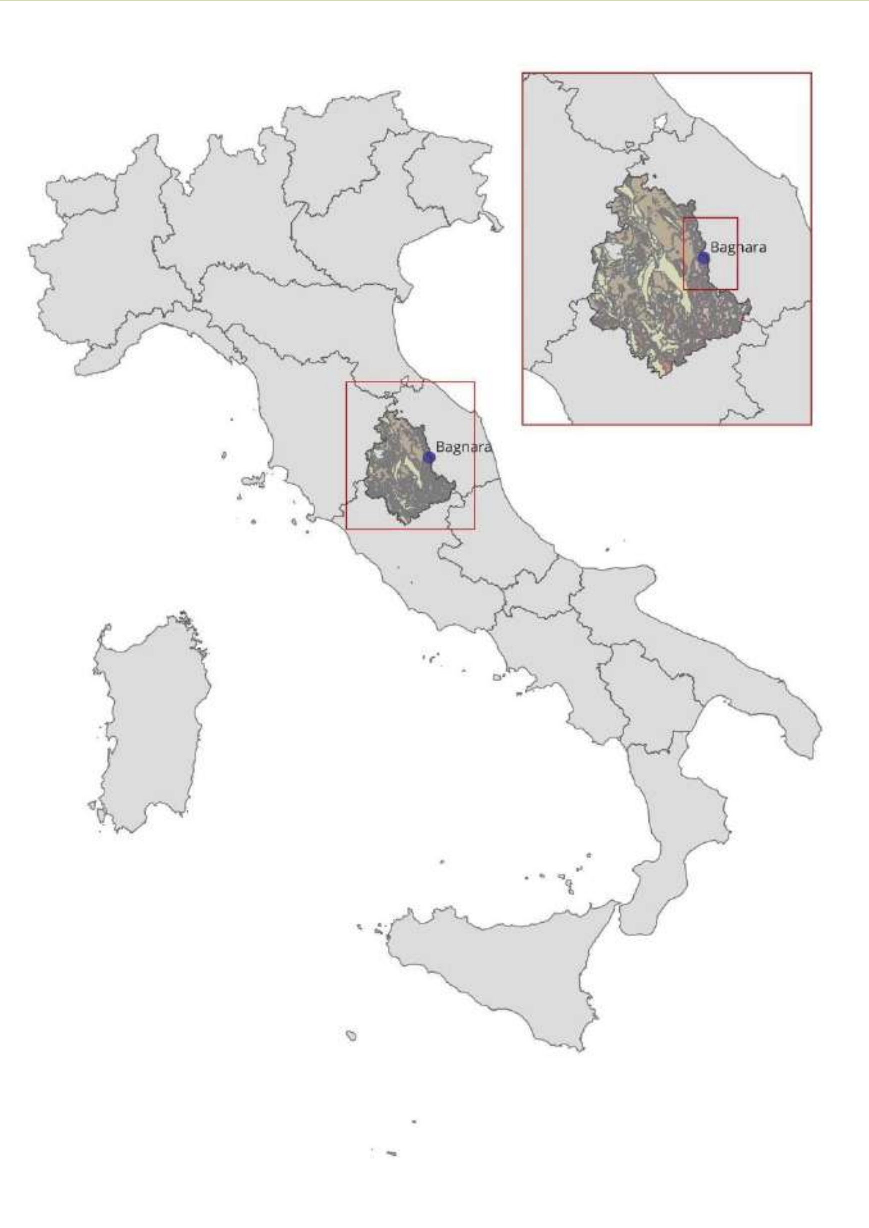
IMPACT OF CLIMATE CHANGE ON WATER RESOURCES: CONSIDERATIONS REGARDING THE UNCERTAIN FUTURE OF WATER RESOURCES IN THE CENTRAL APENNINES (ITALY)

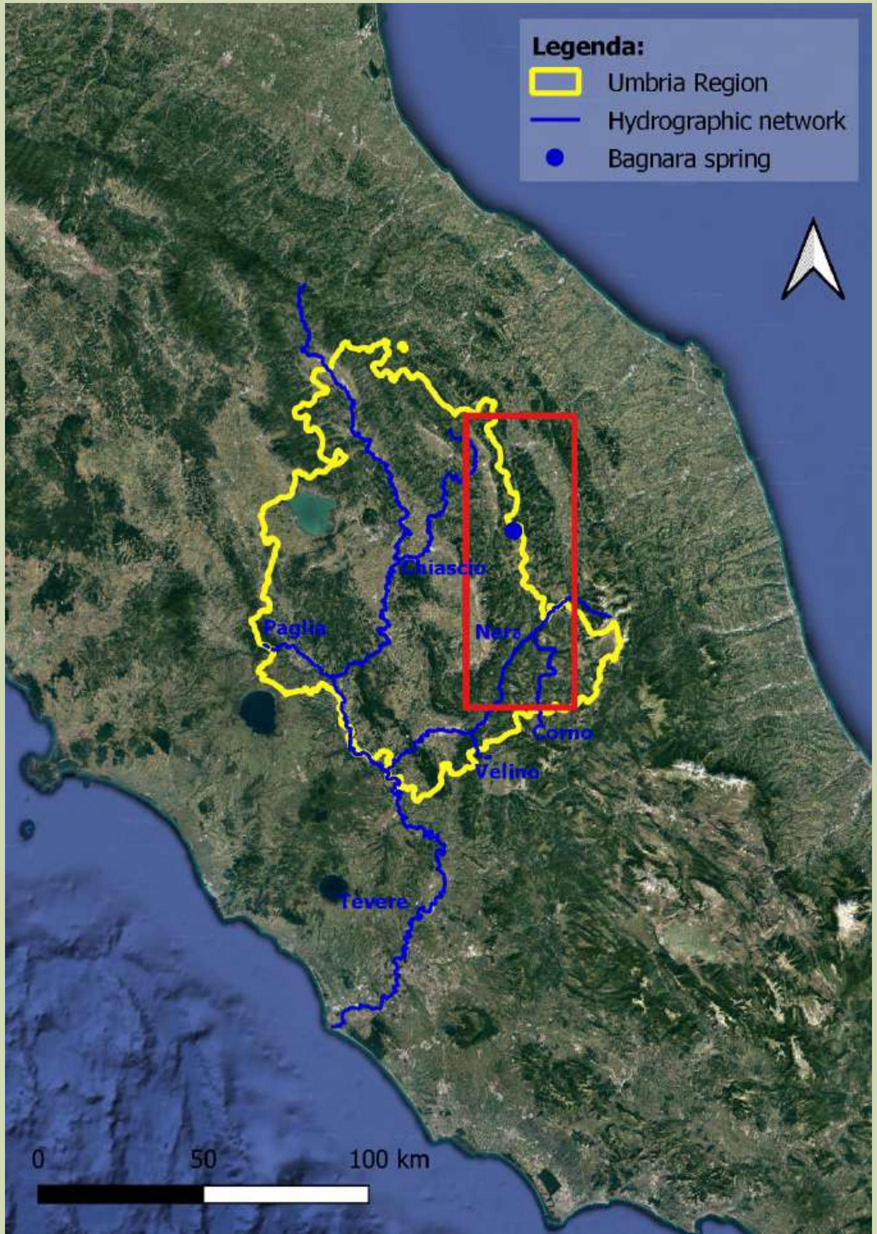
W. Dragoni[1], M. Melillo[2], C. Cambi[1], S. Camici[2], D. Valigi[2]

[1] Dipartimento di Fisica e Geologia, Università degli Studi di Perugia, Italia

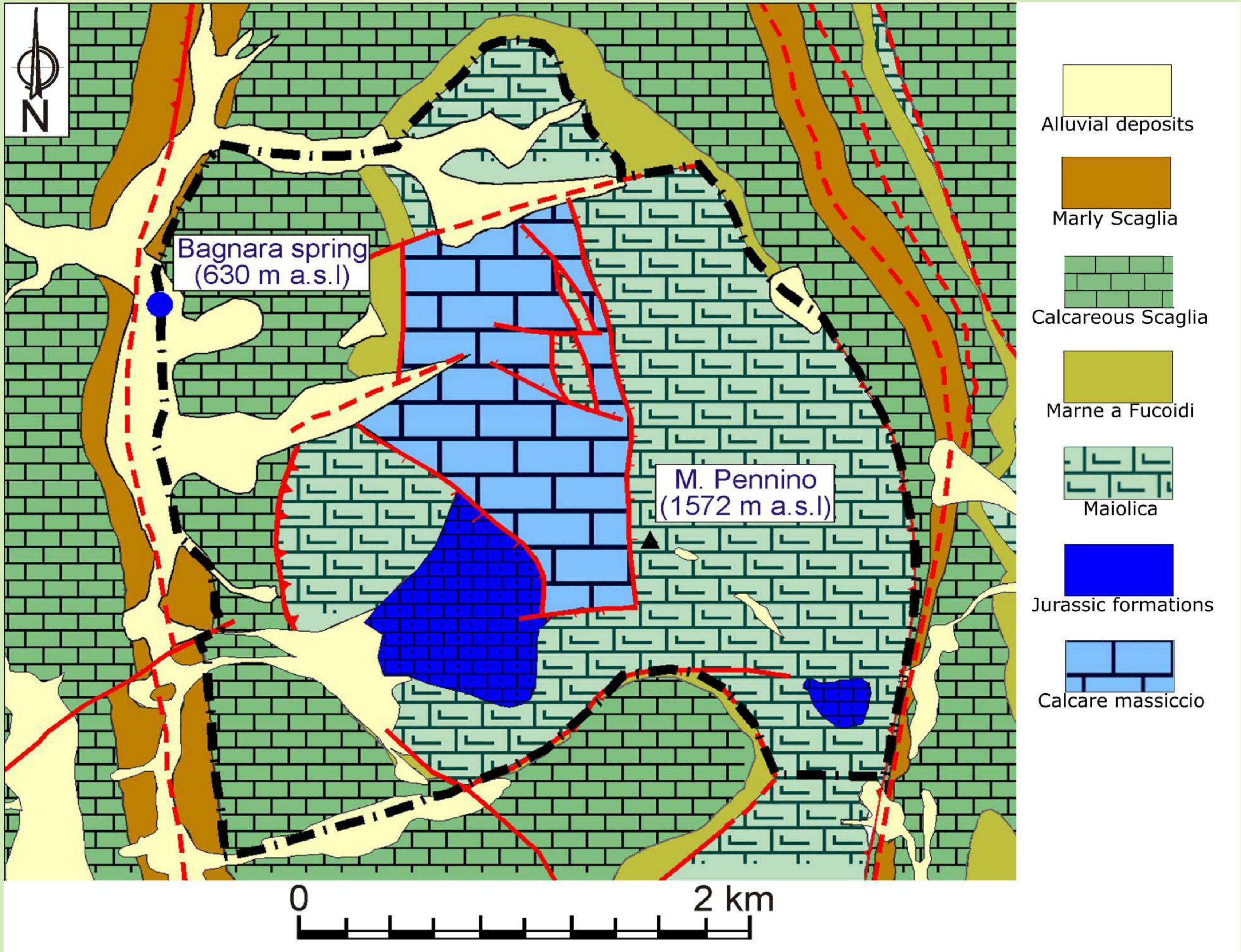
[2] Istituto di Ricerca per la Protezione Idrogeologica, CNR, Perugia, Italia

AIMS: to investigate the impacts of the ongoing climate change on springs in the Central Apennines (Italy).
The chosen representative case is Bagnara Spring (111 l/s); currently, the groundwater recharge of the limestone area in the Umbria region is around 450 mm/year (45 m^3/s).





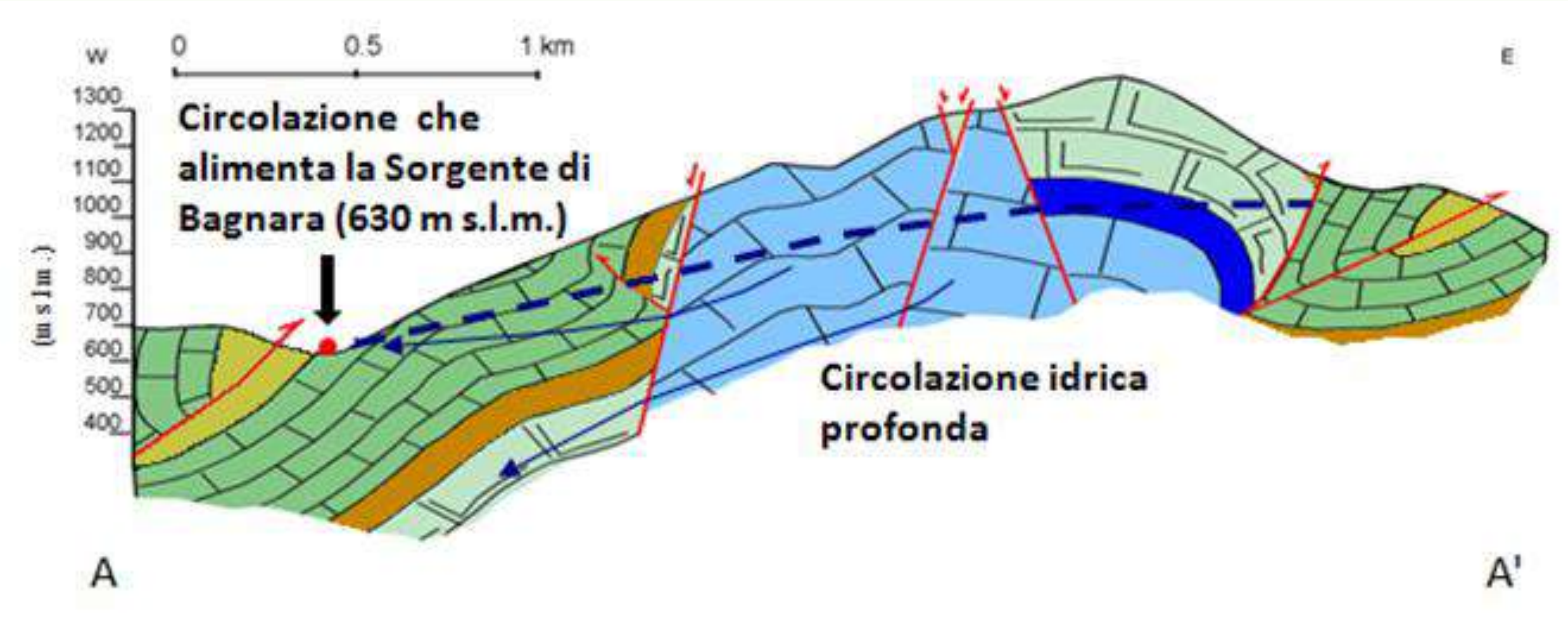
Hydrogeological setup of Bagnara spring



Recharge area 7,5 km^2 ,
Average el. 1150 m a.s.l.,
Spring elevation 630 m a.s.l.;
Monthly temperature and rain, NOCERA UMBRA station, at 535 m a.s.l.; missing data estimated from GUBBIO station (36 km from the spring).

After Cambi and Dragoni, 2000; Dragoni et al., 2015

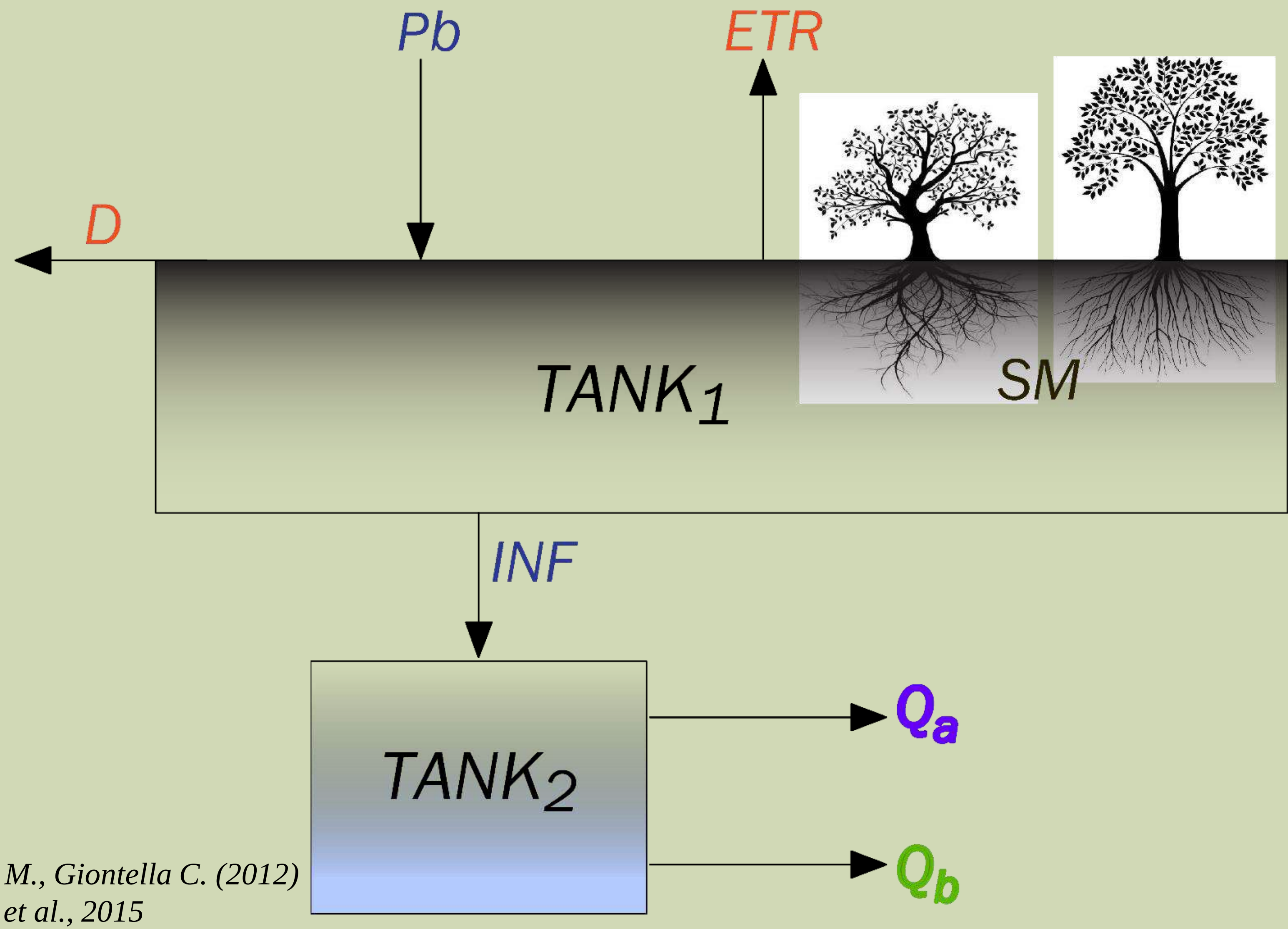
GEOLOGICAL SETUP OF THE AQUIFER



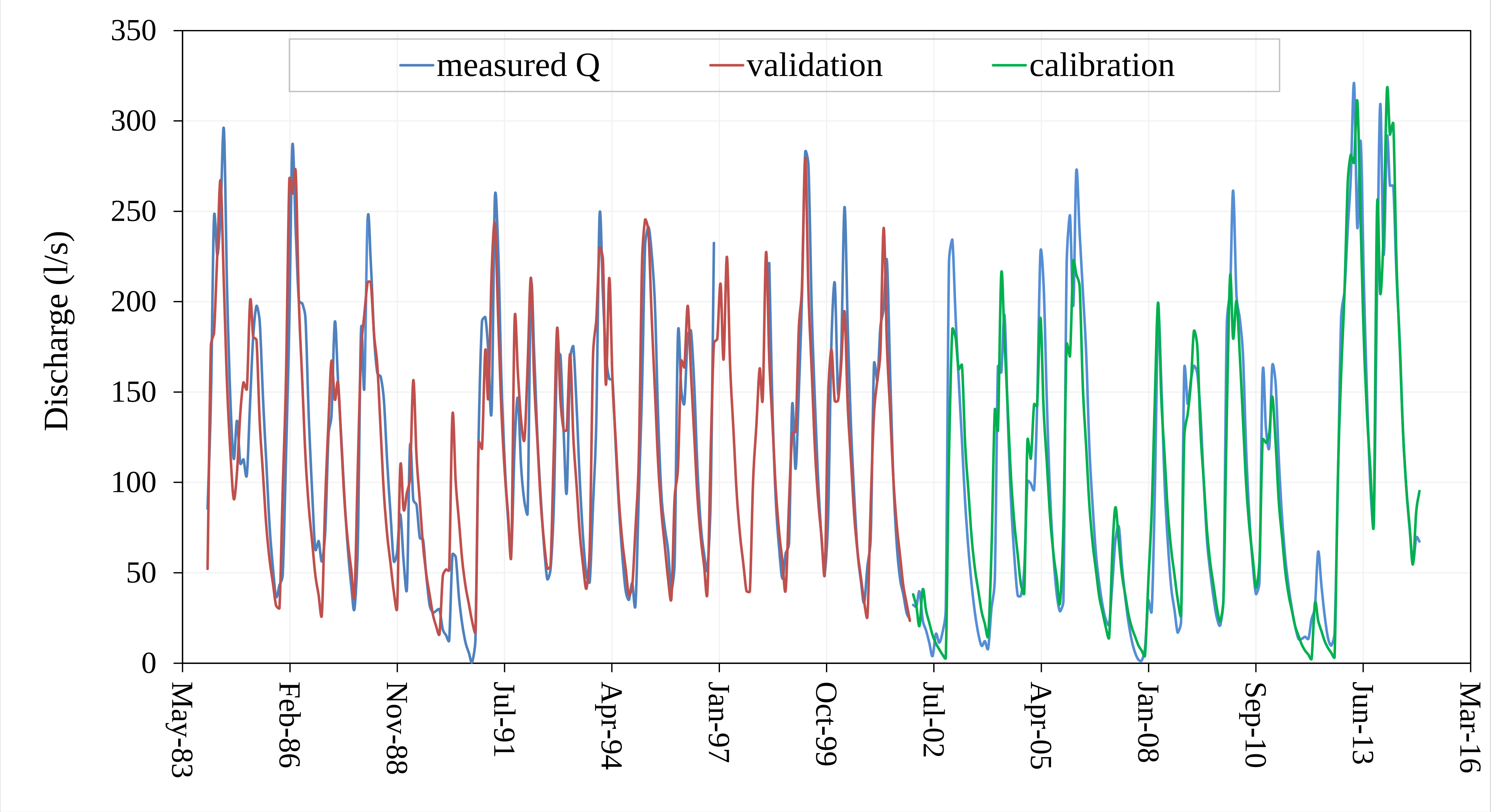
After Cambi and Dragoni, 2000; Dragoni et al., 2015

Structure of the model SPRING

- the model is lumped and on a monthly basis;
- the transformation of rainfall into evaporation, runoff, and aquifer recharge is simulated by semi-empirical formulas;
- groundwater flow is simulated with the Darcy equation, neglecting non-Darcian flow;
- the model performs month-by-month water balance of each component and the whole system;
- the optimization criterion is based on least squares.



After Dragoni W., Melillo M., Giontella C. (2012)
Giontella, 2013; Dragoni et al., 2015



Measured data P & T 1984 - 2014

GCMs used to built future climates scenarios: CMCC, Ecearth, Hadcm3, with downscaling (IPCC, 2021).

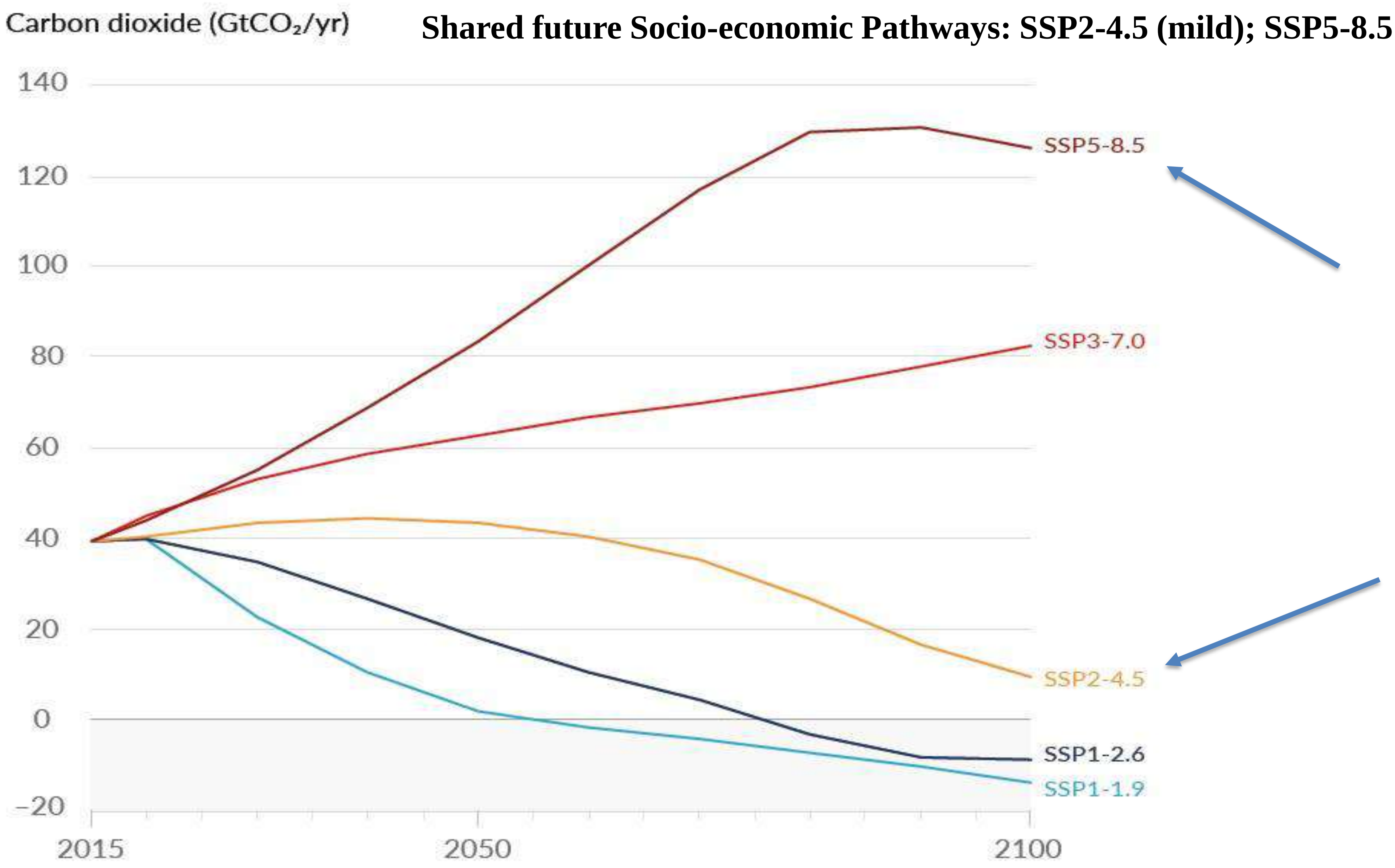
IPCC Shared future Socio-economic Pathways: SSP2-4.5 (mild); SSP5-8.5 (severe).

Measured data (HISTORICAL): T, P, Q (1984 – 2014).

6 Simulated data sets of the future (2024 -2054) 6 Scenarios of monthly T & P

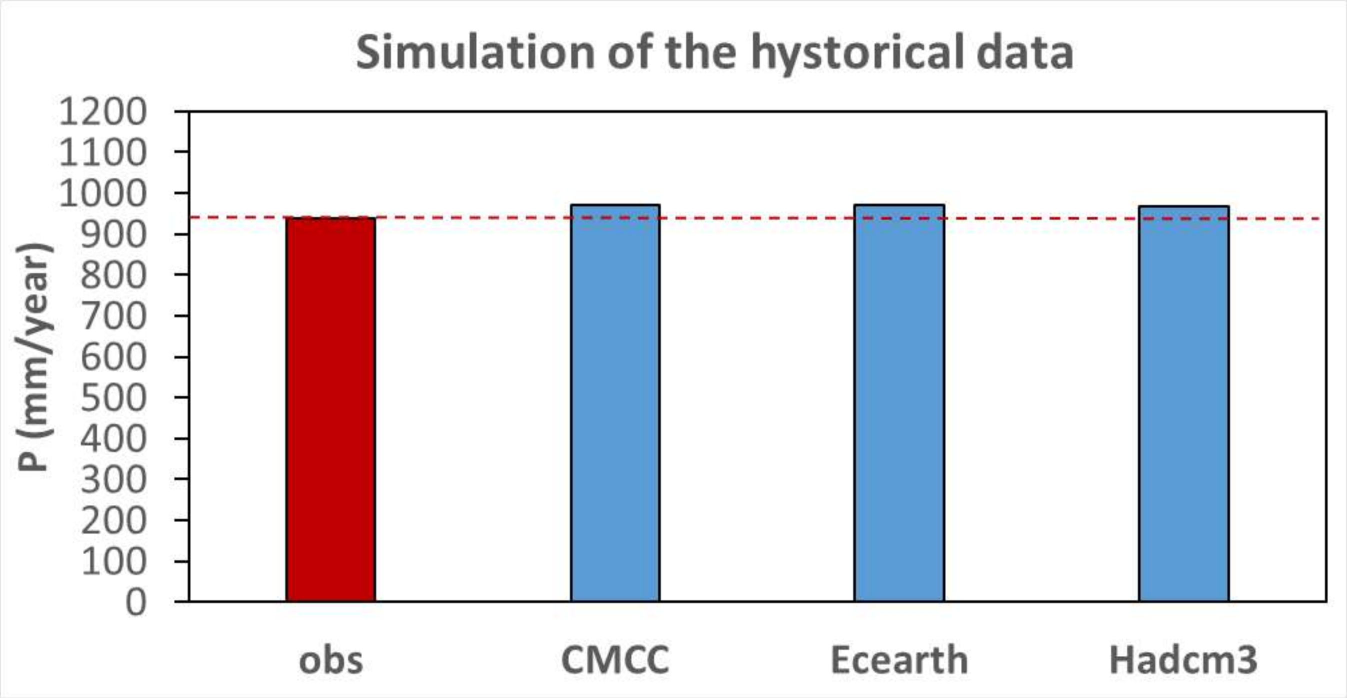
3 Simulated data sets of the HISTORICAL T & P (1984-2014), as a control of the performance of the Climatic Models

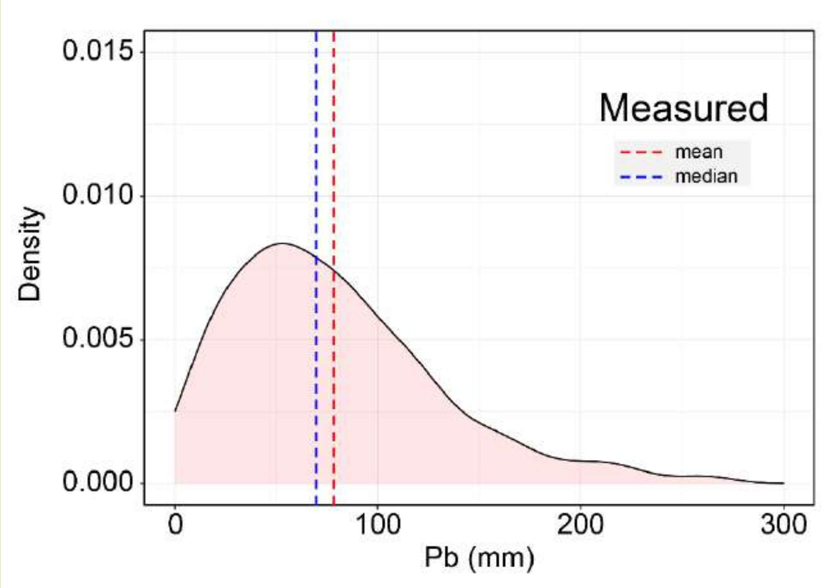
Shared future Socio-economic Pathways: SSP2-4.5 (mild); SSP5-8.5 (severe).

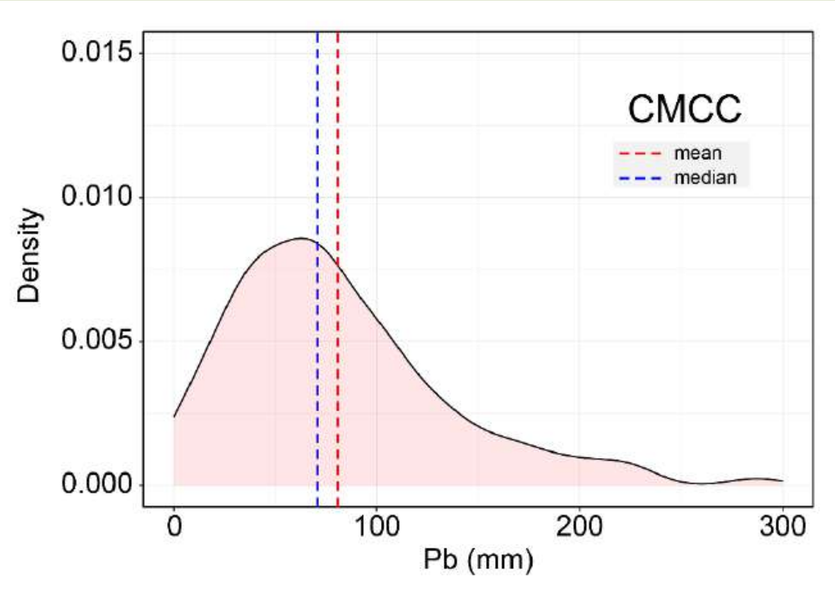


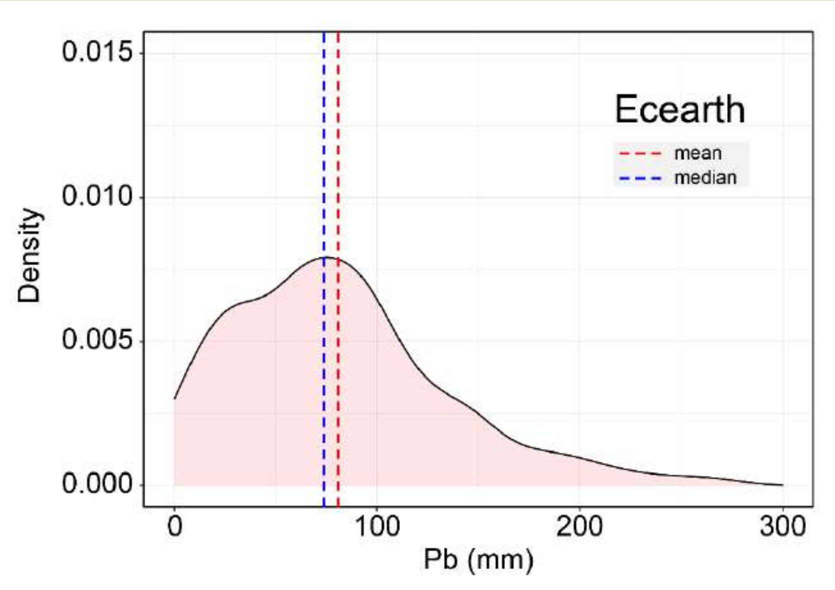
RESULTS (on a yearly basis)

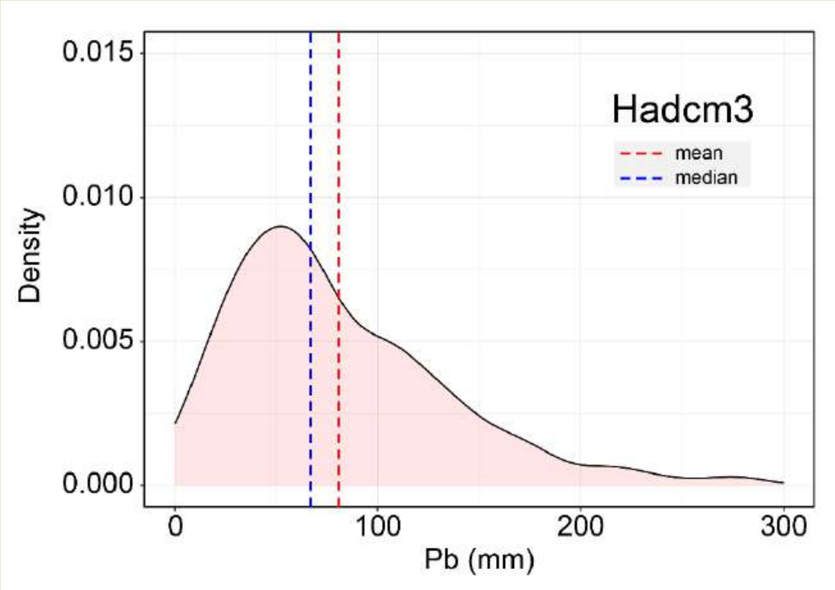
Serie	P med (mm)	DP (%)	T med (°C)	DT (°C)	Q med (l/s)	DQ (%)
Measured	940		8,5		119	
HIST_CMCC	969	3	8,8	0,3	117	6
HIST_Ecearth	971	3	8,8	0,3	119	7
HIST_Hadcm3	969	3	8,8	0,3	117	6
ssp245_CMCC	805	**-14**	10,5	2,1	82	**-27**
ssp585_CMCC	826	**-12**	10,9	2,4	93	**-16**
ssp245_ECearth	1022	9	10,0	1,6	141	27
ssp585_ECearth	1066	13	9,9	1,4	155	39
ssp245_Hadcm3	975	4	10,9	2,4	124	12
ssp585_Hadcm3	906	**-4**	11,4	2,9	111	0

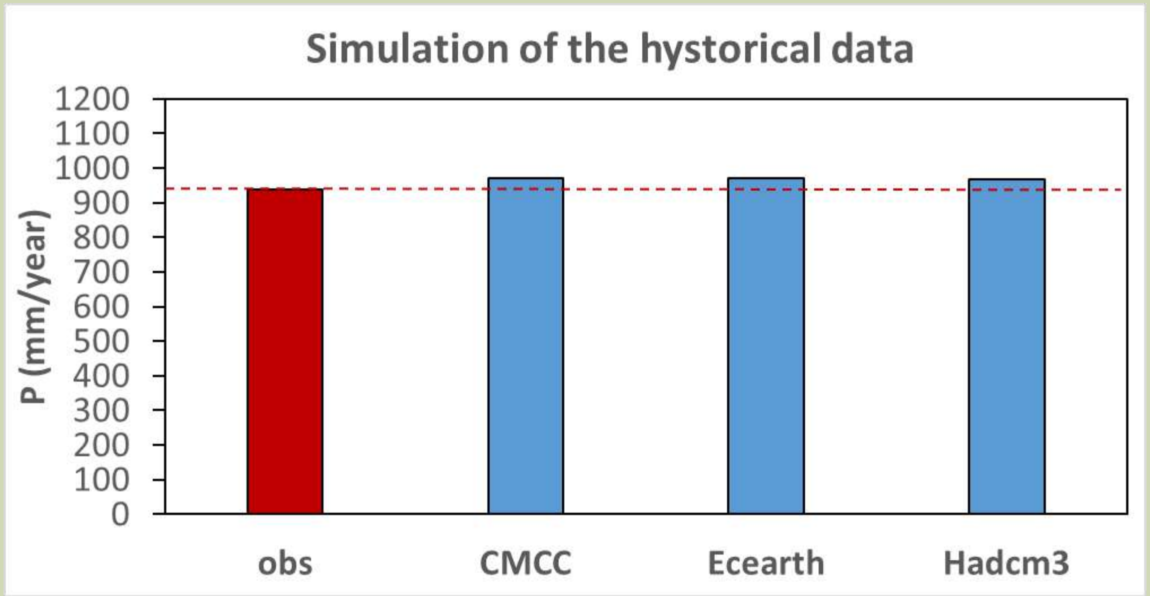

Simulation of the hystorical data
P (mm/year)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
obs
CMCC
Ecearth
Hadcm3


Measured
mean
median
Density
0.015
0.010
0.005
0.000
0
100
200
300
Pb (mm)

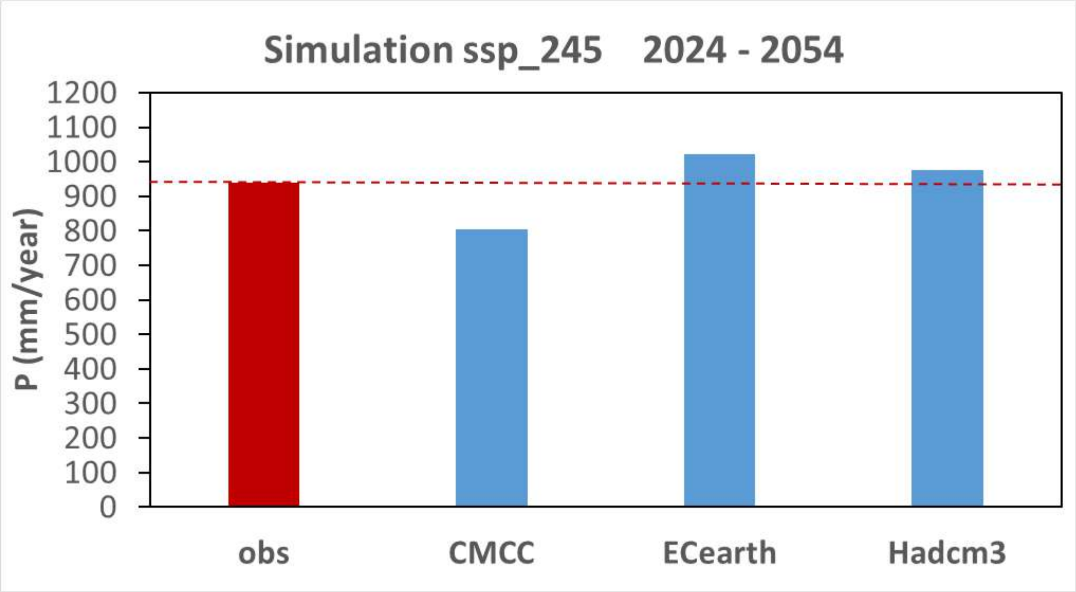

CMCC
mean
median
Density
0.015
0.010
0.005
0.000
0
100
200
300
Pb (mm)

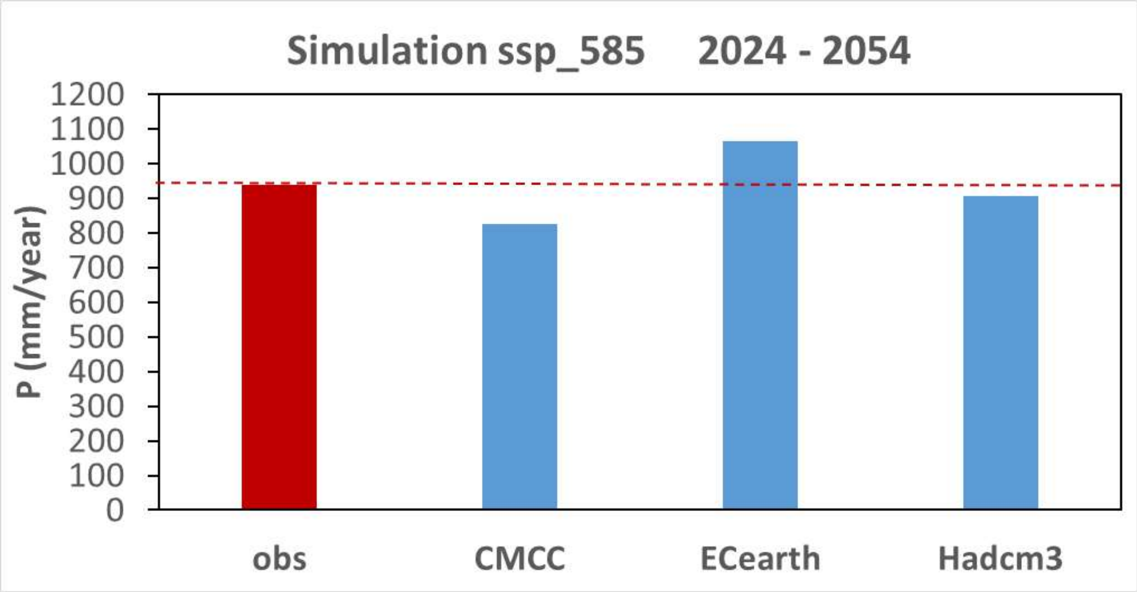

Ecearth
mean
median
Density
0.015
0.010
0.005
0.000
0
100
200
300
Pb (mm)


Hadcm3
mean
median
Density
0.015
0.010
0.005
0.000
0
100
200
300
Pb (mm)

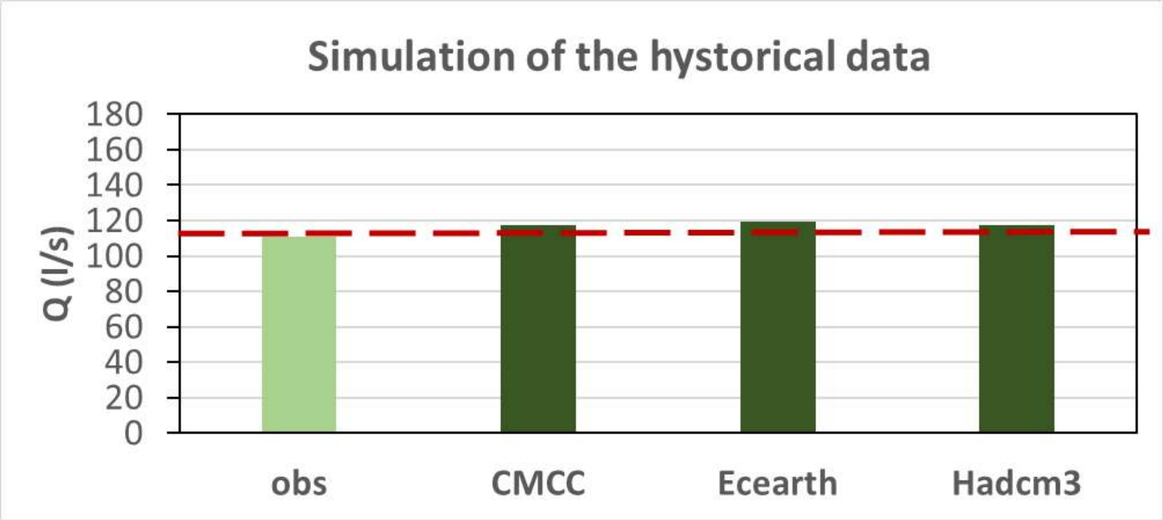


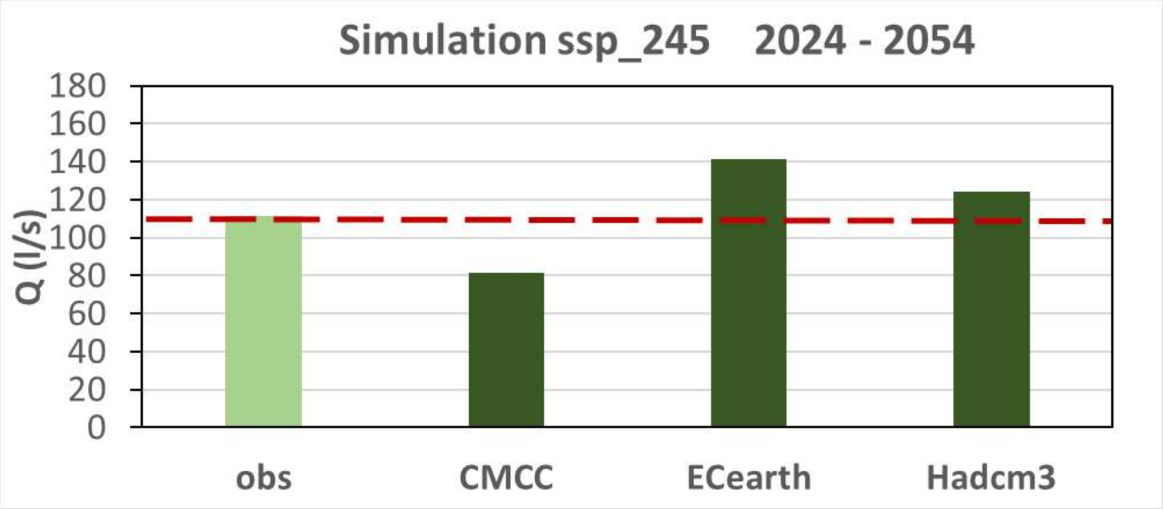
Average yearly precipitations P (mm/y)

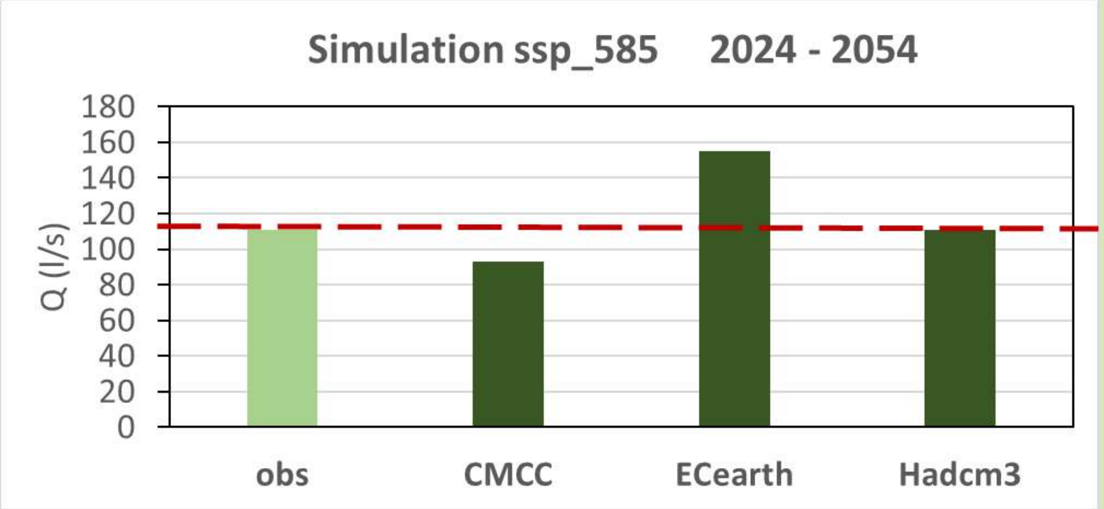




Average Bagnara Spring Discharge Q (l/s)







This uncertainty, in mountainous areas, is not uncommon. In the Tiber headwaters area, e.g., the models give the following scenarios:

Measured precipitation: 1981 – 2013 1320 (mm/y)

Future scenarios: 2070 – 2100 ~ 1120 (mm/y): Bucchignani et al., 2017, IPCC scenario RCP8.5.

~1300 (mm/y): Bucchignani et al., 2017, IPCC scenario RCP4.5.

~ 570 (mm/y) or less: Alessandri et al., 2014, statistical approach.

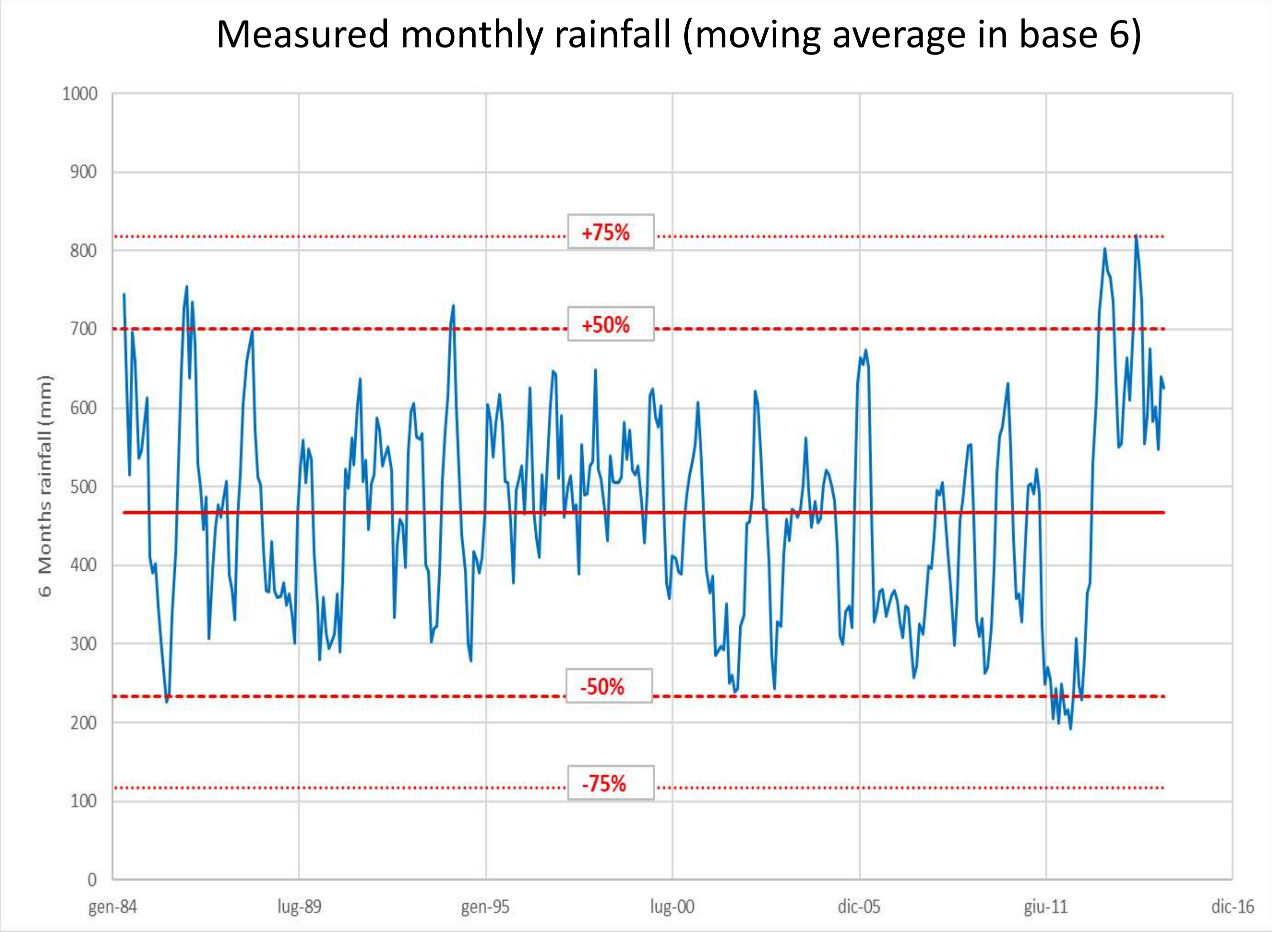
Di Matteo, Dragoni et al., 2017, obtained a scenario in the range of Bucchignani et al. by extrapolating present trends on a yearly and seasonal basis.

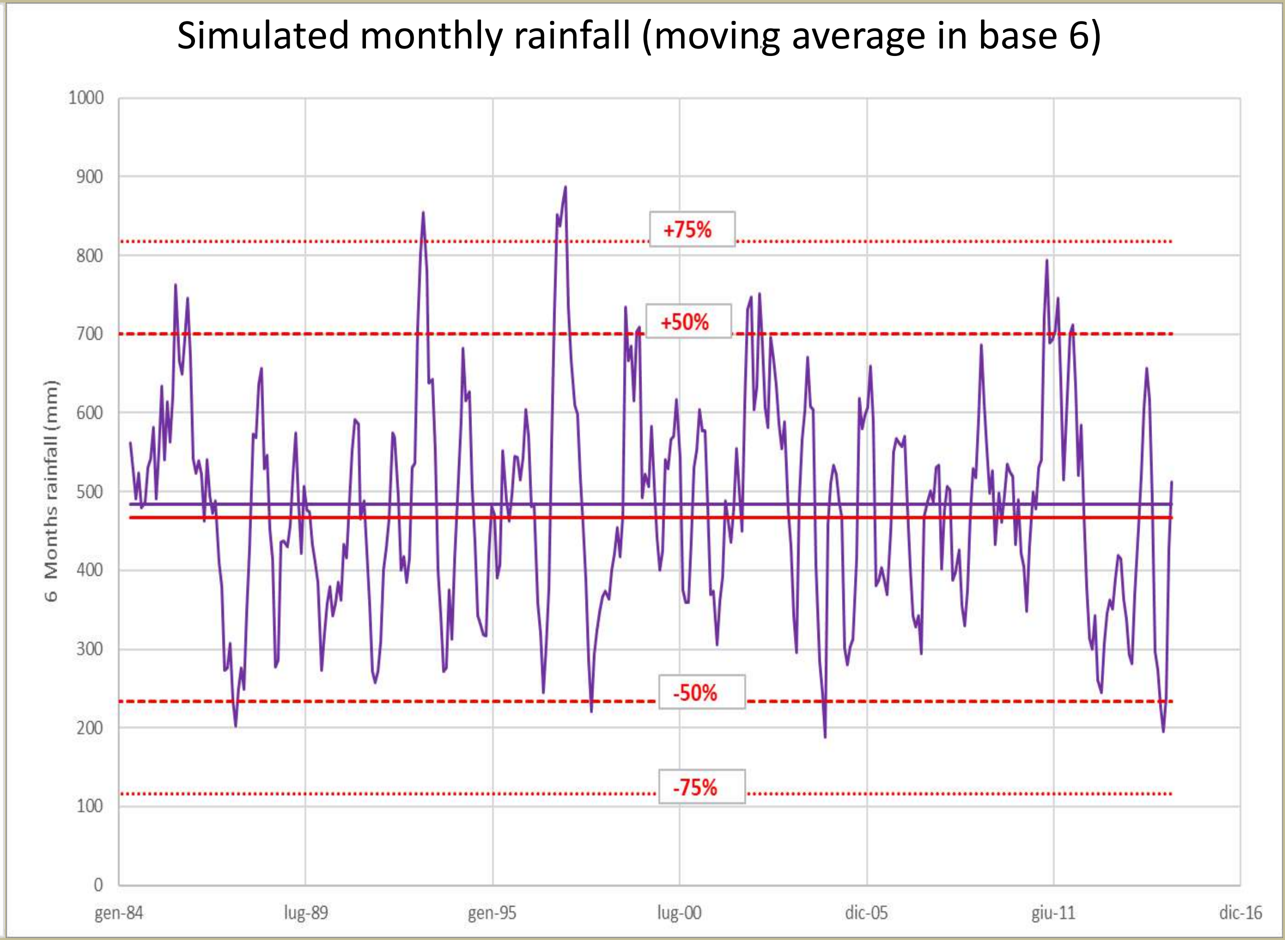
Smerdon, 2017: “A synopsis of climate change effects on groundwater recharge”, Journal of Hydrology:

This synopsis identified six recent publications that review the state of climate change and Groundwater….
The reviews have several common conclusions. The uncertainty in GCMs and downscaling method ……leads to widely varying results for predicted recharge. Often, recharge studies are not able to clearly indicate the magnitude and direction (increase or decrease) of future groundwater recharge because the GCMs themselves do not agree.

Monthly rainfall 1984 – 2014 (moving average in base 6)

Difference between measured and simulated rainfall by CMCC model.

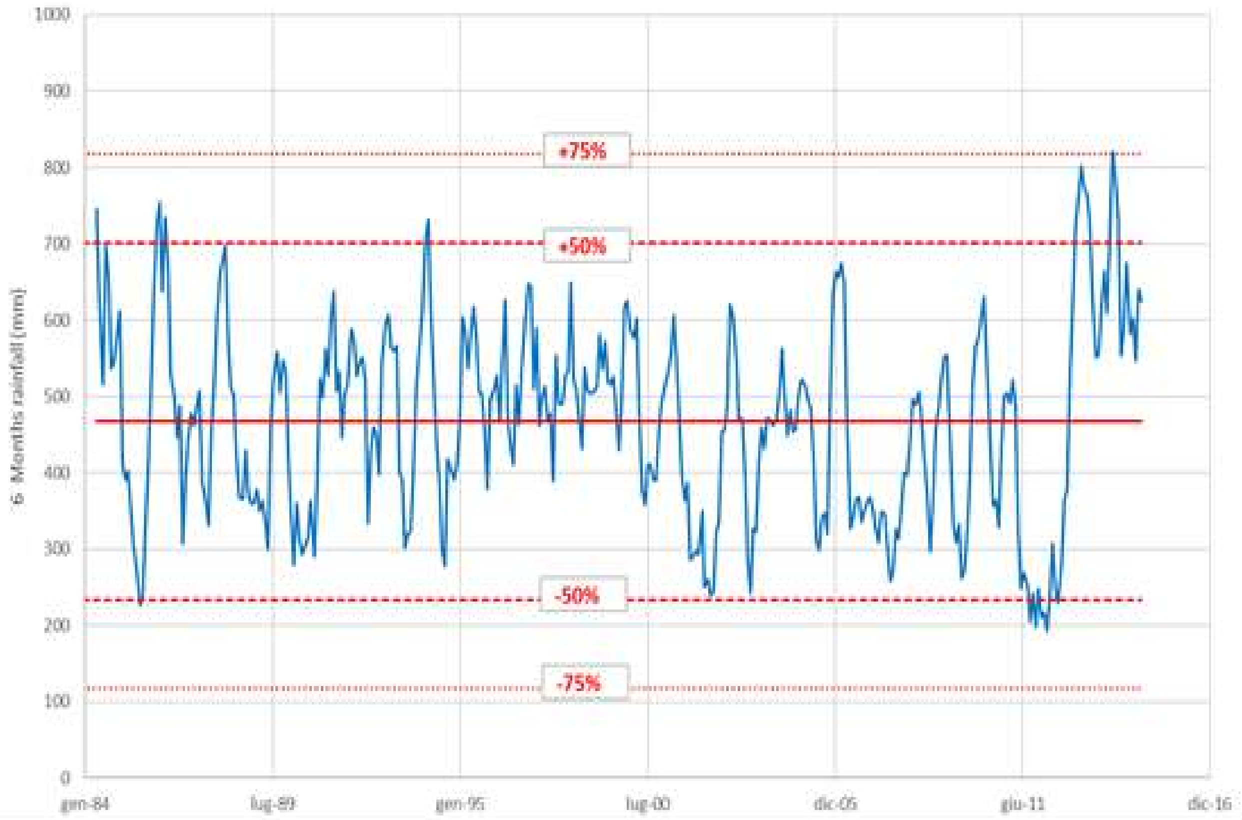




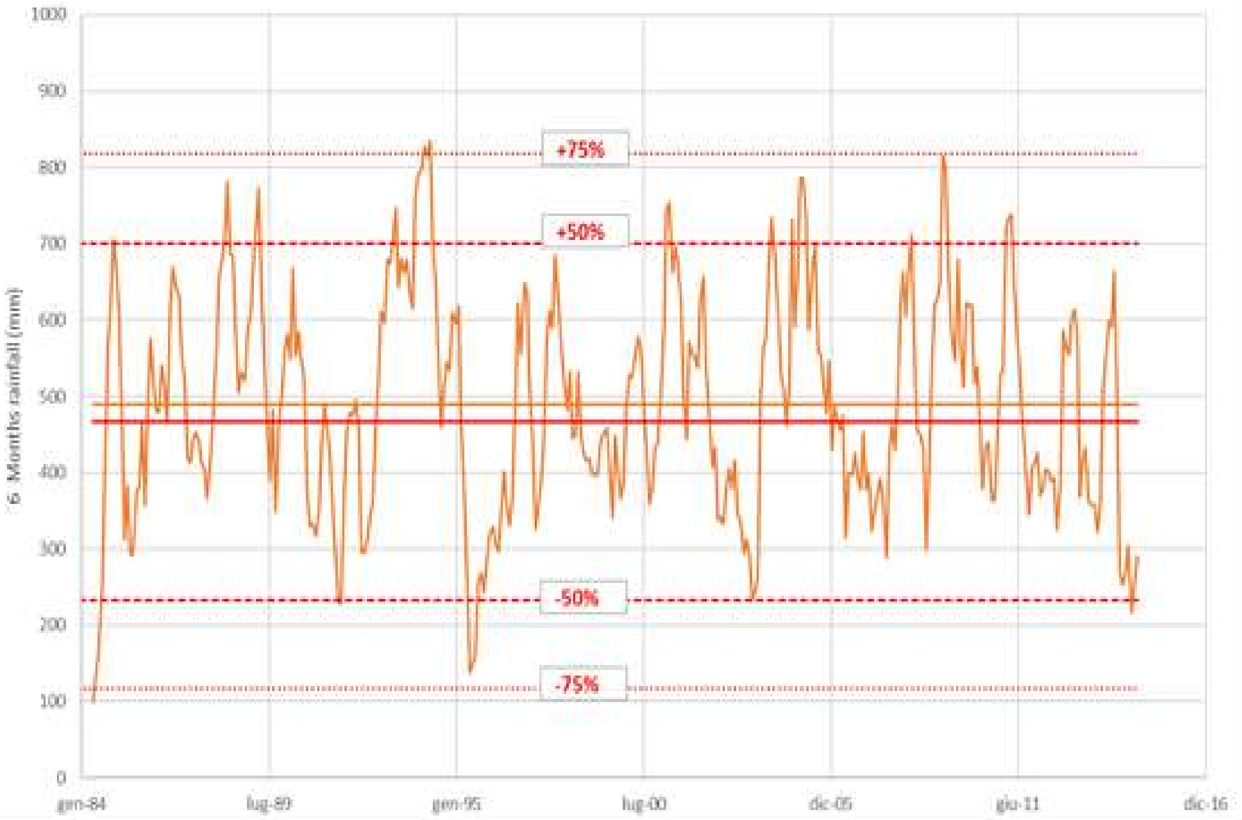
Monthly rainfall 1984 – 2014 (moving average in base 6)

Difference between measured and simulated rainfall by

Measured monthly rainfall (moving average in base 6)



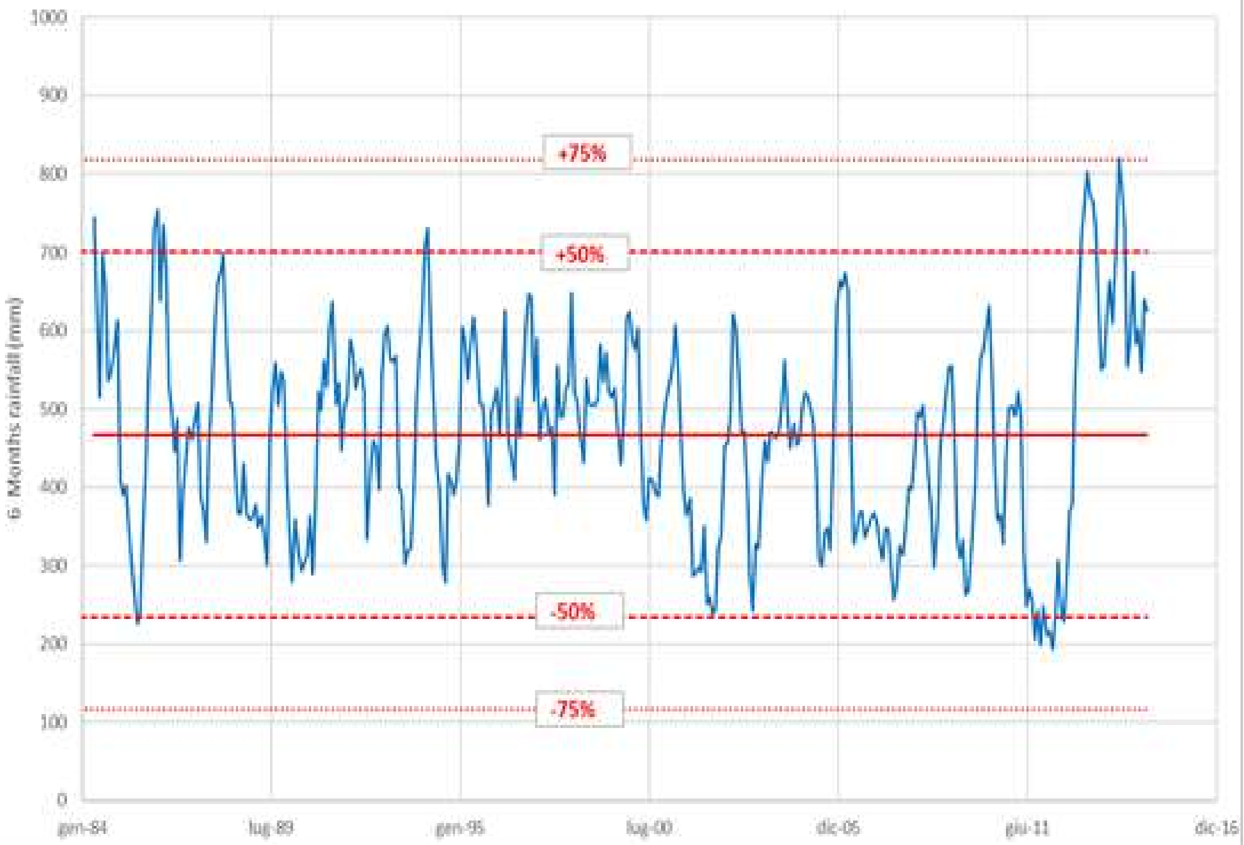
Simulated monthly rainfall (moving average in base 6)



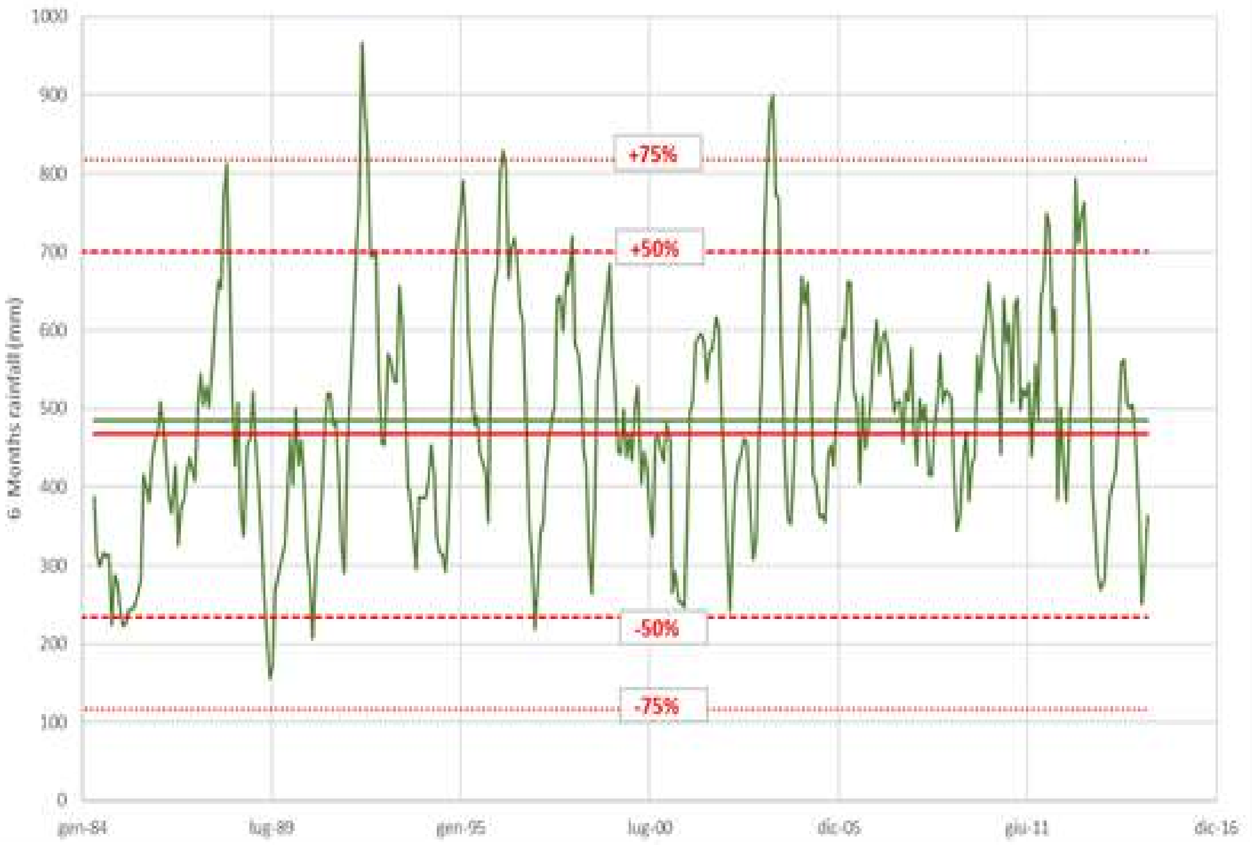
Monthly rainfall 1984 – 2014 (moving average in base 6)

Difference between measured and simulated rainfall by model Hadcm3

Measured monthly rainfall (moving average in base 6)



Simulated monthly rainfall (moving average in base 6)



Similar results are also obtained with base 3, 6, 12, 24 and moving averages.

DISCUSSION & CONCLUSIONS

- This work confirms that, at present, GCMs provide conflicting rainfall scenarios in the area considered here.

- Uncertainty affects both the annual averages and the variability of the series.

- For consecutive periods of several months, the models amplify rainfall variability, with a tendency for high rainfall events to increase. This should be considered a bias, since amplification also affects the simulation of measured data.

- The characteristics of the simulated rainfall series impact the flow rates generated by the SPRING model, which are more variable than the measured ones, also in terms of periods with very high rainfalls.

- In these areas, it is impossible to confidently plan drastic actions to minimize not clearly defined impacts. At present, the goal to be pursued should be "not-regret actions," i.e., actions that in any case are not negative, neither from the points of view of water resources nor of the environment and economy: For instance, simply not polluting and not wasting water. And, of course, monitoring the evolution of the climate and of the yield of springs.


THANK YOU

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Towards groundwater-level prediction using Prophet forecasting method by exploiting a high-resolution hydrogeological monitoring system

Davide Fronzi[1], Alessandro Galdelli[2], Gagan Narang[2], Alessandro Pepi[1], Adriano Mancini[2], Alberto Tazioli[1]

1. Department of Science, Materials, Environmental Sciences and Urban Planning, Università Politecnica delle Marche

2. Department of Information Engineering , Università Politecnica delle Marche

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Climate change and Hydrological drought

The **causes are often debated**, while the **effects are worldwide recognized**, one of these is the **groundwater depletion**

The **Mediterranean area** is one of the most important "**hotspots**" where **the effects of climate change are more evident**

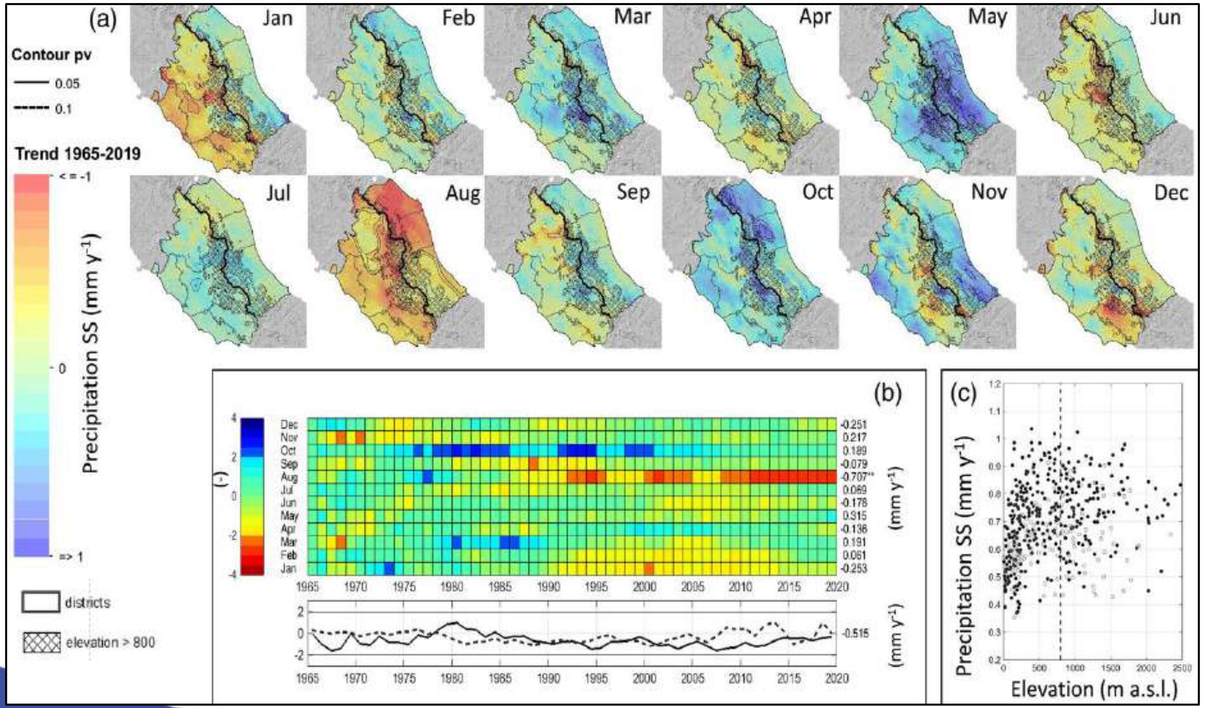
- **ITALIAN CONTEXT**

D.L. 39/2023 "**Decreto Siccità**"

Establishes a steering committee for **droughts monitoring and containment**

- **Art. 11**

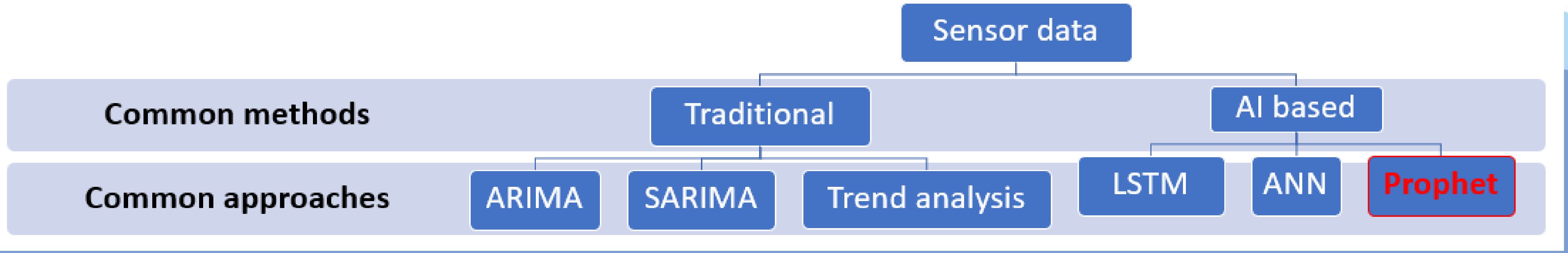
"The Permanent Observatory produces **FORECAST SCENARIOS**"



Romano et al., 2022

Groundwater Prediction and Artificial Intelligence

- Rapid increase in **sensor data** collected for groundwater management
- More than a hundred articles indicate **difficulty in dealing with nonlinear relationships between variables in groundwater time series** and make **suggestions for the use of intelligent models for improving prediction accuracy**
- Popular techniques such as Auto Regressive Integrated Moving Average **(ARIMA)**, Long Short-Term Memory **(LSTM)**, Artificial Neural Networks **(ANN)**
- Among the methods that are AI-based, **Prophet** seems to be an acceptable option to model groundwater time series due to its capability to capture different periodicities, including **seasonal patterns** associated with special events, and its ability to **incorporate non-periodic abrupt changes** (earthquakes, etc.)

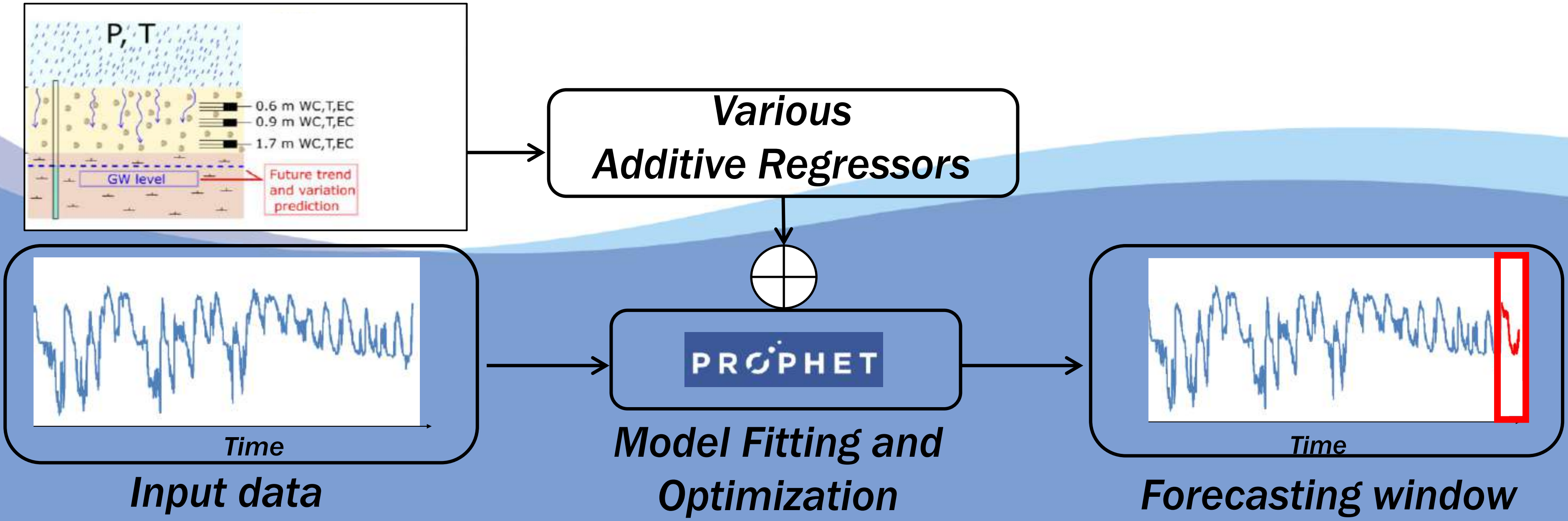


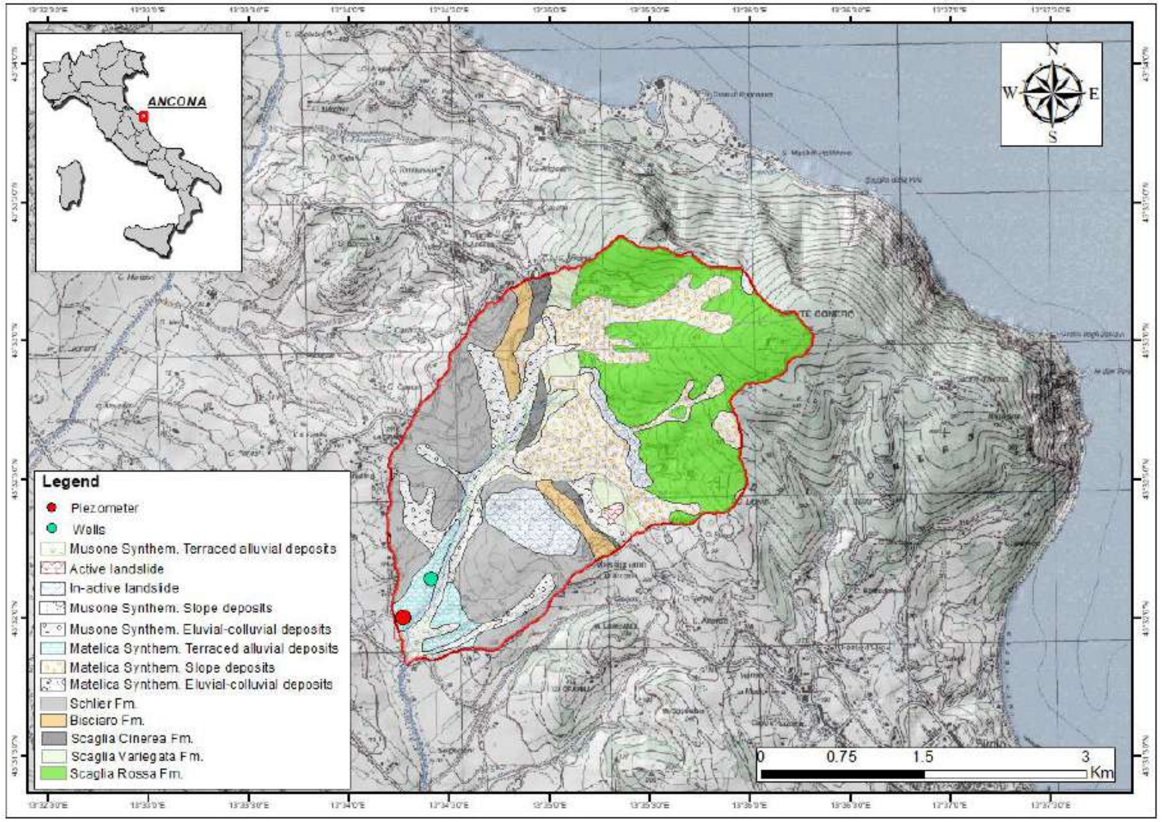
- Prophet is a ***machine learning-based forecasting model*** to make high-quality forecasts
- Decomposable ***time series model with three main model components: trend, seasonality, and holidays***

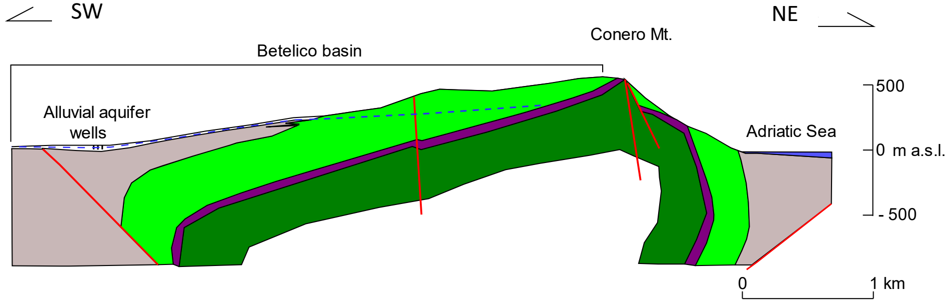
$$y(t)=g(t)+s(t)+h(t)+\varepsilon_t$$

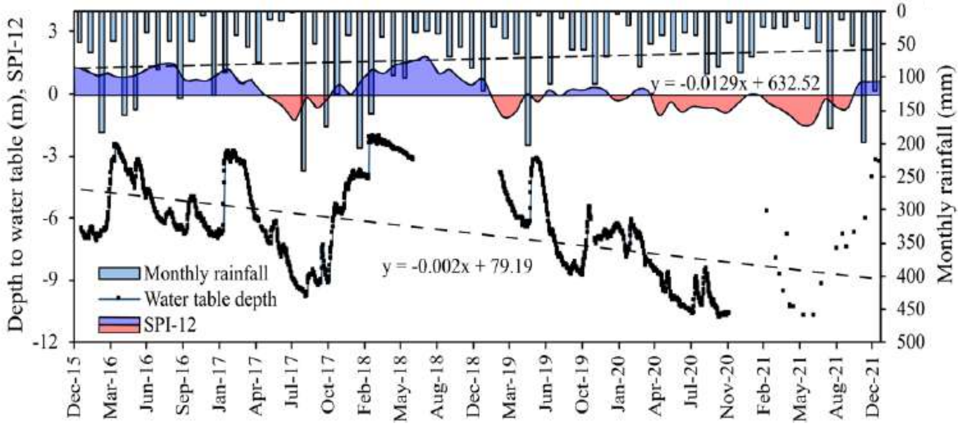
Where:

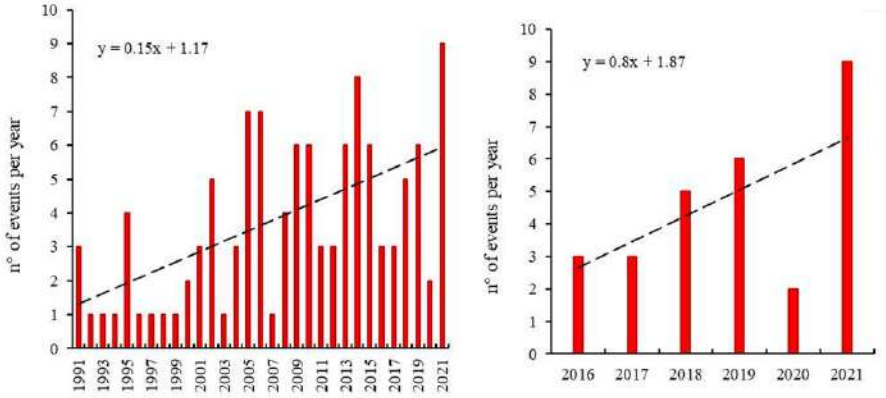
g(t): linear or logistic growth curve for modelling non-periodic changes in time series
s(t): periodic changes (e.g., weekly/yearly seasonality)
h(t): effects of holidays (user provided) with irregular schedules
ε_t: error term accounts for any unusual changes not accommodated by the model





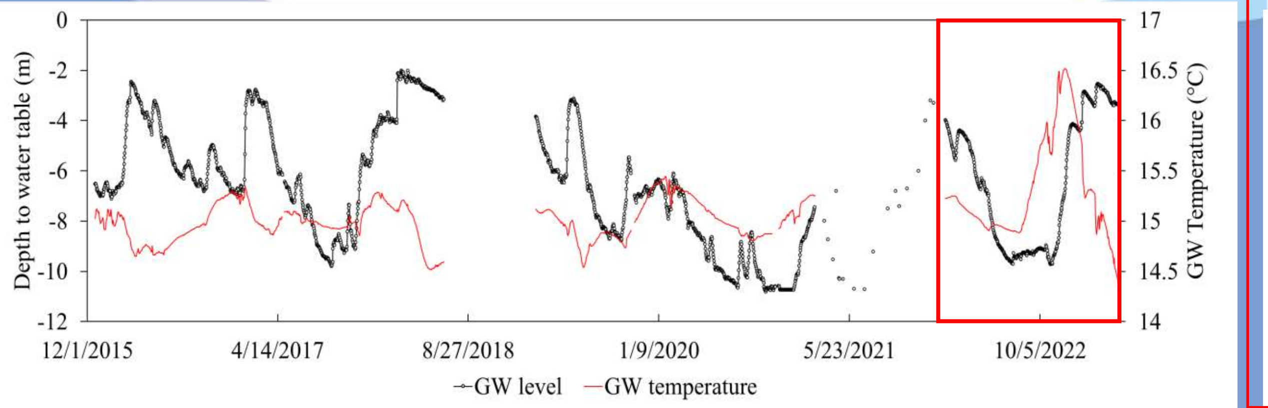


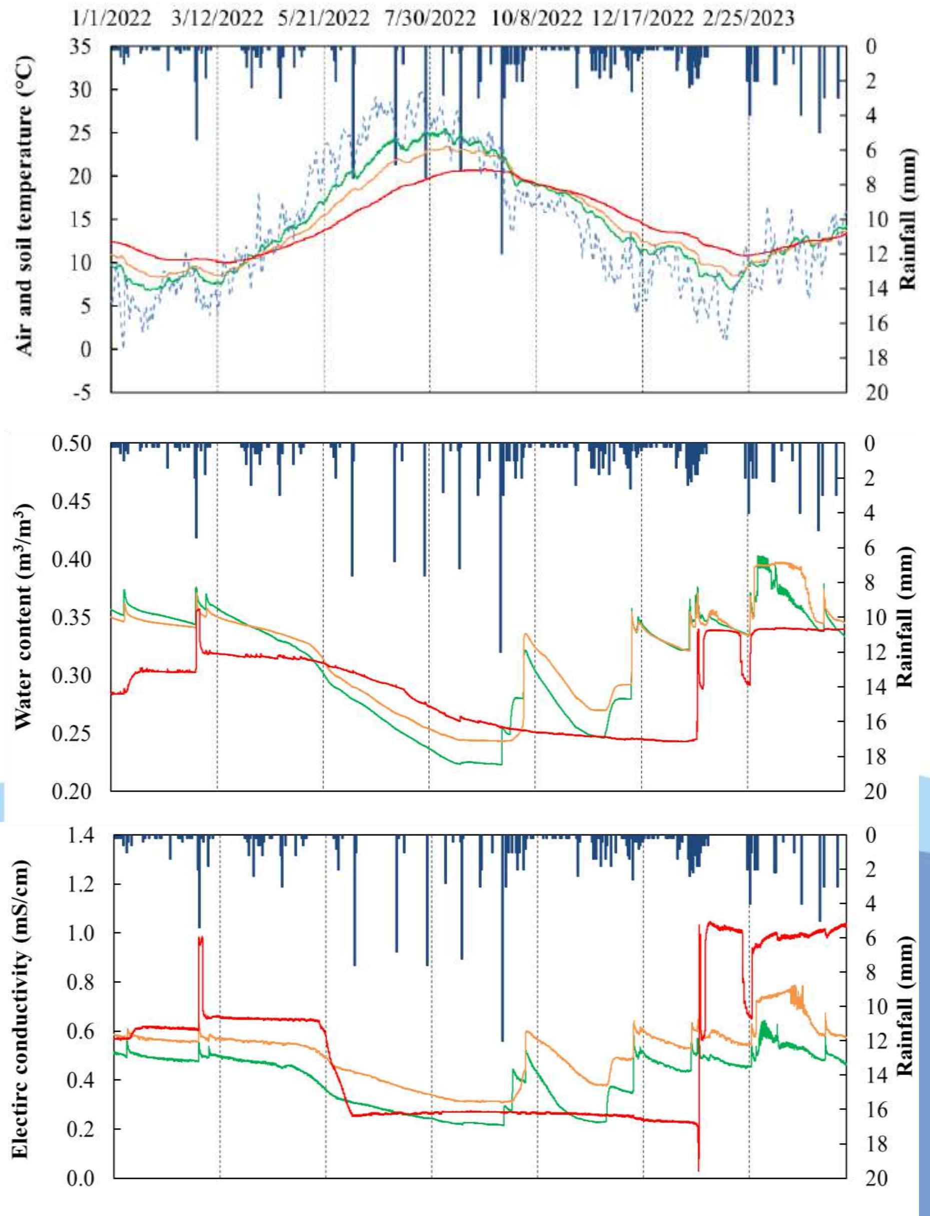




Fronzi et al., 2022

The lack of the meteoric recharge, due to a combined effect of decreasing precipitation trend and increase in storm rainfall events, was identified as the key driver of the water table drawdown for the years 2020 and 2021





Legend

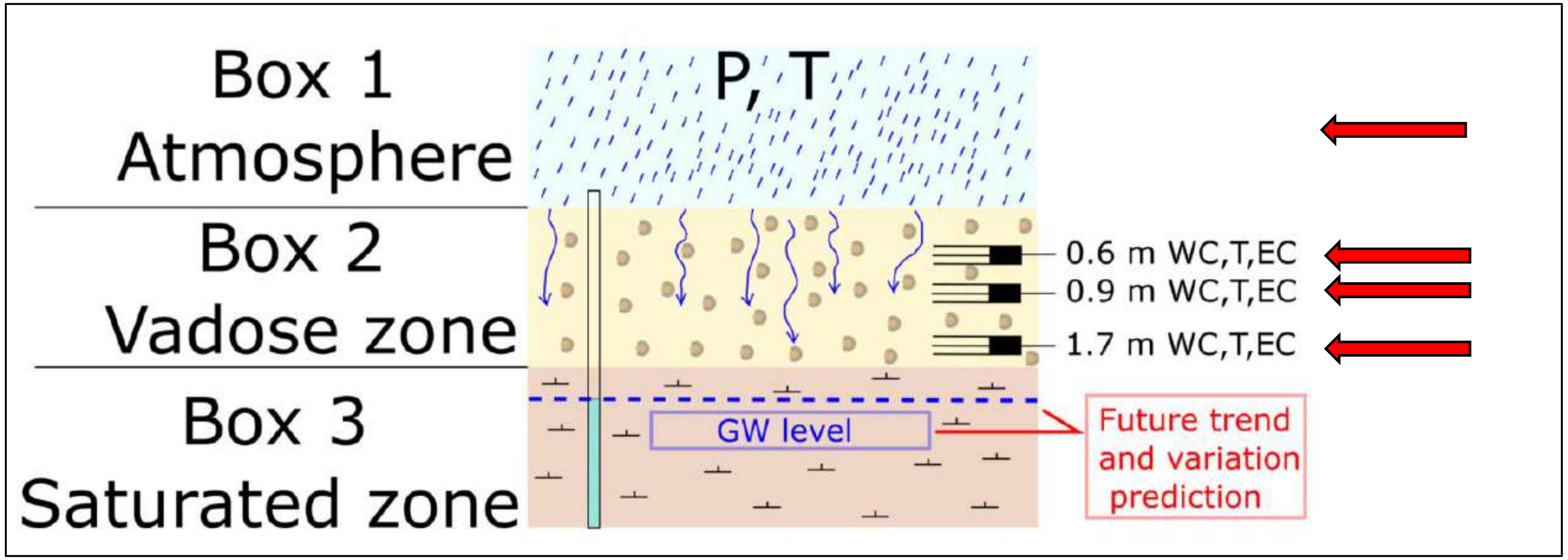
Rainfall

Air temperature

0.6 m b.g.l.

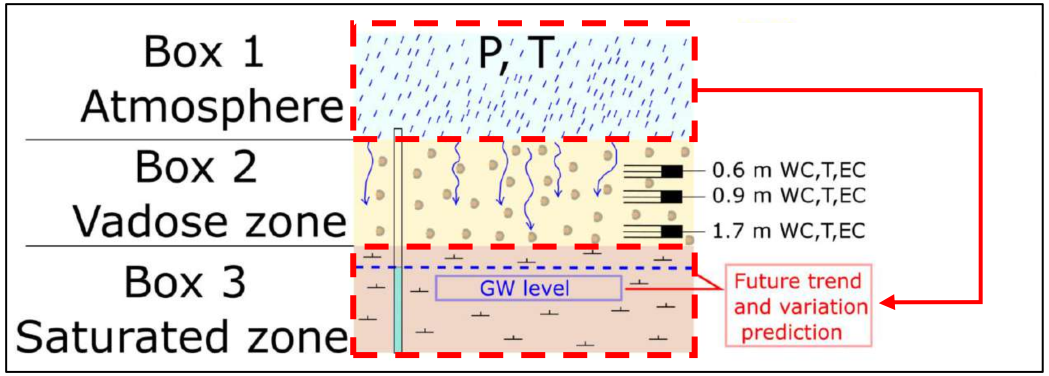
0.9 m b.g.l.

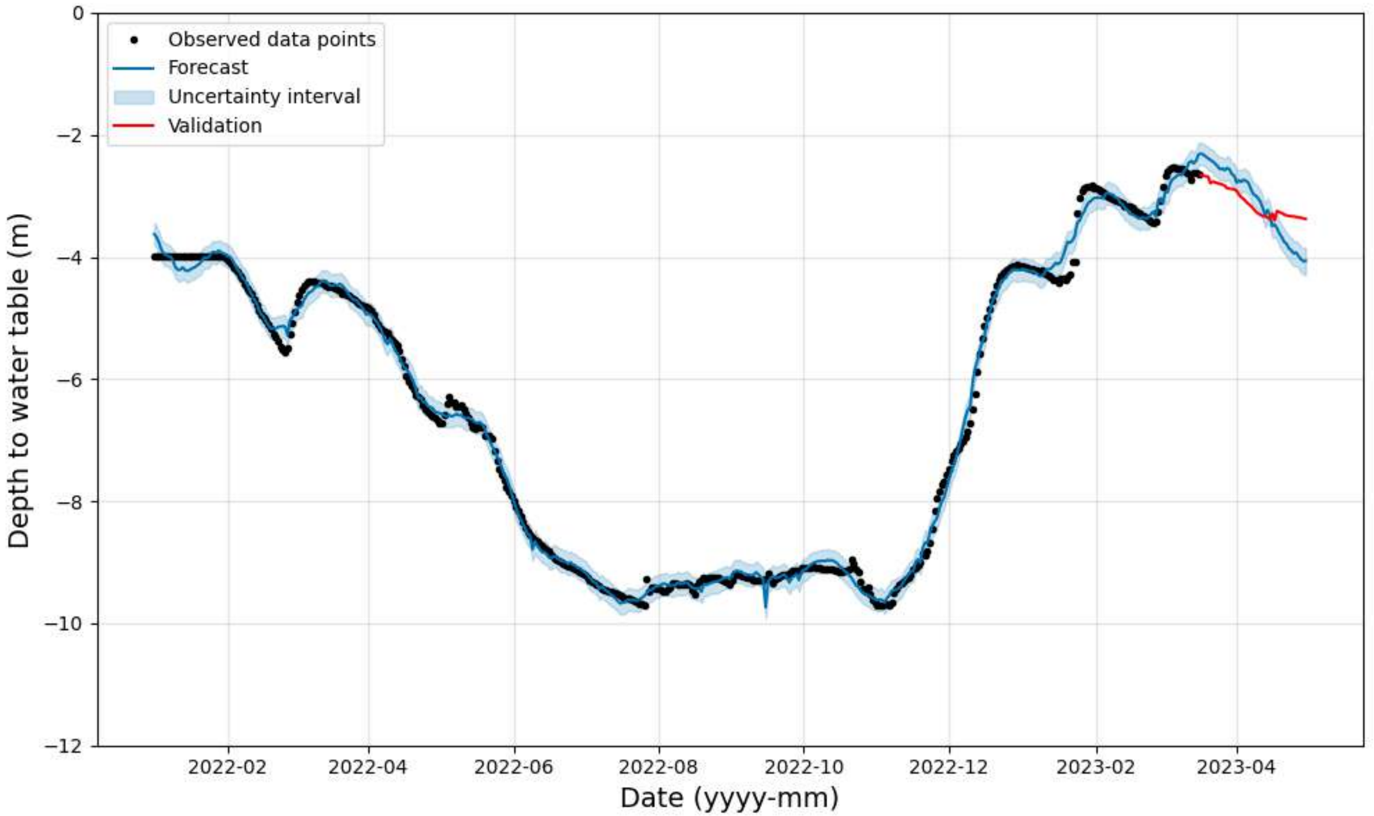
1.7 m b.g.l.



Test Serial No.	Scenario	Prediction using Prophet	Regressor
Test 1	Box 1 → Box 3	GW level	Precipitation, Air Temperature
Test 2	Box 2 → Box 3	GW level	Water Content, Soil Temperature, Electrical Conductivity

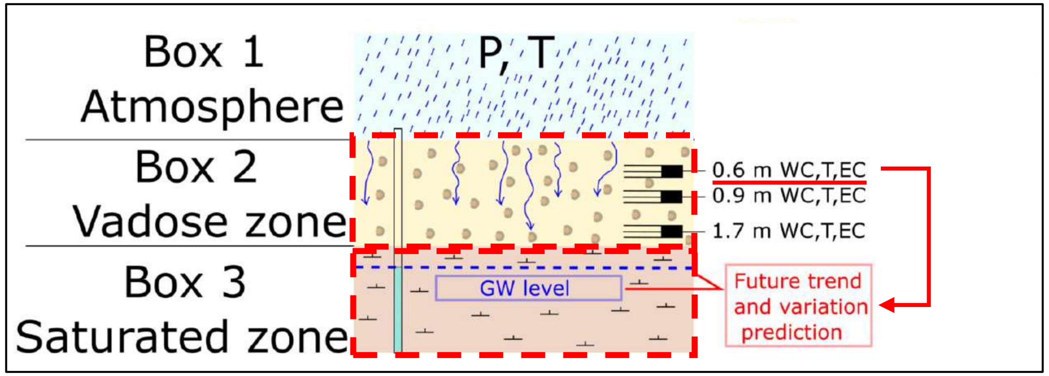
Test 1: Box 1 → Box 3



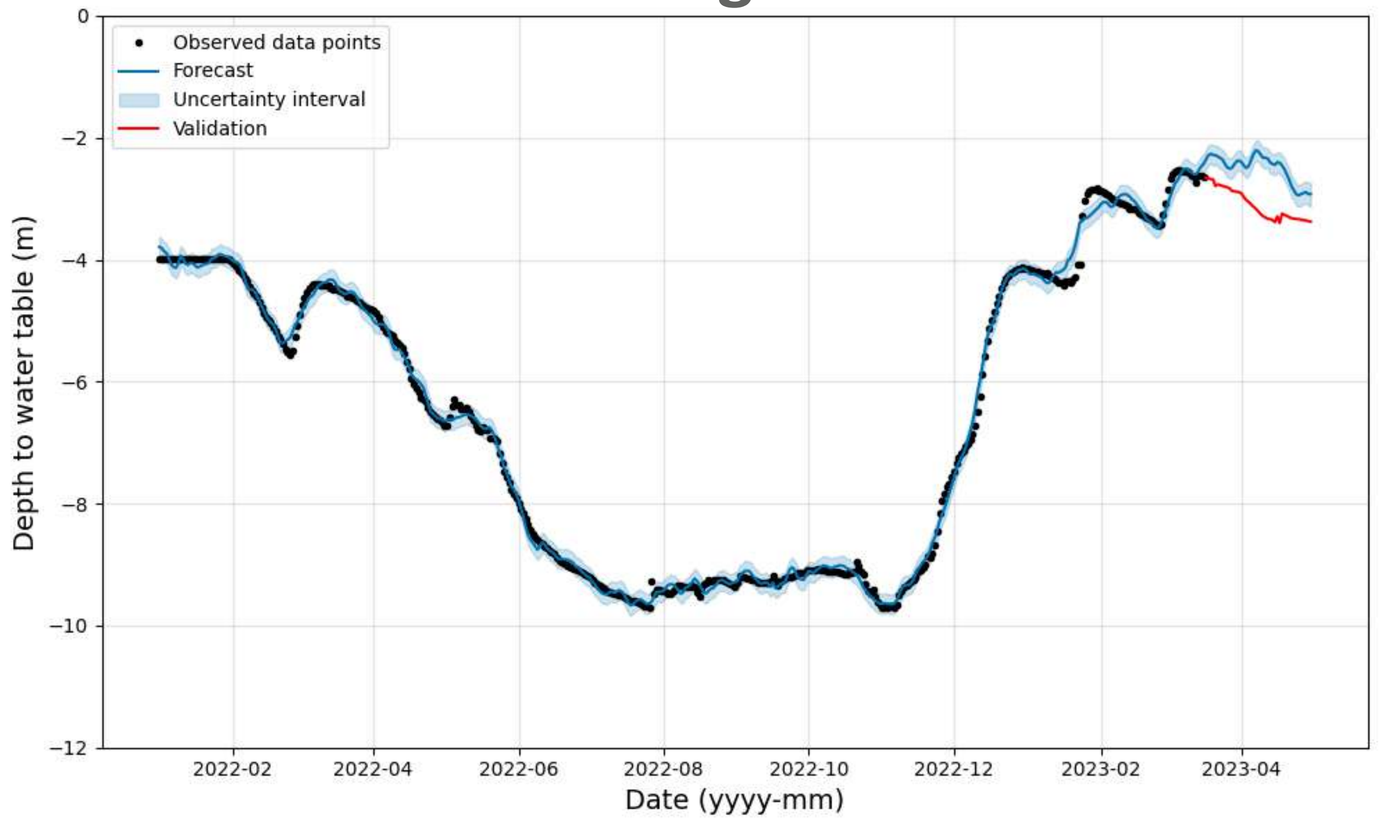


Test Serial No.	Scenario	Additive Regressors	Forecast Metric	Value
Test 1	**Box 1 → Box 3**	Precipitation, Air Temperature	MAE	0.33
			MAPE	0.11
			Correlation (%)	**89.01%**

Test 2.1: Box 2 at 0.6 m → Box 3

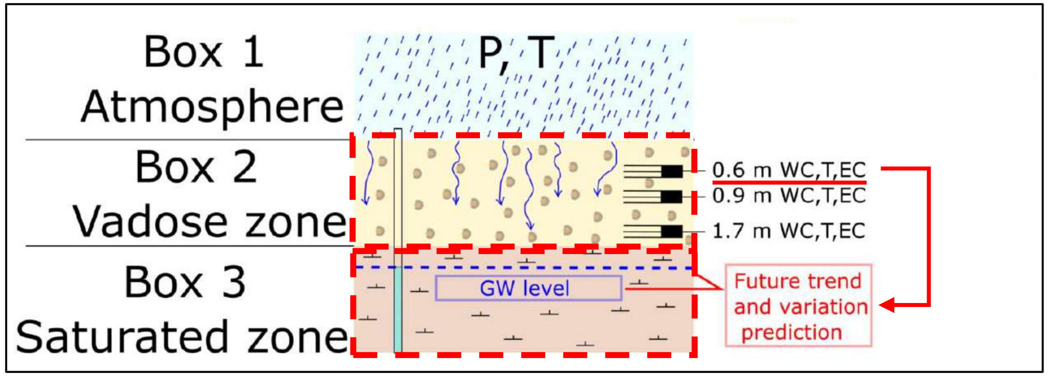


All regressors

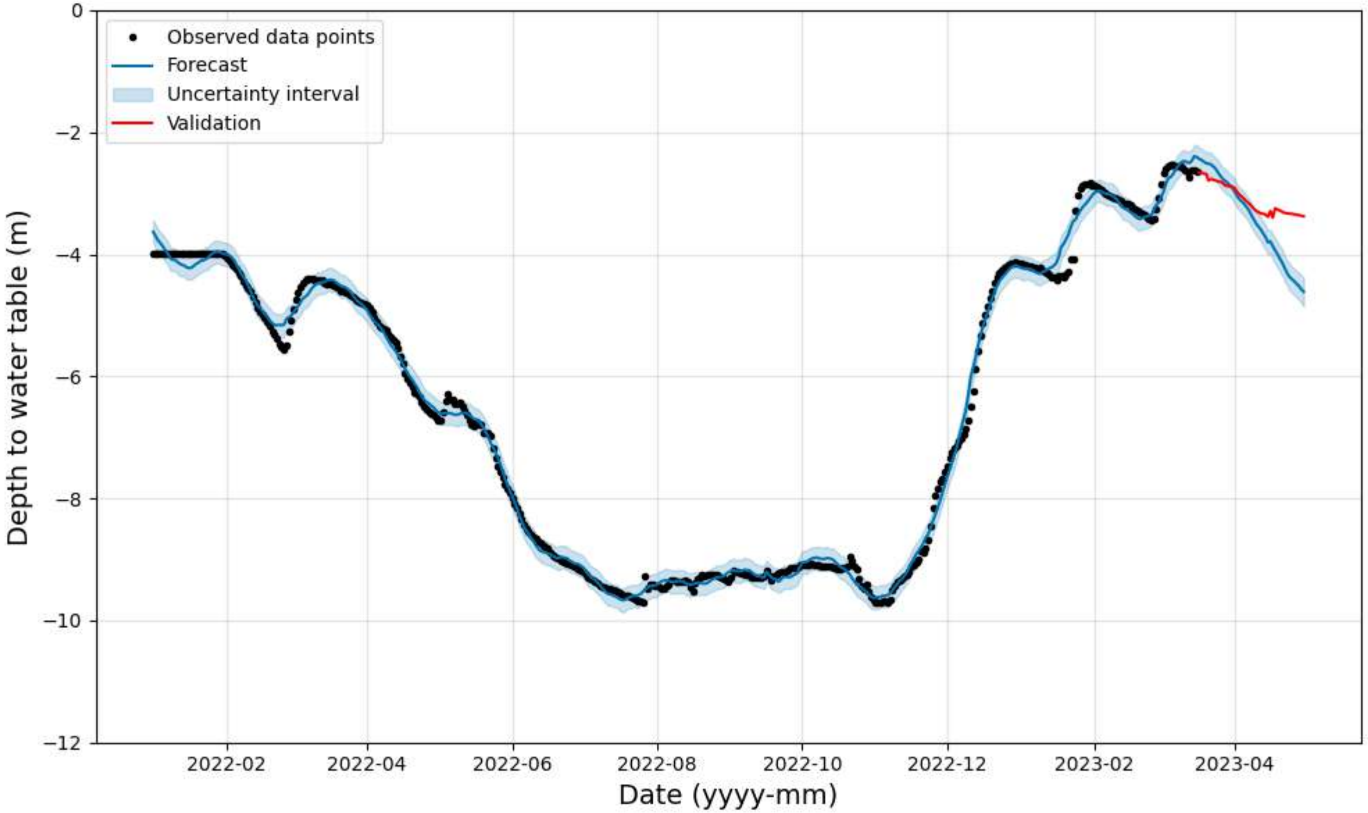


Test Serial No.	Scenario	Additive Regressors	Forecast Metric	Value
Test 2.1	**Box 2 → Box 3**	Water Content, Soil Temperature, Electrical Conductivity measured at 0.6 m	MAE	0.61
			MAPE	0.19
			Correlation (%)	**53.16%**

Test 2.1: Box 2 at 0.6 m → Box 3

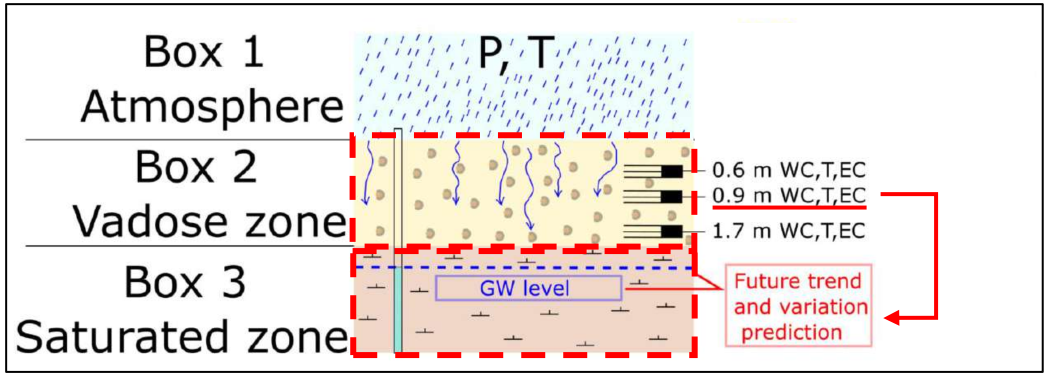


Excluding soil temperature

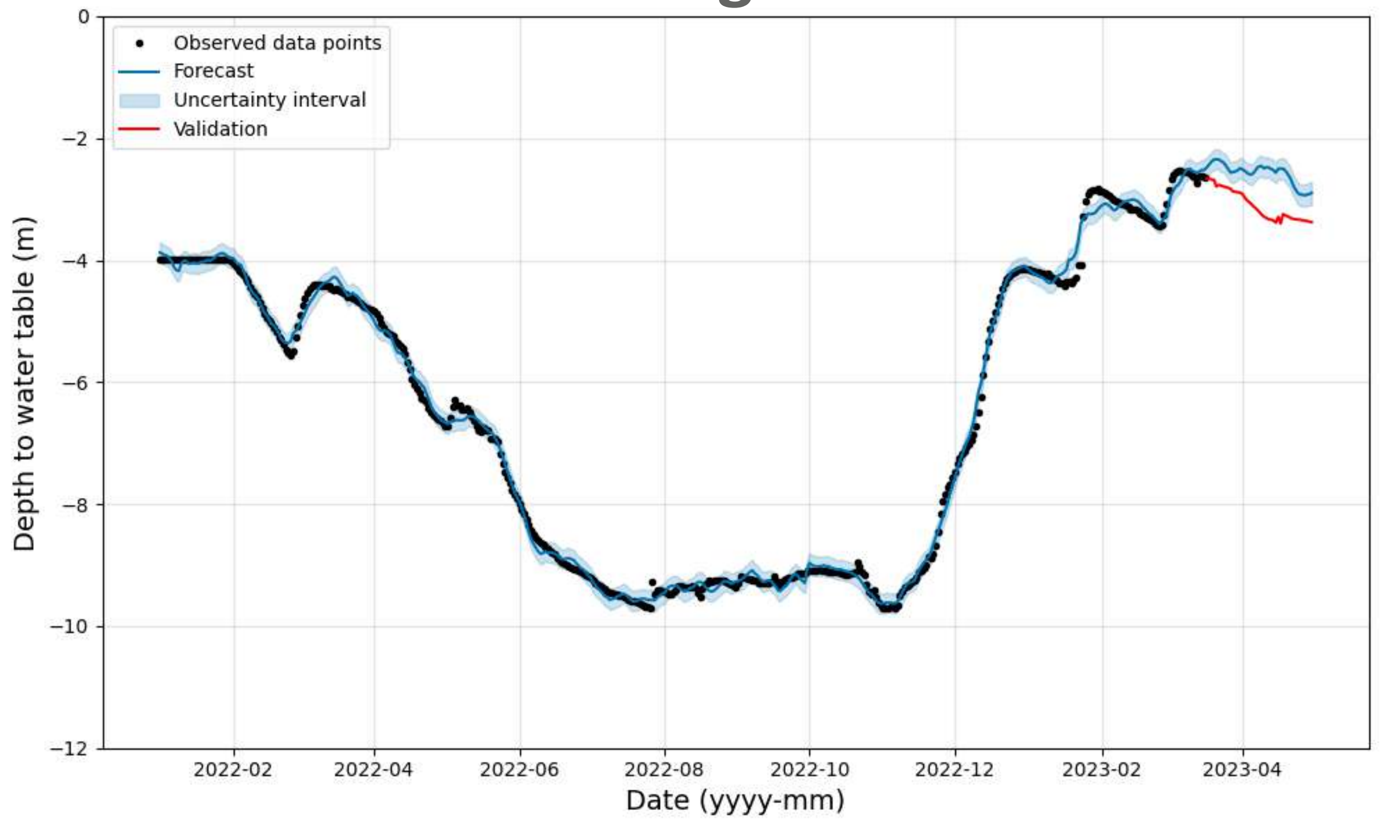


Test Serial No.	Scenario	Additive Regressors	Forecast Metric	Value
Test 2.1	**Box 2 → Box 3**	Water Content, Electrical Conductivity measured at 0.6 m	MAE	0.42
			MAPE	0.13
			Correlation (%)	**92.49%**

Test 2.2: Box 2 at 0.9 m → Box 3

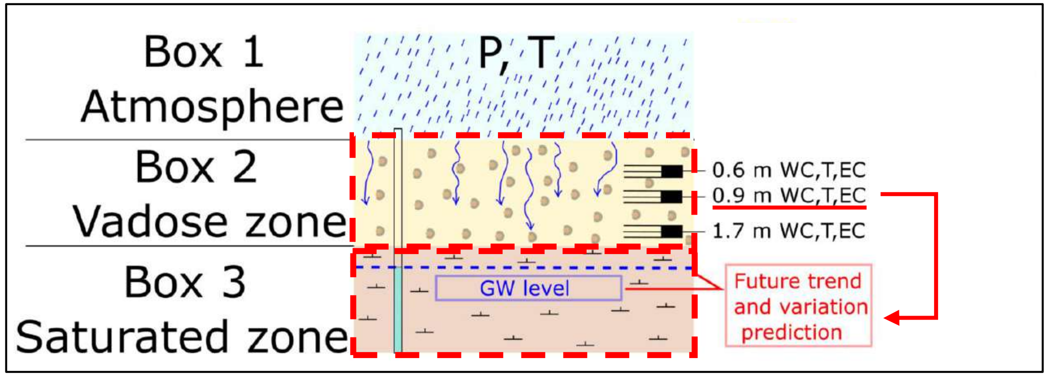


All regressors

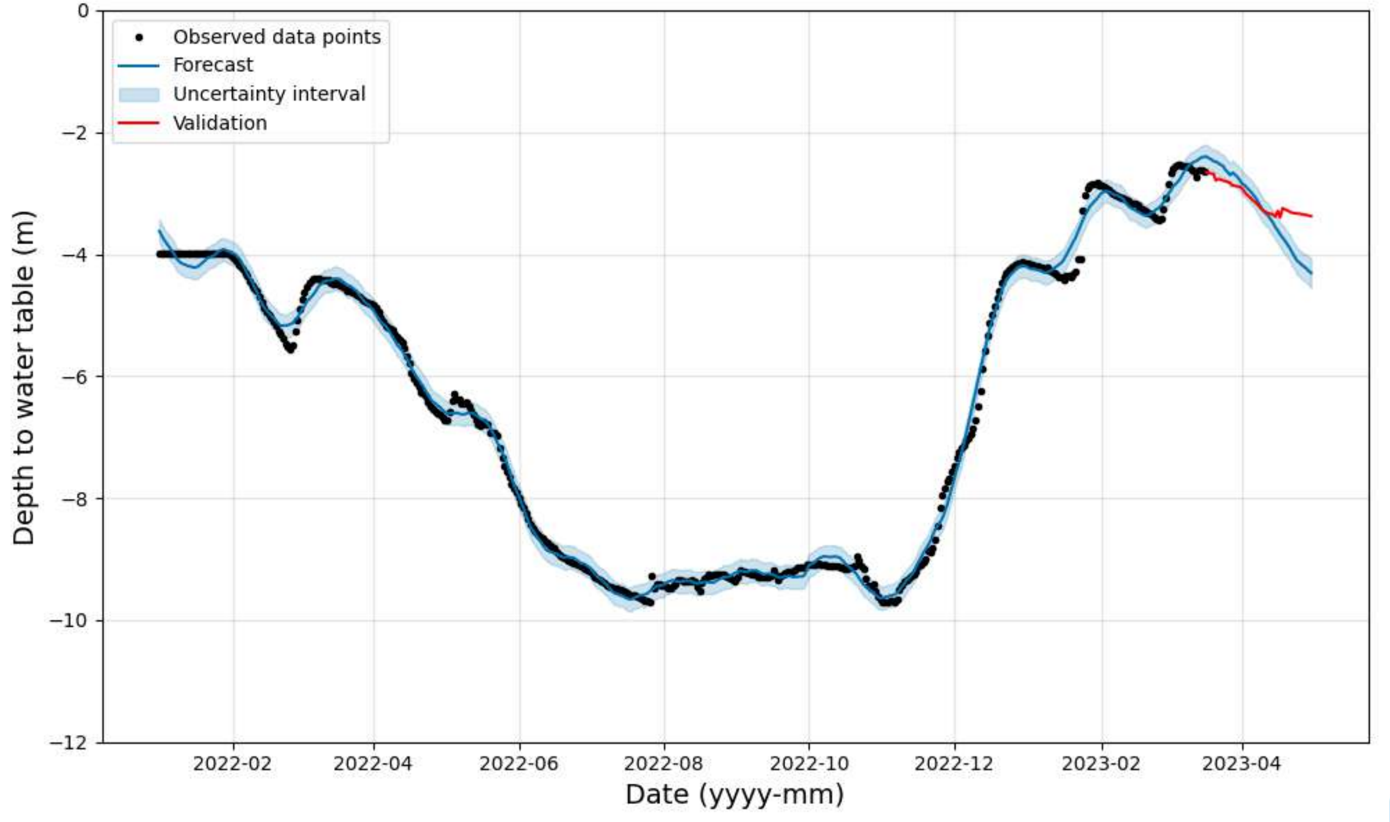


Test Serial No.	Scenario	Additive Regressors	Forecast Metric	Value
Test 2.2	**Box 2 → Box 3**	Water Content, Soil Temperature, Electrical Conductivity measured at 0.9 m	MAE	0.53
			MAPE	0.17
			Correlation (%)	**61.91%**

Test 2.2: Box 2 at 0.9 m → Box 3

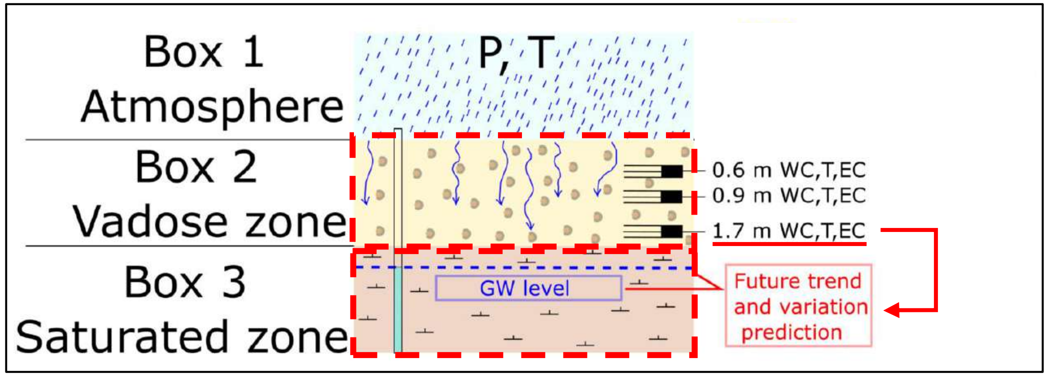


Excluding soil temperature

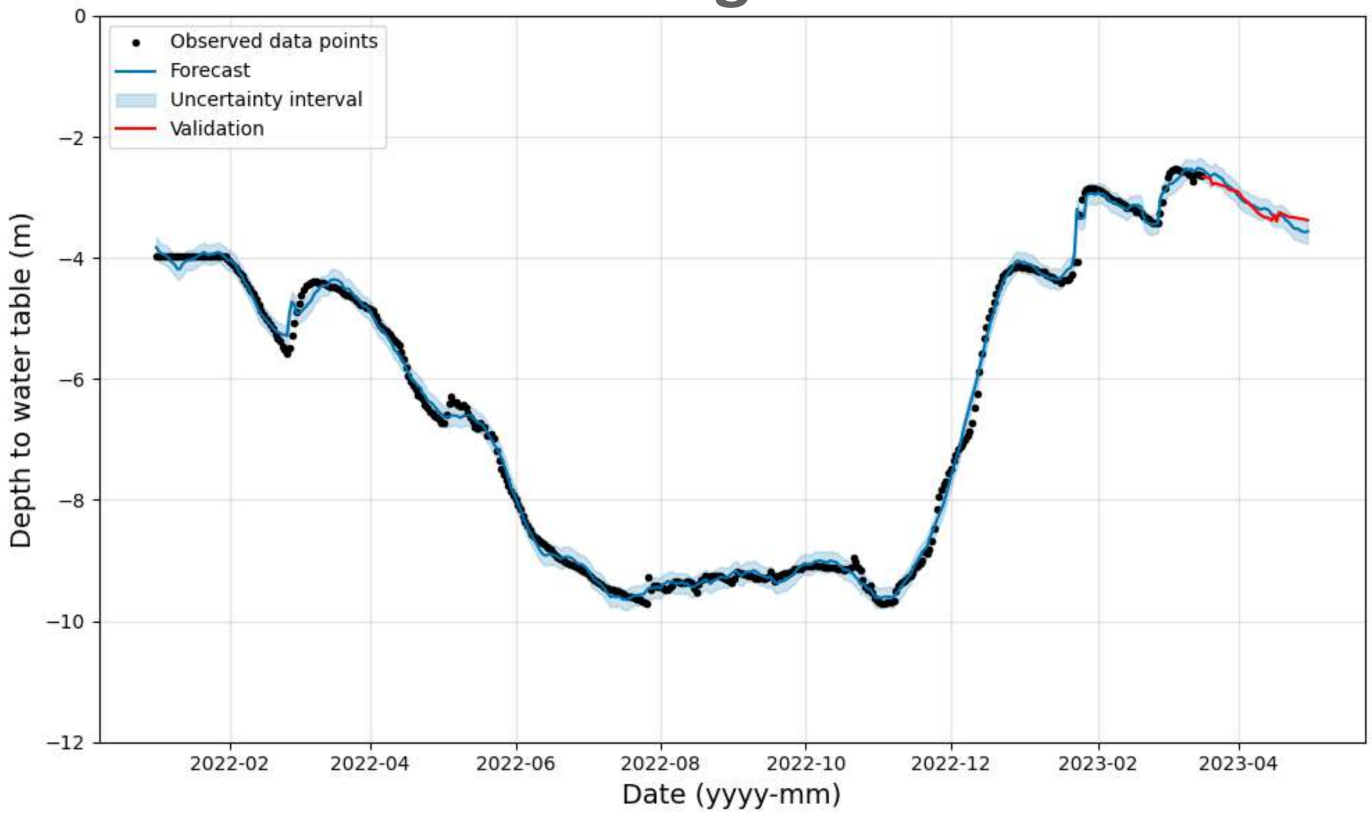


Test Serial No.	Scenario	Additive Regressors	Forecast Metric	Value
Test 2.2	**Box 2 → Box 3**	Water Content, Electrical Conductivity measured at 0.9 m	MAE	0.32
			MAPE	0.1
			Correlation (%)	**91.34%**

Test 2.3: Box 2 at 1.7 m → Box 3



All regressors



Test Serial No.	Scenario	Additive Regressors	Forecast Metric	Value
Test 2.3	**Box 2 → Box 3**	Water Content, Soil Temperature, Electrical Conductivity measured at 1.7 m	MAE	0.09
			MAPE	0.03
			Correlation (%)	**95.19%**

Test Serial No.	Scenario	Additive Regressors	Forecast Metric	Value
Test 1	**Box 1 → Box 3**	Precipitation, Air Temperature	MAE	0.33
			MAPE	0.11
			Correlation (%)	**89.01%**
Test 2.1	**Box 2 → Box 3**	Water Content, Electrical Conductivity **measured at 0.6 m**	MAE	0.42
			MAPE	0.13
			Correlation (%)	**92.49%**
Test 2.2	**Box 2 → Box 3**	Water Content, Electrical Conductivity **measured at 0.9 m**	MAE	0.32
			MAPE	0.1
			Correlation (%)	**91.34%**
Test 2.3	**Box 2 → Box 3**	Water Content, **Soil Temperature**, Electrical Conductivity **measured at 1.7 m**	MAE	0.09
			MAPE	0.03
			Correlation (%)	**95.19%**

Scenario	Additive Regressors	Forecast Metric	Value
Test 2.1	Water Content, **Soil Temperature,** Electrical Conductivity measured at 0.6 m	MAE	0.61
		MAPE	0.19
		Correlation (%)	53.16%
Test 2.2	Water Content, **Soil Temperature,** Electrical Conductivity measured at 0.9 m	MAE	0.53
		MAPE	0.17
		Correlation (%)	61.91%

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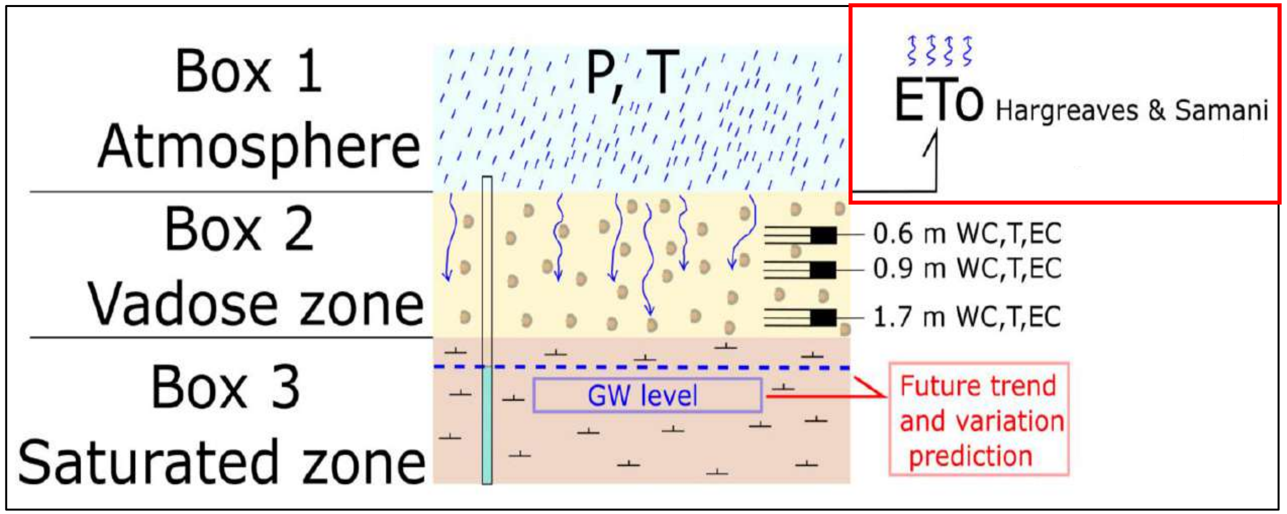

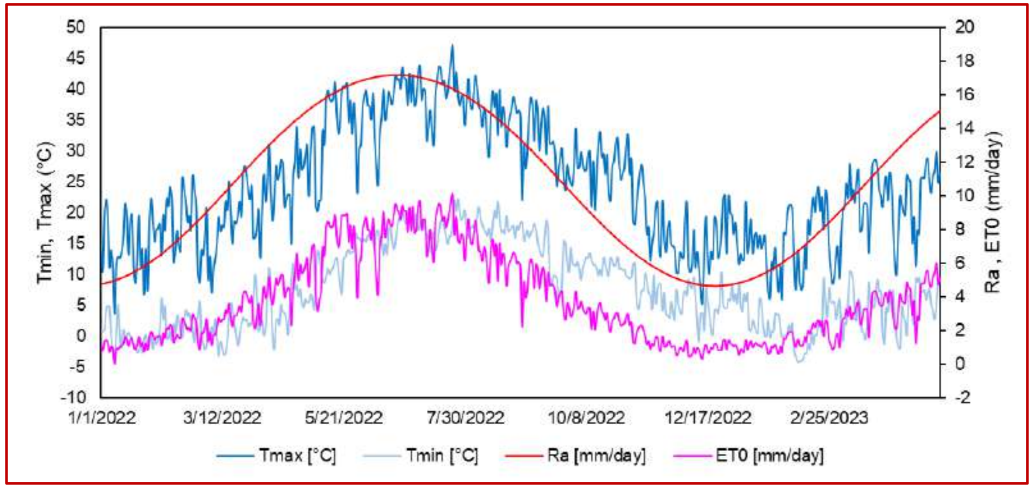

- ✓ The Prophet is proven to be a **good and easy** instrument **to predict near future groundwater level**
- ✓ The vadose zone hydrologic variables have been demonstrated to be much "powerful" than the meteoric variables to predict groundwater level (**the actual infiltration process is considered**) only if temperature is excluded or the noise is naturally reduced

- \+ Implement the model by using the **effective rainfall** as regressor by calculating the evapotranspiration and compare the prediction with the ones depicted from the vadose zone (on going)
- \+ **Continue the monitoring** during the years to "catch" and strengthen the **seasonal effect**
- \+ Predict the groundwater level for **specific periods** potentially related to an increase in water demand

flowpath Malta 2023
14th – 16th June
National Meeting on Hydrogeology

UNIVERSITÀ POLITECNICA DELLE MARCHE

THANKS FOR YOUR ATTENTION

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Do you want to know more?

Please scan the QR code and feel free to contact me!

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IGAG Istituto di Geologia Ambientale e Geoingegneria

unesco Intergovernmental Hydrological Programme

AIGA ASSOCIAZIONE ITALIANA GEOLOGIA APPLICATA E AMBIENTALE

ENGEOL IAEG AIGI

IRSA CNR

ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale

Sistema Nazionale per la Protezione dell'Ambiente

EUROPEAN UNION
European Regional Development Fund

VisitMalta

water services corporation

iah aih Italian Chapter

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Malta 2023

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National Meeting on Hydrogeology

JUNE 14-16, 2023

WATER.ORG.MT

DIVERSITY, TRAITS, SERVICES, VULNERABILITY, AND CONSERVATION OF GROUNDWATER ECOSYSTEMS

Tiziana Di Lorenzo IRET CNR
tiziana.dilorenzo@cnr.it

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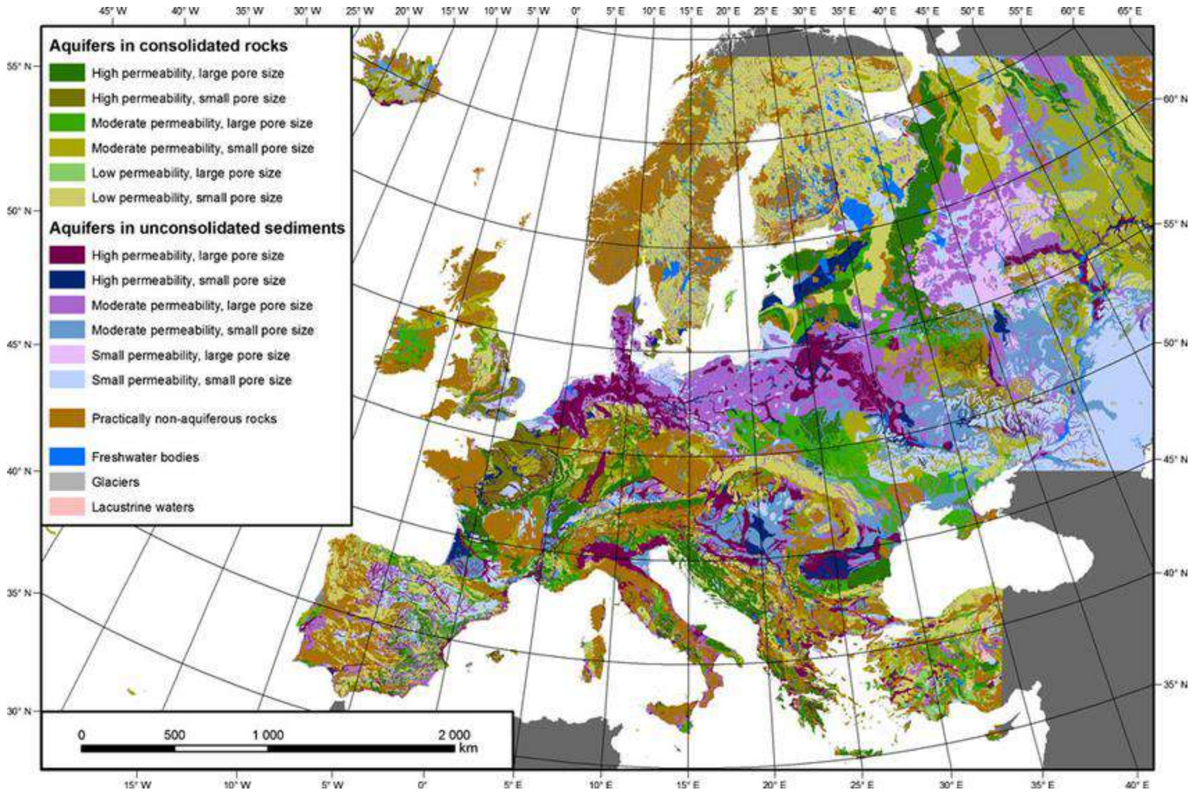
SETTING THE SCENE – HABITAT TEMPLATE

- ▶Groundwater is the world's largest freshwater ecosystems
- ▶In the upper 1 km of the continental crust, groundwateris likely fresh and has has an estimated volume of 15.9 million km^3 (Ferguson et al., 2021)
- ▶Modern groundwater (< 50 years old) has a global volume of about 1.3 million km^3 (Gleeson et al., 2016)

Cornu et al. (2013). The distribution of groundwater habitats in Europe. Hydrogeology Journal, 21(5), 949.



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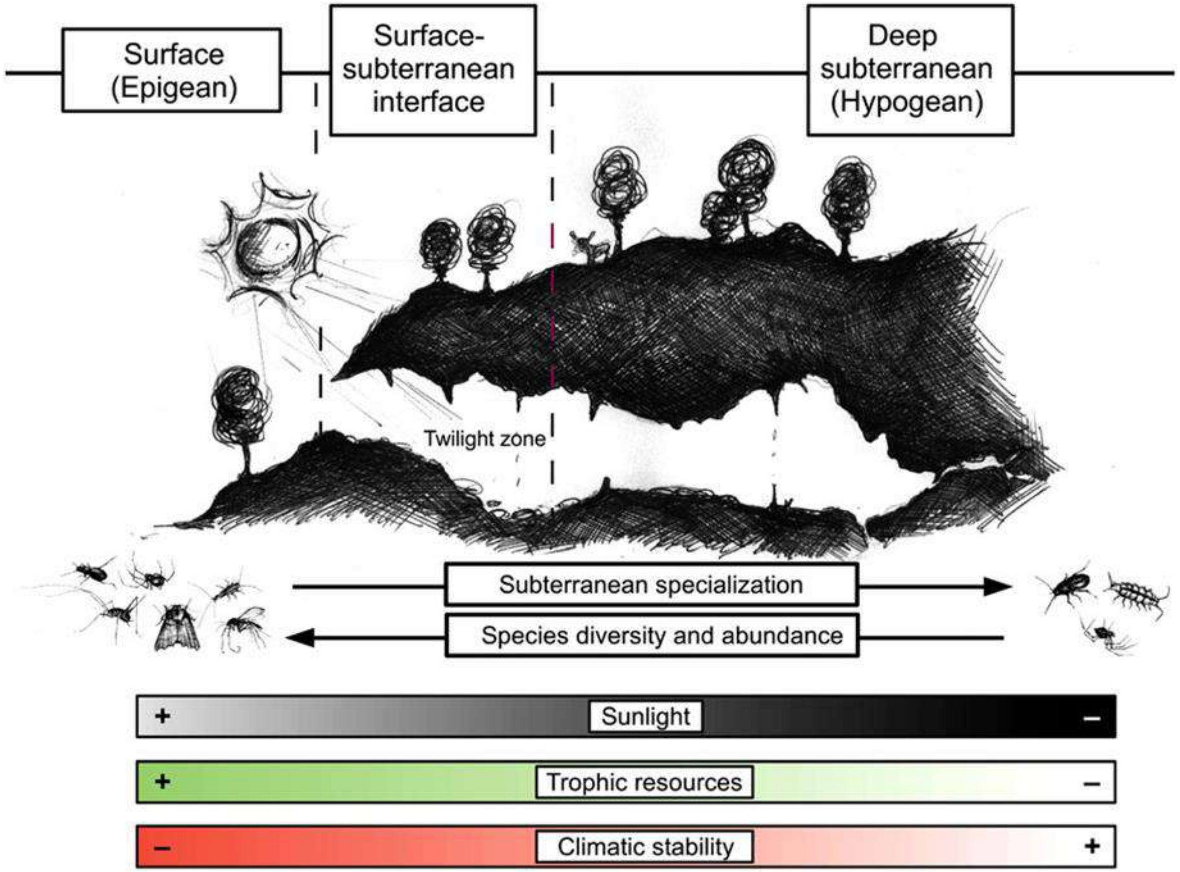
SETTING THE SCENE – HABITAT TEMPLATE

Mammola, S. (2019). Finding answers in the dark: caves as models in ecology fifty years after Poulson and White. Ecography, 42(7), 1331-1351.



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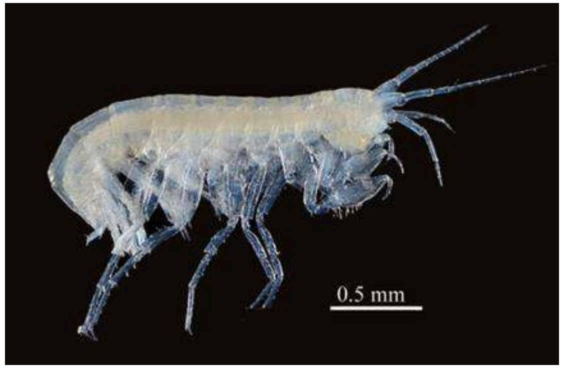
DARKNESS SYNDROME

- MORPHOLOGICAL TRAITS
  - Depigmentation
  - Anophtamly/Microphtalmy
  - Elongation of sensory organs



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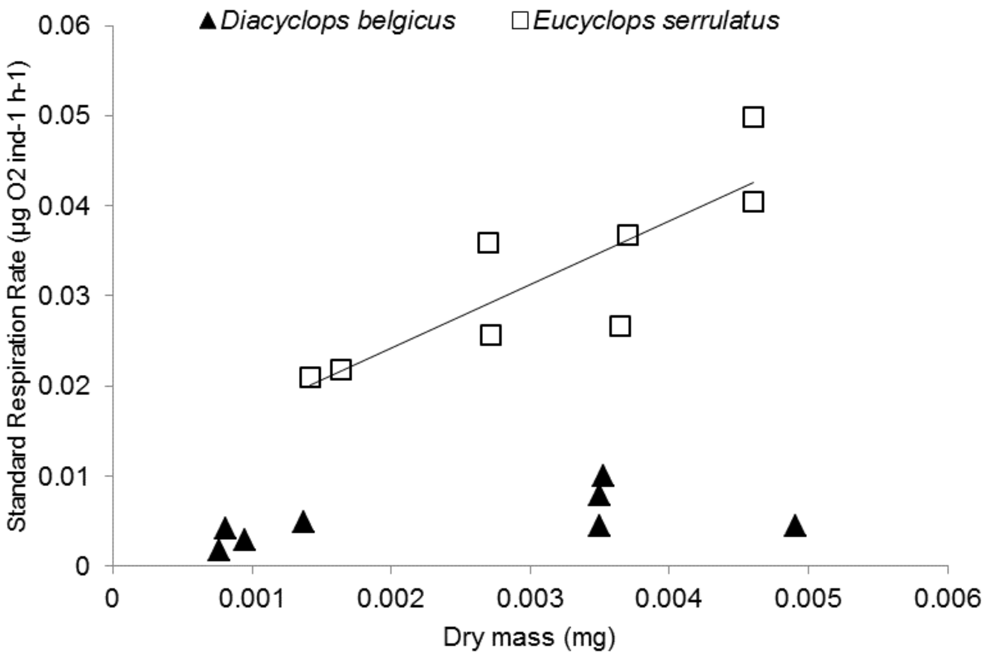
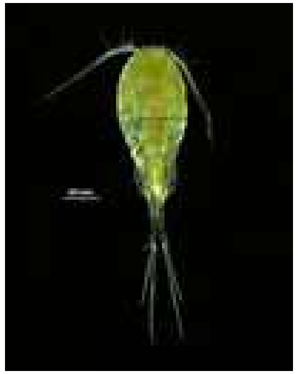
ADAPTATION TO FOOD SCARCITY

- PHYSIOLOGICAL TRAITS
  - **Low metabolism**
  - Low acclimation ability
  - Low fertility
  - Longevity





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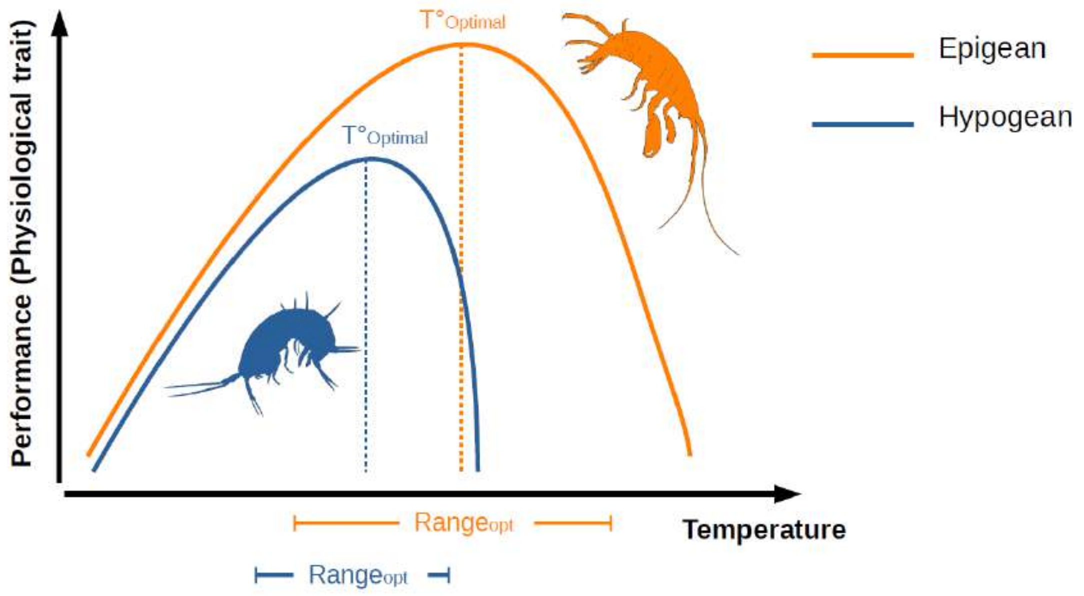
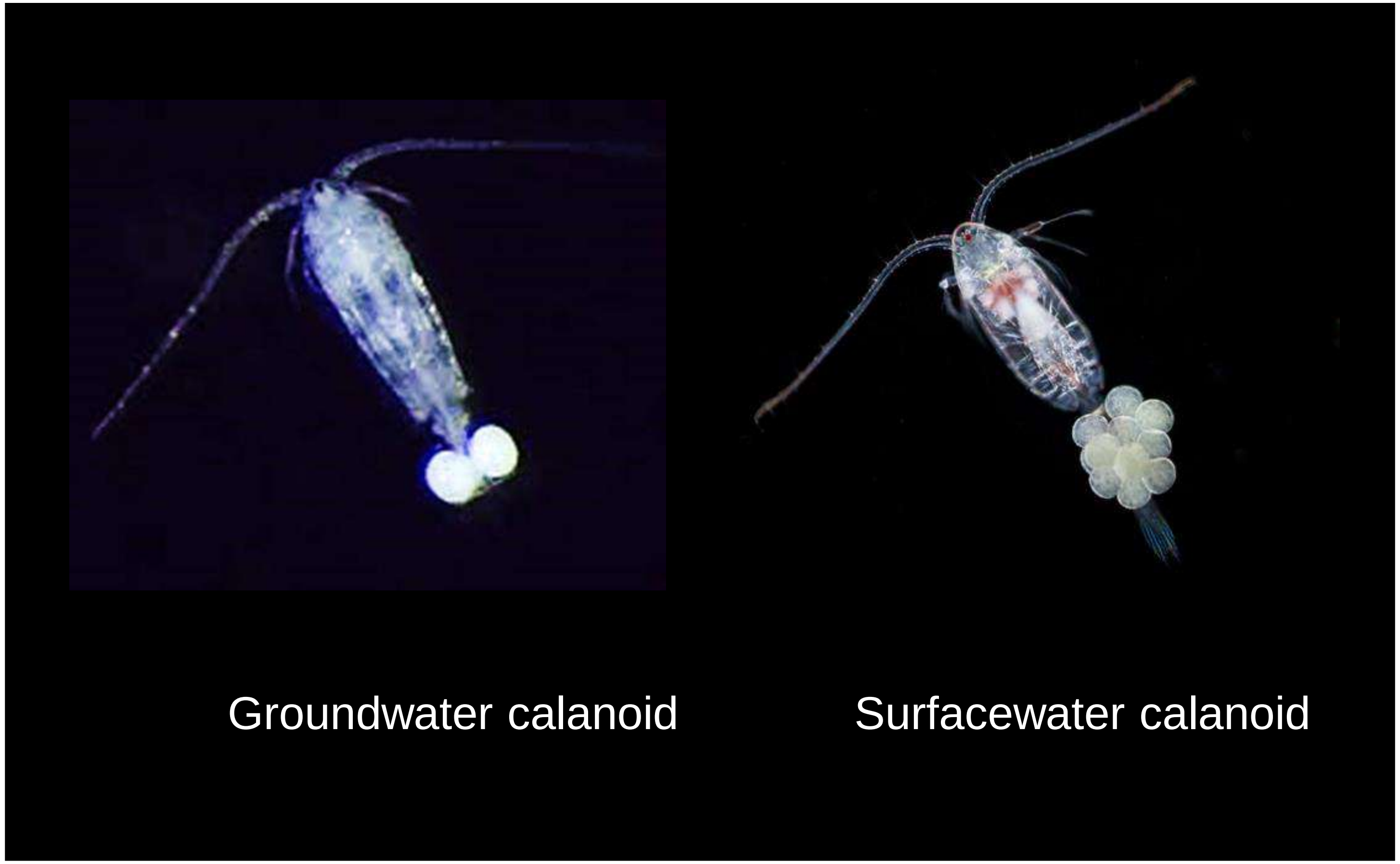
ADAPTATION TO STABLE TEMPERATURES

- PHYSIOLOGICAL TRAITS
  - Low metabolism
  - **Narrow thermal niche**
  - Low fertility
  - Longevity



ADAPTATION TO FOOD SCARCITY

- PHYSIOLOGICAL TRAITS
  - Low metabolism
  - Low acclimation ability
  - **Low fertility**
  - Longevity



ADAPTATION TO FOOD SCARCITY

- PHYSIOLOGICAL TRAITS
  - Low metabolism
  - Low acclimation ability
  - Low fertility
  - **Longevity**

Proteus anguinus

Cave salamander

Nitocrella achaiae

Groundwater copepod

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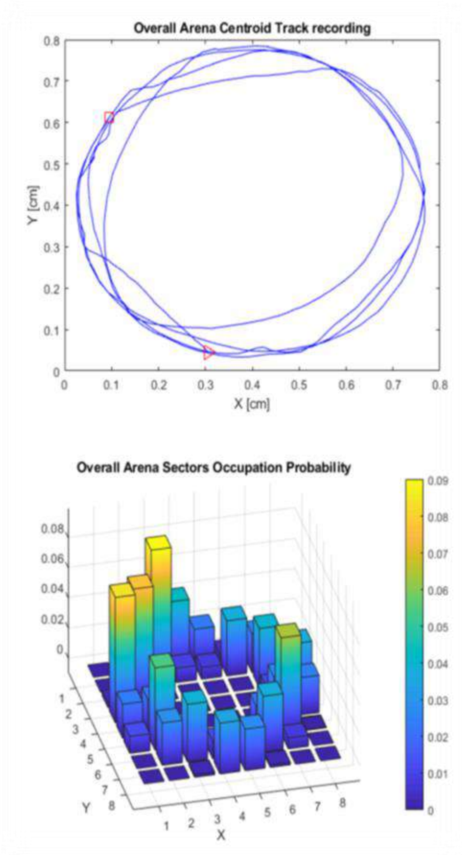
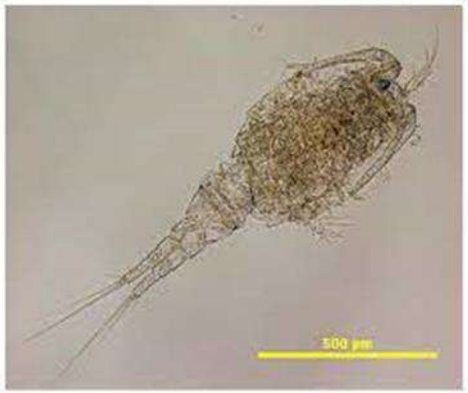
ADAPTATION TO FOOD SCARCITY

- BEHAVIOURAL TRAITS
  - Wandering
  - Thigmotaxis
  - Slow locomotion





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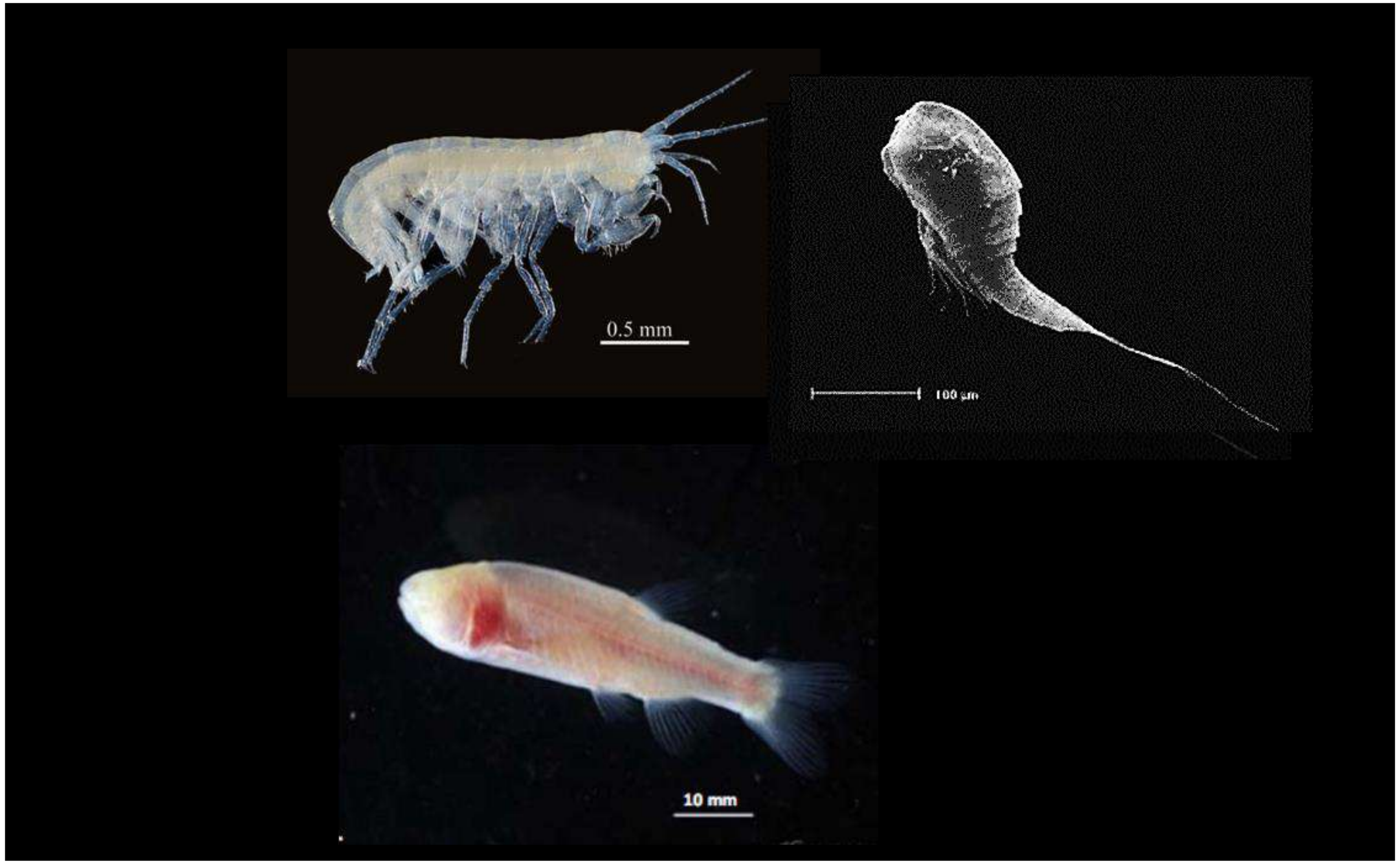
GROUNDWATER BIODIVERSITY



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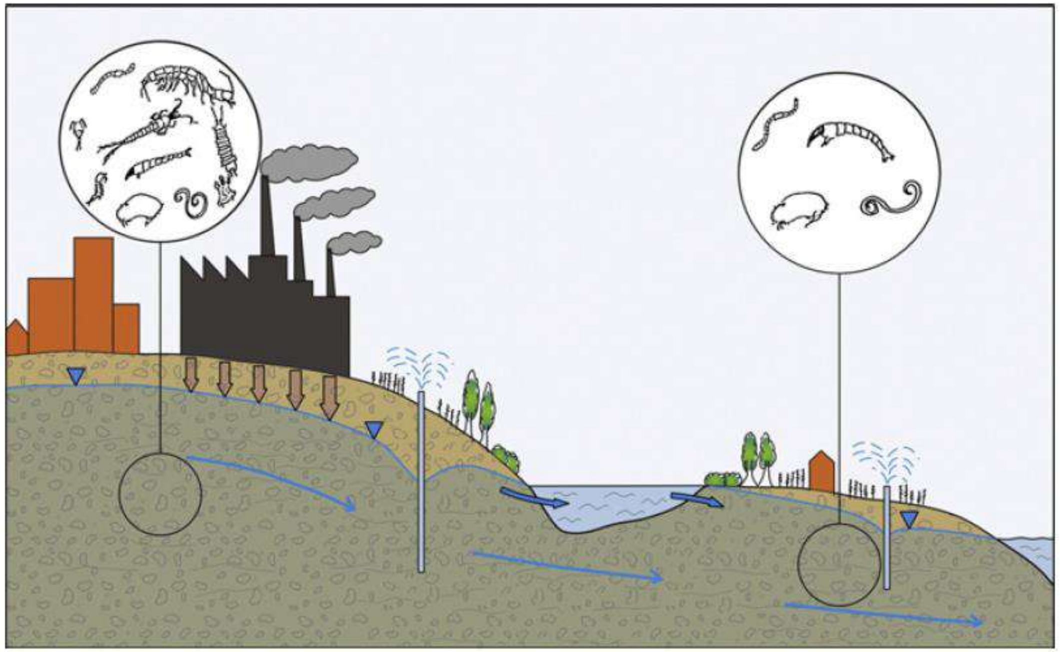
RISKS POSED BY ANTHROPIC PRESSURES

Habitat reduction/depletion

Contamination

Climate change



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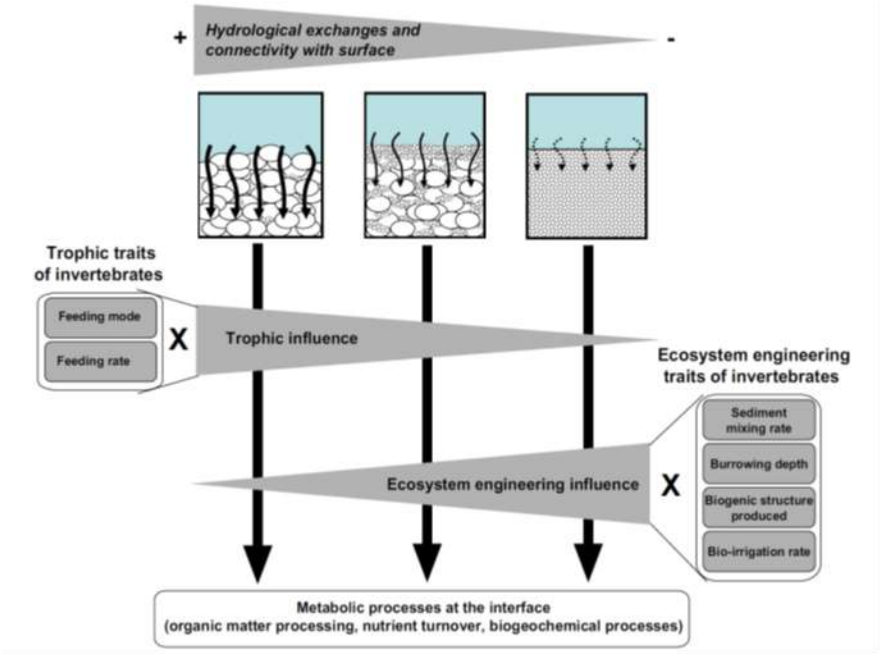
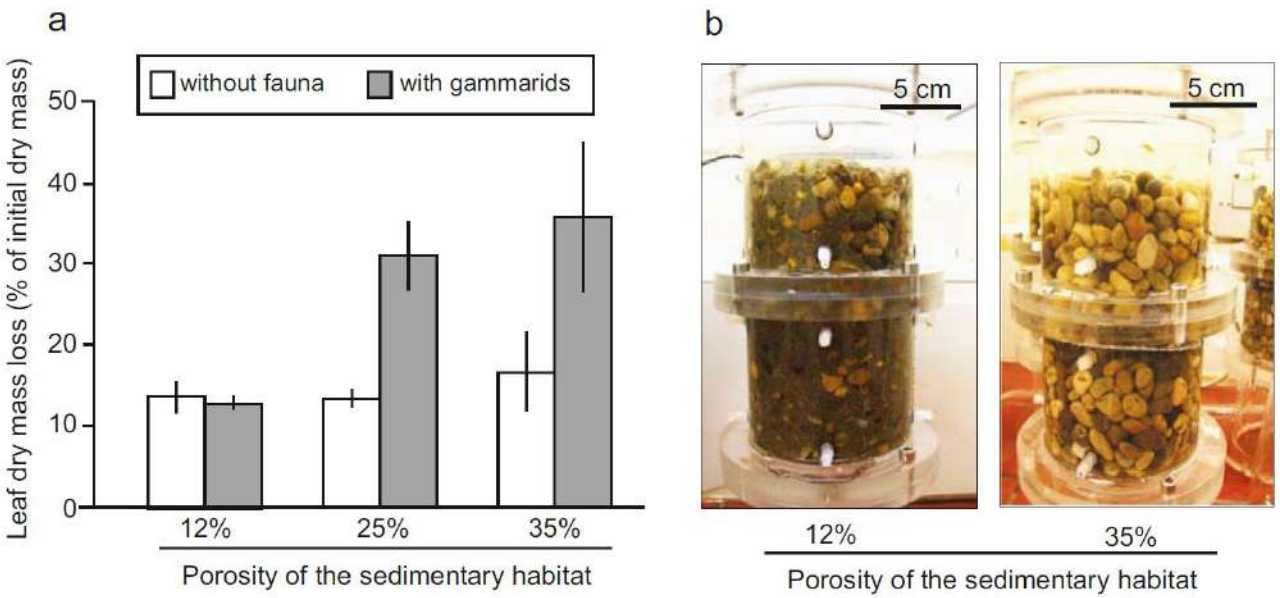
LOSS OF ECOSYSTEM SERVICES

C recycling and engineering



C recycling

<u>(they also feed on viruses and pathogens!)</u>



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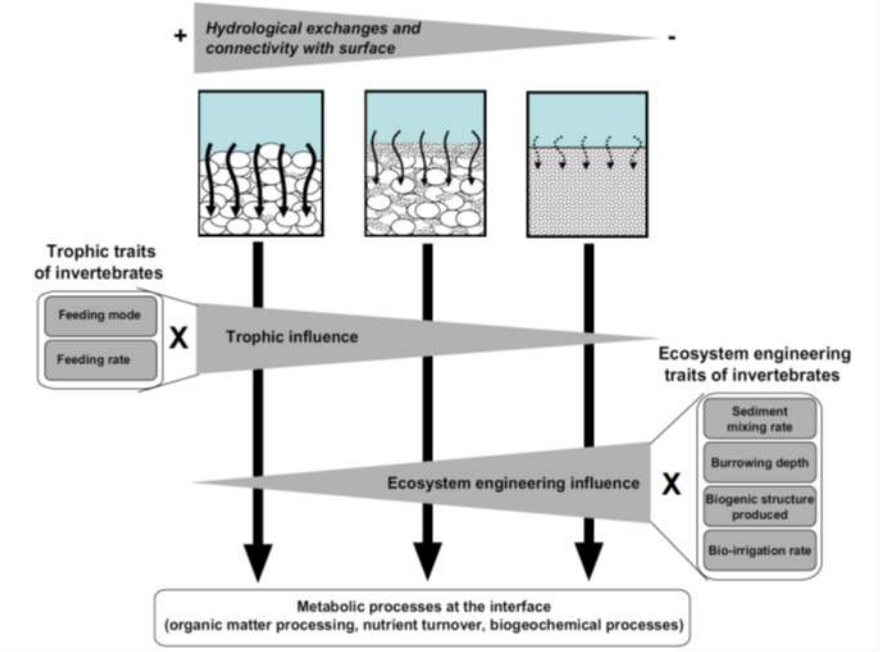
LOSS OF ECOSYSTEM SERVICES

C recycling and engineering



- Burrowing

FIGURE 1 Network of channels due to stygofauna burrowing observed at the bottom of a sediment column 5 months after start of the experiments

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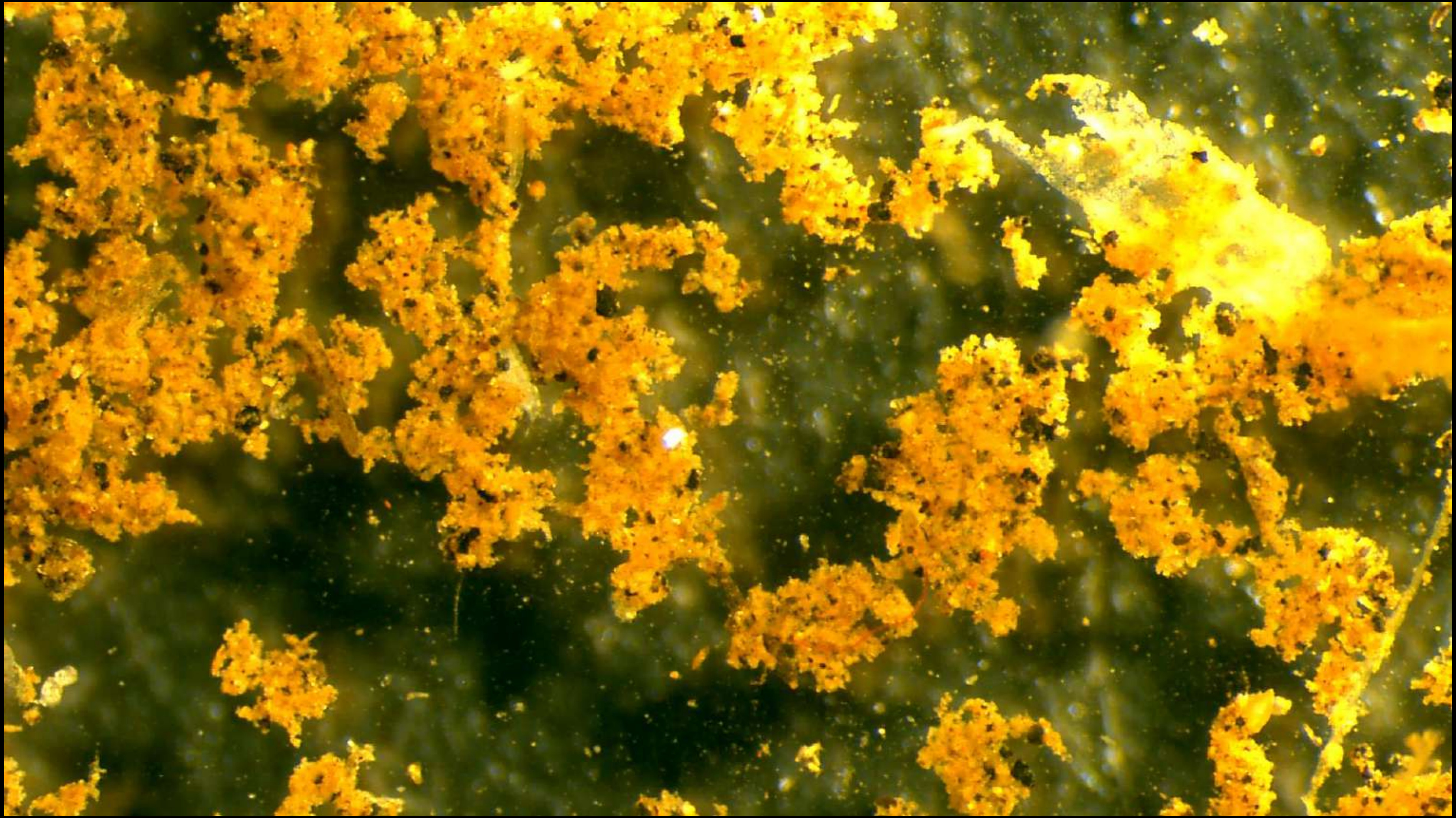
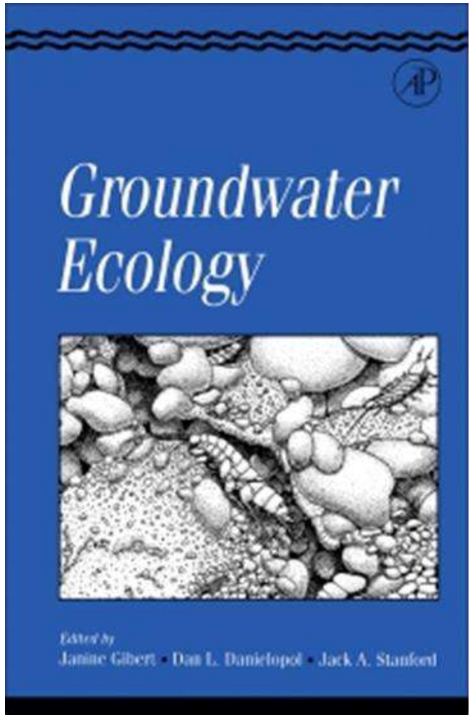
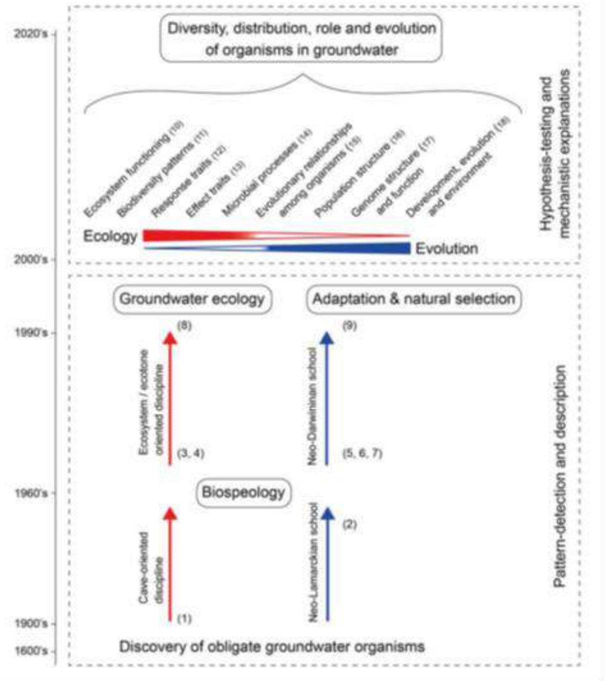
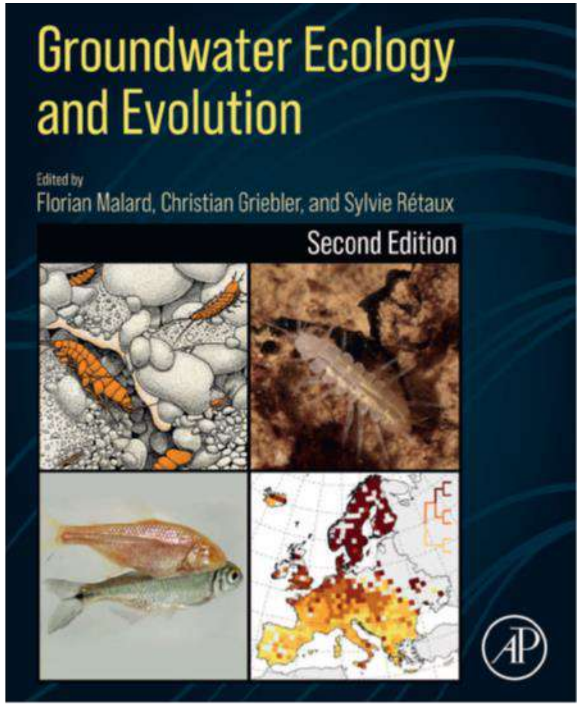


GROUNDWATER ECOLOGY AND EVOLUTION







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- XXVI International Conference of Subterranean Biology

Thank you!

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European Regional Development Fund

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water
services corporation

iah aih
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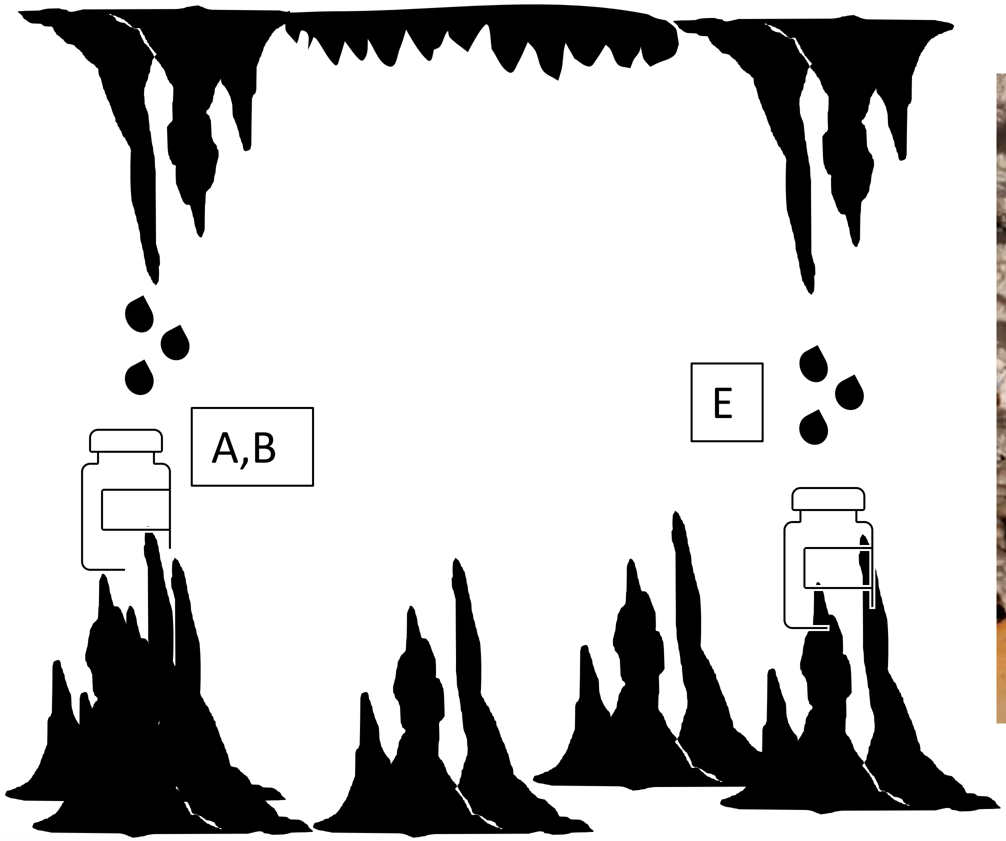
SAMPLING METHODS



GROUNDWATER ECOSYSTEM INDEX

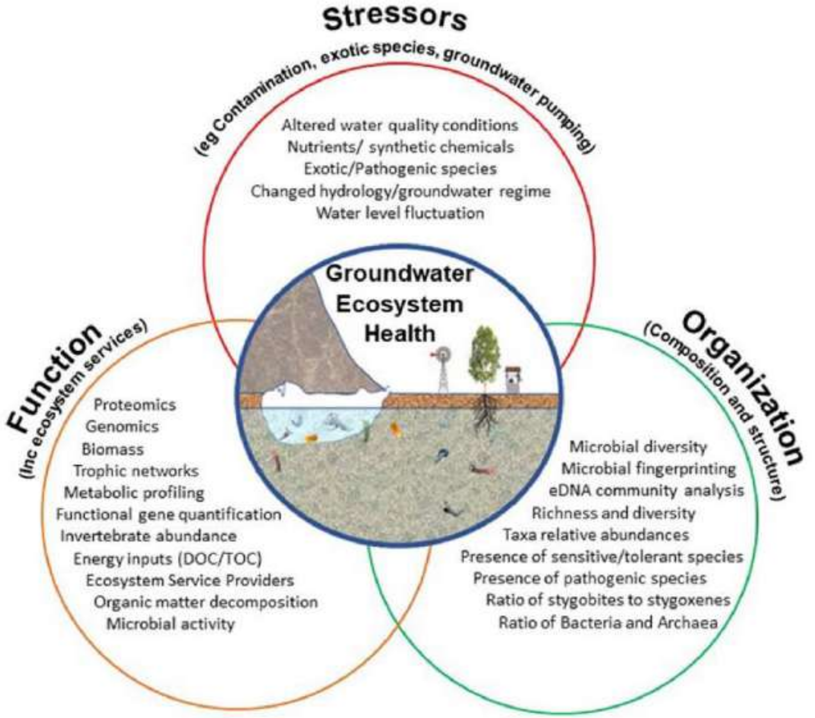
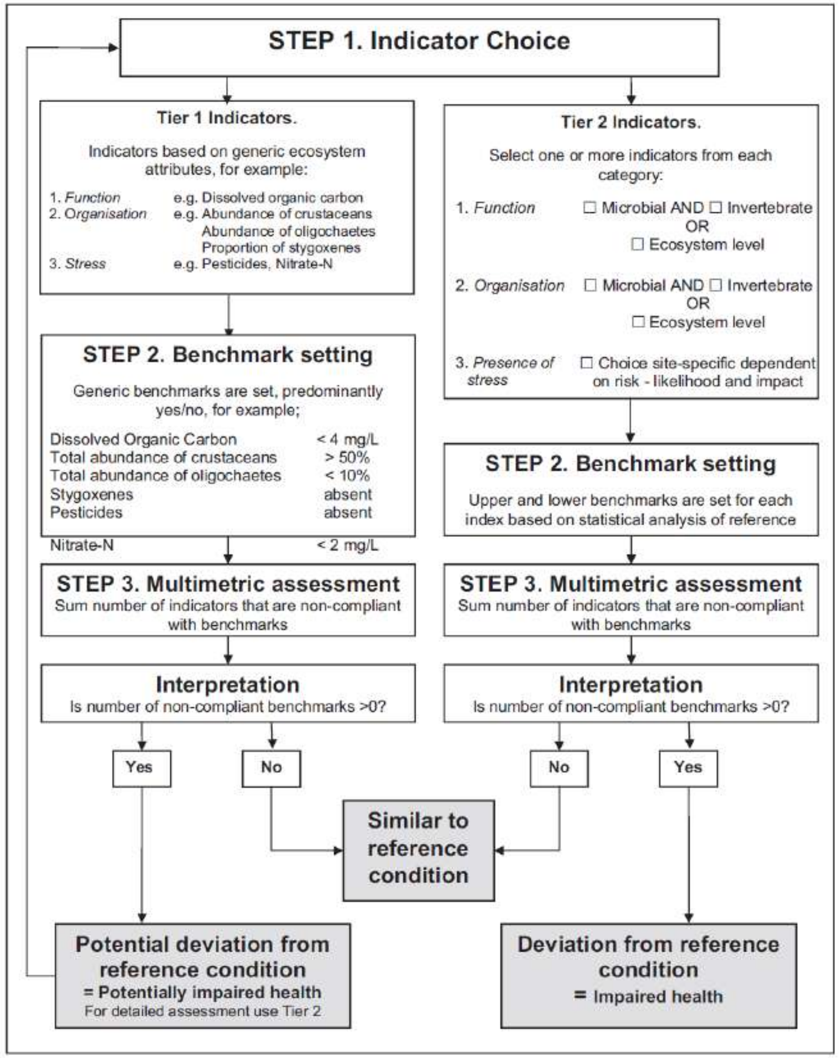
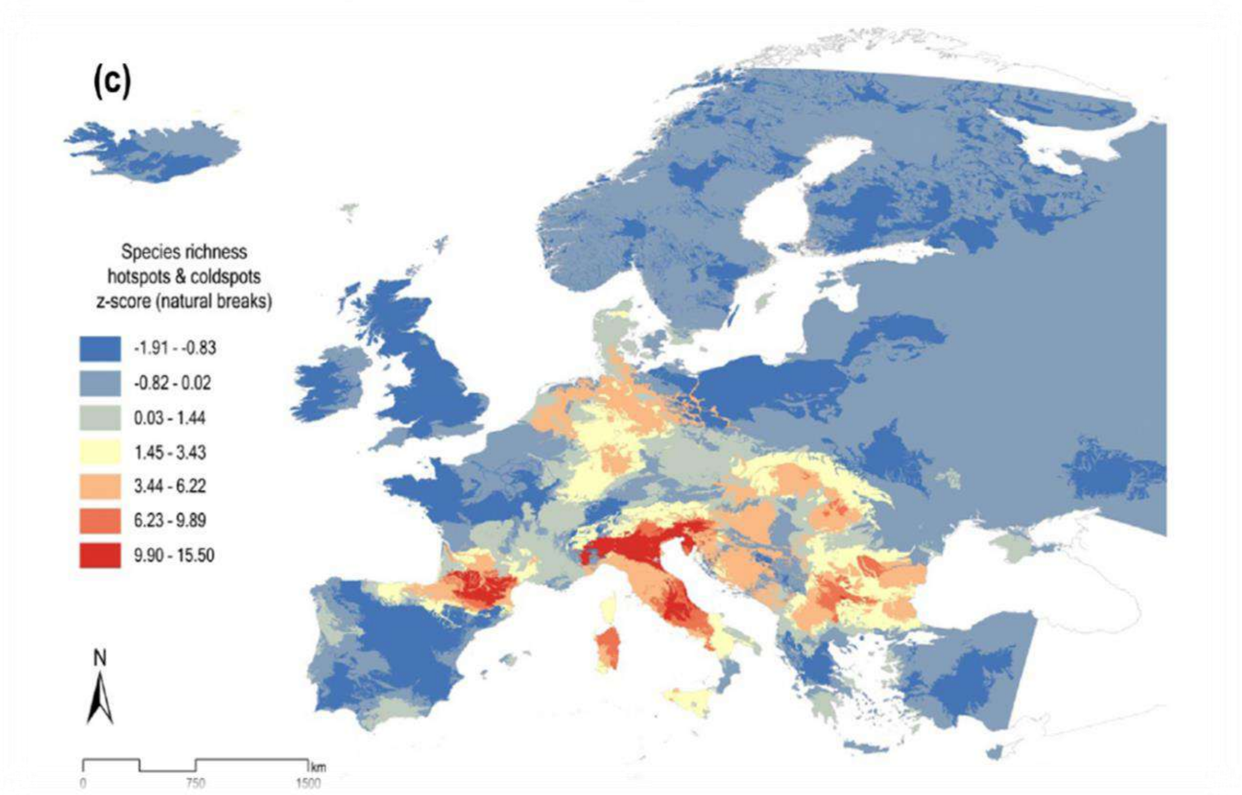


FIGURE 22.1 Types of indicators required for assessment of groundwater ecosystem health.



GROUNDWATER BIODIVERSITY DISTRIBUTION



Novel experimental approaches in Ecohydrodynamics of real vegetated rivers

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University of Napoli Federico II (Italy)

giuseppefrancescocesare.lama@unina.it

In-situ ecohydraulic conditions of vegetated water bodies

Submergence

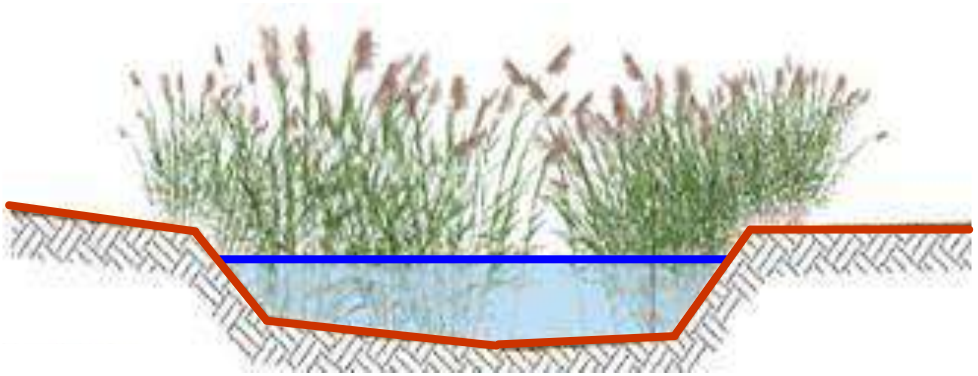
- Emergent vegetation
- Floating vegetation
- Submerged vegetation

Bio-mechanical behaviour

- Rigid stems
- Flexible stems

Water flow - riparian vegetation interaction

Natural conditions

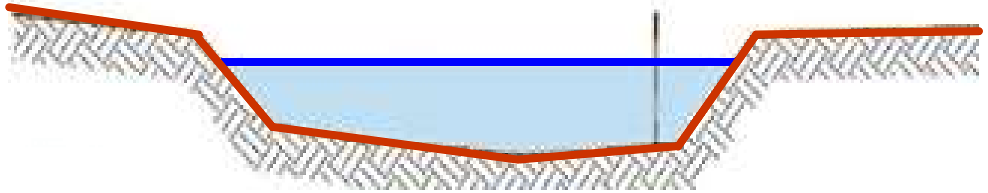


High environmental quality

Low hydraulic efficiency

How to balance these two needs?

Vegetation removal



High hydraulic effciency

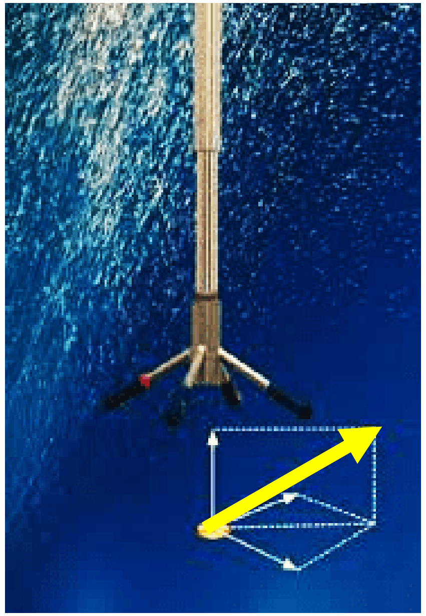
Negative environmental impact

Study step 1

Field hydrodynamic experiments in a vegetated reclamation channel colonized by Giant Reed beds.

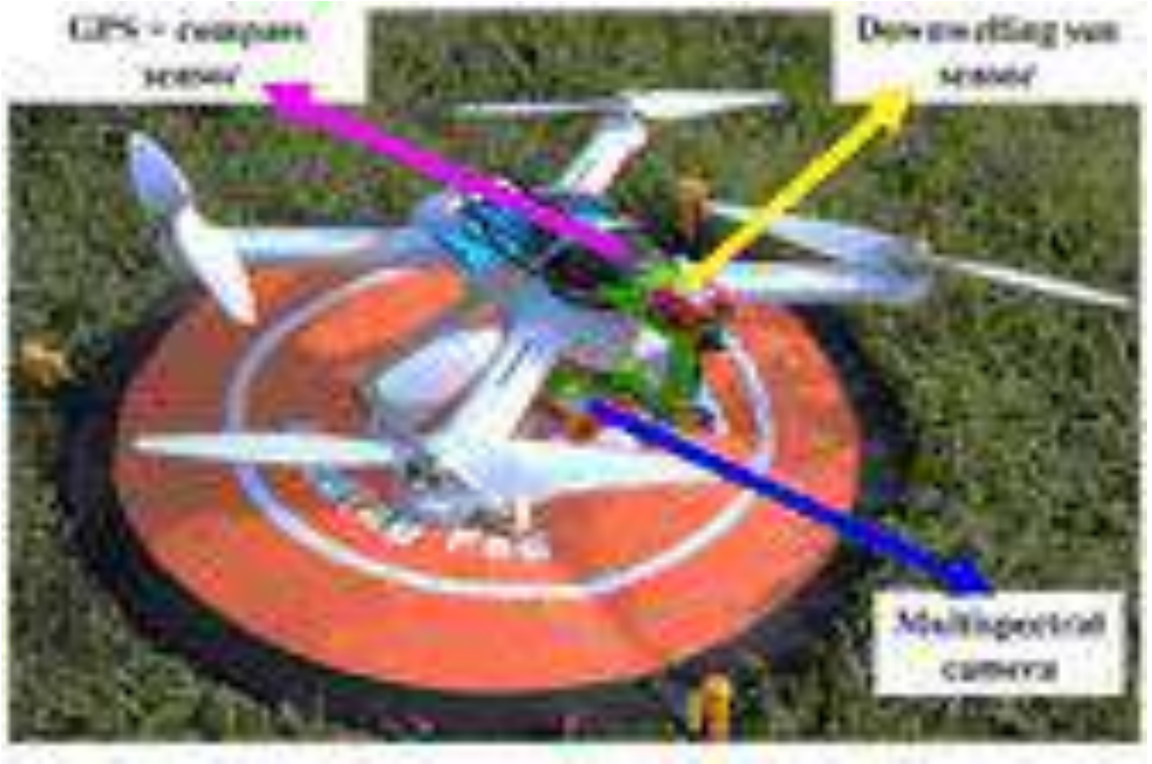
Vegetated channel

Acoustic Doppler Velocimeter (ADV)



Study step 2

Impact of Uncertainty of Drone-based imagery in estimating Leaf Area Index (LAI) on Flow Resistance Models for Rigid Vegetation



Real-scale hydrodynamic experiments: three riparian vegetation scenarios

Vegetated reclamation channel colonized by *Arundo donax L.* (Giant Reed beds)

Full Vegetation

Central Cut

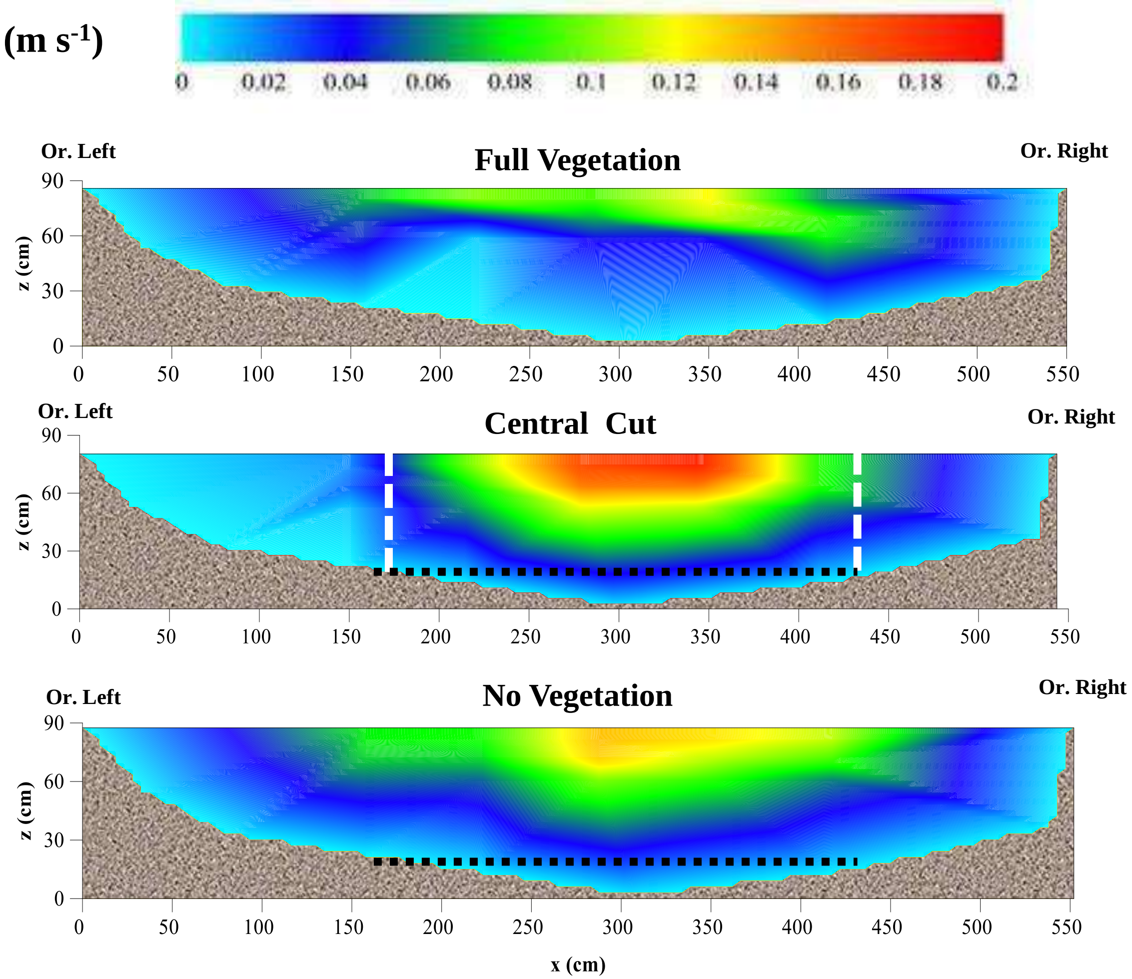
No Vegetation

Upstream pumps

Downstream pumps

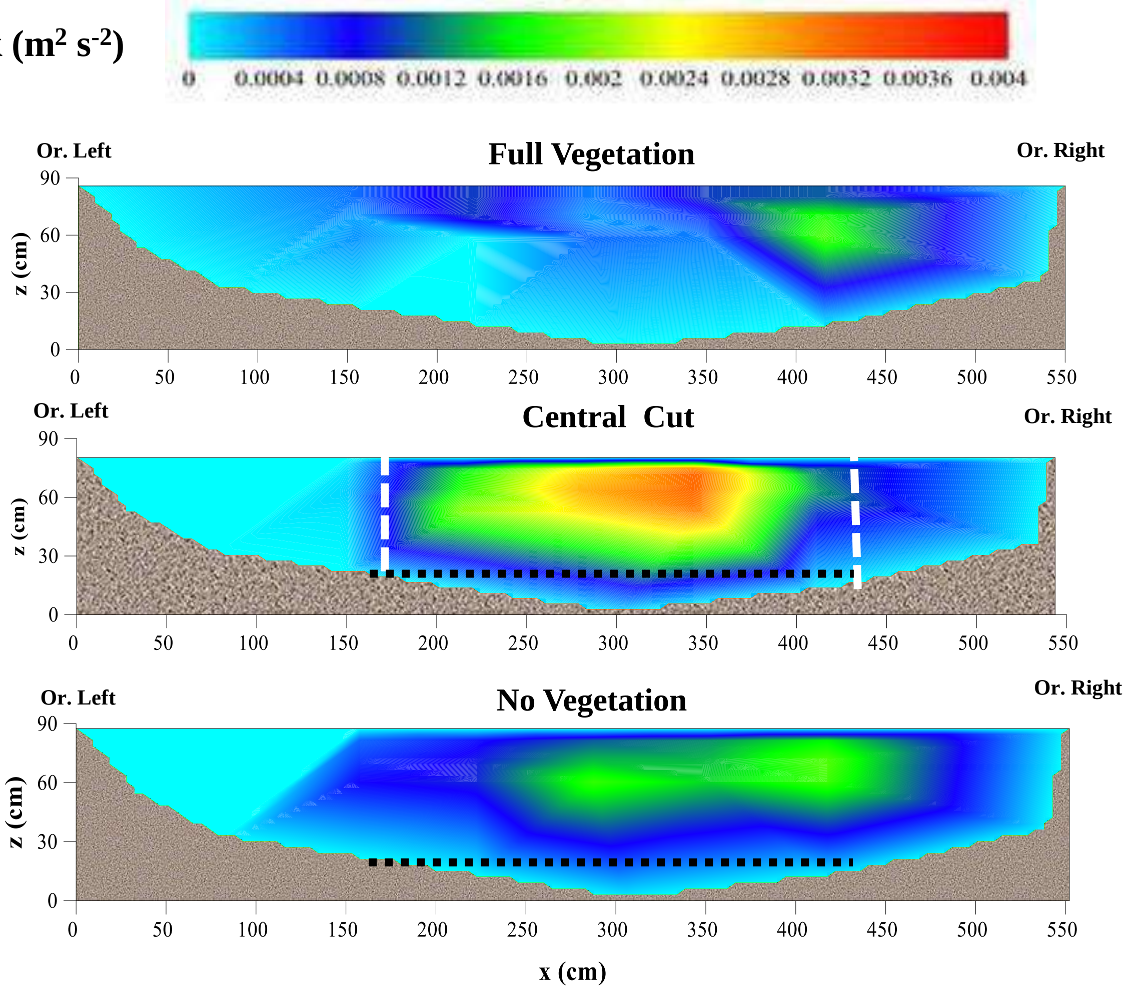
Water flow velocity fields

Riparian vegetation scenario



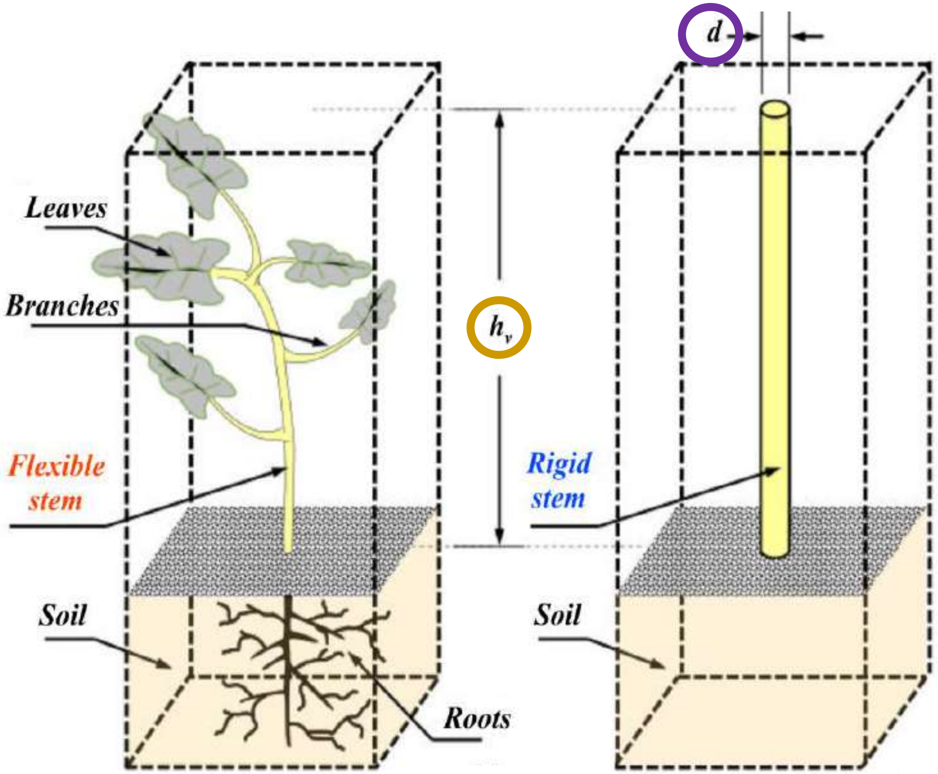
Turbulent Kinetic Energy fields

Riparian vegetation scenario



Flow resistance models for rigid plants - 1

“Rigid-cylinder” analogy



Vargas-Luna et al. (2015)

Riparian vegetation features

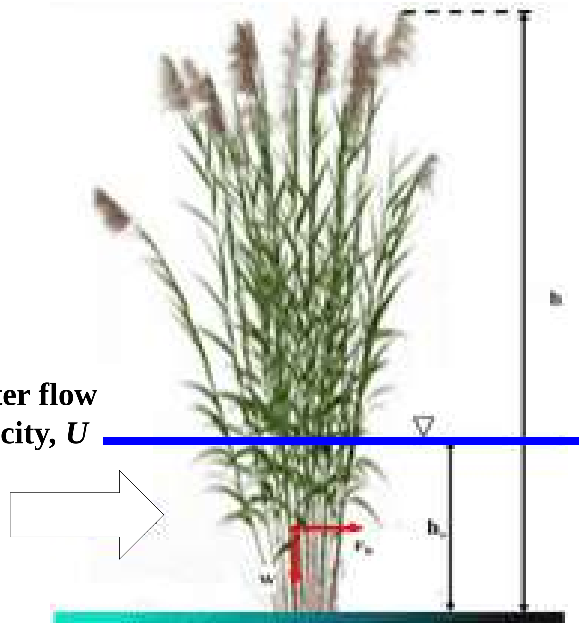
- Stem diameter (m)
- Plant height (m)
- Stem density (m^{-2})

Flow resistance models for rigid plants - 2

"LAI is the total one-sided leaf tissue area per unit ground area" (*Watson, 1947*)

Drag force

$$F_D \propto \mathbf{U}^2$$

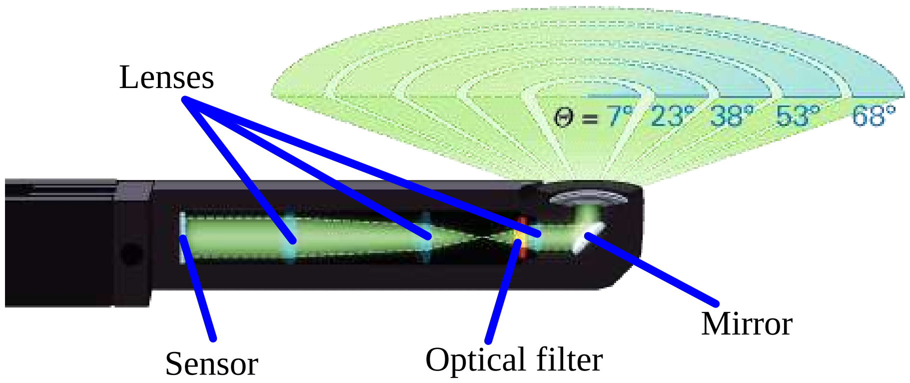


Water flow velocity

$$\mathbf{U} \propto \frac{1}{\sqrt{\mathbf{LAI}}}$$

Järvelä (2014)

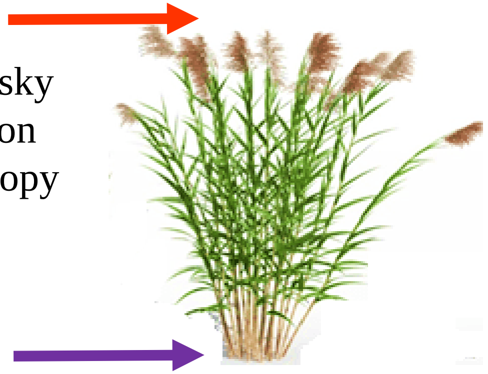
Indirect LAI measurements - 1



Above Canopy

Attenuation of sky diffuse radiation through the canopy

Below Canopy



Giant reed beds

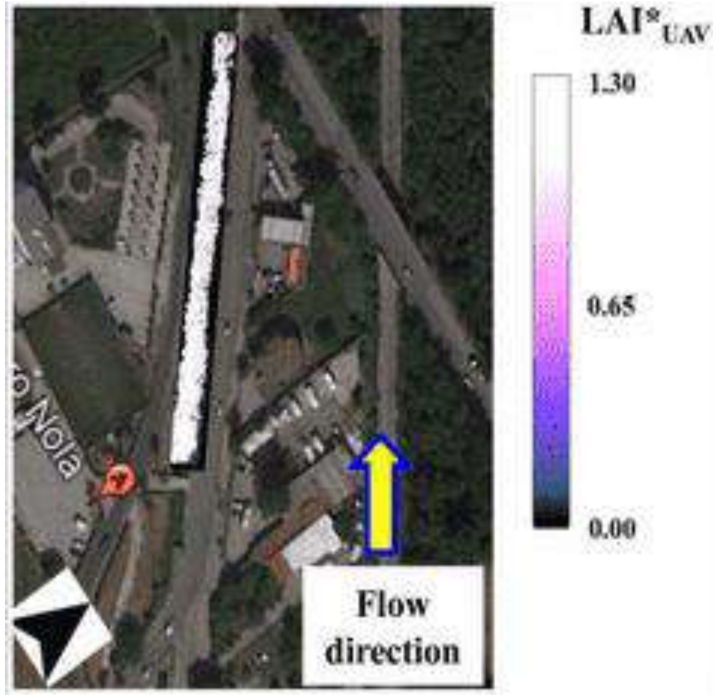
Plant Canopy Analyzer (LI-COR)

- **Digital** LAI computing
- Highly **time consuming**

Indirect LAI measurements - 2

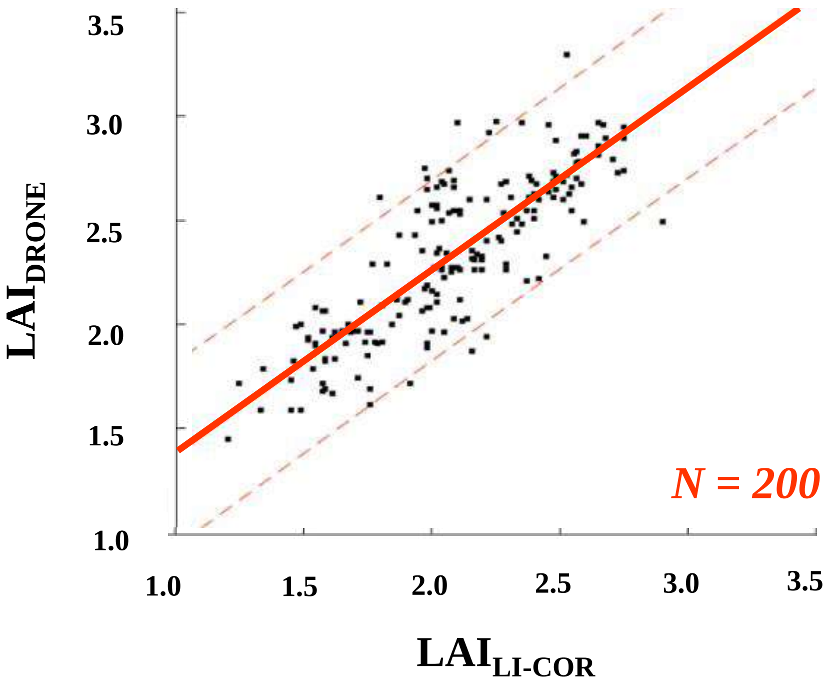
Drone-based imagery

- **Multiple** bands
- **No time** consuming



Indirect LAI assessments: LI-COR *vs*. Drone-based imagery

Giant Reed beds



R^2 = 0.70

***BIAS* = 0.30**

Drone-based imagery is a valuable alternative to **LI-COR** for assessing **LAI** of **Giant Reed beds**.

Sensitivity of Flow Velocity to LAI_{DRONE} Uncertainty

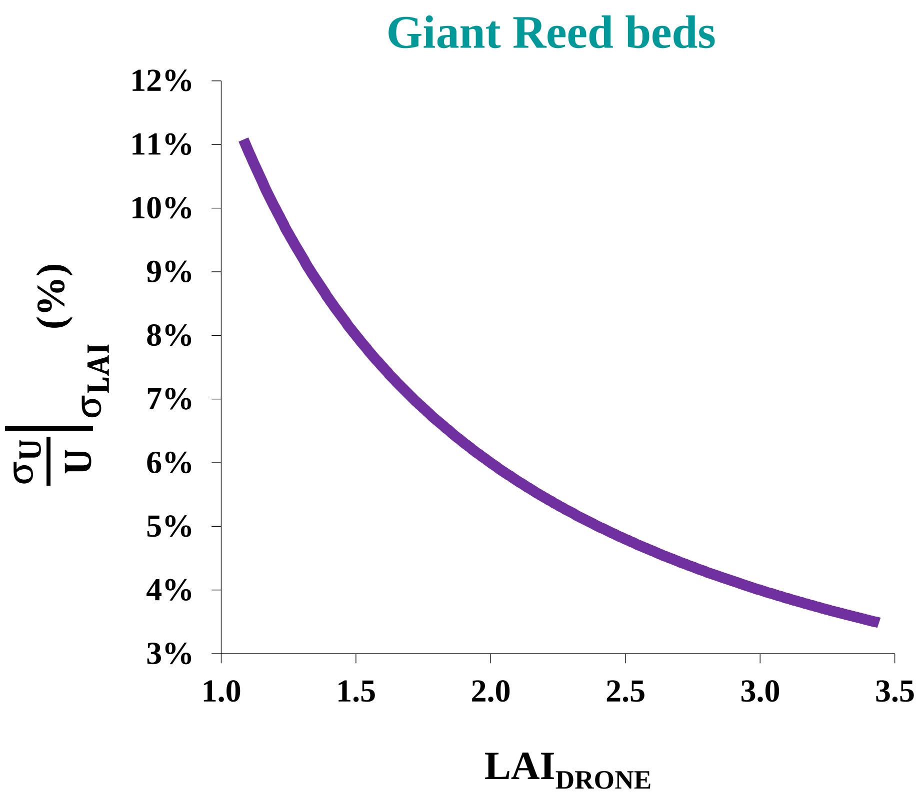
Water flow velocity

$$\mathbf{U} \propto \frac{1}{\sqrt{\mathbf{LAI}}}$$

Järvelä (2014)

Sensitivity

$$\left.\frac{\sigma_U}{U}\right|_{\sigma_{LAI}} = \frac{1}{2}\frac{\sigma_{LAI}}{LAI}$$



Conclusions

- The hydraulic efficiency of the vegetated channel for central cut scenario is comparable to that obtained for no vegetation scenario.

- Drone-based image processing can be effectively employed for assessing LAI of rigid riparian stands, to be employed in flow resistance modeling.

- Need for further field campaigns, aiming at analyzing a wider range of riparian species, and a larger spectrum of in-situ ecohydraulic conditions.

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Thank you

for your attention

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Malta 2023

14th – 16th June
National Meeting on Hydrogeology

JUNE 14-16, 2023

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Hydrogeological assessment and modelling for the authorisation of water recharge in the Bereg marshes

Éva Kun, György Tóth, Teodóra Szőcs, Nóra Edit Gál, Andrea Szűcs Jordánné, Julianna Mekker, Zoltán Püspöki

flowpath
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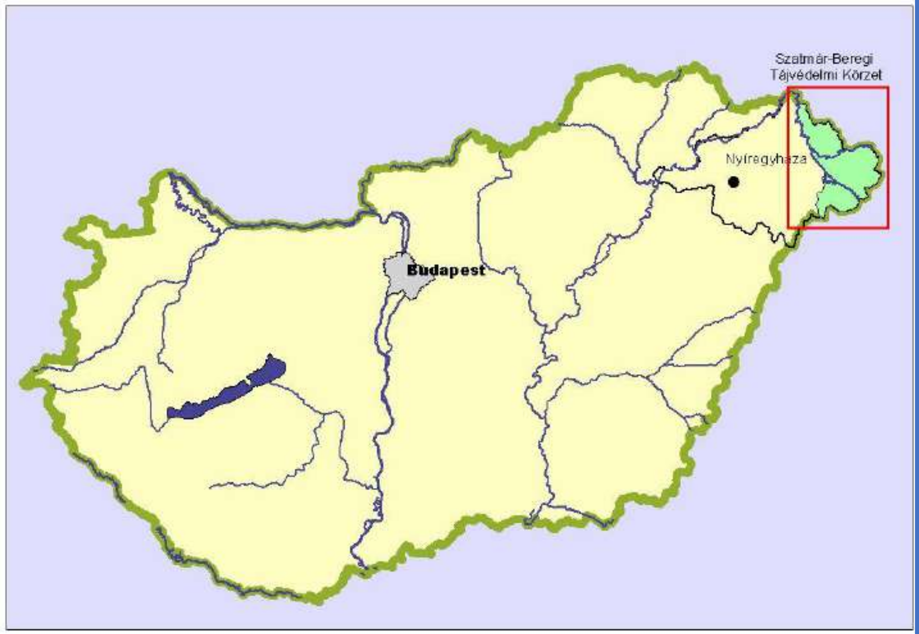
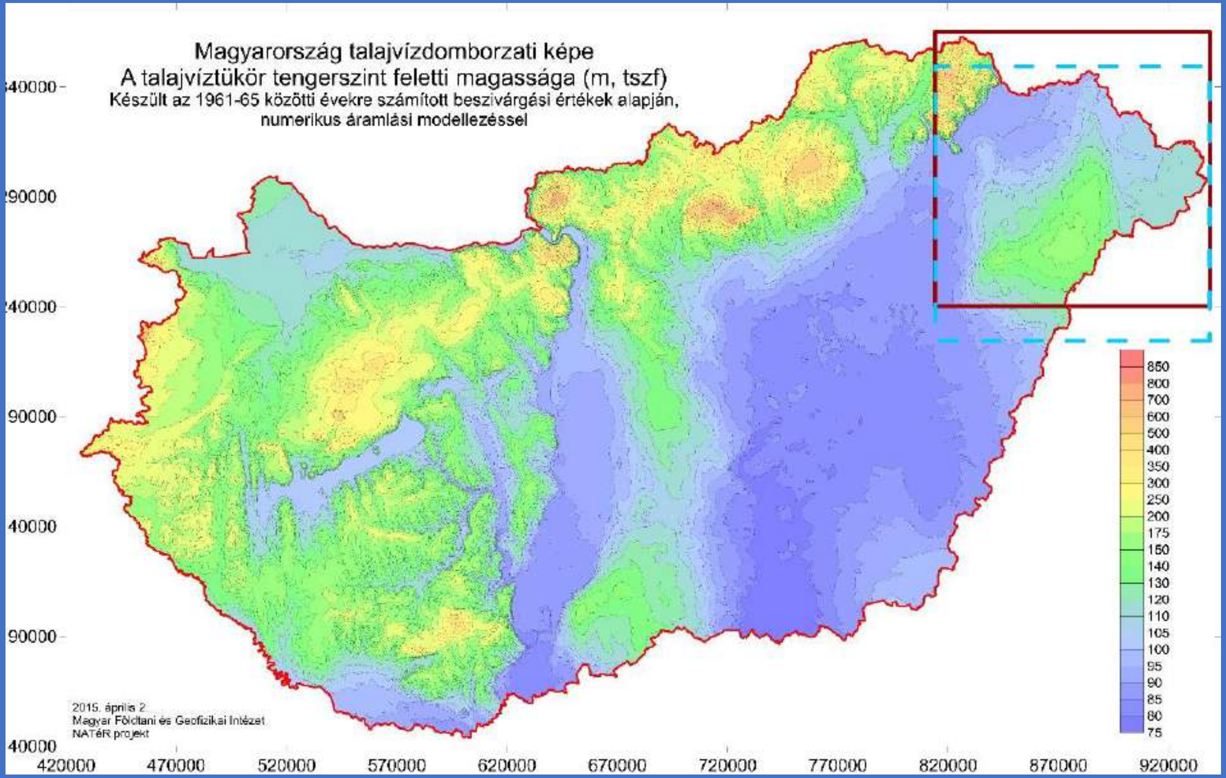
Hydrogeological assessment and modelling for the authorisation of water recharge in the Bereg marshes

1. Introduction – Bereg marshes
    1. Background information, research area
    2. 4.7 exemption of WFD
2. Possible causes of the decrease in groundwater levels
    1. Climate change
    2. Sinking of the Tisza riverbed
    3. Increased groundwater production
3. Geological background
4. Modelling processes & results
5. Conclusions and further suggested activities

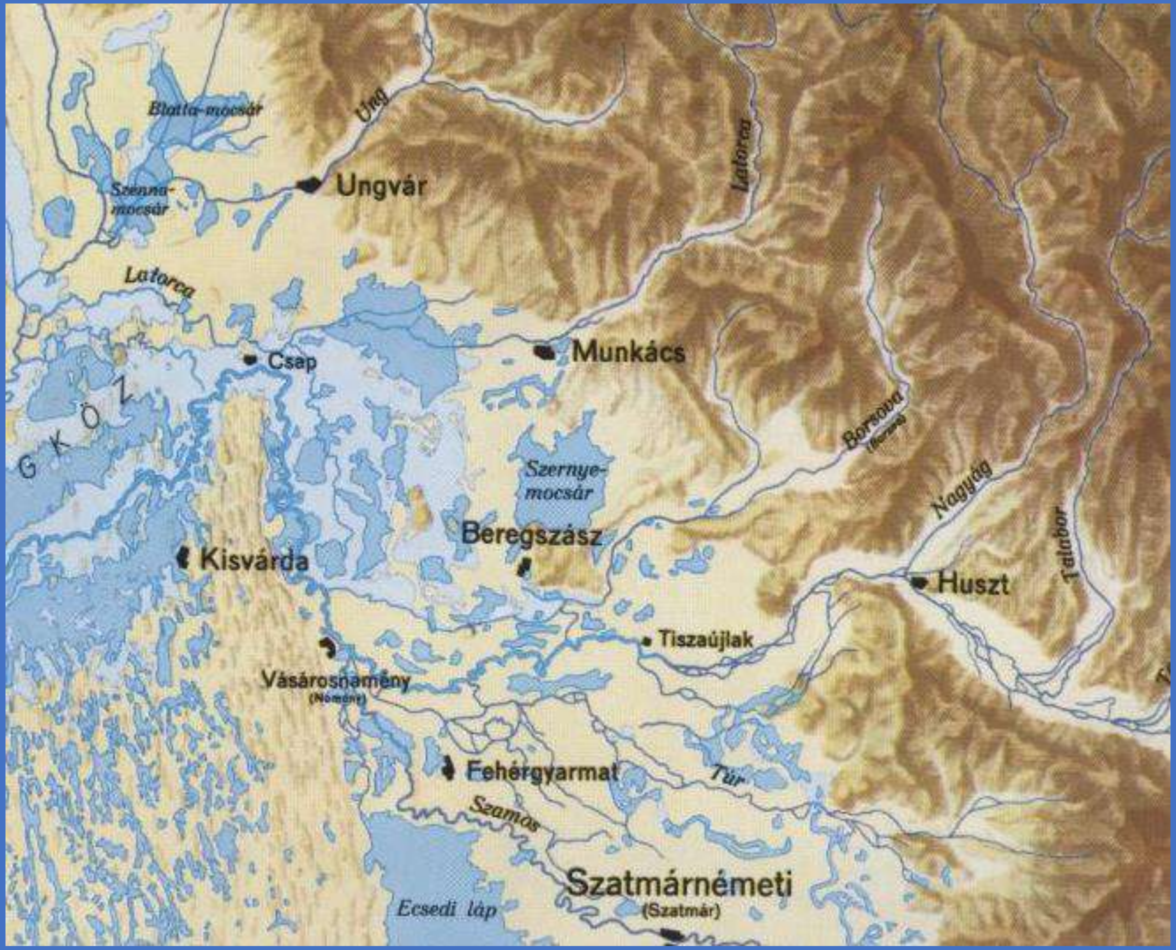


Bereg area

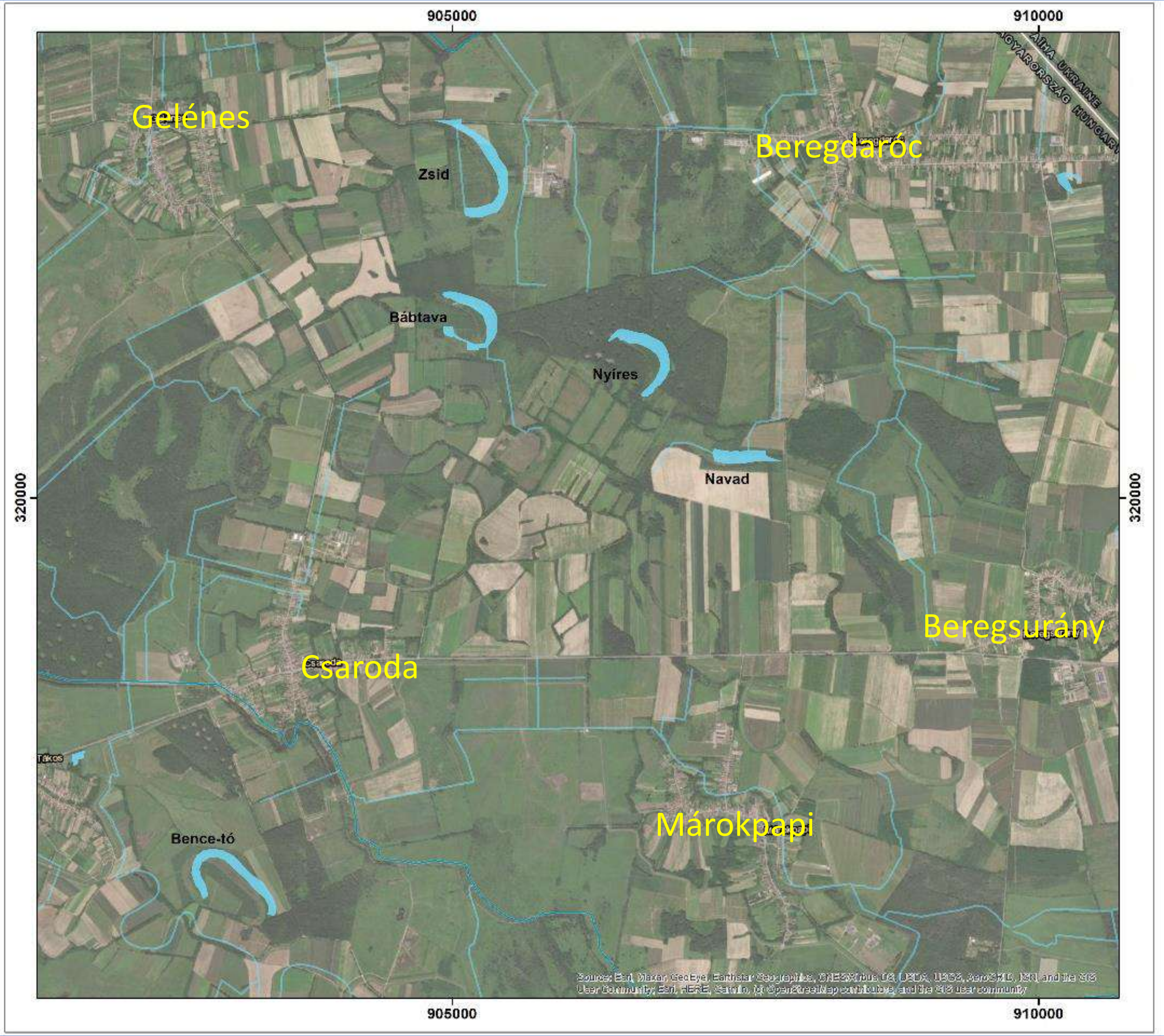
Background information, research area



The shallow groundwater level distribution of Hungary [m.a.s.l]



Hydrographic map of the Carpathian Basin before extensive river and lake regulations in the 19th century



Research area

- Beregdaróc settlements:

Nyíres-lake

Navad,

Bábtava,

Zsid-lake

- Csaroda settlements:

Bence-lake

The exemption under Article 4.7 of the Water Framework Directive allows Member States to grant certain exemptions or derogations from the requirements of the directive under specific circumstances. The Water Framework Directive (WFD) aims to protect and achieve sustainable use of the EU's water environment. The exemption under Article 4.7 provides an opportunity to establish exemptions or derogations for specific water bodies regarding the objectives and requirements of the directive.

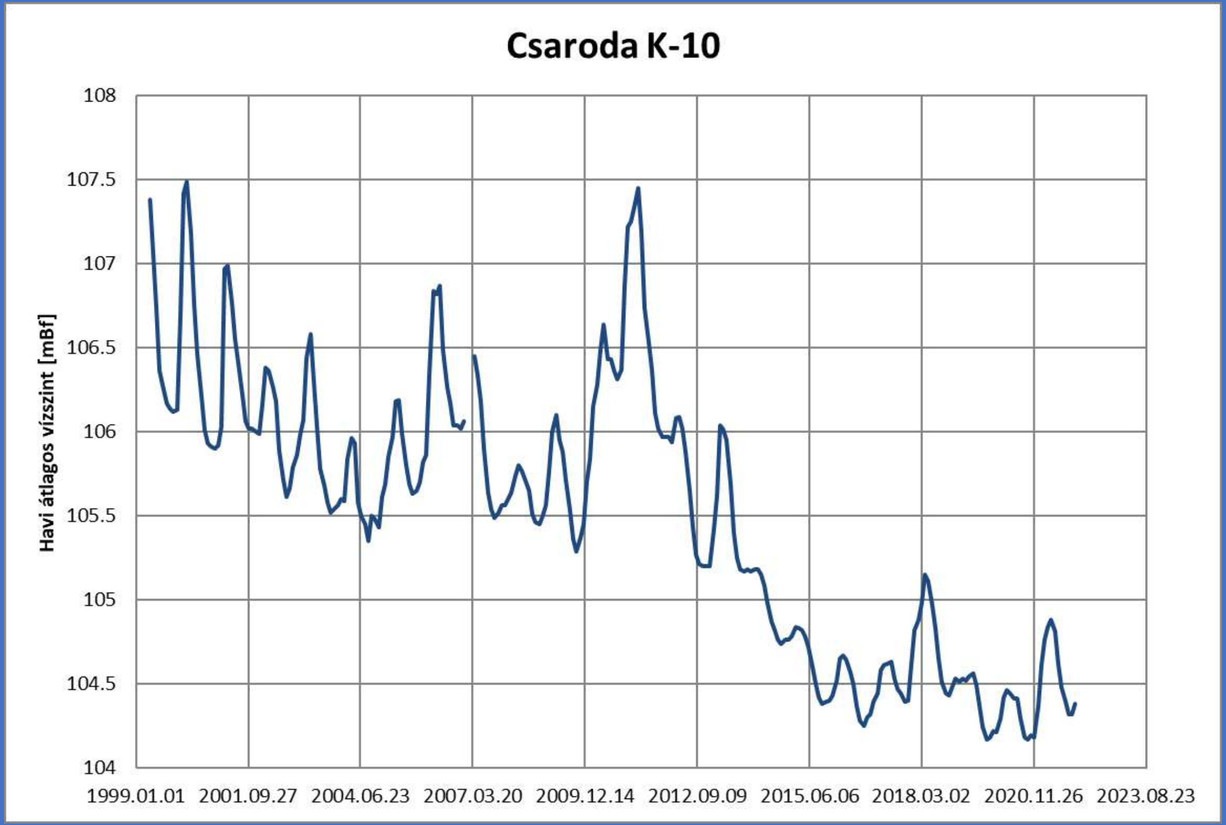
4.7 exemption procedure of the Water Framework Directive in the Hortobágy National Park.

- the number of wetlands drastically reduced,
- the ecological condition of the remaining ones has deteriorated (e.g. due to decreasing groundwater level)
- the objective of upgrading the water recharge systems of the bogs/marshlands in the Bereg and Nyírség areas, among others

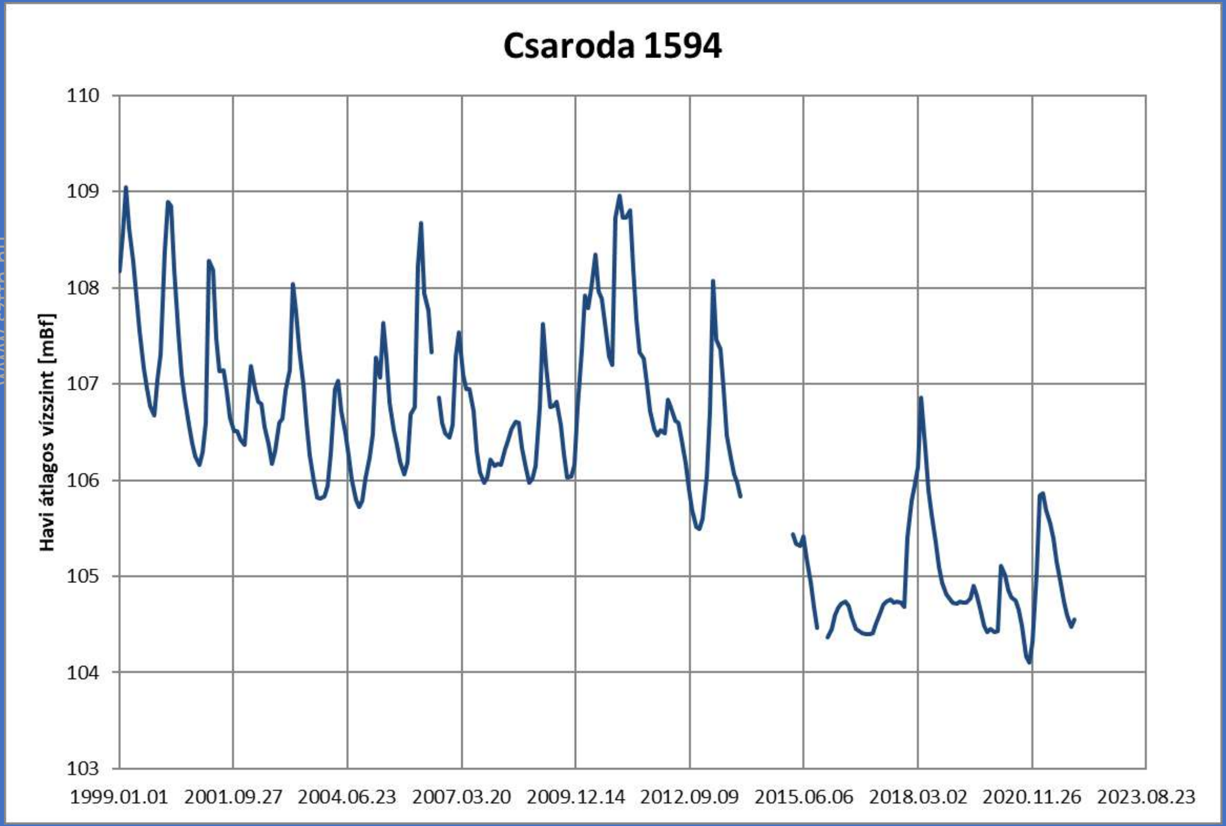


ECOSYSTEM

Decrease in groundwater levels:



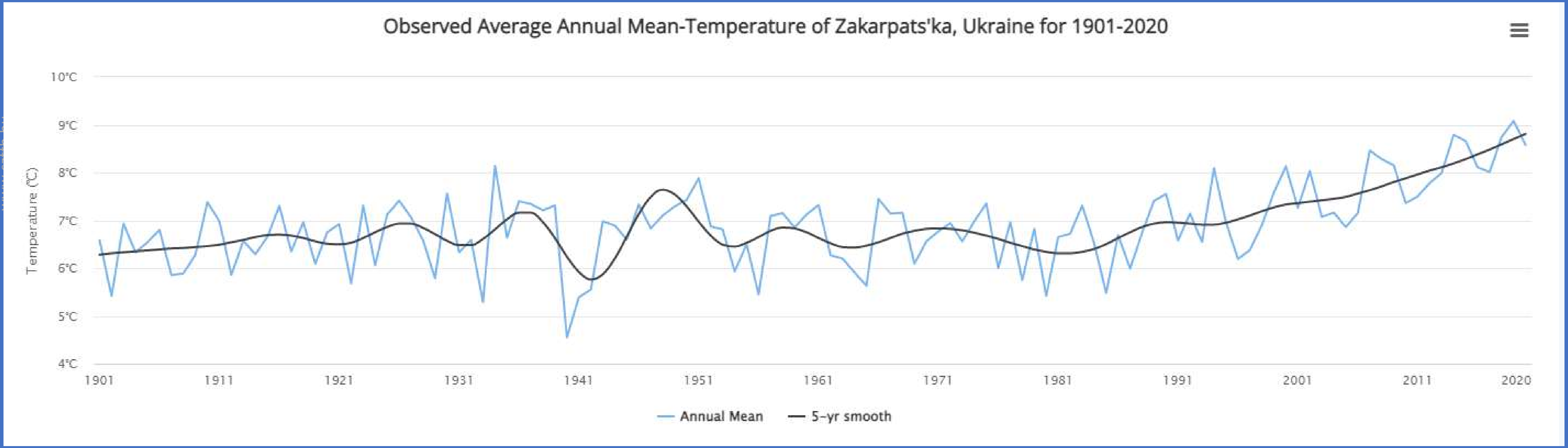
Observed deeper groundwater-level of 2nd aquifer in Csaroda K-10 (monthly average water level time series [1999-2021])



Observed groundwater-level of 1st aquifer in Csaroda 1594 (monthly average water level time series [1999-2021])

Possible causes of the decrease in groundwater levels:

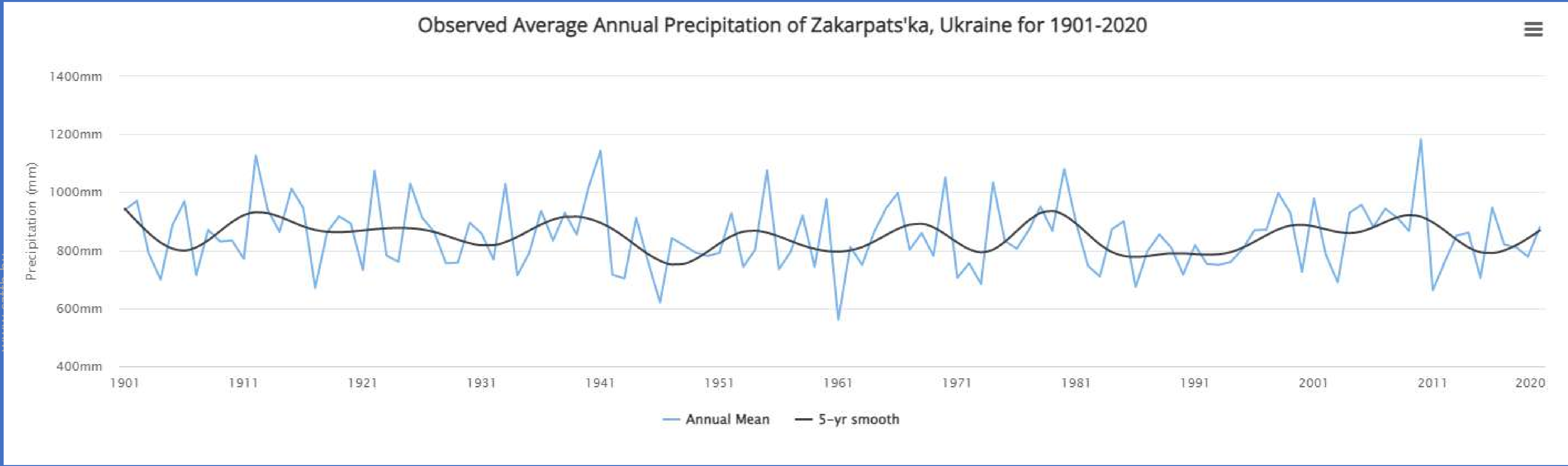
- Climate change
- Riverbed erosion of the Tisza
- Increased groundwater production



Annual average temperature data for the Transcarpathian region (1901-2020)

/source: https://climateknowledgeportal.worldbank.org/country/ukraine/climate-data-historical

Climate change



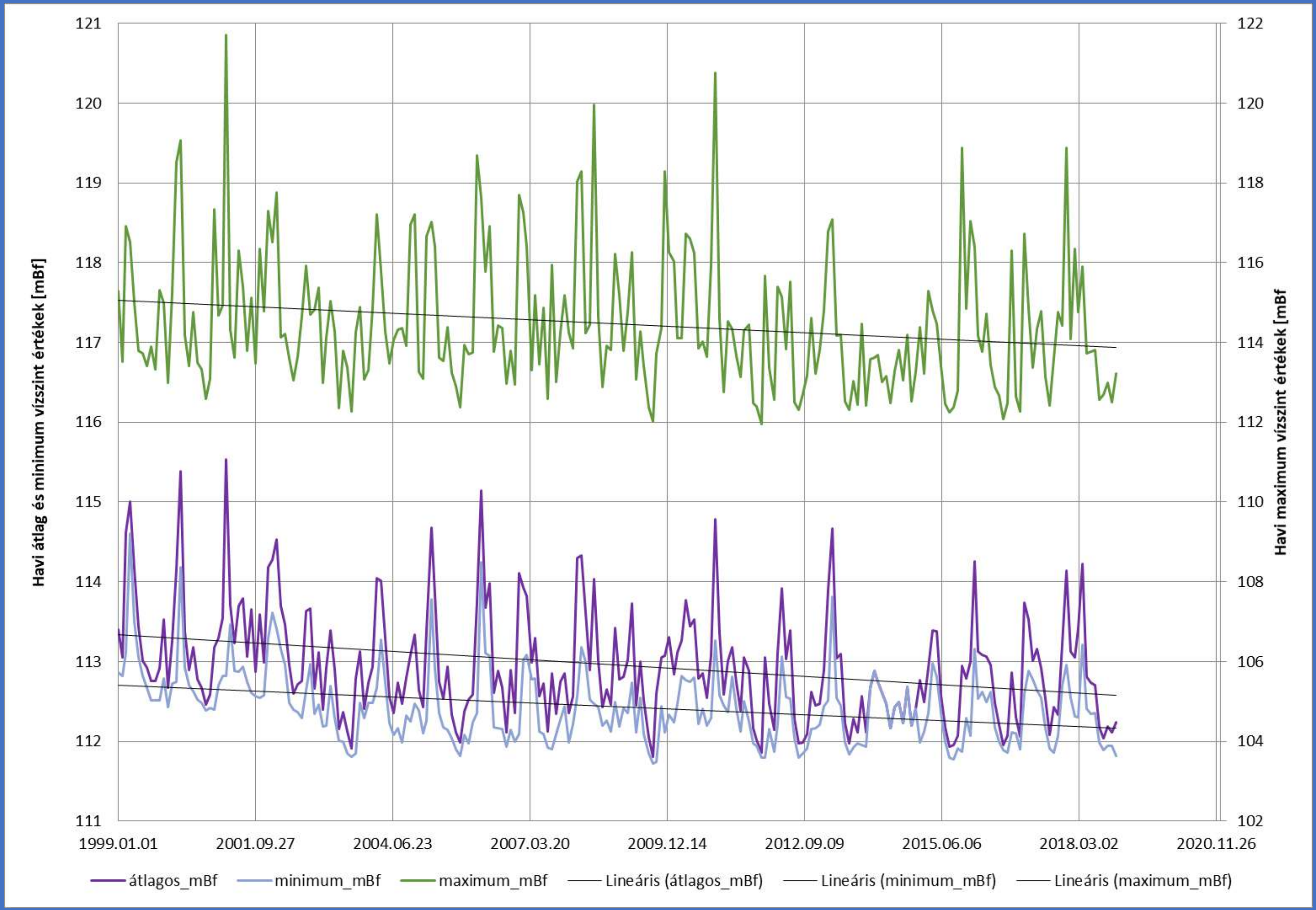
Precipitation data for the Transcarpathian region (1901-2020)

/source: https://climateknowledgeportal.worldbank.org/country/ukraine/climate-data-historical

Possible causes of the decrease in groundwater levels:

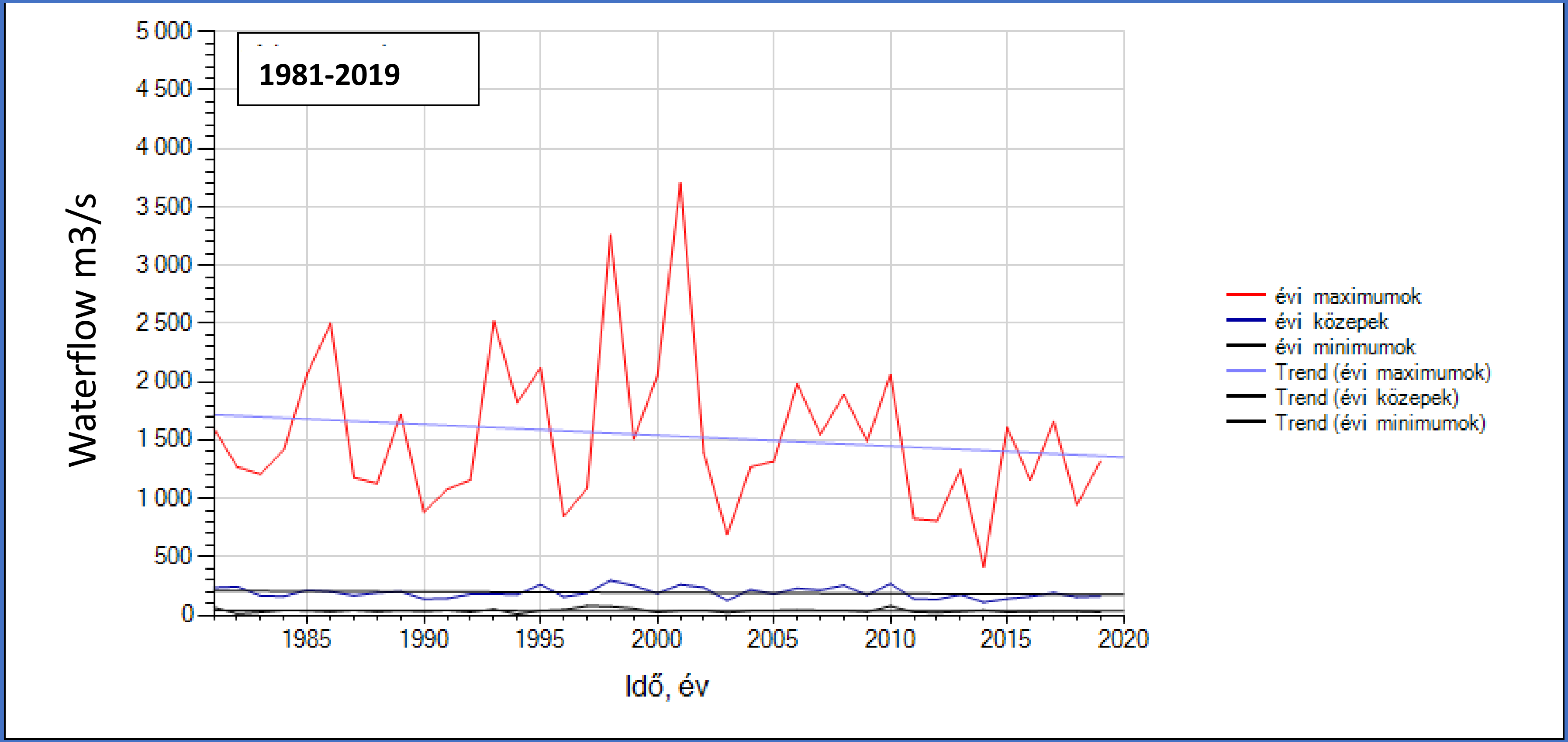
- Climate change
- Riverbed erosion of the Tisza
- Increased groundwater production

10



Tisza river water level at Tiszabecs station - monthly minimum, average and maximum values [mBf]

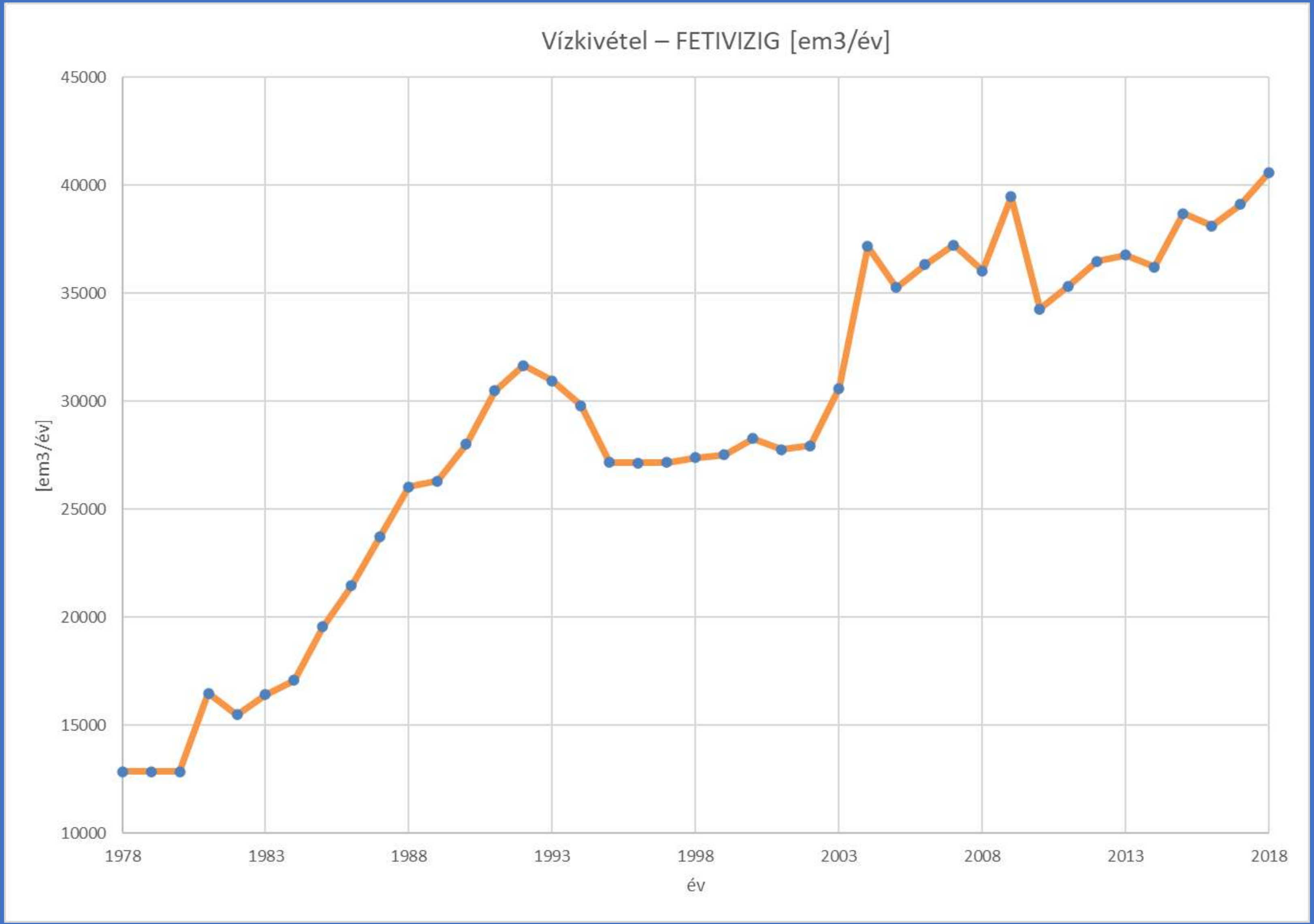
Riverbed erosion of the Tisza



Water flow characteristics at the Tisza river section in Tiszabecs
source: FETIVIZIG: Time series analysis

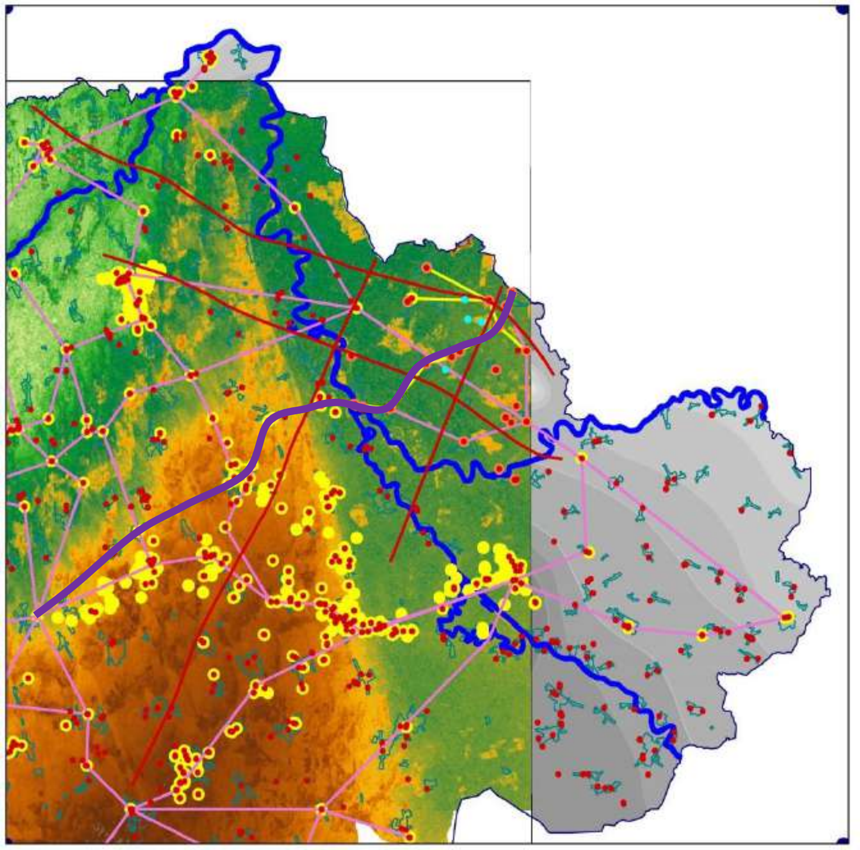
Possible causes of the decrease in groundwater levels:

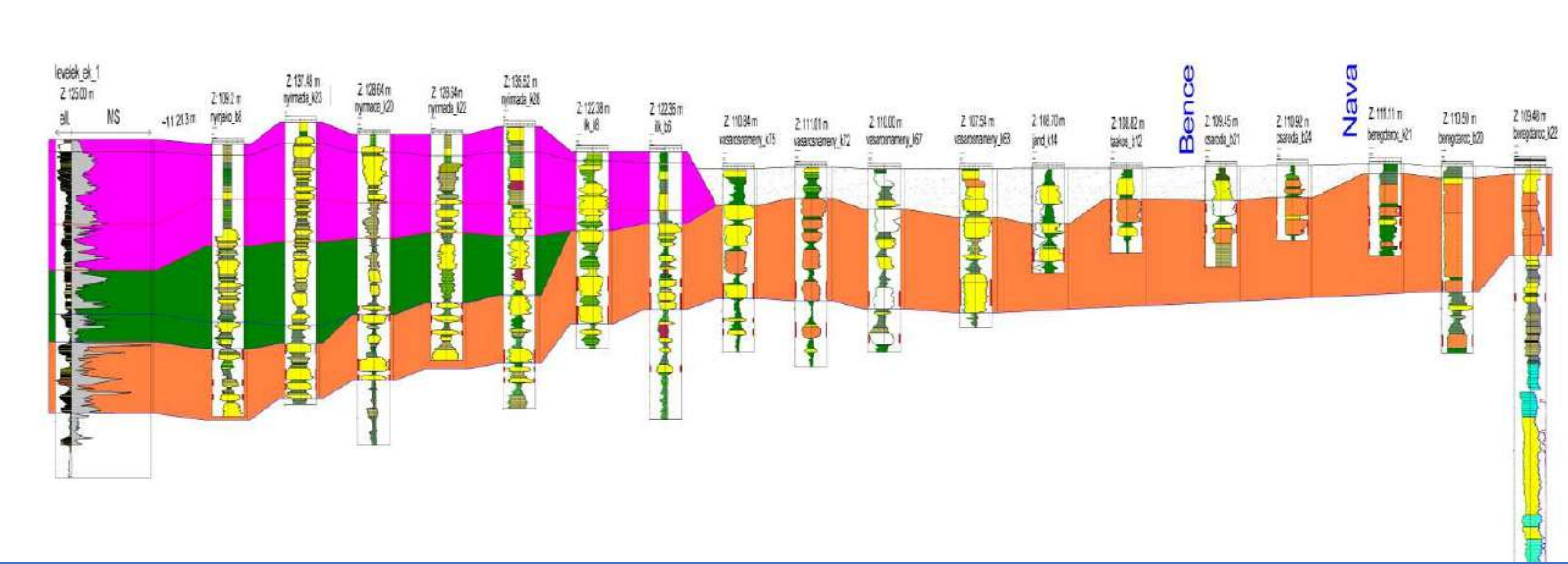
- Climate change
- Riverbed erosion of the Tisza
- Increased groundwater production



FETIVIZIG water production values (1000 m^3/year, 1978-2018)

Geological background – I.

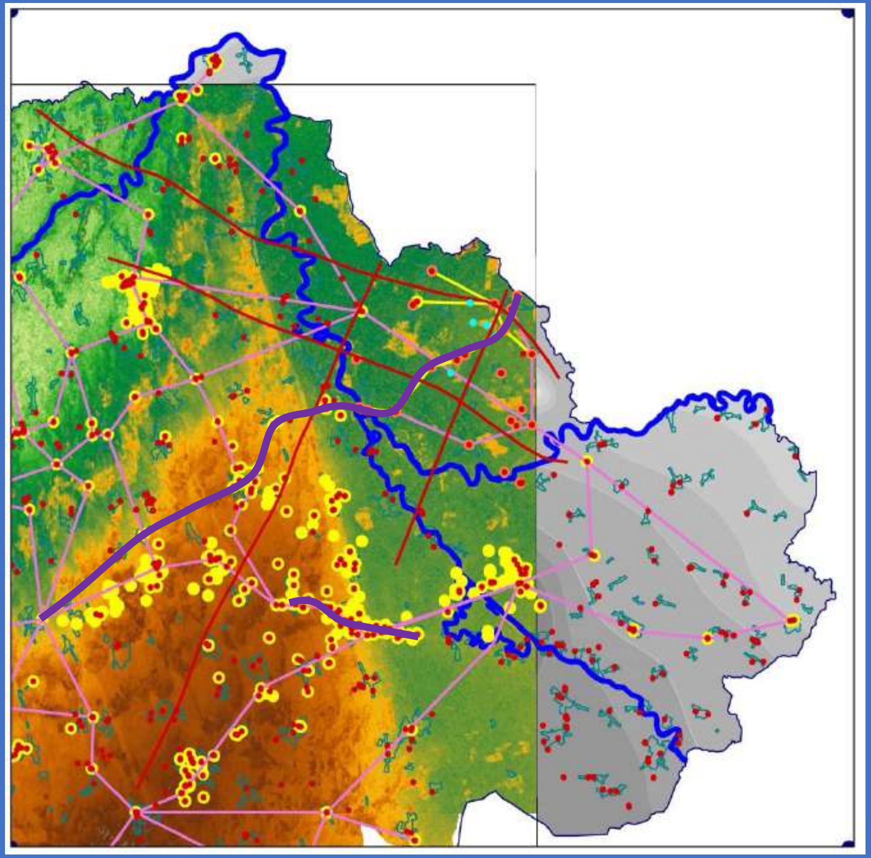


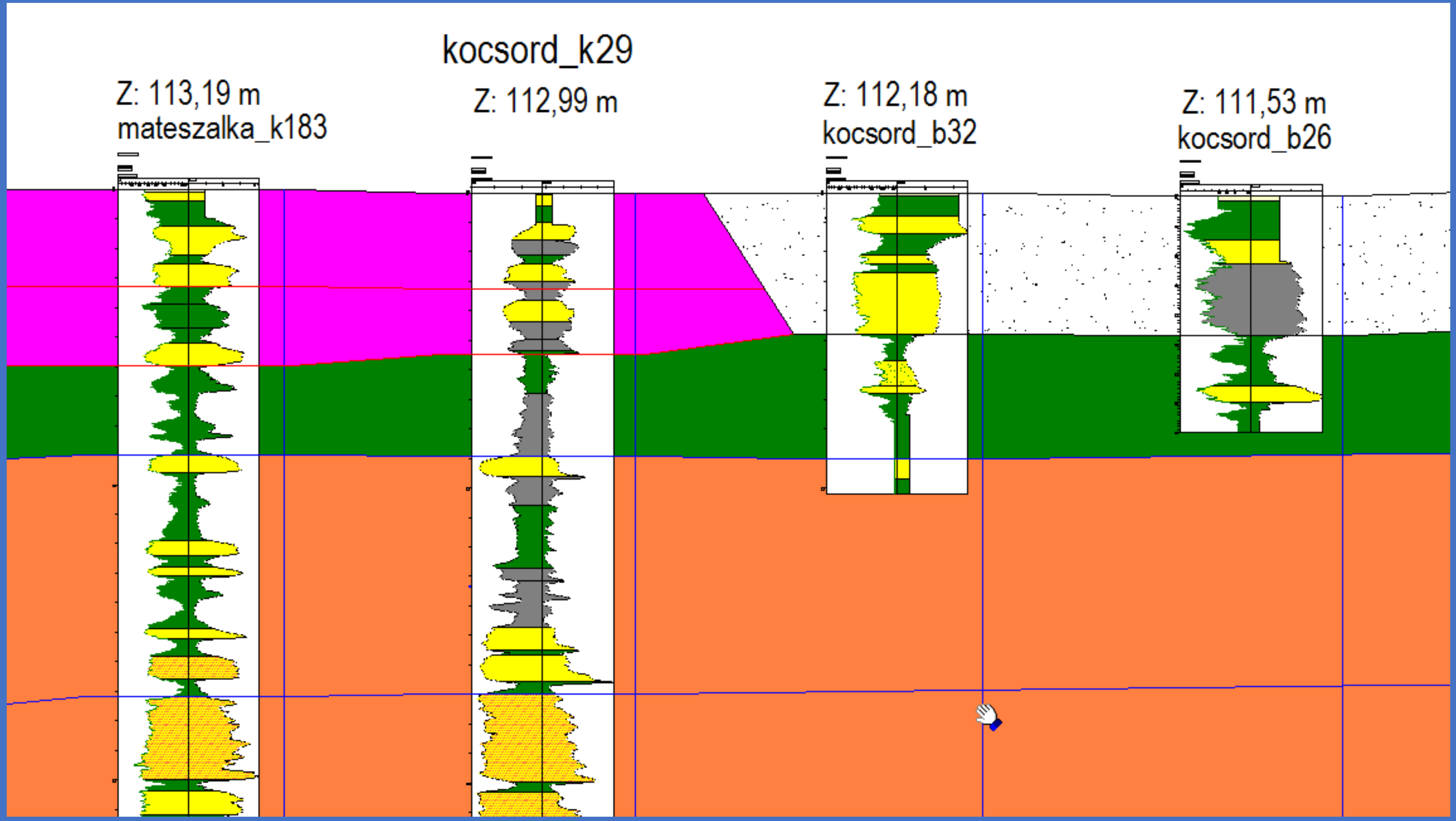


4 sedimentary system unit for the upper part:

1. Lower Pleistocene alluvial cone (orange):
2. Lower Pleistocene lake formations (green):
3. Middle – (Upper?) Pleistocene alluvial cone (cyclamen)
4. (Middle?) – upper Pleistocene alluvial system (dotted)

Geological background – II.





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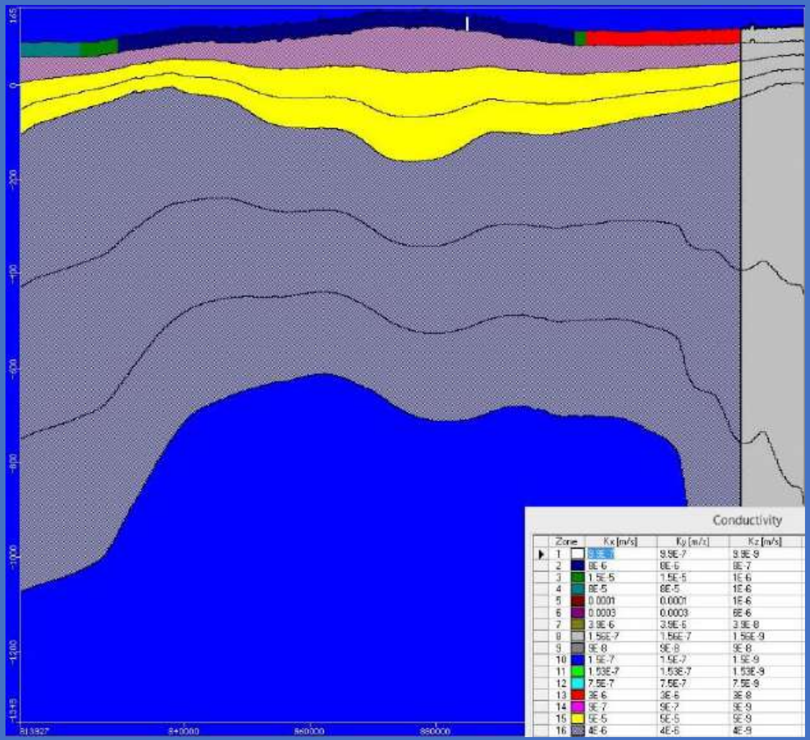
3. Middle – (Upper?) Pleistocene alluvial cone (cyclamen)
4. (Middle?) – upper Pleistocene alluvial system (dotted)

Groundwater model studies – I.

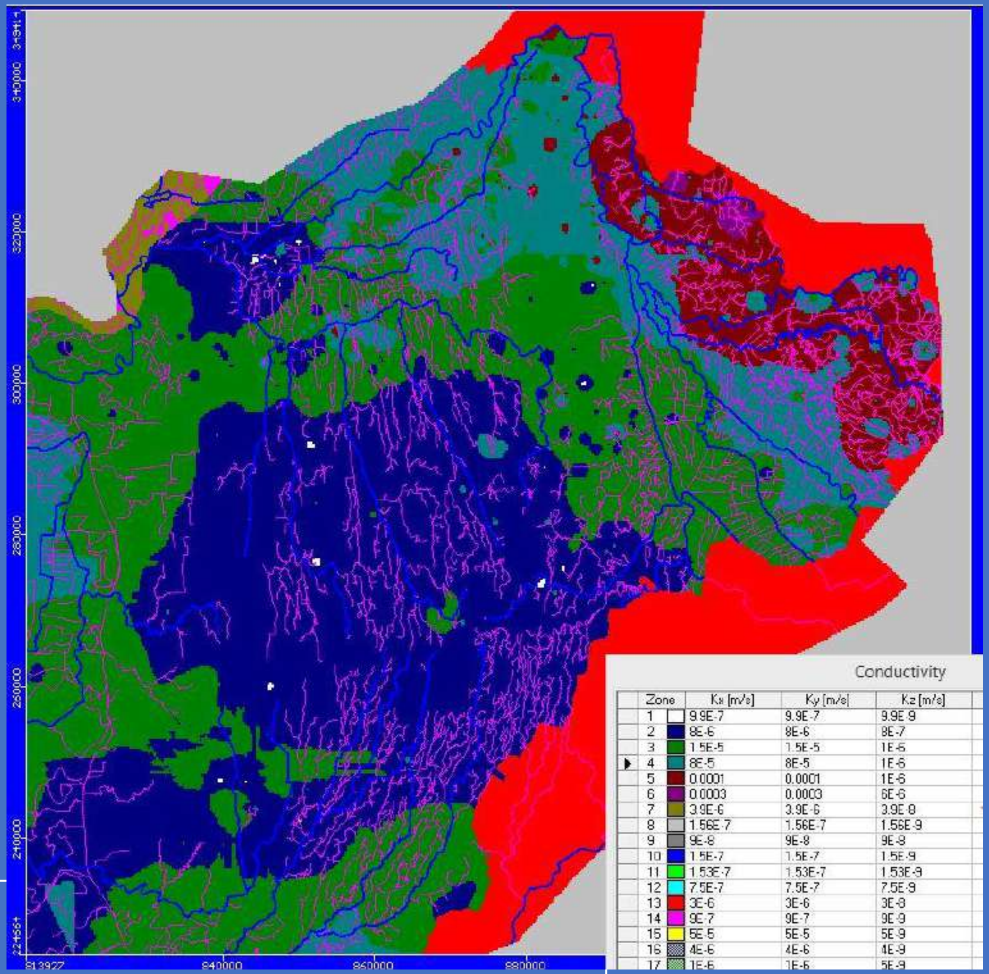
Horizontal division

Defining the horizontal extent of the model.

1. extends across national borders in the north and east;
2. includes the most significant regional water abstraction districts
3. the number of model cells should not exceed 500x500, — neither in the N-S nor in the W-E direction



subregional scale: model area 124.5×124.5 km^2
cells 250×250 m in size



Vertical division: 7 model layers

1st layer → groundwater aquifer

2nd layer → upper Pleistocene complex

3rd layer → middle Pleistocene complex

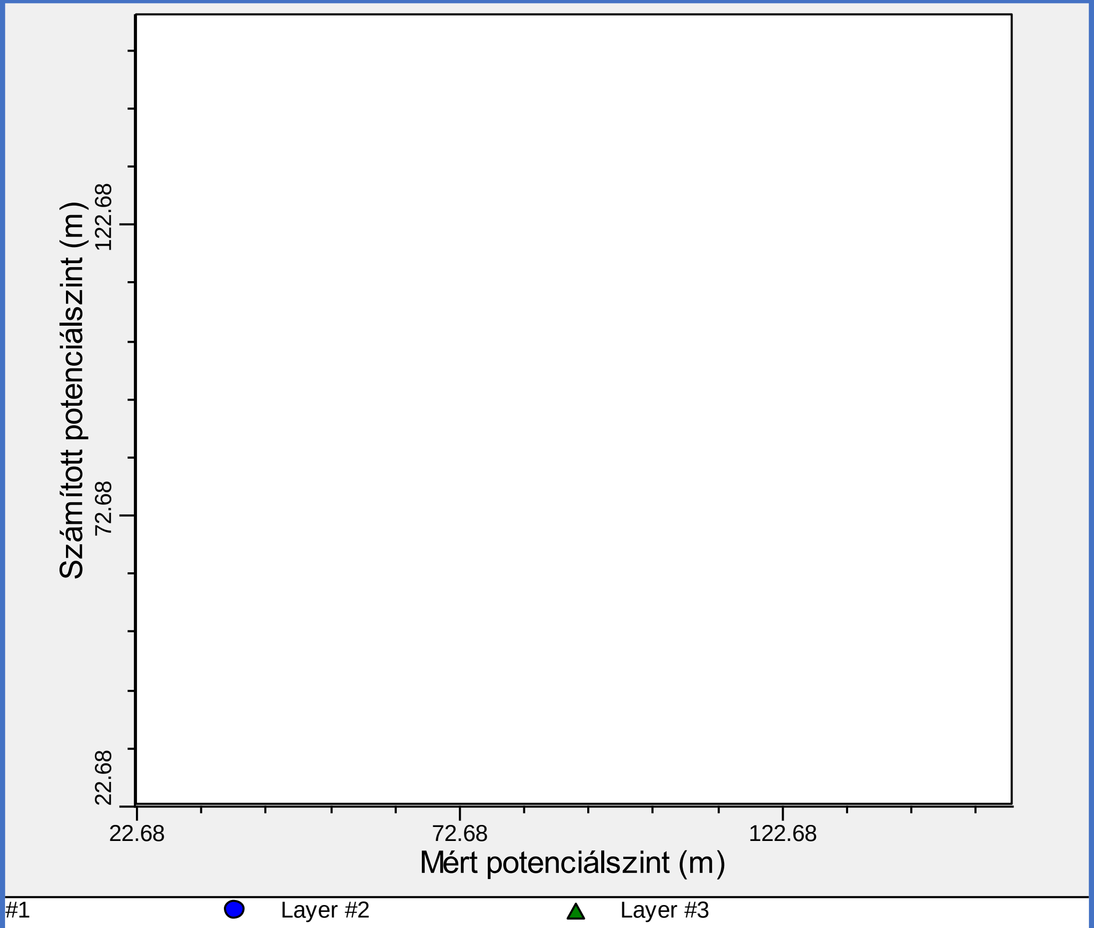
4th layer → lower Pleistocene complex

Layer 5 → Upper part of the Upper part of Pannonian complex

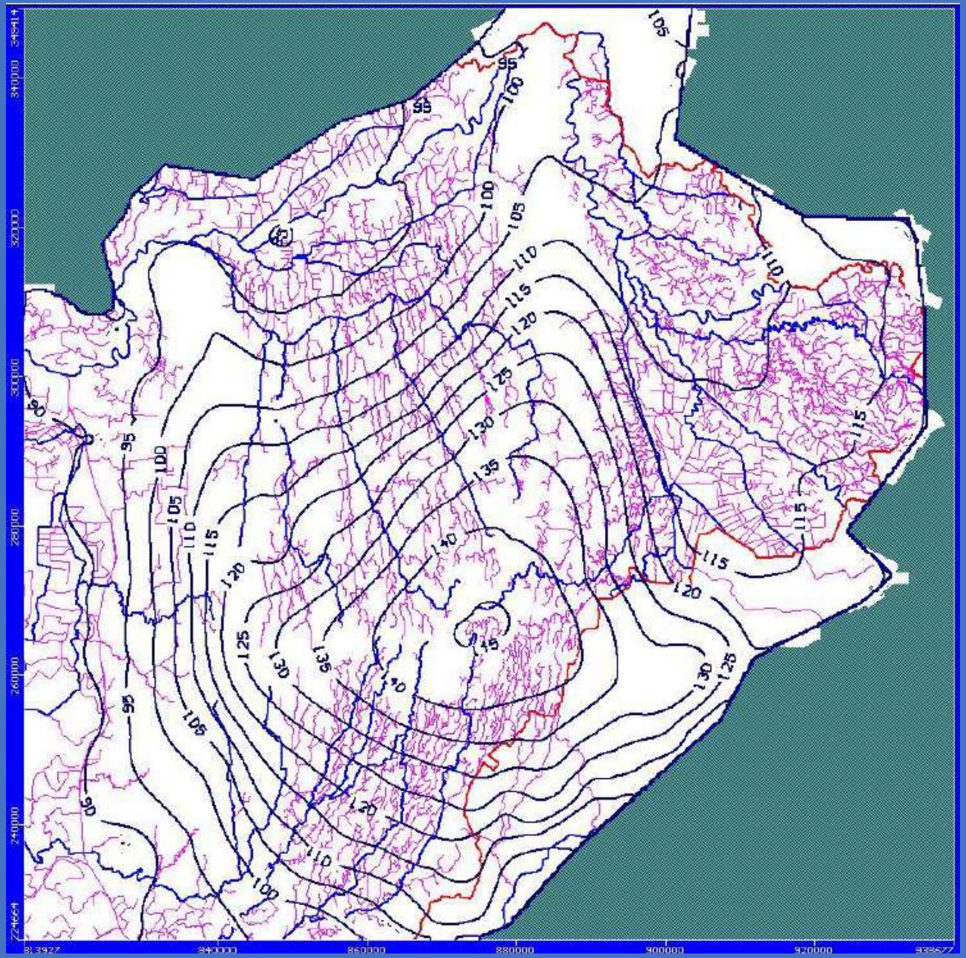
Layer 6 → Middle part of the Upper part of Pannonian complex

Layer 7 → Lower part of the Upper Pannonian complex

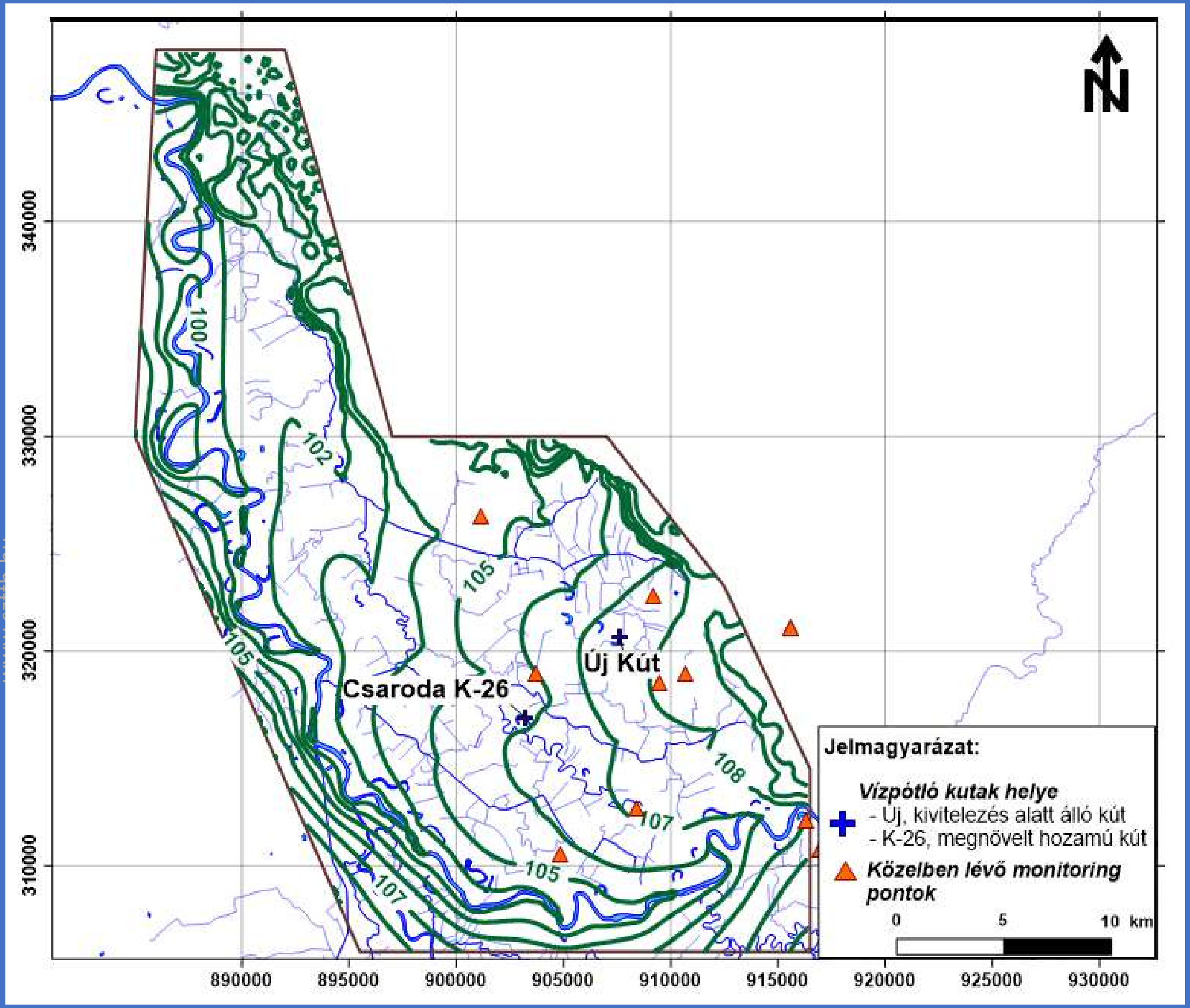
Groundwater model studies – II.



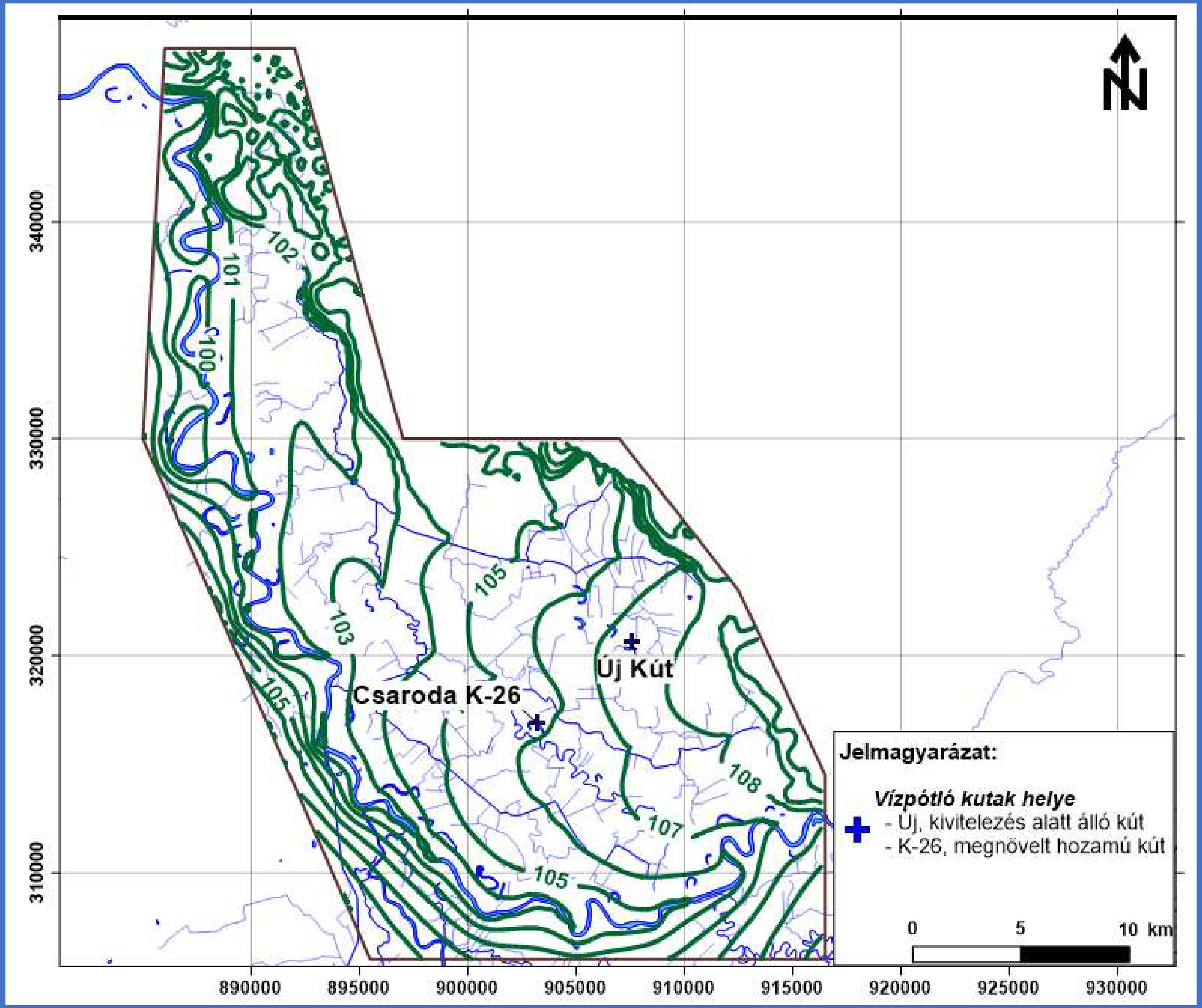
Measured and modelled water levels in model layer 2 (based on water production in the period 2012-18)



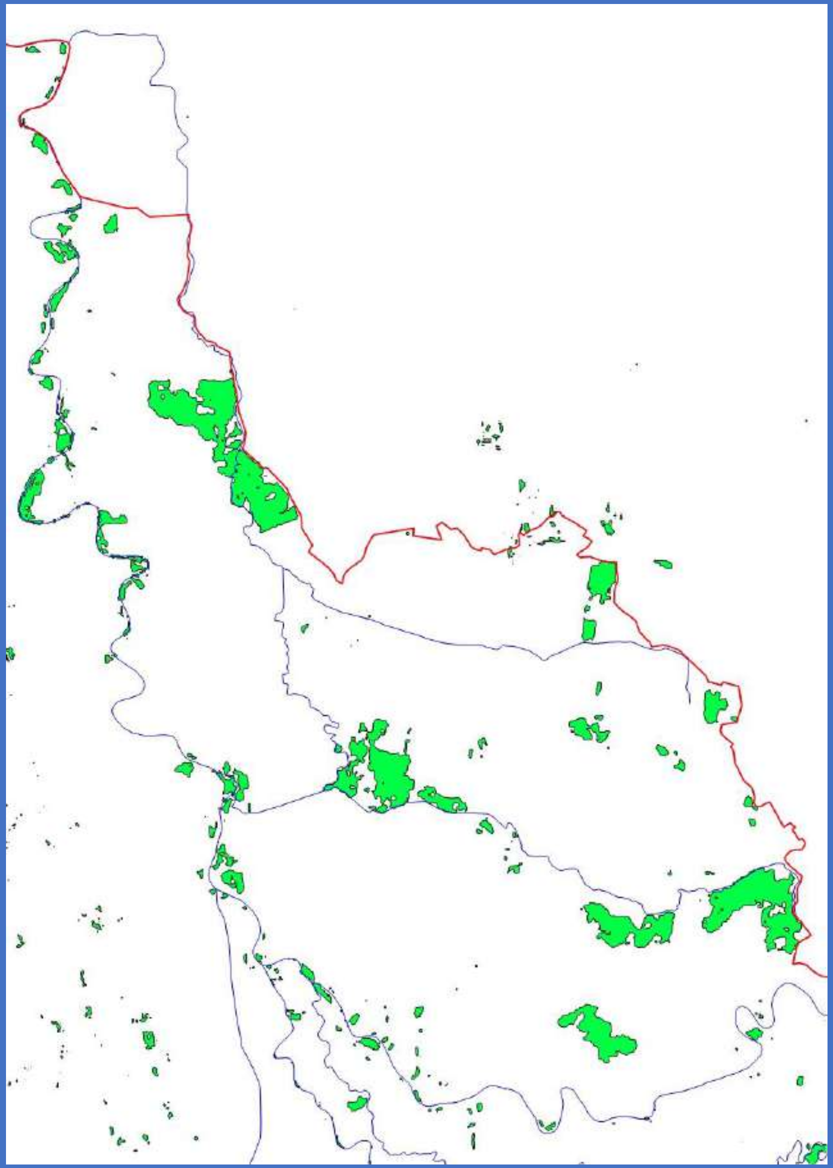
Modeled potential levels [masl] in model layer 2 in case of water production (2012-18)



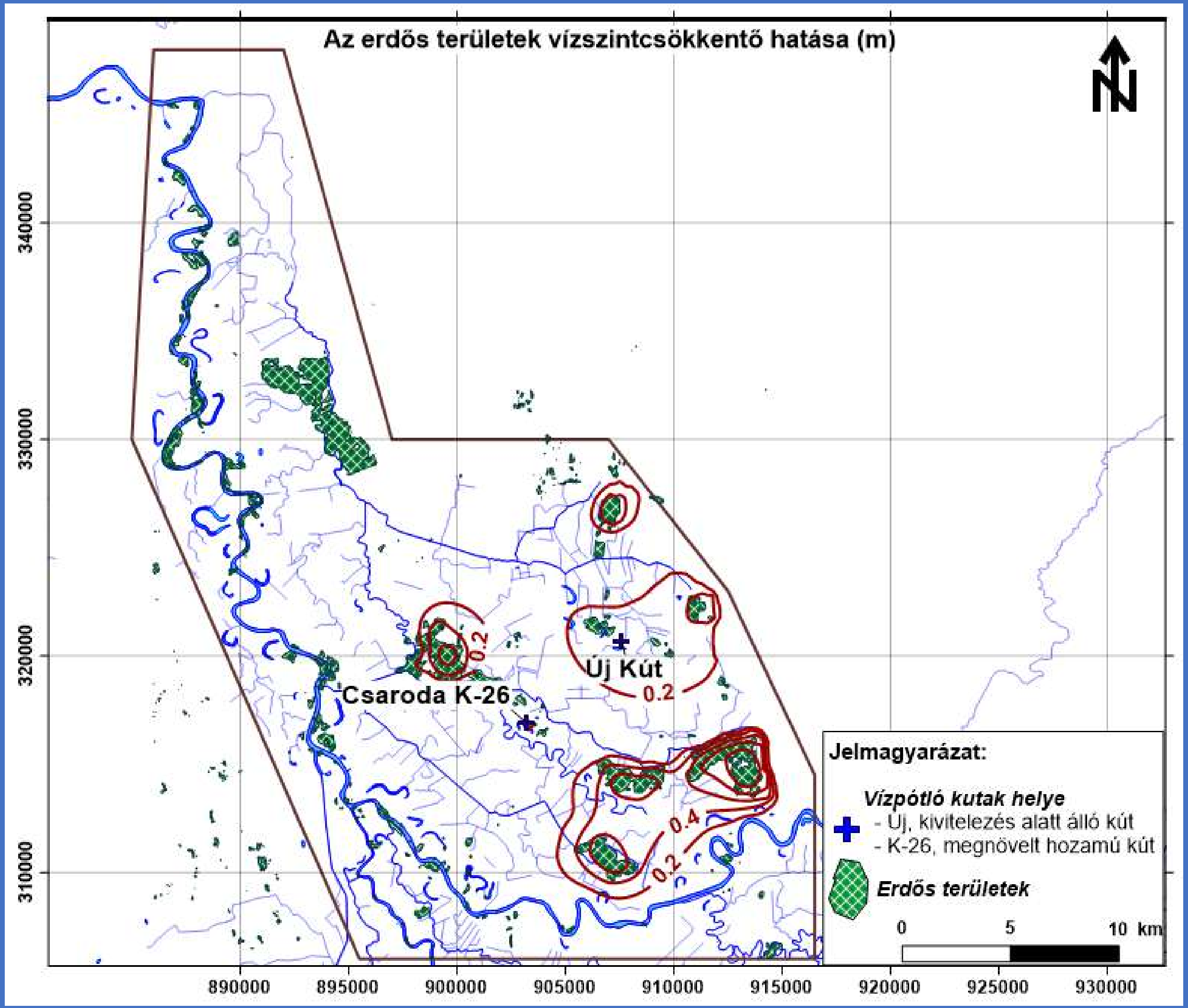
Groundwater level distribution [mBf] (Initial version: SZSZB production data, 115 mBf GHB, MWL at Tisza water level)



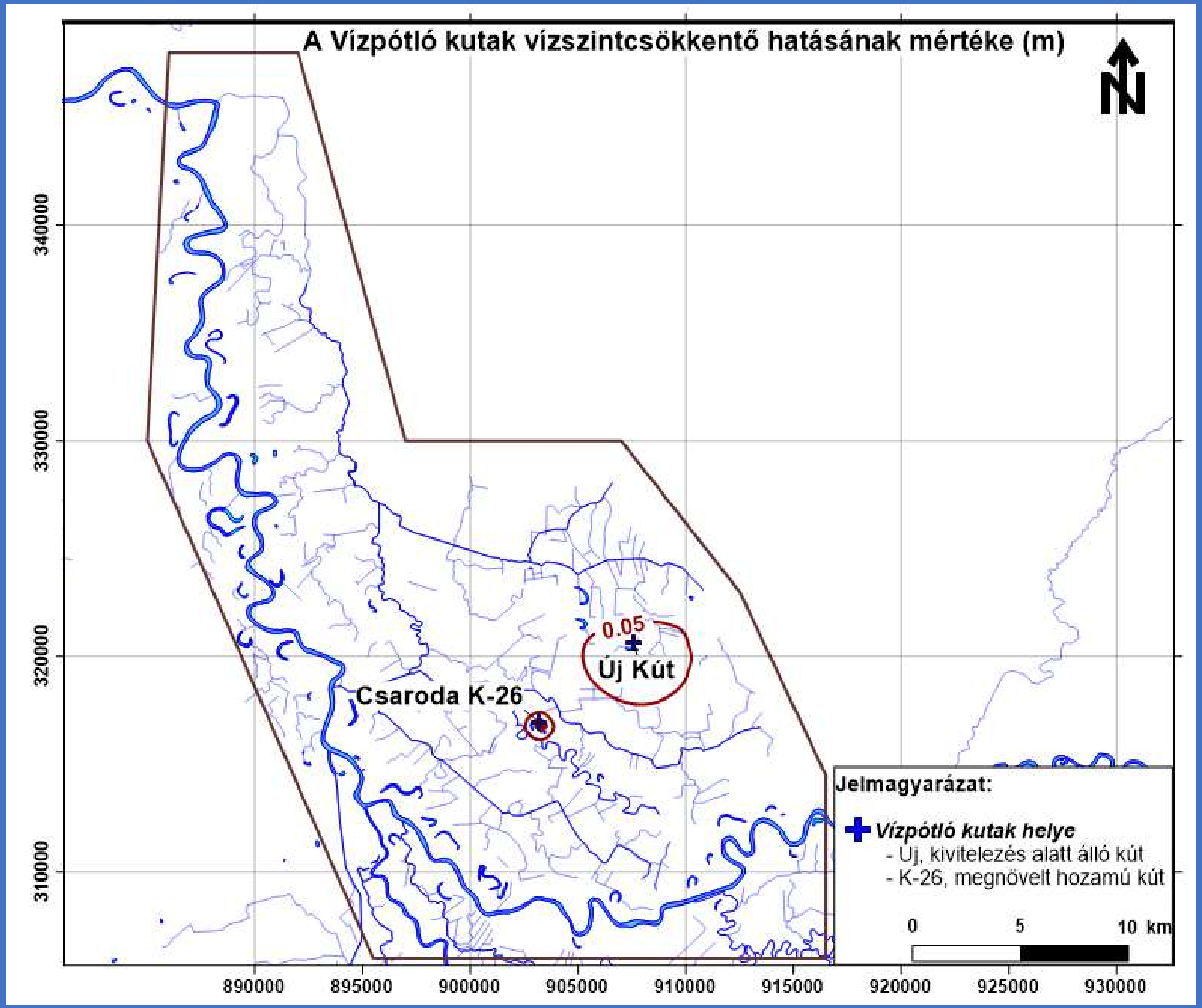
Groundwater level distribution [mBf] (version V1: SZSZB production data, also increased production of the new well and Csaroda K-26, cancellation of the blocked well, 115th GHB, MWL Tisza water level)

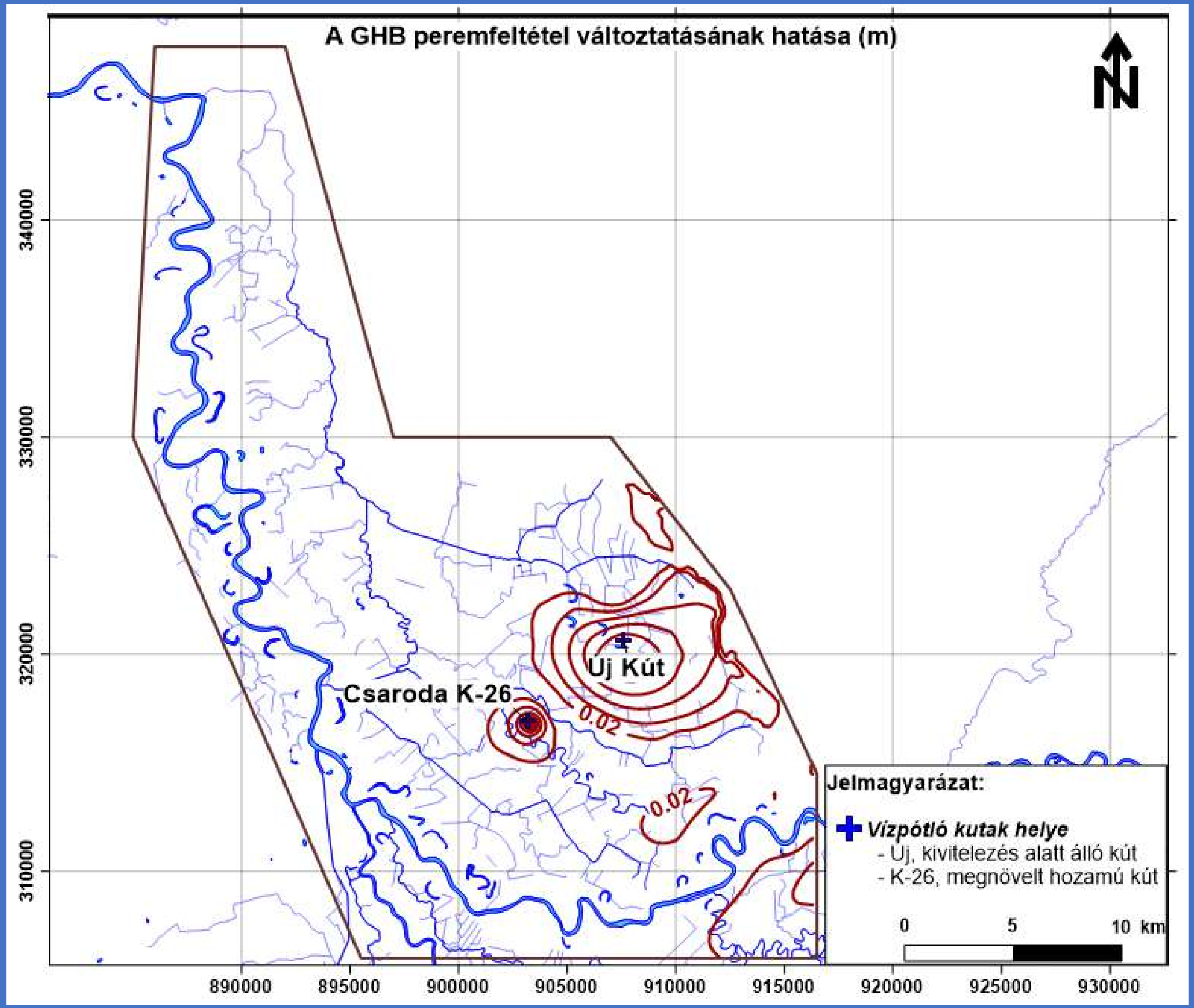


Location of forested areas



Water level lowering effect of forested areas [m]

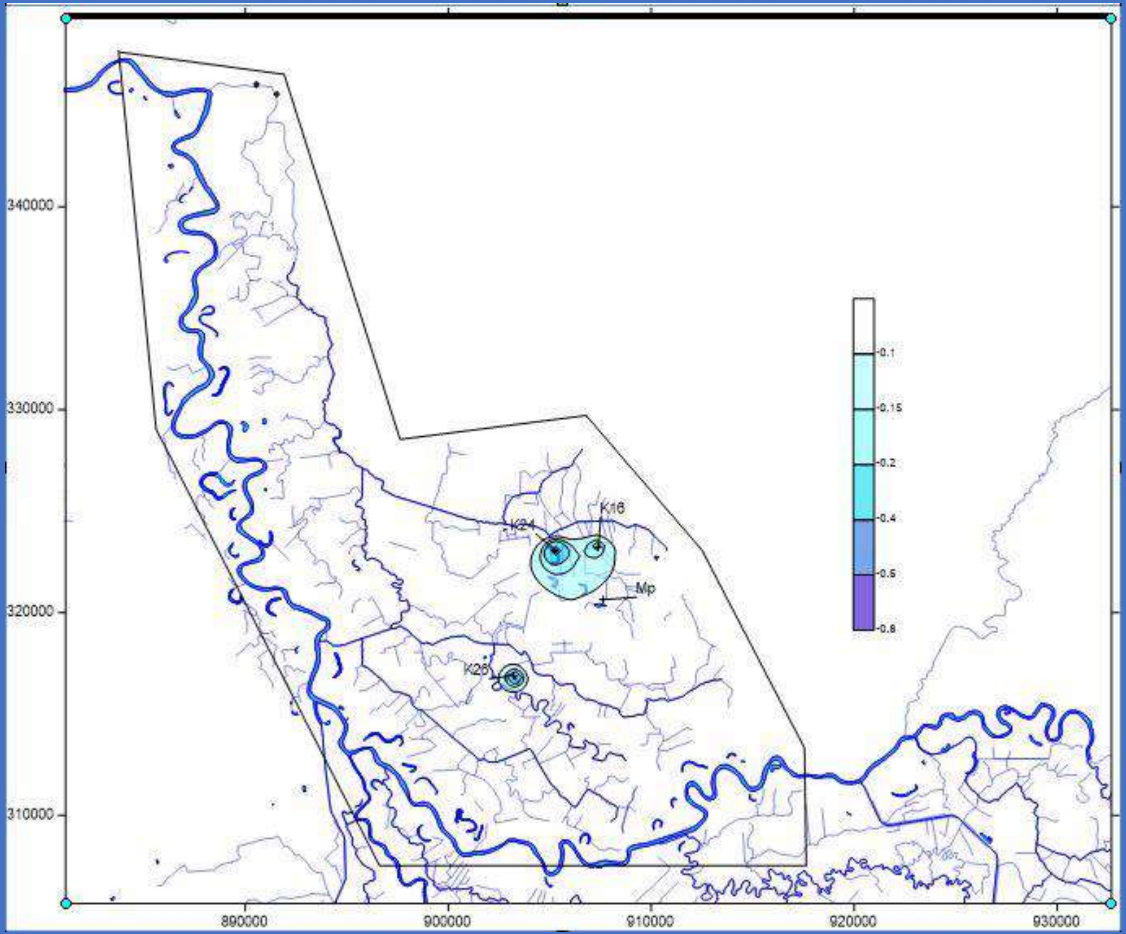




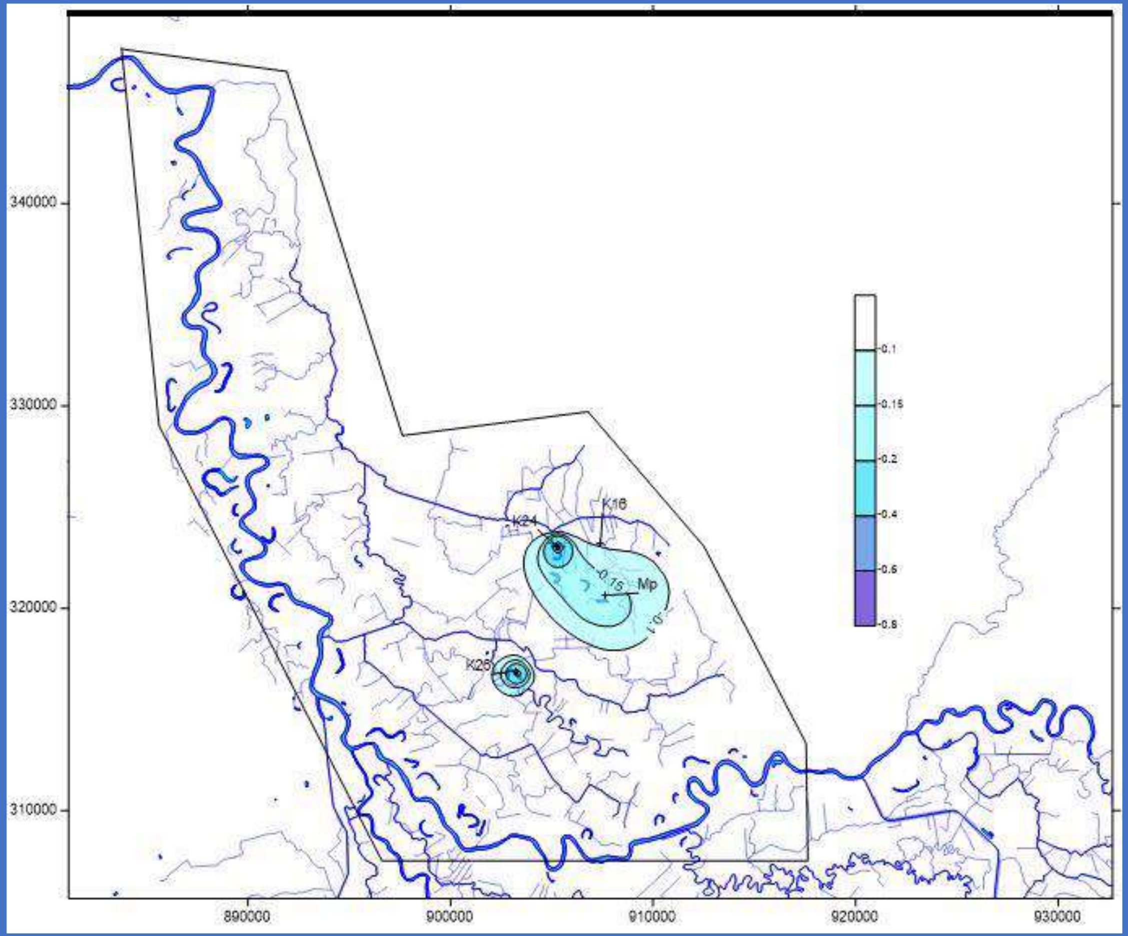
Depression level values distribution of water-supply wells [m]
st version GHB: 125 m.a.s.l; 2nd version GHB= 115 m.a.s.l

Water production values old/new:

❖ K-16 well:	270 m^3/d	liquidated
❖ K-24 well:	322 m^3/d	369.9 m^3/d
❖ K-26 well:	170 m^3/d	246.6 m^3/d
❖ Márokpapi new well:	X	356.2 m^3/d



The modeled value of the decrease (depression) in groundwater levels as a result of the production of the wells K-16, K-24 and K-26 between 2012-2018, [m]



Modelled value of the expected decrease (depression) in groundwater levels when increasing water supply to bog lakes [m]

Water-supply wells

Water-supply fountains Nyíres- lake and Zsid-lake

New water-supply well at Márokpapi

Conclusions:

- To maintain the good environmental status of groundwater-dependent ecosystems, it is very important to ensure and maintain good groundwater status in harmony with the objectives of the WFD
- The primary determinant for the maintenance of wetlands is the quantitative demand on groundwater
- The necessity of monitoring activities for timely intervention

Further suggested activities:

- Complex groundwater level observation e.g. with frequency within a day (transmitters)
- to coordinate water management goals with other water uses in order to mitigate the harmful effects of climate change
- take into consideration of cross-border information (wetlands, water production)

Thank you for your kind attention!

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National Meeting on Hydrogeology

JUNE 14-16, 2023

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

Francesca Gori[1] *, Marino Domenico Barberio*[2]*, Maurizio Barbieri*[3]*, Tiziano Boschetti*[4]*, Francesco Latino Chiocci*[1]*, Marco Petitta*[1]

[1] *Department of Earth Sciences, Sapienza University of Rome, Italy*

[2] *National Institute of Volcanology and Geophysics, Rome, Italy*

[3] *Department of Chemical Engineering and Environmental Materials, Sapienza University of Rome, Italy*

[4] *Department of Chemistry, Life Sciences and Environmental Sustainability, University of Parma, Italy*

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Dipartimento di Scienze della Terra
Dipartimento di Biologia Ambientale
Dipartimento di Biologia e Biotecnologie Charles Darwin

IGAG Istituto di Geologia Ambientale e Geoingegneria

Isola di Pantelleria Parco Nazionale

Multidisciplinary study

Project “Conservazione della Biodiversità del Lago Bagno dell’Acqua (Isola di Pantelleria)”

Goals:

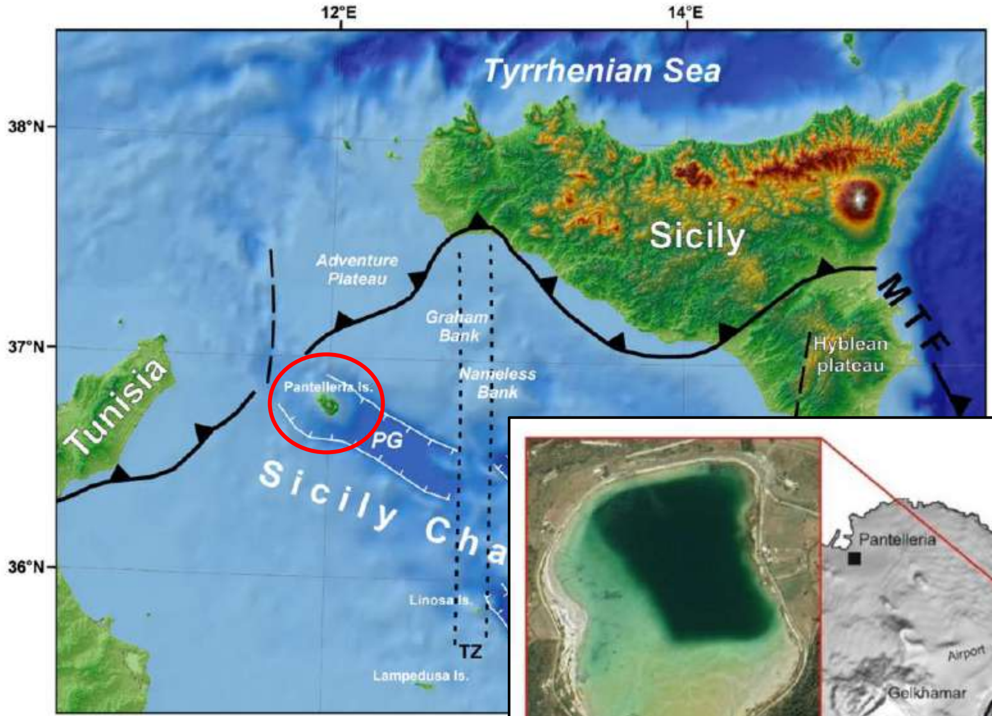
Providing a contribution to a wide multidisciplinary study for the conservation of the biodiversity of the Bagno dell’Acqua lake and new insights for the evaluation of the environmental impact associated with climate changes

Expanding our understanding of a such extreme aquatic environment (i.e., alkaline lake) defining origin and mixing of lake water, groundwater and ascending deep thermal fluids

Work in progress

LOADING

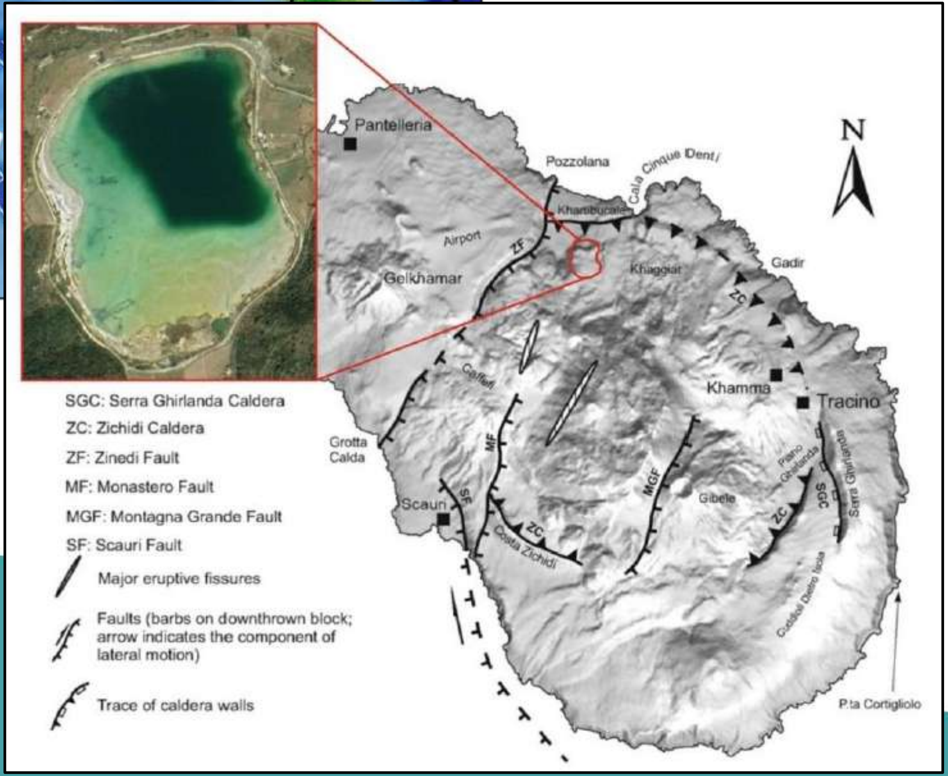
Pantelleria Island (Southern Italy)



(Civile et al. 2010)

Pantelleria island is the emerging summit of a very large submarine volcano rising from the seafloor located in the **Sicily Channel Rift Zone** (about 100 km southwest of Sicily and 70 km north of Tunisia)

The island is totally covered by volcanic products of both effusive (mainly basalts) and explosive activity (trachytes to peralkaline rhyolites)



(Catalano et al. 2009)

The volcanic system of Pantelleria is still active

At present volcanic activity is limited to low temperature fumarolic emissions and thermal springs

The only surface water is represented by

Bagno dell'Acqua Lake

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Bagno dell'Acqua Lake
also known as "Specchio di Venere Lake"

- Endorheic alkaline lake located inside the Cinque Denti caldera depression
- Sub-circular shape ca. 450 m long and ca. 350 m wide
- Maximum depth of 12.5 m
- Surface area extending up to 0.2 km^2 is strongly controlled by water input by rainfall, runoff, and a contribution from the thermal aquifer
- The SW shoreline of the lake is affected by hydrothermal activity exhaling mainly CO_2 (98%)

(Aiuppa et al. 2007)

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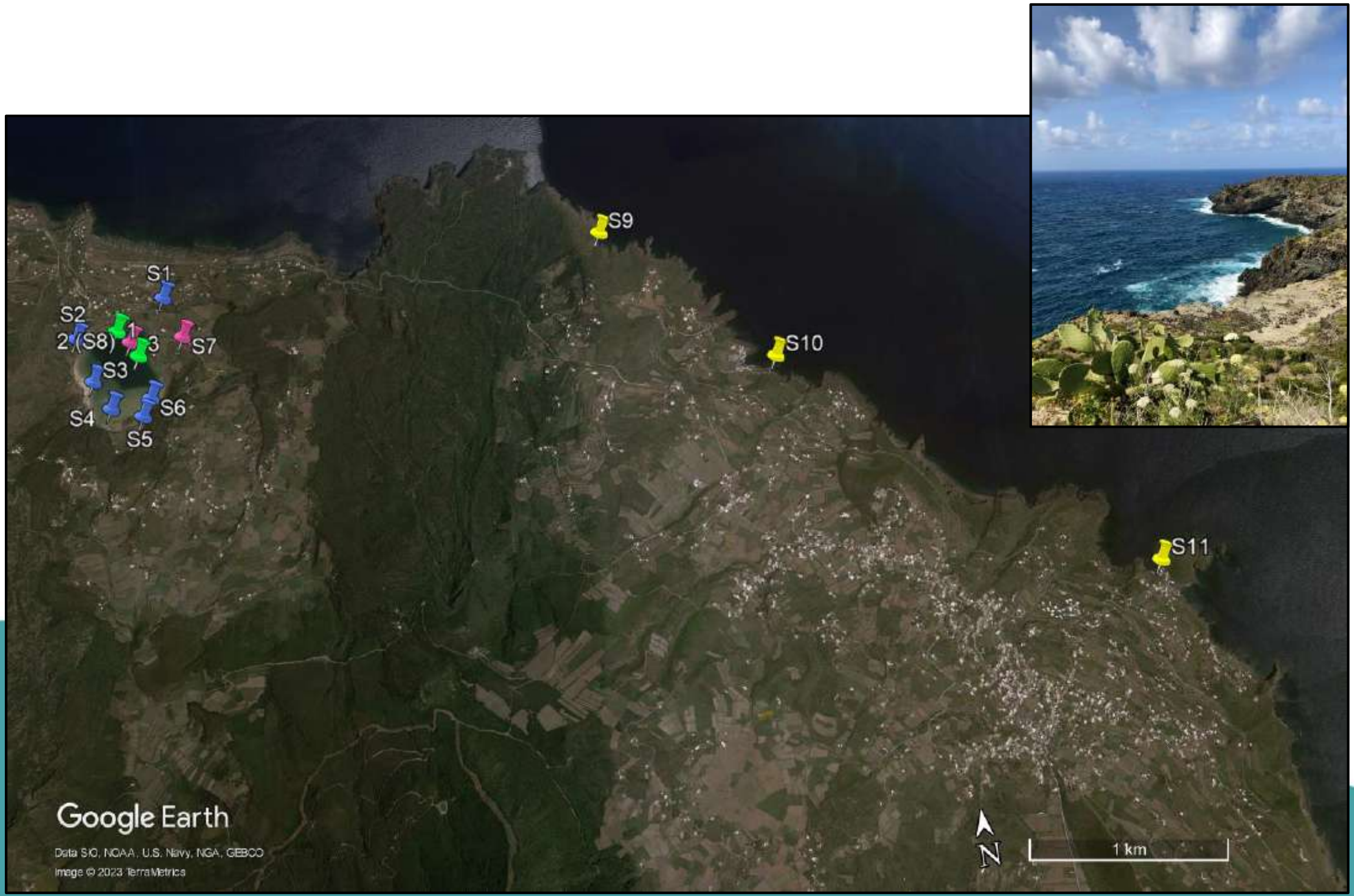
Monitoring

Campaign surveys:
May 2021; May 2022; February 2023; June 2023

- Sampling points (S1, S2, S3, S4, S5, S6, S8)
- Other sampling points (S9, S10, S11) along the coast

Discrete hydrogeological and hydrogeochemical monitoring

- pH
- Temperature
- Electrical conductivity
- Major ions
- Trace elements
- Isotope contents ($\delta^{18}O$; $\delta^{2}H$; $\delta^{11}B$; $\delta^{34}S$; $^{87}Sr/^{86}Sr$)



Monitoring

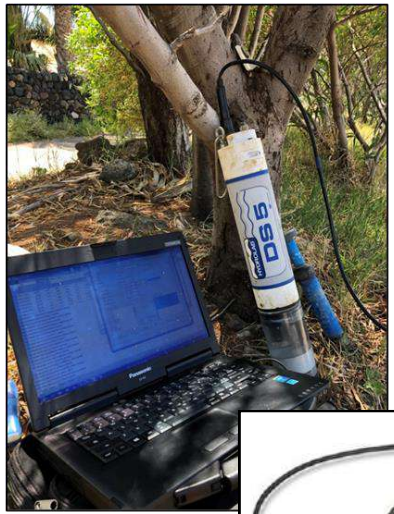
Campaign surveys:
May 2021; May 2022; February 2023; June 2023

Discrete hydrogeological and hydrogeochemical monitoring

- pH
- Temperature
- Electrical conductivity
- Major ions
- Trace elements
- Isotope contents ($\delta^{18}O$; $\delta^{2}H$; $\delta^{11}B$; $\delta^{34}S$; $^{87}Sr/^{86}Sr$)

Continuous hydrogeological monitoring

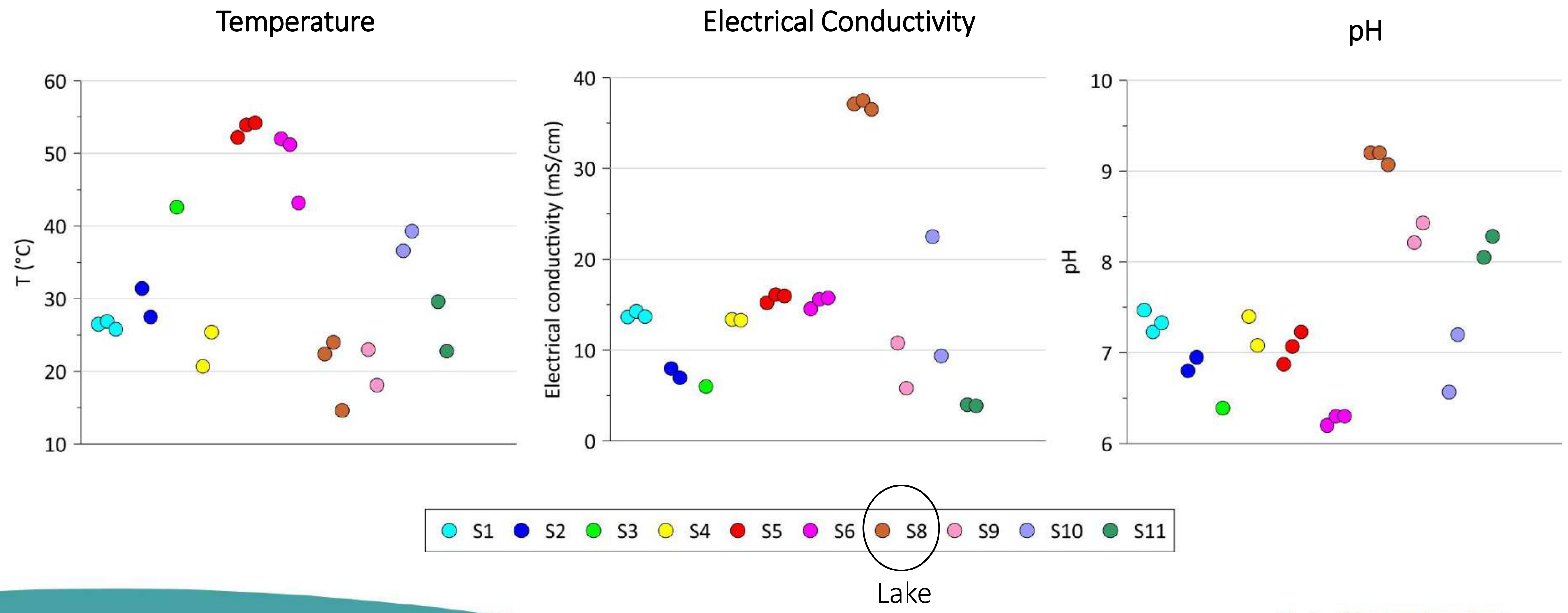
- Water level
- pH
- Temperature
- Electrical conductivity
- Turbidity



(Point 2)

- Sampling points (S1, S2, S3, S4, S5, S6, S8)
- Other sampling points (S9, S10, S11) along the coast
- Vertical log of chemical-physical parameters (1, 2, 3)
- Continuous multiparametric probes: HL4 and DS5

Chemical-physical parameters



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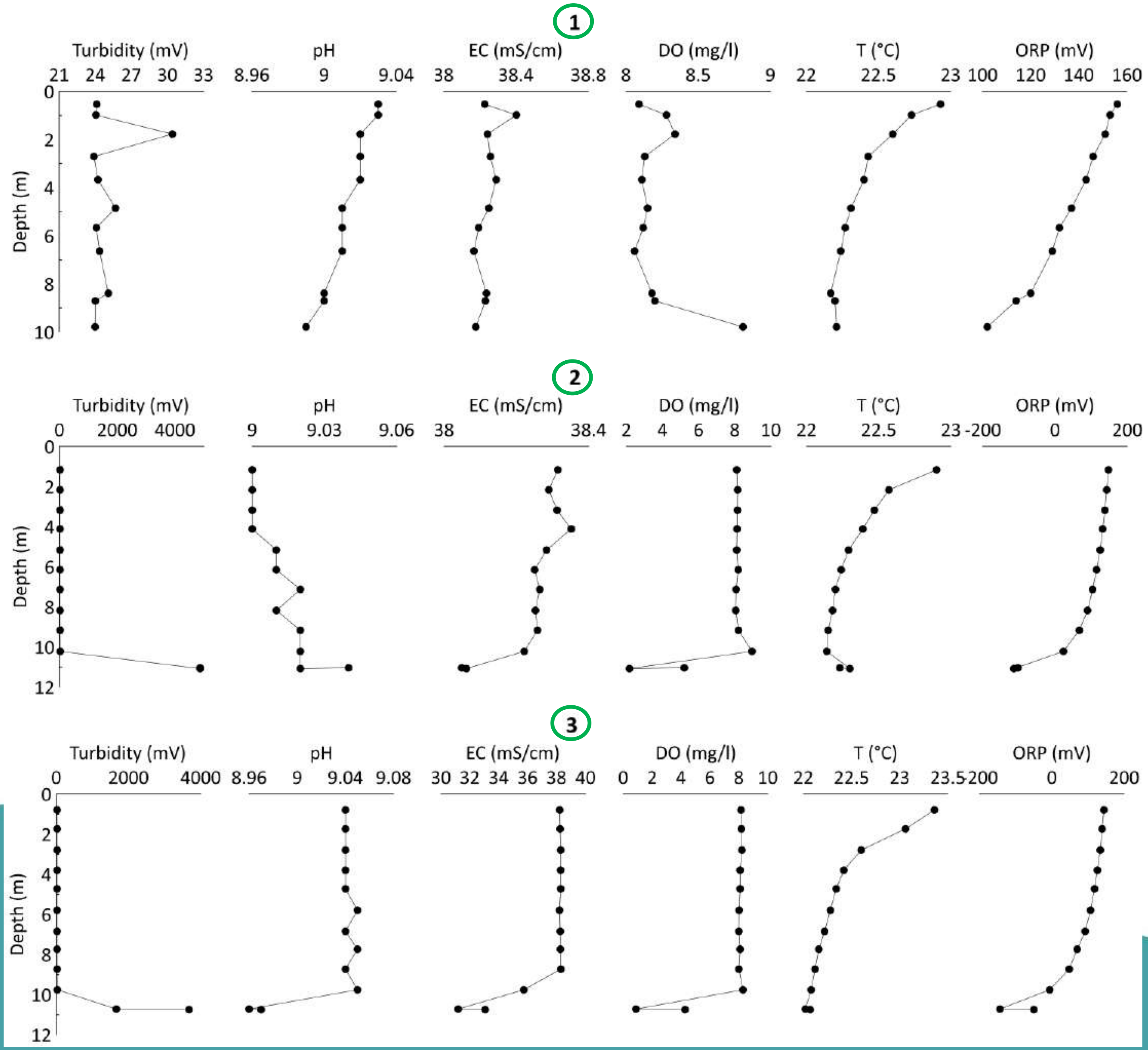
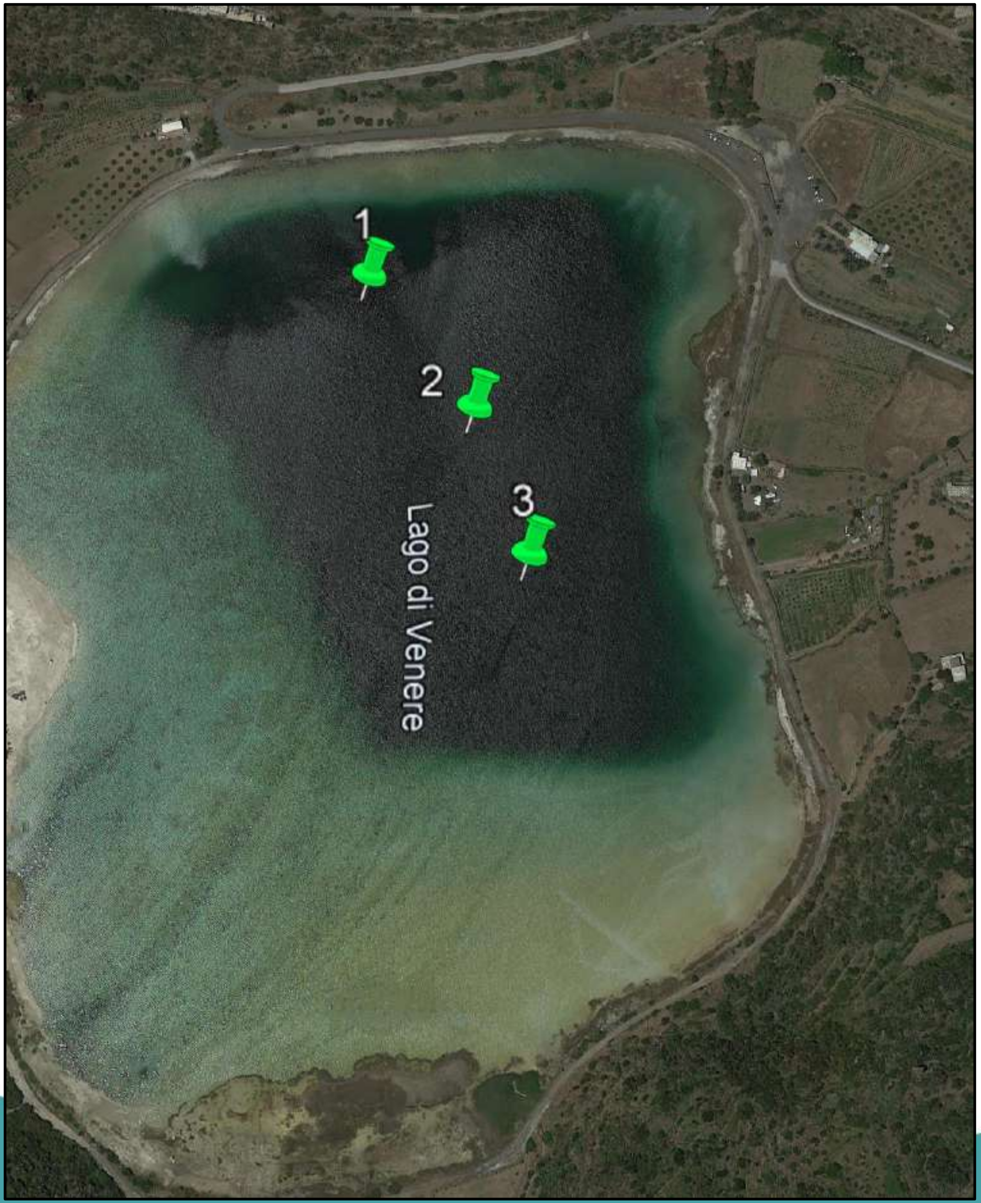
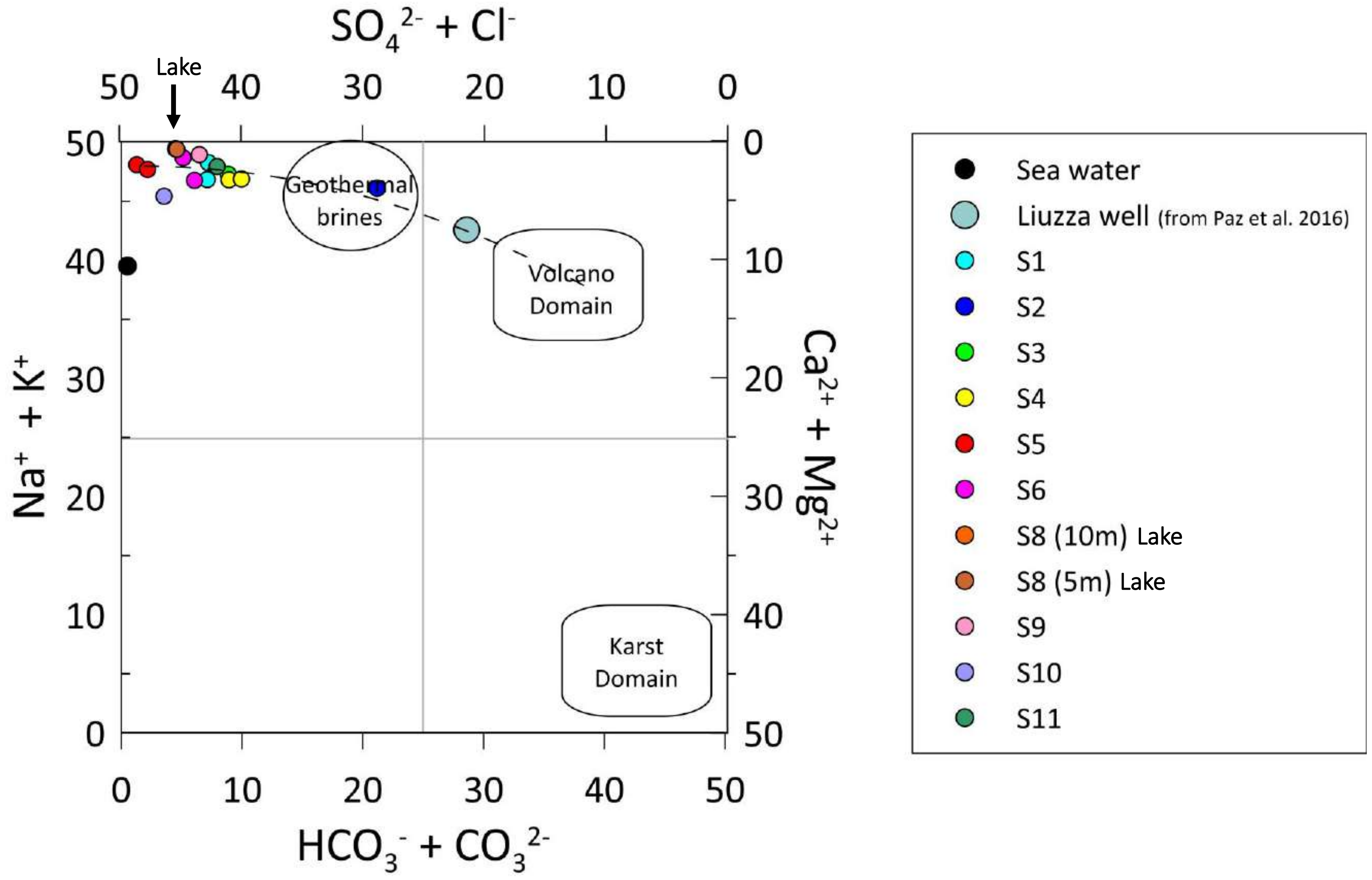
Vertical Log



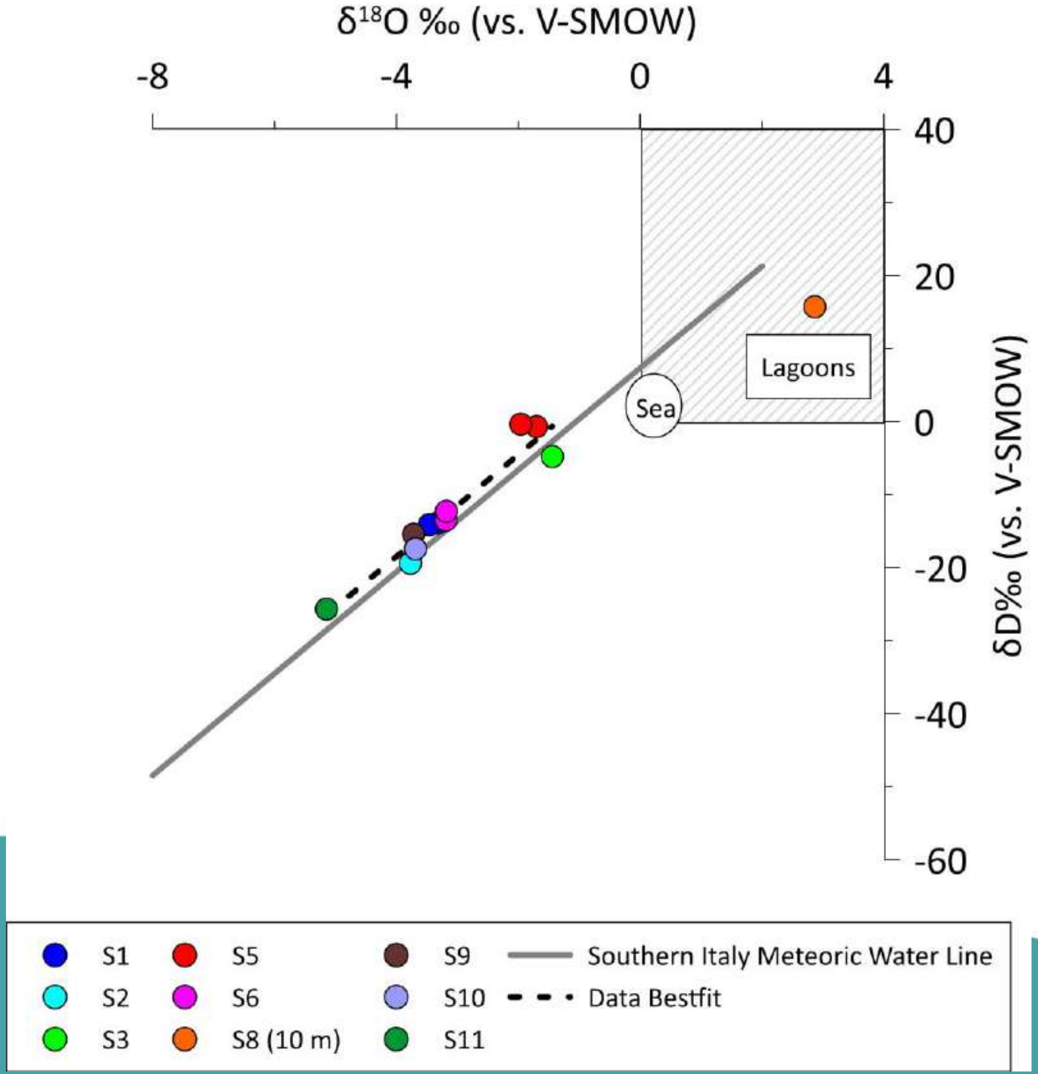


Hydrogeochemical characterization

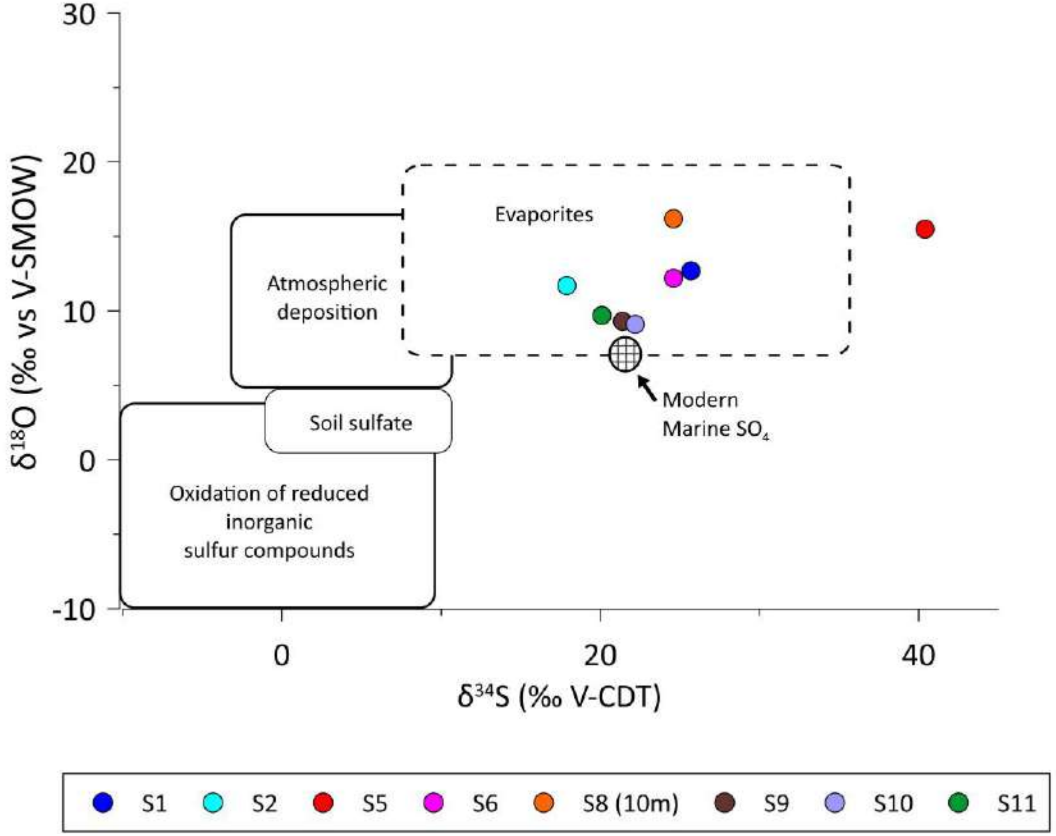


Isotope content

Stable water isotope ($\delta^{18}O$ and $\delta^{2}H$)



Sulphate isotope ($\delta^{18}O$ and $\delta^{34}S$)



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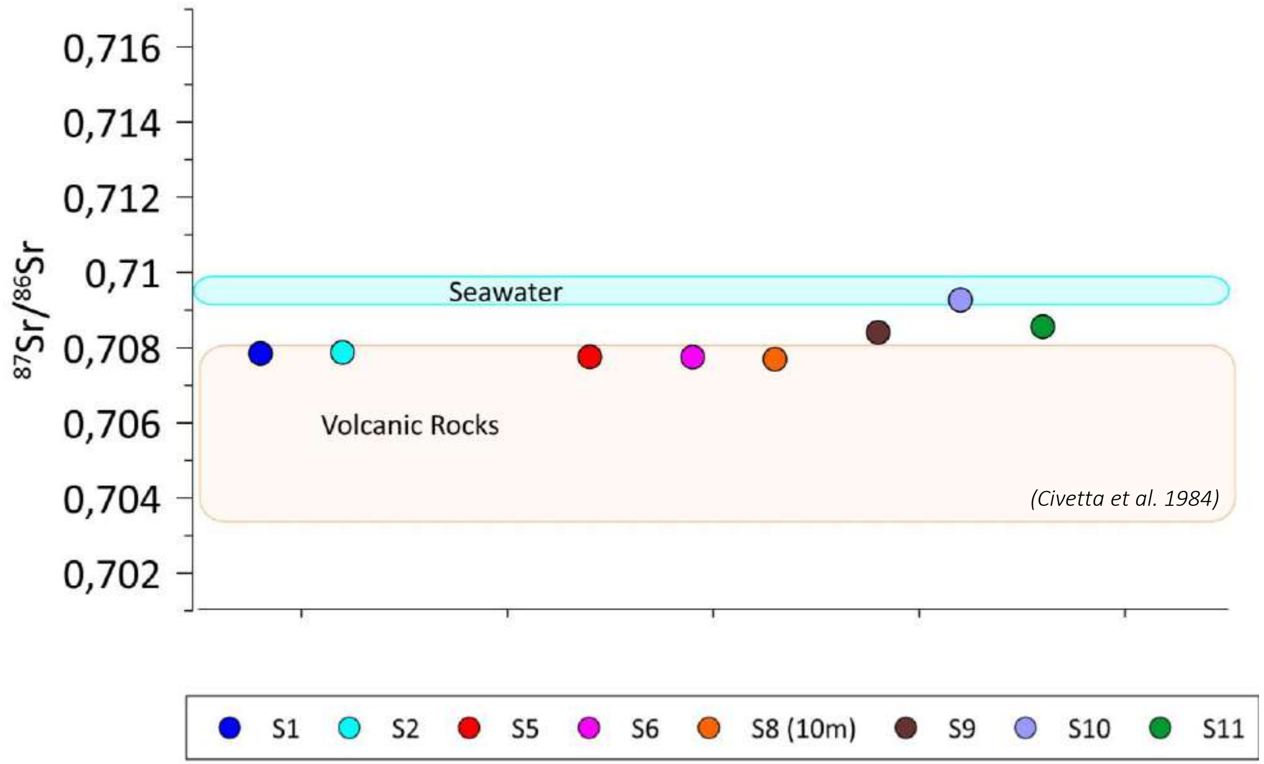
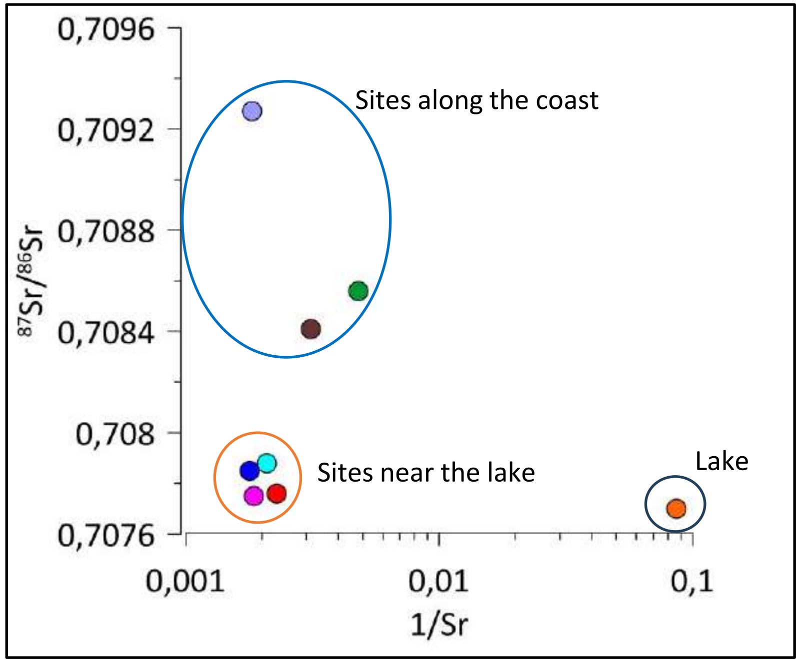
Isotope content

Strontium Isotope ($^{87}Sr/^{86}Sr$)





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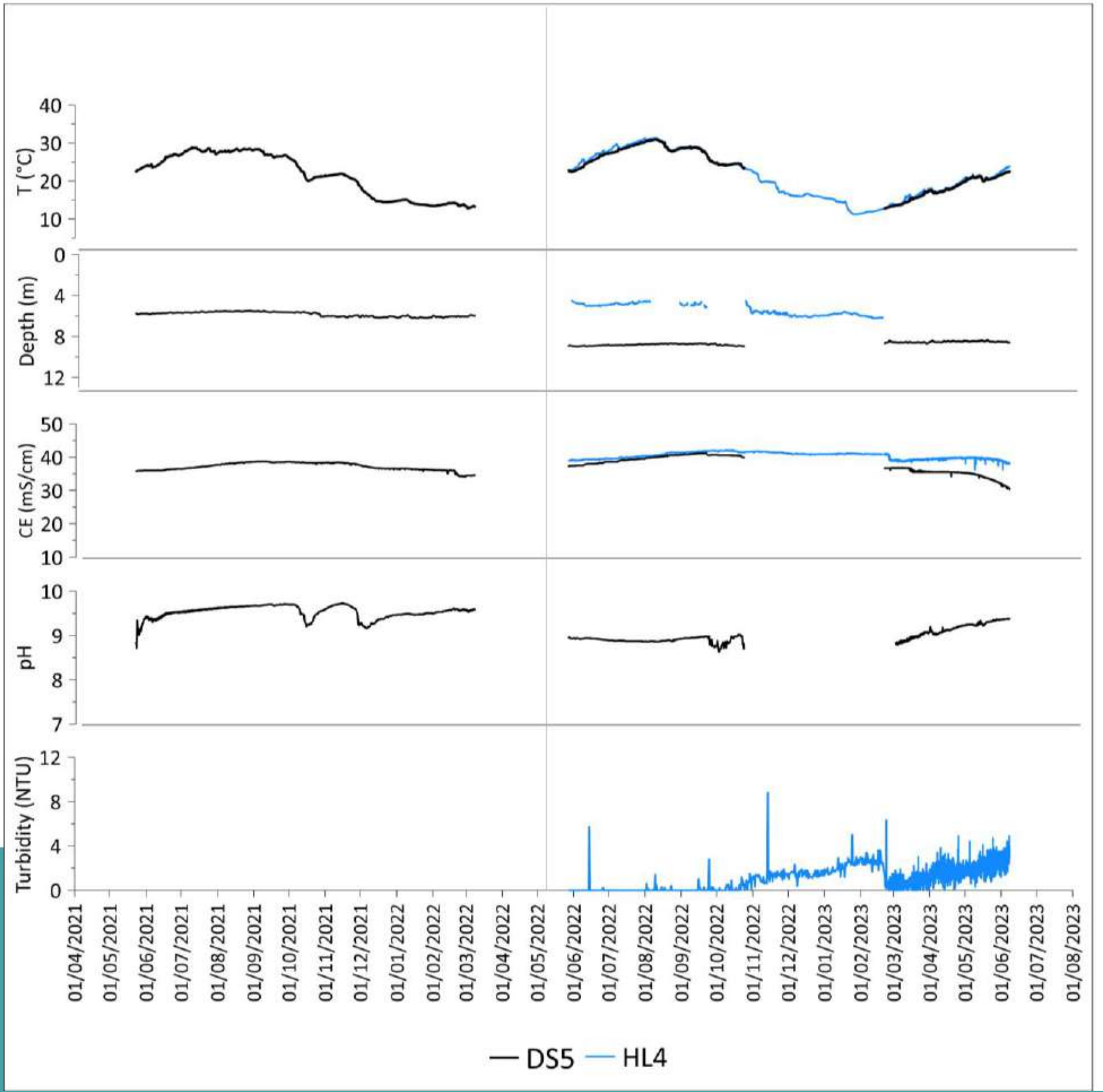
Continuous data from multiparametric probes



2021-2022:
DS5: lake 6m-deep

2022-2023:
DS5: lake 9m-deep
HL4: lake 5m-deep

Sampling frequency: 12h
Between May 2021 and February 2023

Sampling frequency: 1h
Between February 2023 and June 2023

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Last field activity: June 2023

● Continuous monitoring by **3** new multiparametric probes (Eureka Manta)

1 probe: Pockmark
2 probes: Point 2

Sampling frequency: 12h

- Water level
- pH
- Temperature
- Electrical conductivity
- Turbidity
- Chlorophyll

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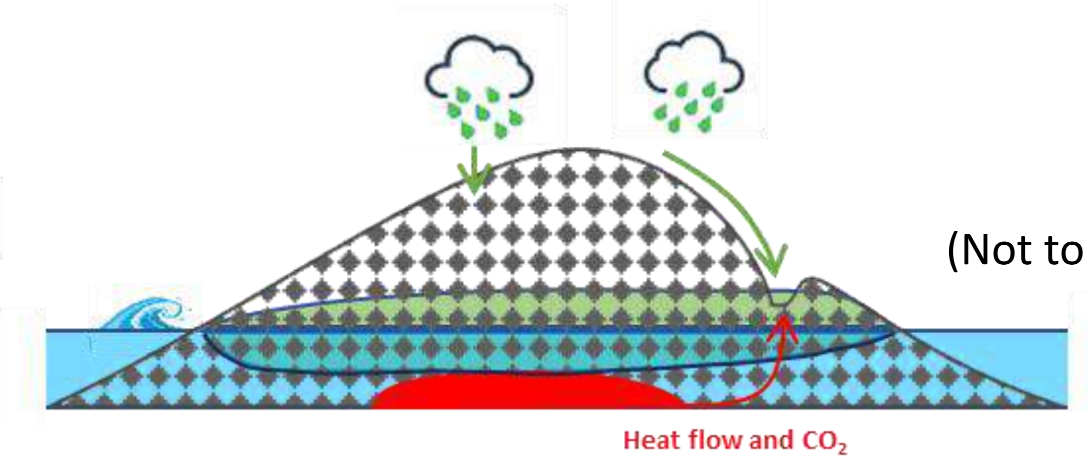
Main findings

The hydrogeological and hydrogeochemical monitoring allowed to delineate the conceptual model of groundwater flow.



(Not to scale)

In detail, we suppose that 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., CO_2)

iii) salinization due to the high evaporation rate

iv) efficient removal of Ca and Sr elements from lake water by mineral precipitation (because of pH and biological activity)

And what about the next steps?

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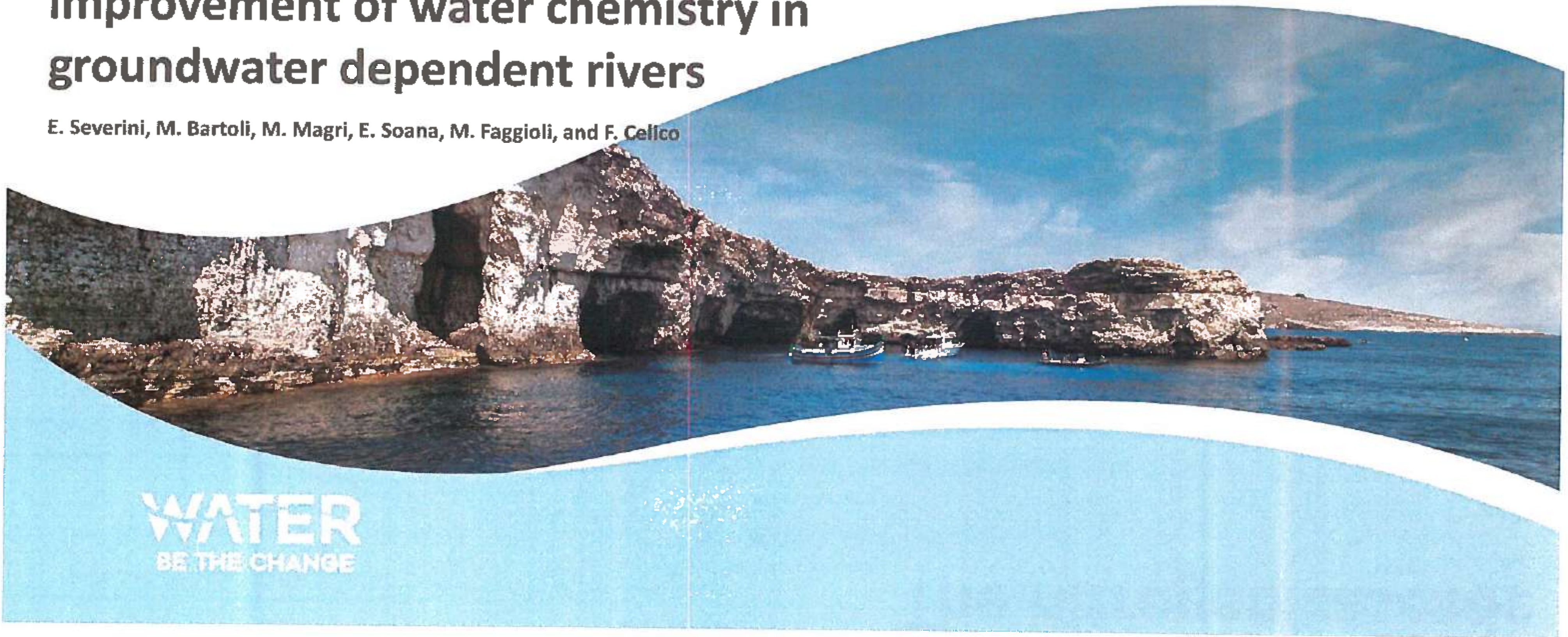
In-depth analysis of elements (e.g., Boron and major ions) and continuous data acquisition with new probes to better understand interaction with biological processes and to deepen the comprehension of potential effects due to climate changes.

Thanks for your attention!

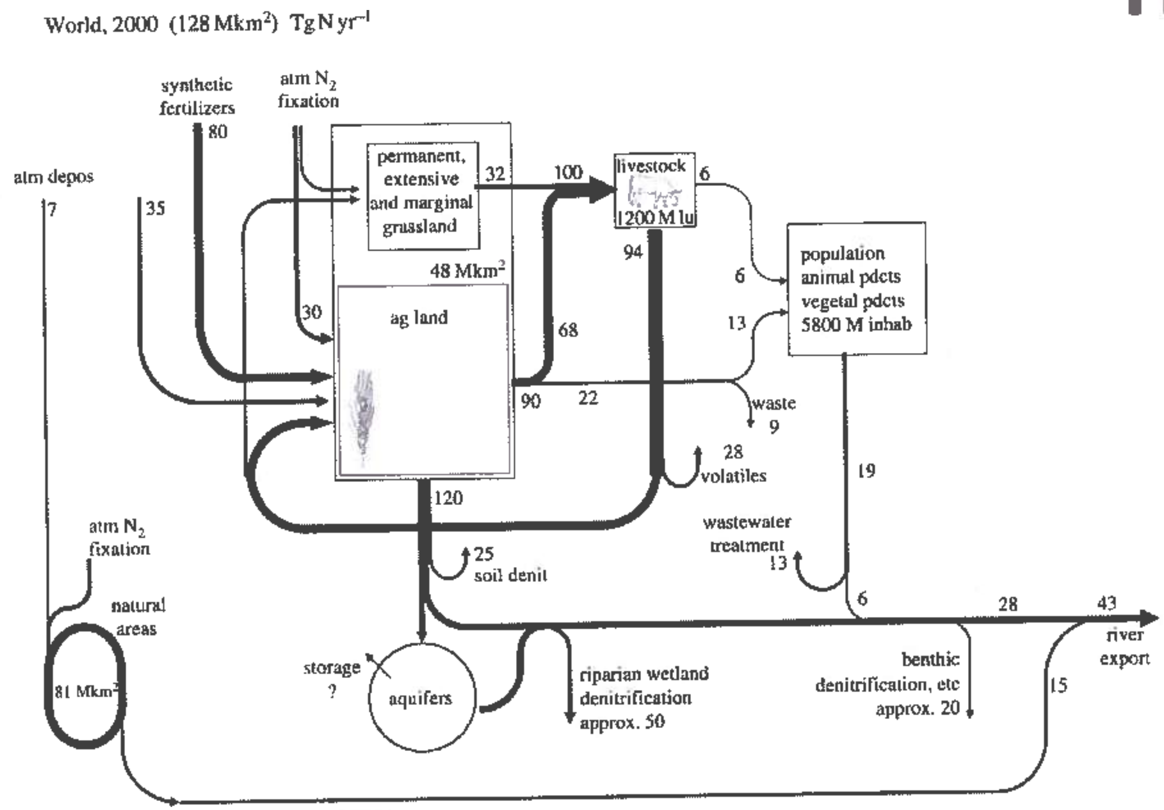
UNIVERSITÀ DI PARMA
Università degli Studi di Ferrara

Climate change and irrigation practices dissociate reduction of N fertilizers from the improvement of water chemistry in groundwater dependent rivers

E. Severini, M. Bartoli, M. Magri, E. Soana, M. Faggioli, and F. Celico



The nitrogen cascade



From Billen et al., 2013, modified. https://doi.org/10.1098/RSTB.2013.0123

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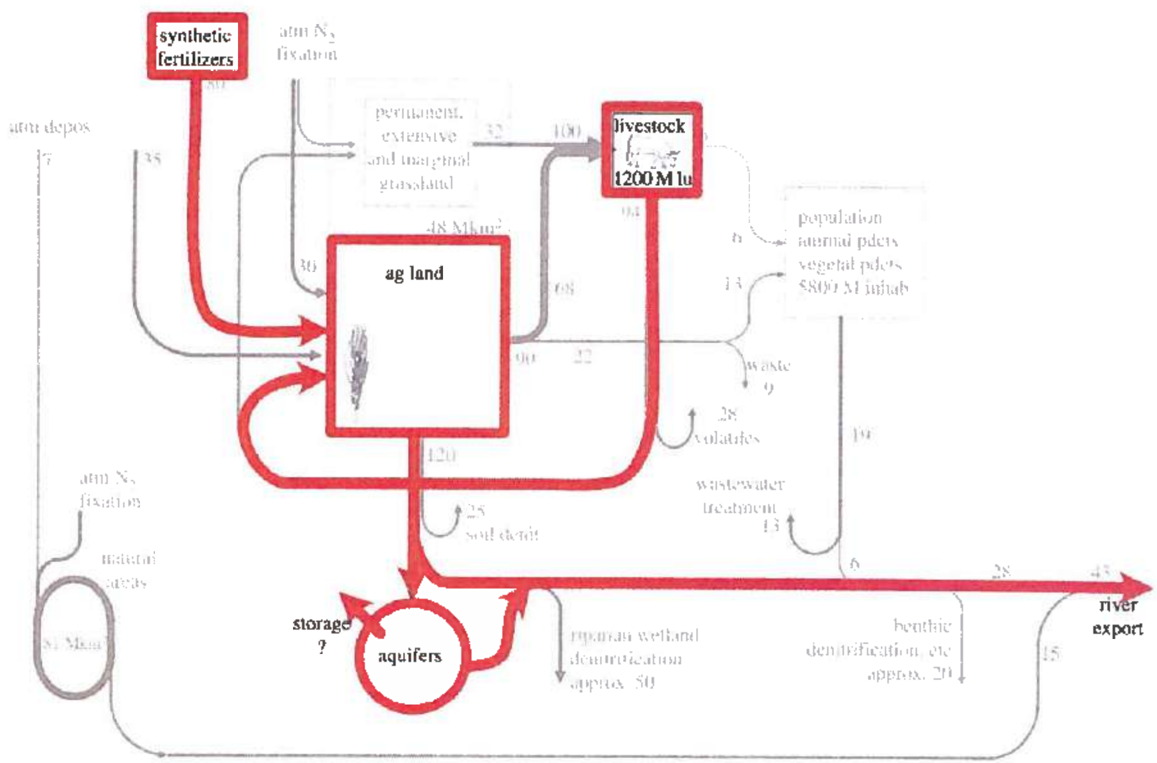
The nitrogen cascade



From Billen et al., 2013, modified. https://doi.org/10.1098/RSTB.2013.0123

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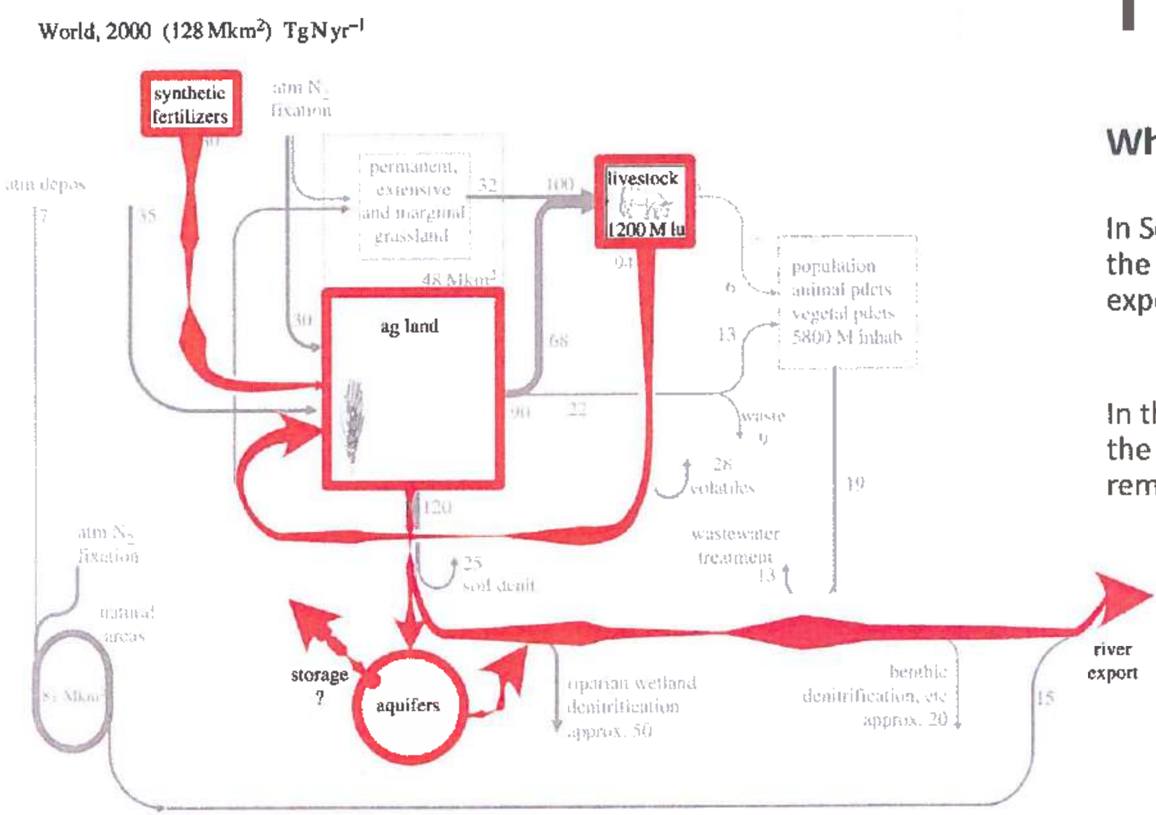
The nitrogen cascade

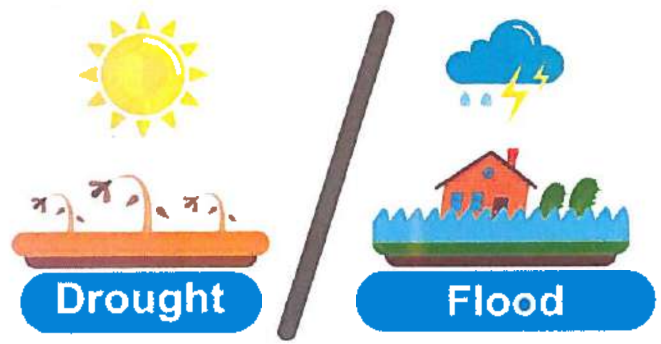


From Billen et al., 2013, modified. https://doi.org/10.1098/RSTB.2013.0123

What about climate change?

In Southern Europe, severe droughts and low discharge in the summer and flash floods in the other seasons are expected (Sperna Weiland et al., 2021).

In the Po Valley, persistent negative rainfall anomalies like the ones that characterised the 2022 event could remarkably increase their frequency (Bonaldo et al. 2023)



WATER
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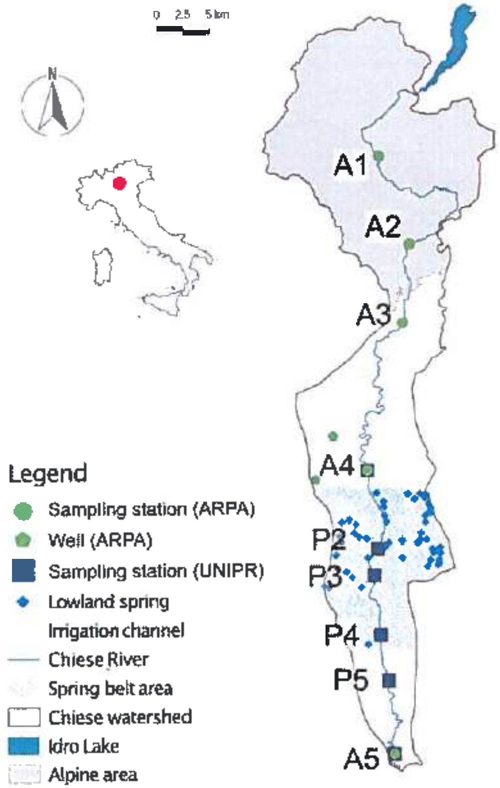
Working hypothesis

- A **positive feedback on N contamination** due to:
  - rapid percolation and solubilisation of soil N excess
  - maintenance of oxidised microbial N pathways
  - accumulation of nitrate in groundwater
  - mobilization of nitrate polluted groundwater to the surface drainage system.

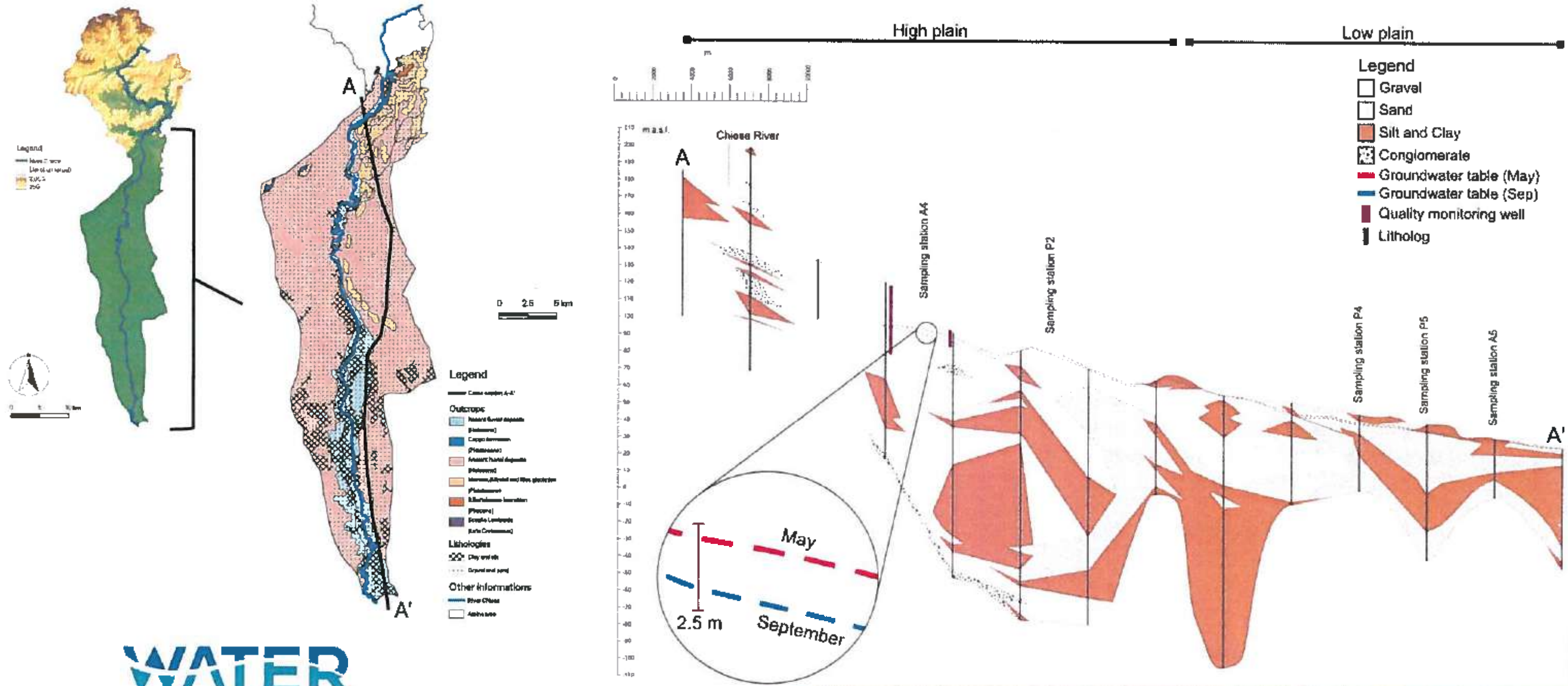
- The **climate-change driven shift to wells irrigation** may **offset past and present policies** targeting the reduction of diffuse N pollution.

The River Chiese and its watershed



- Intensive agriculture and animal farming within **Nitrate Vulnerable Zones (NVZs)**
- The main agricultural practices include **N overfertilization** and **flood irrigation** over high highly permeable soil and aquifer
- The watershed was investigated using sampling points, wells and river, from the regional environmental agency (ARPA)
- A specific monitoring has been performed in the more complex area

The River Chiese and its watershed



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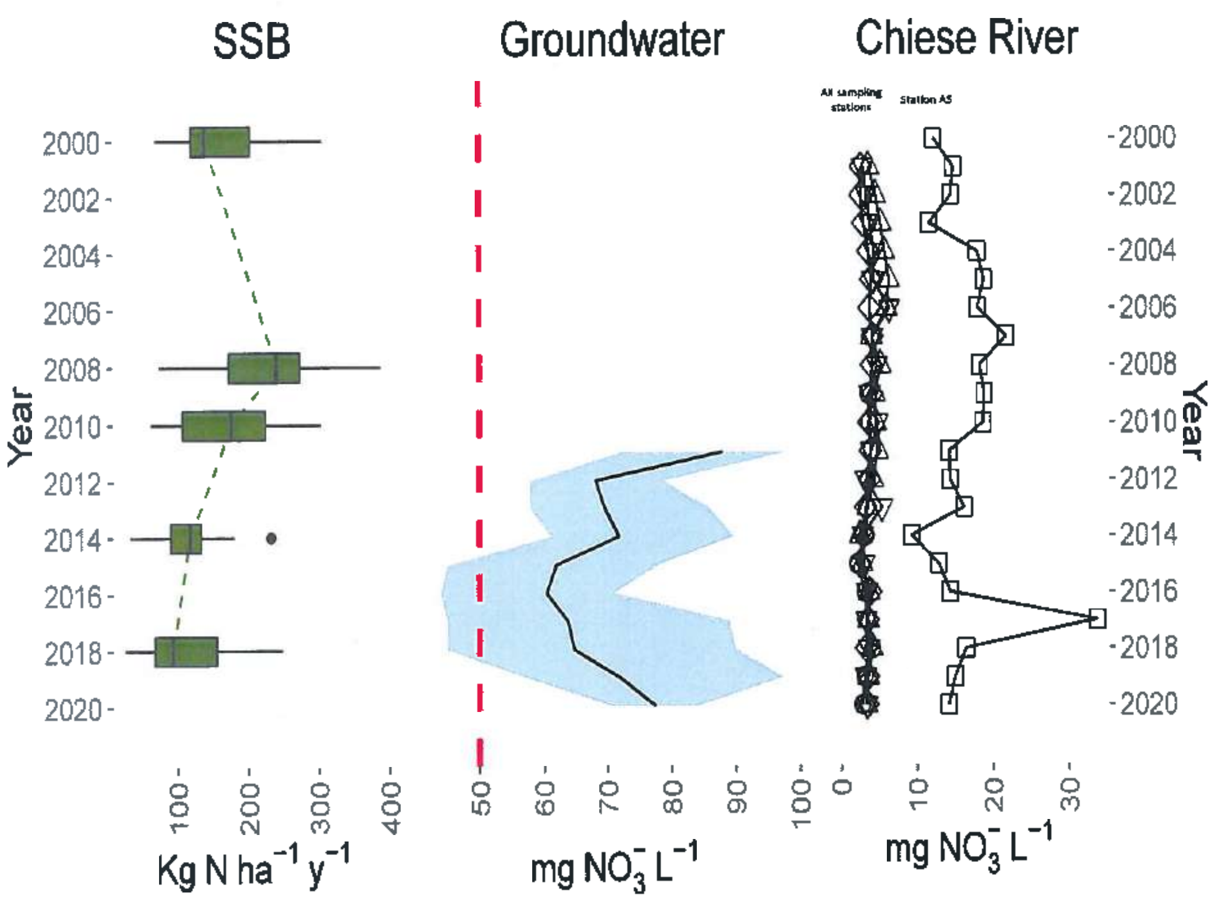
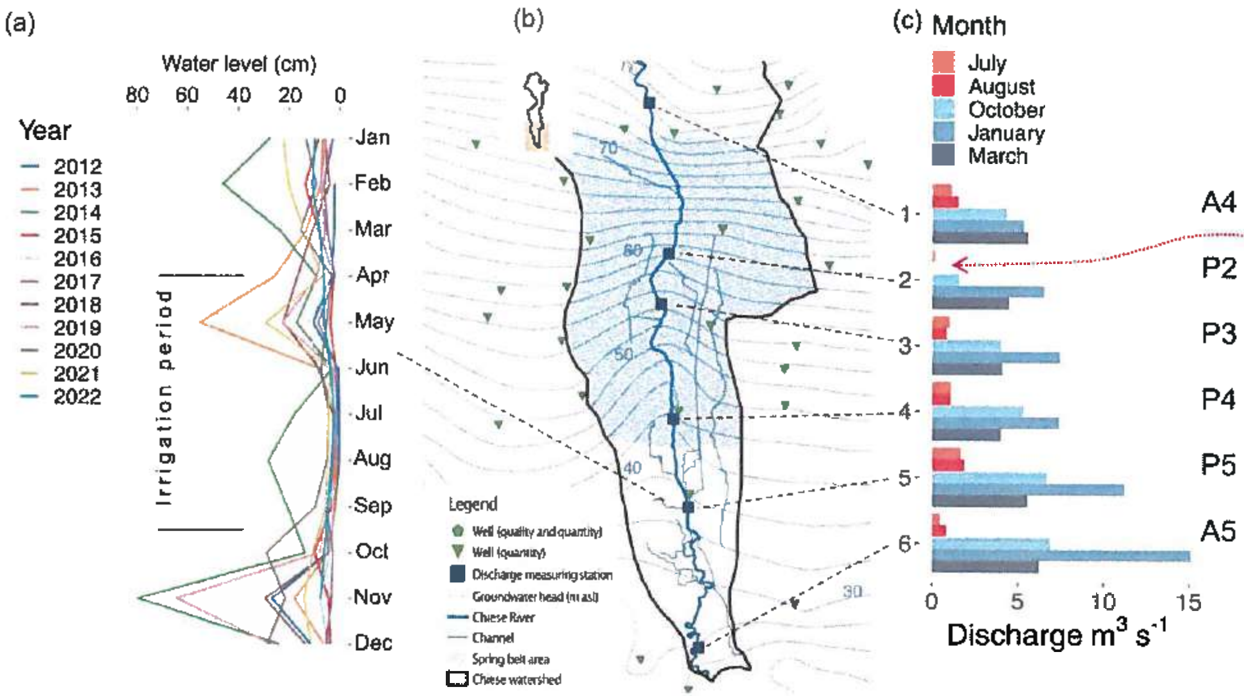
The N input decreased but the contamination did not, how so?



N surplus **decreased** (-43%) in 20 years

In groundwater, **NO_3^- didn't decrease** in a similar manner and remained **above the European thresholds** (50 mg NO_3^- L^{-1}).

In the River Chiese, a **steep increase in NO_3^-** concentrations is observed in the downstream portion of its course, bringing it to the **lower quality class** of the **Water Framework Directive** (21 mg NO_3^- L^{-1}).



To support the **overabundant irrigation necessities** (4x the river discharge during the irrigation period) the river can be **completely dried**.

Irrigation is mostly supported **by wells**.

The **river drains groundwater** from the phreatic aquifer in the southern portion.

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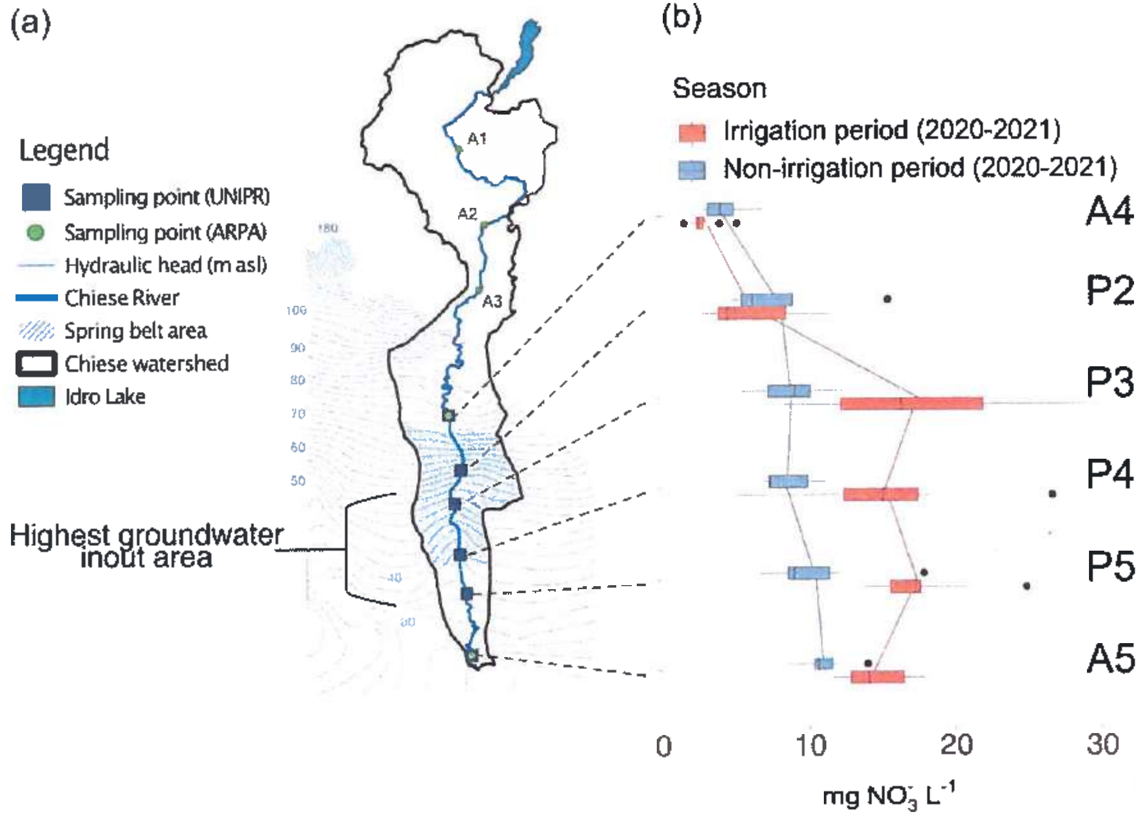

The **groundwater input increases NO_3^- concentrations** in the river (above WFD thresholds).

During the **irrigation period**, its discharge is almost completely **supported by groundwater** and **NO_3^- concentrations** have highest values.

Irrigation period
(August 2022)

Non-irrigation period
(October 2022)

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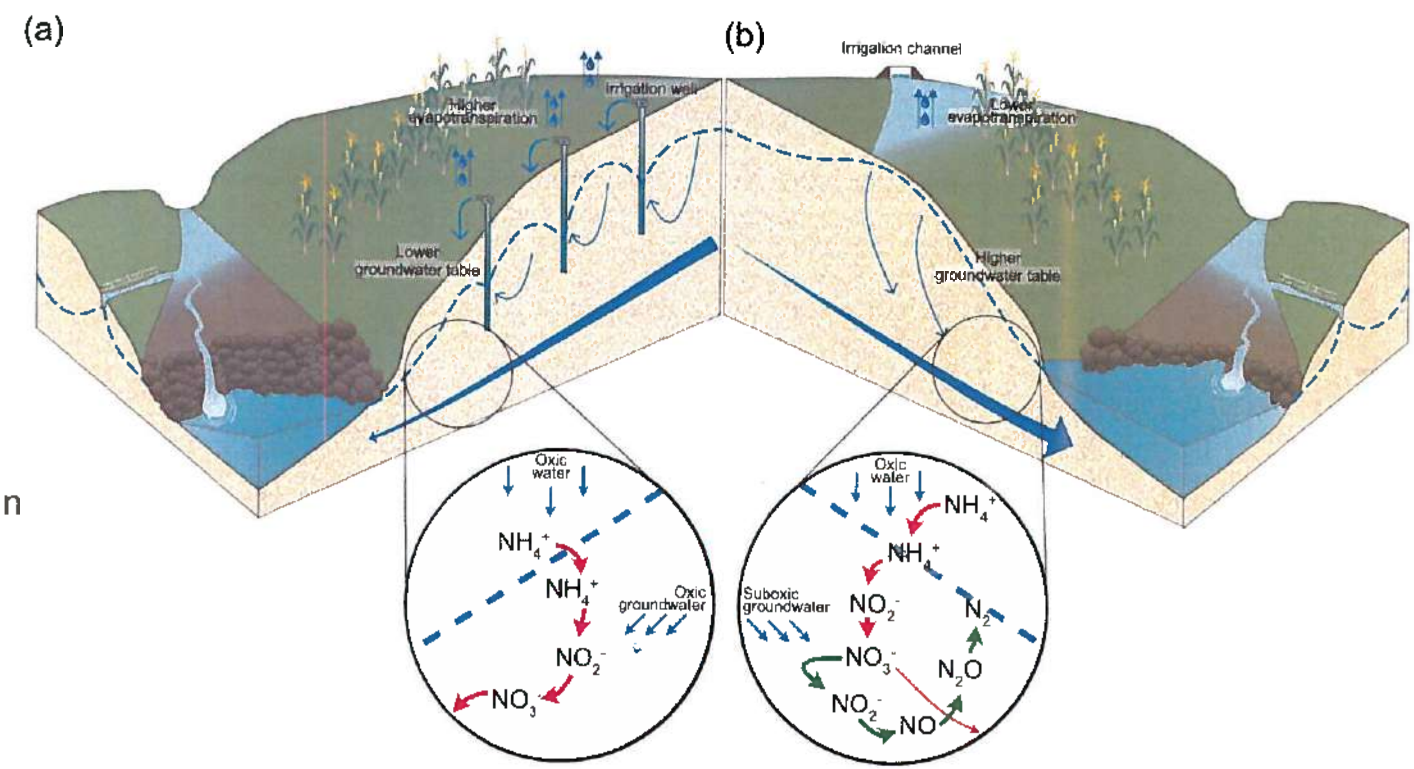
Why these effects are lower in other similar rivers of the Po Plain?

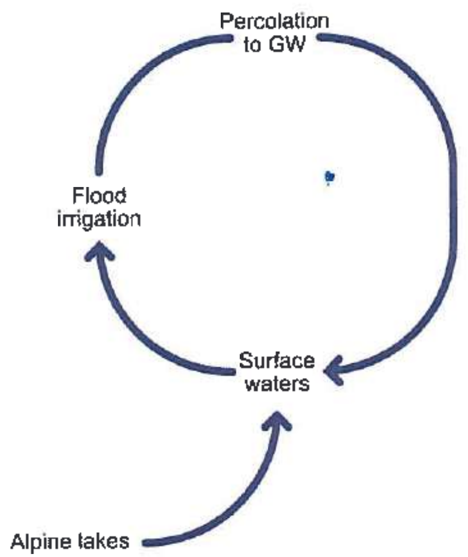


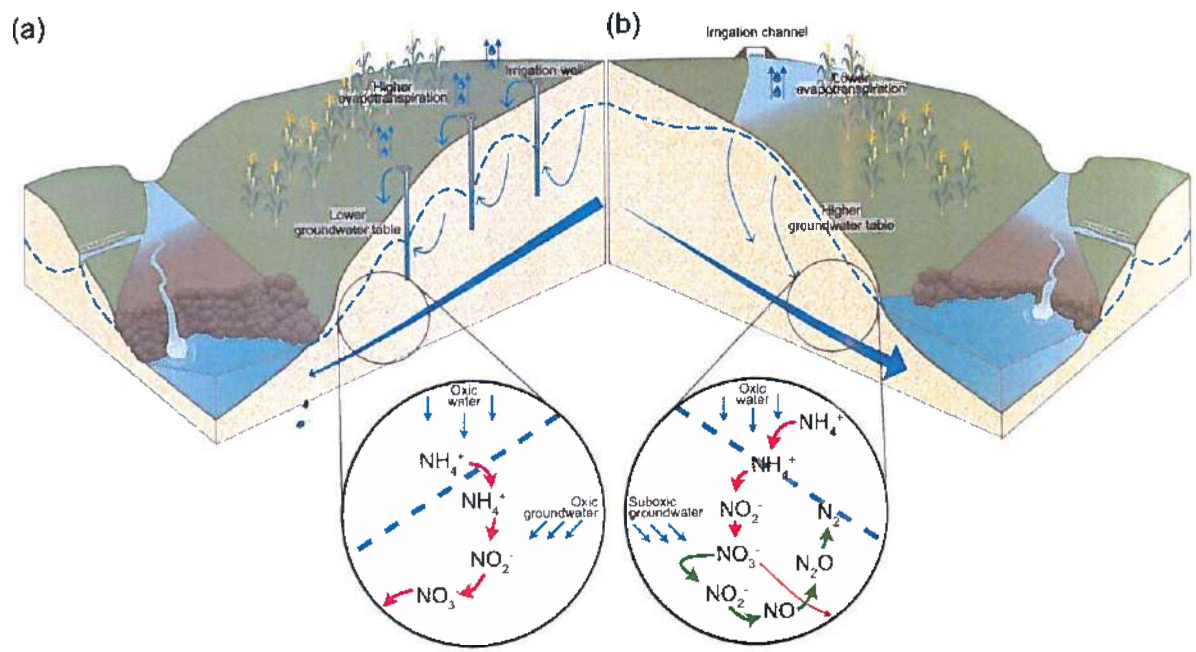
Wells foster evapotranspiration i.e. lower groundwater table.

The overuse of wells for the irrigation promotes:

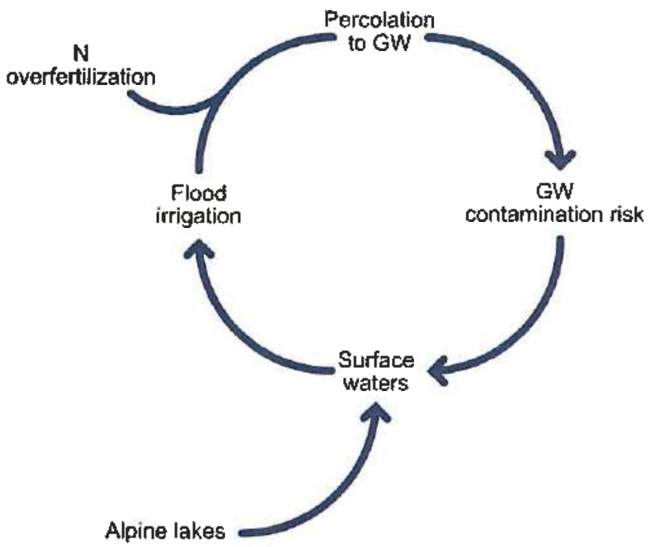
1) accumulation of NO_3^-
2) High O_2 concentrations, hindering denitrification

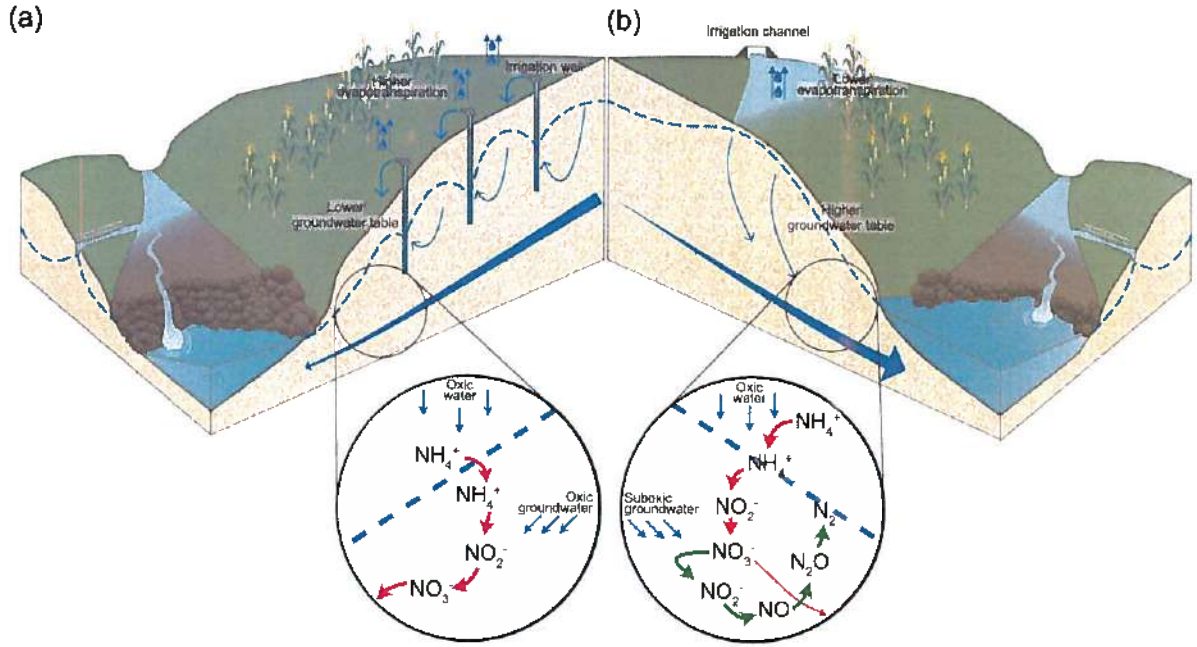
Why these effects are lower in other similar rivers of the Po Plain?



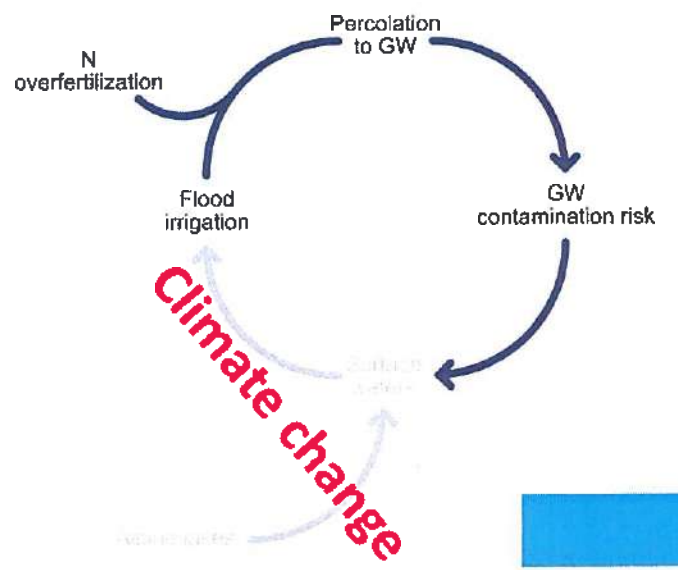


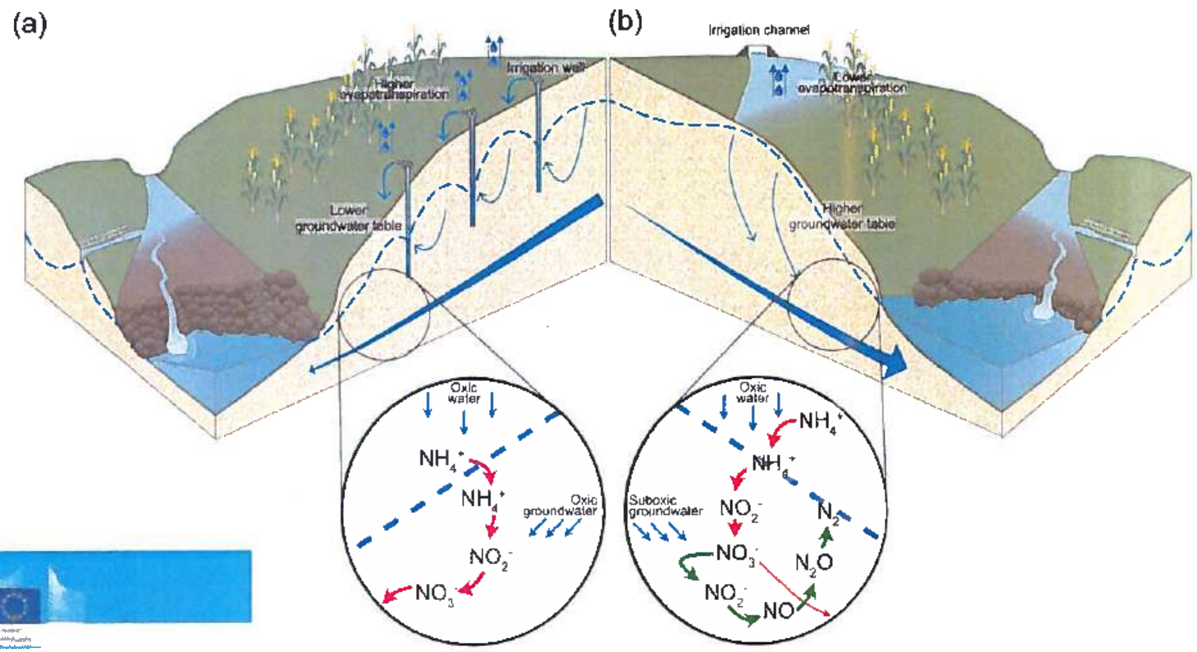
Why these effects are lower in other similar rivers of the Po Plain?





Why these effects are lower in other similar rivers of the Po Plain?

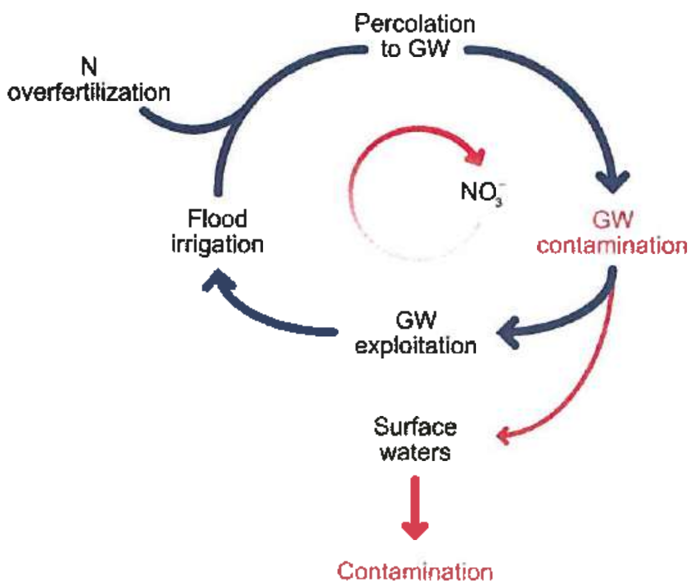


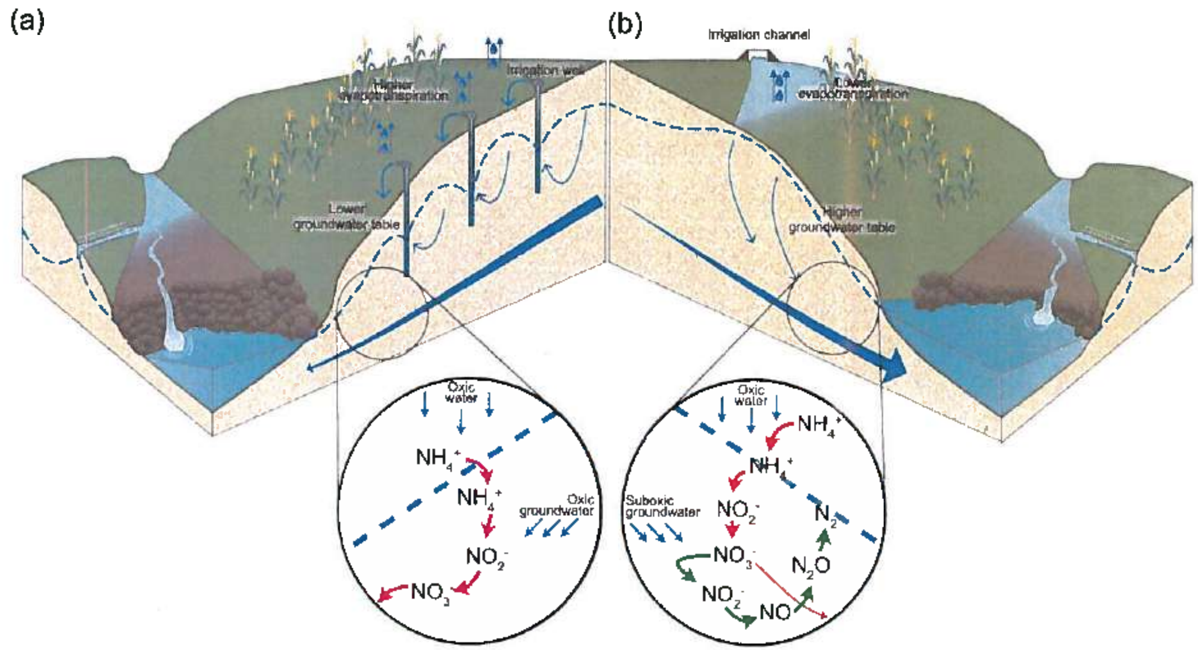


Drought in northern Italy
March 2022

In Southern Europe, severe droughts and low discharge in the summer and flash floods in the other seasons are expected (Sperna Weiland et al., 2021).

Why these effects are lower in other similar rivers of the Po Plain?





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Take home messages

- These results showed the effects of traditional agricultural practices on contamination of surface and groundwater under the effects of climate change.
- Climate change fostered the drying out of the river and the overexploitation of groundwater to support the maize production.
- During the irrigation period, the river becomes a Groundwater Dependent Ecosystem. As such, it's particularly vulnerable to groundwater NO_3^- contamination.
- The prolonged droughts forced the abstraction of groundwater for irrigation. Its subsequent percolation to the aquifer and flow to the river represents a vicious loop that produces a positive feedback to the N contamination (*irrigation loop*).

These results are currently submitted to the

Journal of Environmental Management
Supports open access
13.4 CiteScore
8.91 Impact Factor

Do you want to more info?
Let's chat now or
@Aquatic_Ed / edoardo.severini@unipr.it

Sampling station P2 | Irrigation channels | Cultivated soil

GOVERNMENT OF MALTA

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Associazione ACQUE SOTTERRANEE

SOCIETÀ GEOLOGICA ITALIANA

IGAG
Istituto di Geologia Ambientale e Geoingegneria

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Intergovernmental Hydrological Programme

AIGA
ASSOCIAZIONE ITALIANA GEOLOGIA APPLICATA E AMBIENTALE

ENGEOL IAEG AIGI

IRSA CNR

ISPRA

EUROPEAN UNION
European Regional Development Fund

VisitMalta

water
services corporation

THE ENERGY & WATER AGENCY

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flowpath

Malta 2023

14th – 16th June
National Meeting on Hydrogeology

JUNE 14-16, 2023

WATER.ORG.MT

Karst lakes fragile environments to be known and protected

Luca Zini, Chiara Calligaris, Pietro Rai, Christian Leone, Philippe Turpaud

Università degli Studi di Trieste
Dipartimento di Matematica e Geoscienze (DMG)

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UNIVERSITÀ DEGLI STUDI DI TRIESTE
DIPARTIMENTO DI MATEMATICA E GEOSCIENZE

Aim of the research

In a mature karst area, ephemeral lakes represent a unique but extremely fragile environment for naturality and biodiversity. They are environments strongly linked to the presence of water and to its permanence. Any change, both natural and man-made, has a very rapid response. Therefore, the knowledge of hydrodynamics is essential to understand their adaptation to the changes allowing to protect and preserve them.

Hydrogeological studies

- Geological and Geomorphological survey
- Speleological survey
- CTD Continuous Monitoring
- Tracer test
- Impact evaluation of possible remediation measures

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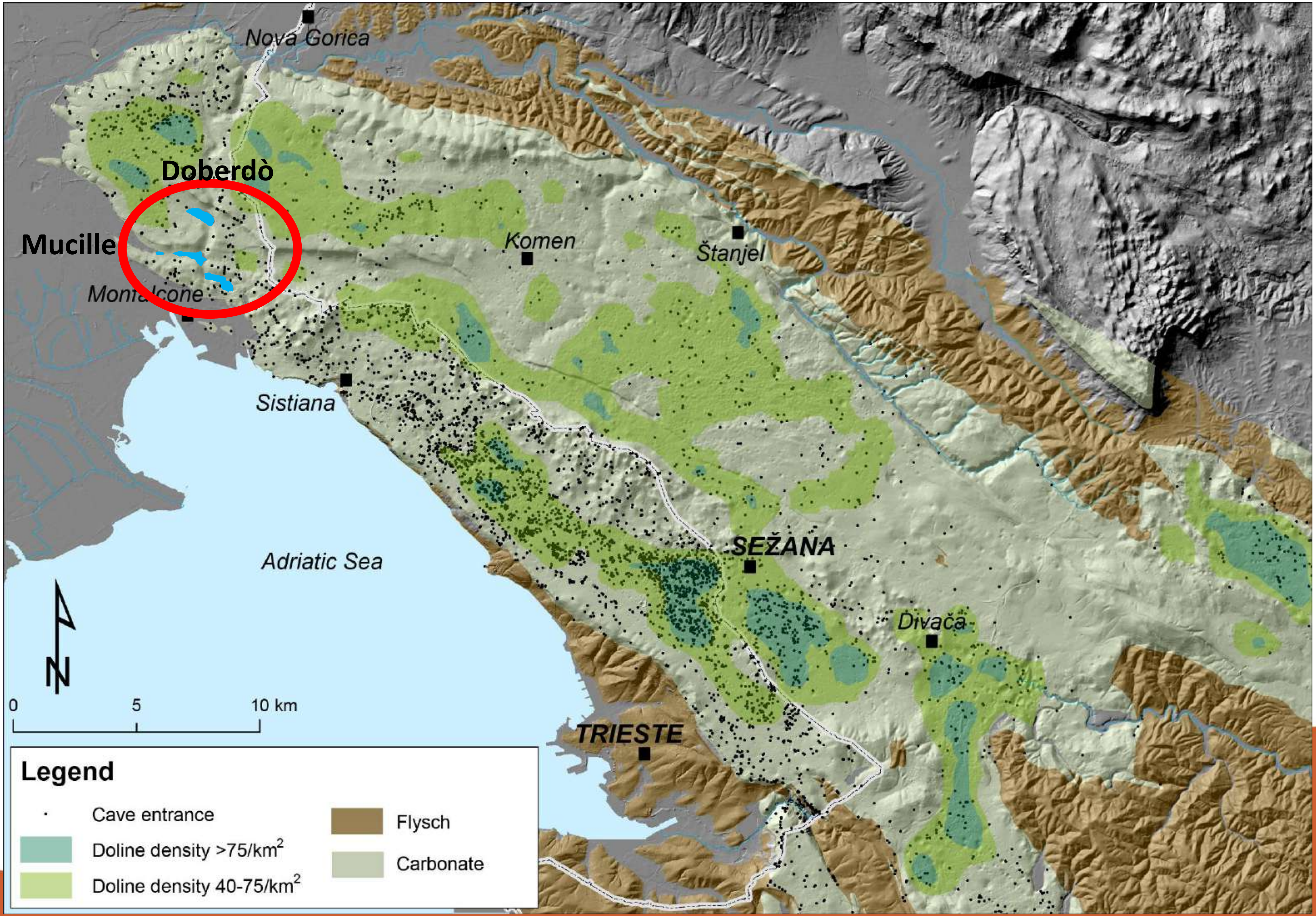
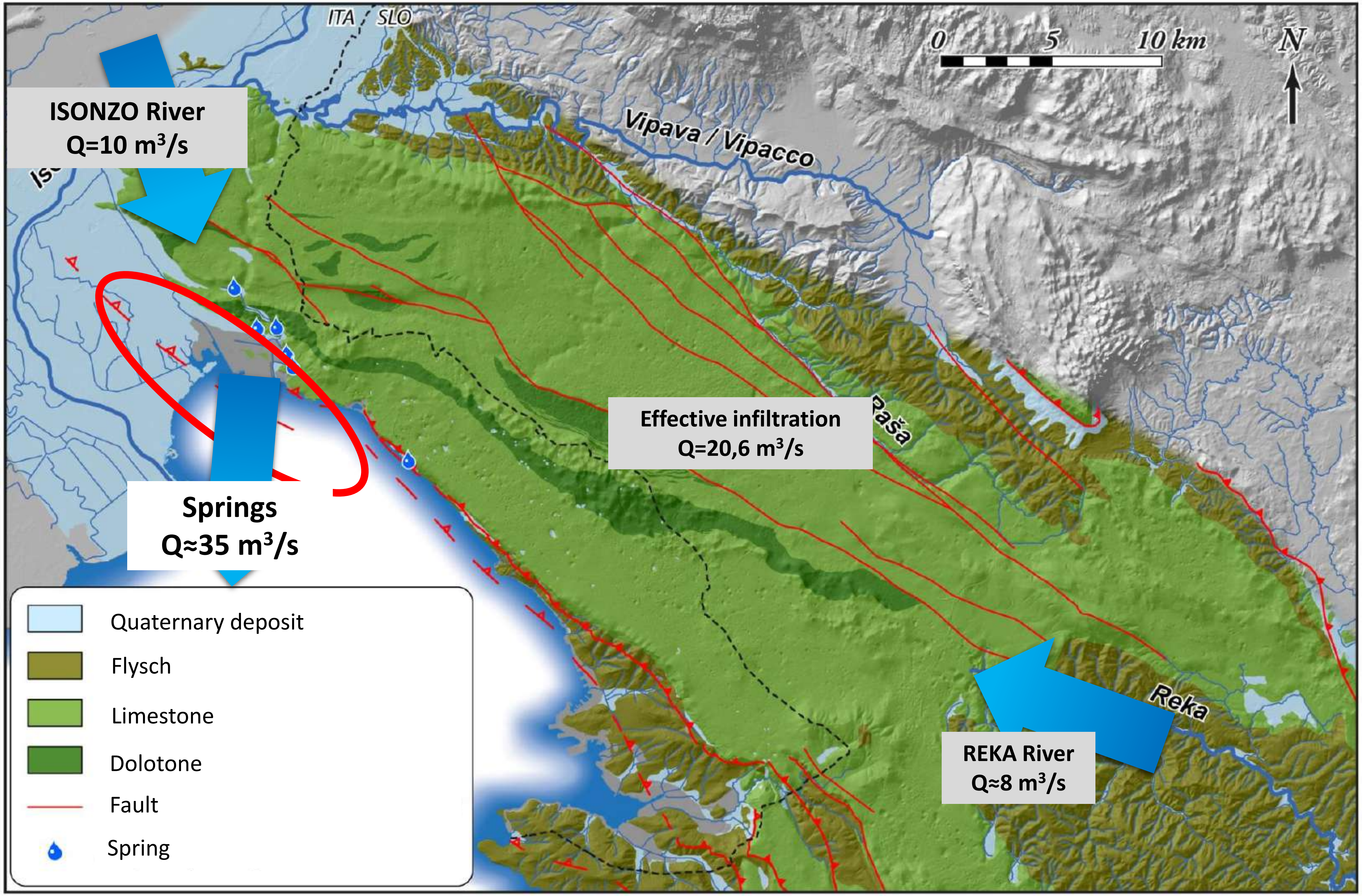
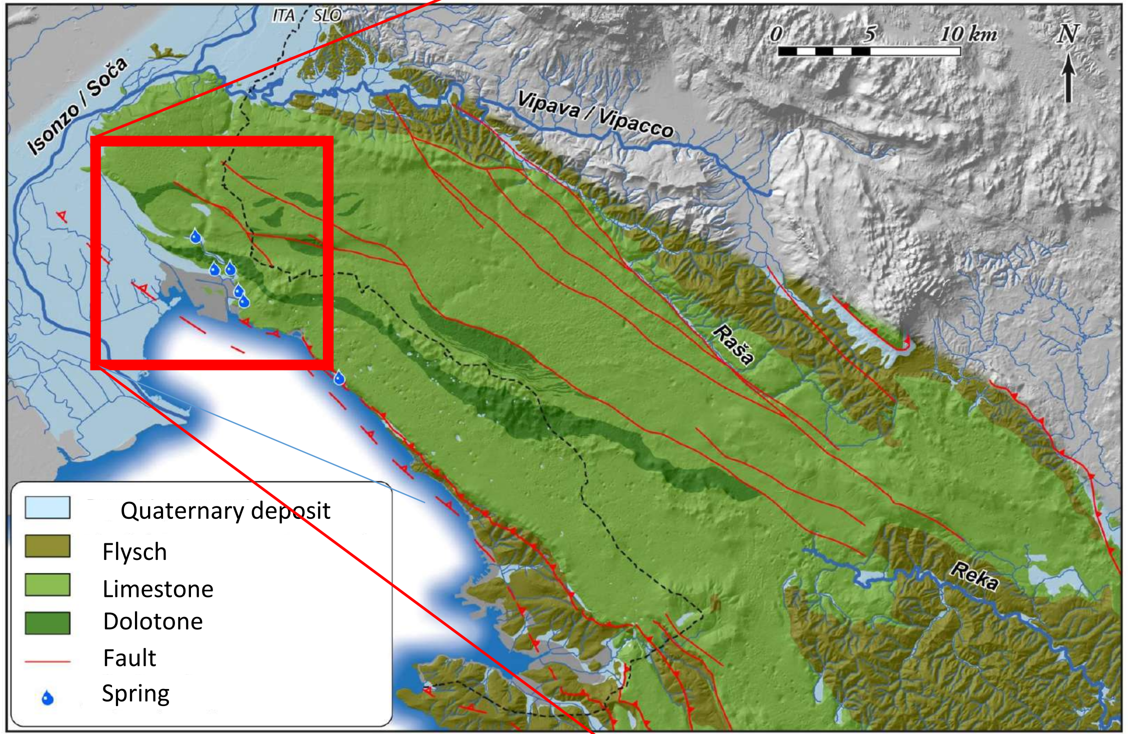
Italy
Slovenia
Gorizia
Slovene Aqueduct
CLASSICAL KARST
TIMAVO SPRING
Trieste
Adriatic sea
San Canziano
cave
REKA /
TIMAVO SUPERIORE
TRENTINO
ALTO
ADIGE
AUSTRIA
VENETO
SLOVENIA
Pordenone
Udine
Gorizia
VENETO
Trieste

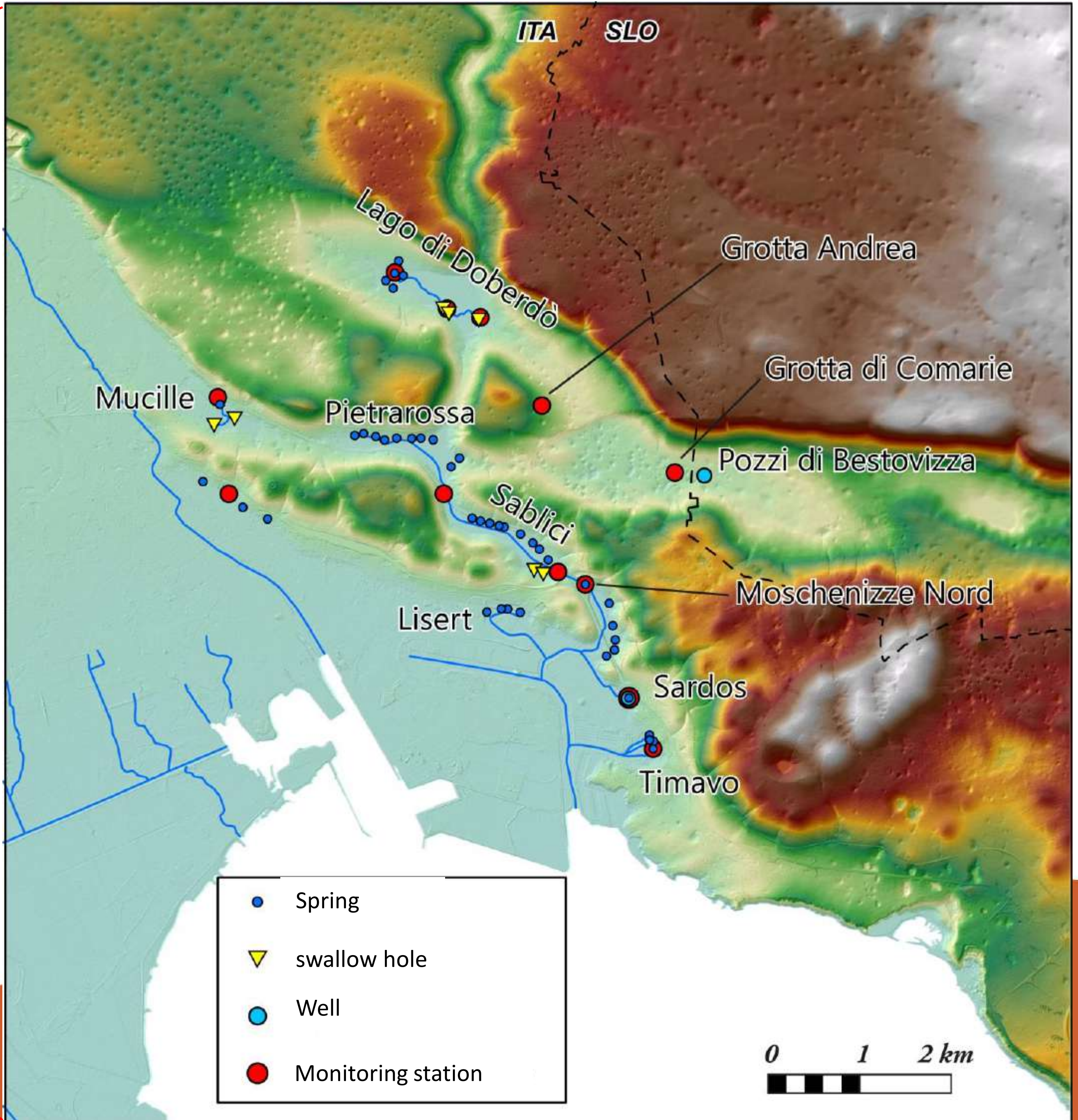
Study Area


Nova Gorica
Doberdò
Mucille
Montalcone
Komen
Štanjel
Sistiana
Adriatic Sea
SEŽANA
Divača
TRIESTE
0
5
10 km
N
Legend
Cave entrance
Doline density >75/km2
Doline density 40-75/km2
Flysch
Carbonate


ITA
SLO
0 5 10 km
N
ISONZO River
Q=10 m³/s
Vipava / Vipacco
Effective infiltration
Q=20,6 m³/s
Raša
Springs
Q≈35 m³/s
Reka
REKA River
Q≈8 m³/s
Quaternary deposit
Flysch
Limestone
Dolotone
Fault
Spring

Hydrogeology





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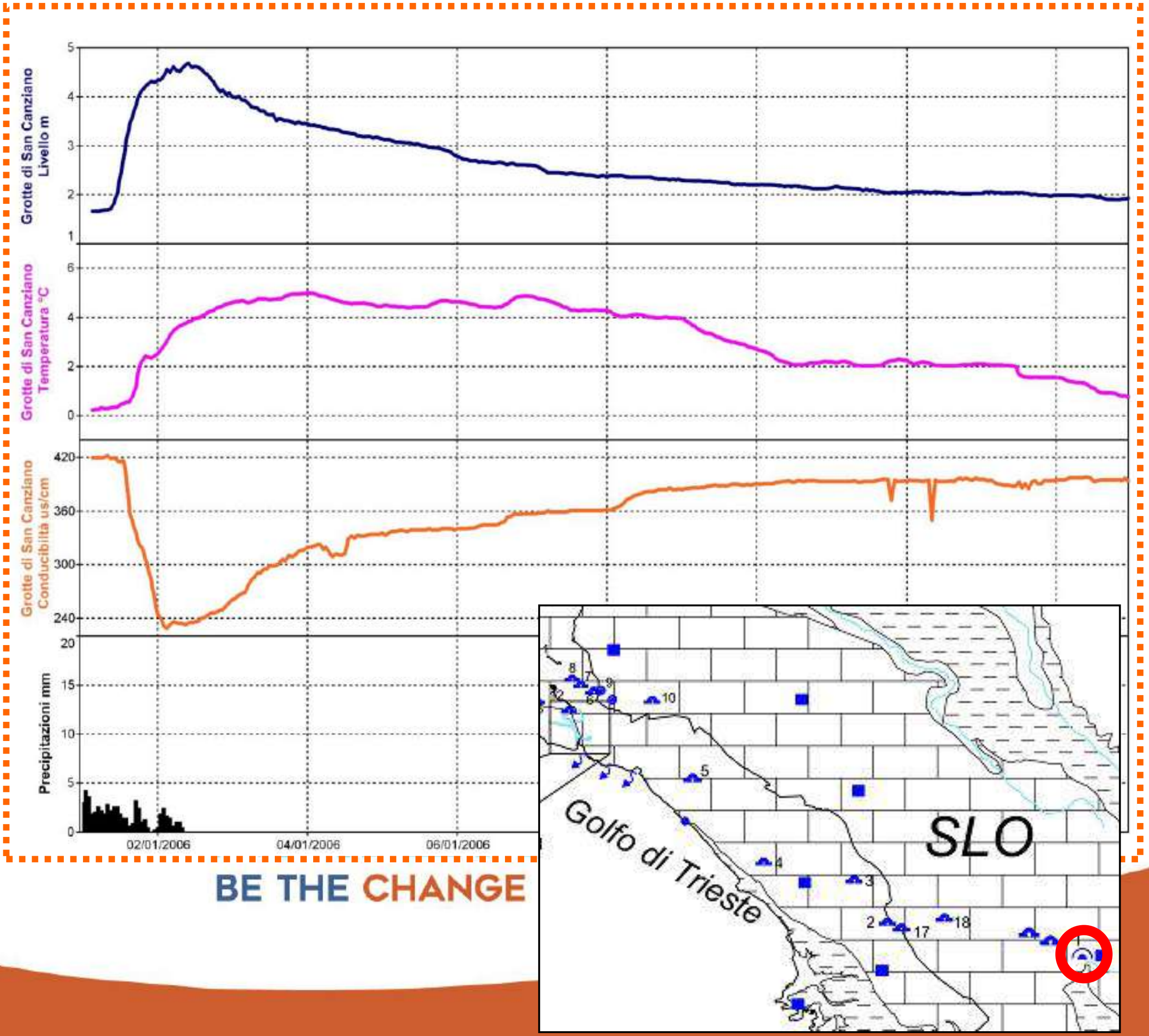
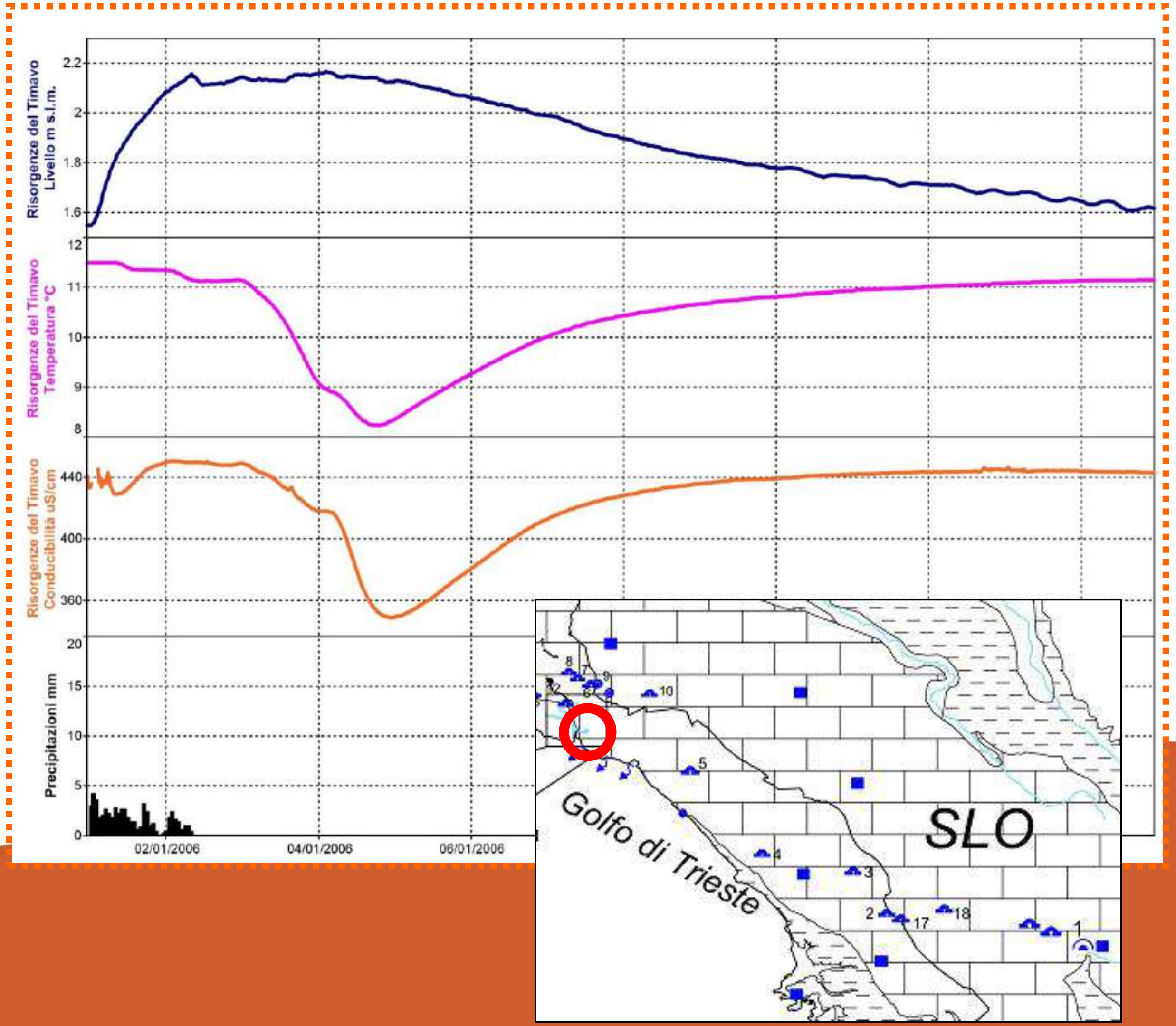
Timavo influence

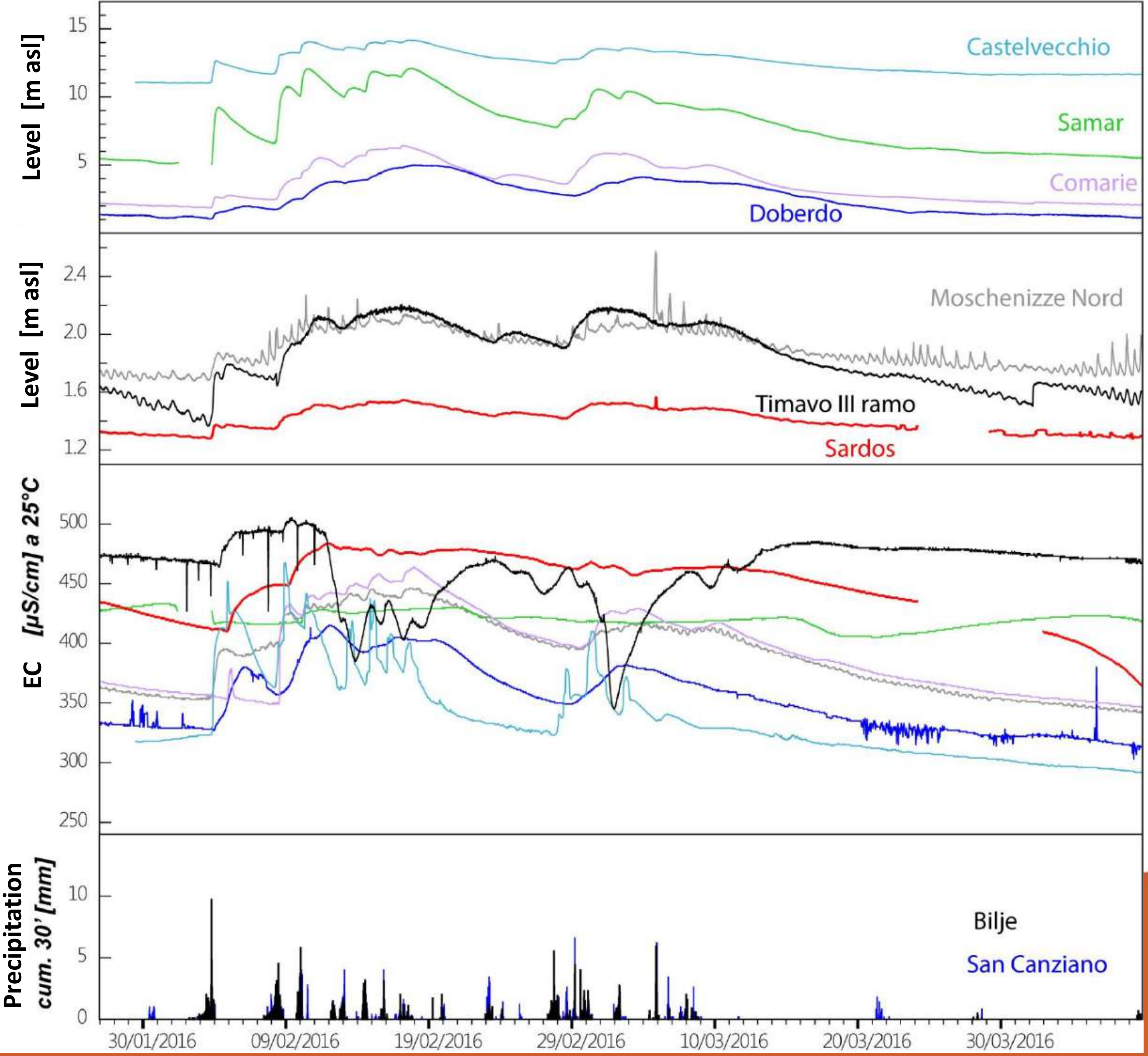
Reka-Timavo Superiore river



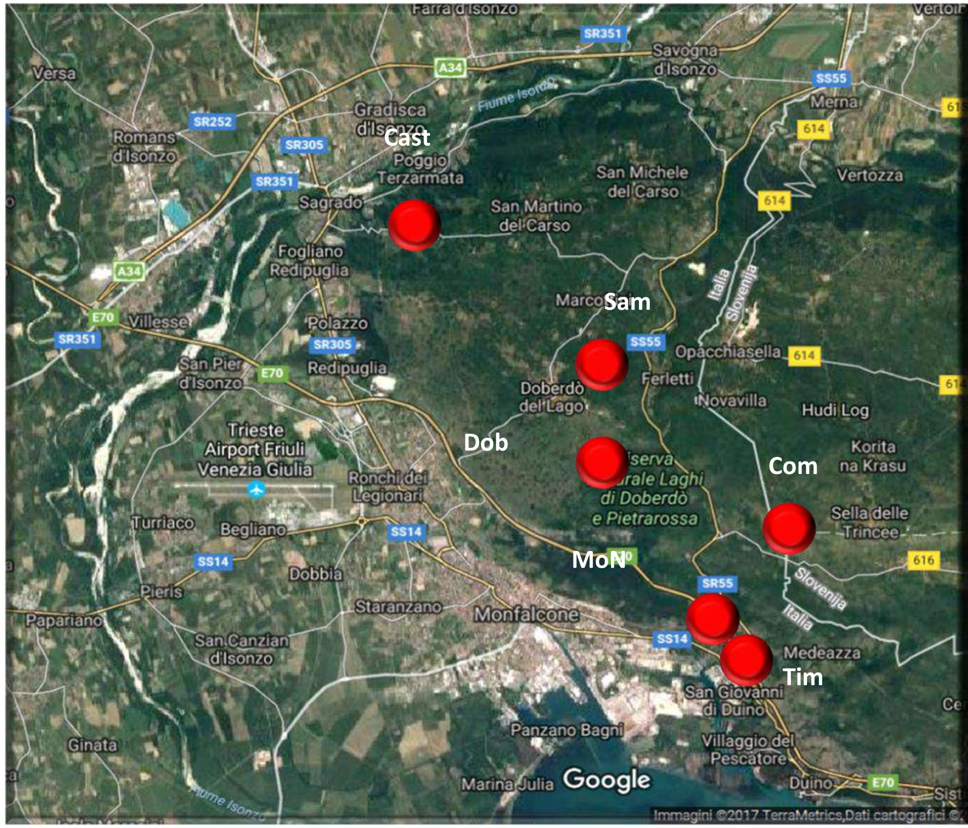
Timavo spring



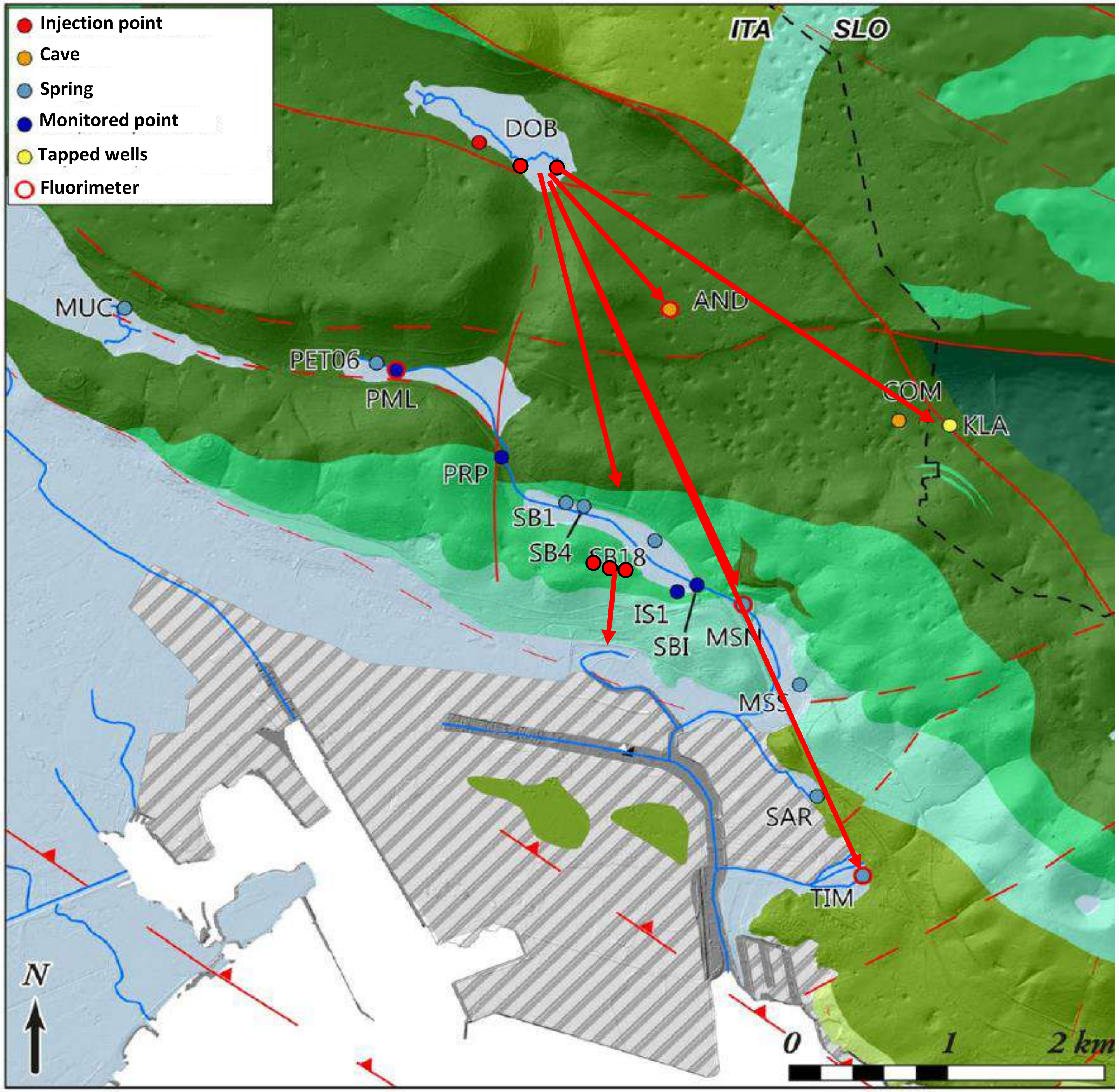
BE THE CHANGE

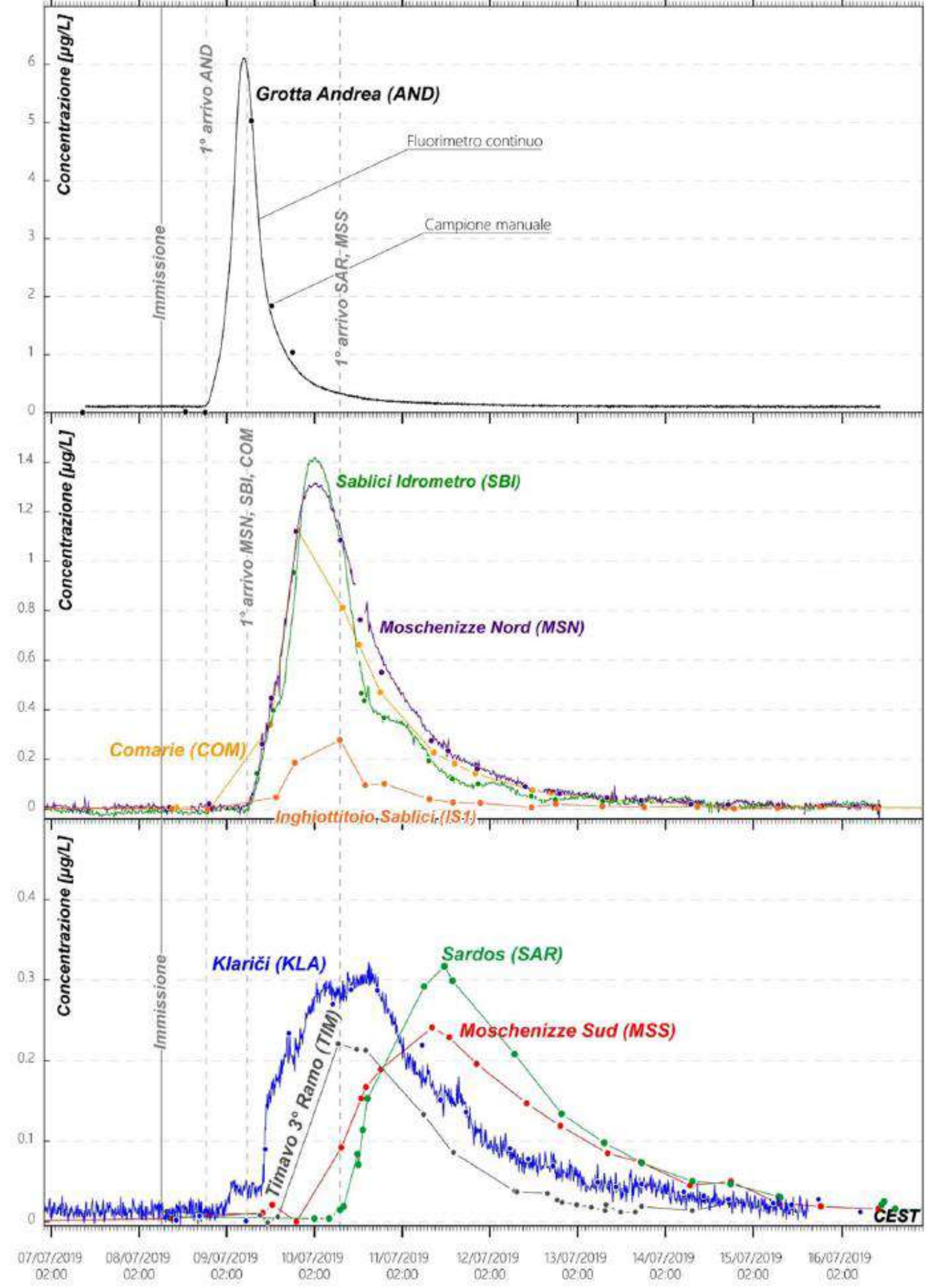


Level [m asl]
Castelvecchio
Samar
Comarie
Doberdo
Level [m asl]
Moschenizze Nord
Timavo III ramo
Sardos
EC [µS/cm] a 25°C
Precipitation cum. 30' [mm]
Bilje
San Canziano
30/01/2016
09/02/2016
19/02/2016
29/02/2016
10/03/2016
20/03/2016
30/03/2016



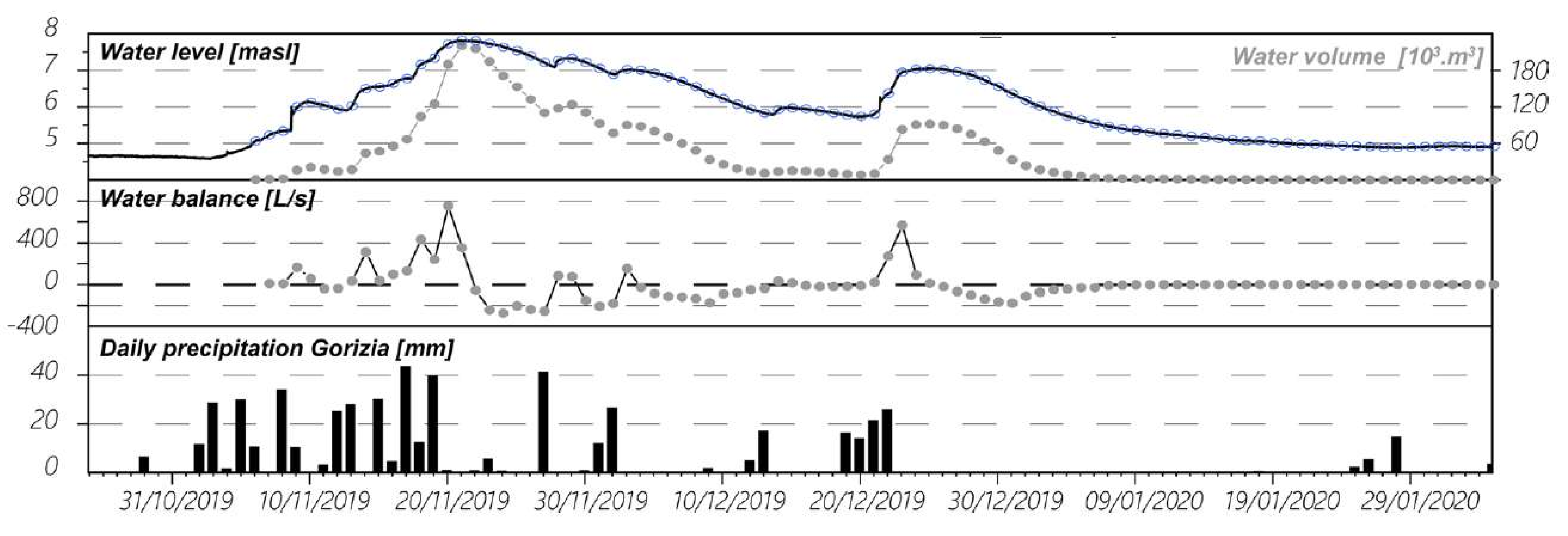
Cast
Sam
Dob
Com
MoN
Tim
Google
Immagini ©2017 TerraMetrics,Dati cartografici ©


Injection point
Cave
Spring
Monitored point
Tapped wells
Fluorimeter
ITA
SLO
DOB
MUC
AND
PET06
PML
COM
KLA
PRP
SB1
SB4
SB18
IS1
SBI
MSN
MSS
SAR
TIM
N
0
1
2 km


Concentrazione [µg/L]
Grotta Andrea (AND)
Fluorimetro continuo
Campione manuale
Immissione
1° arrivo AND
1° arrivo SAR, MSS
Sablici Idrometro (SBI)
1° arrivo MSN, SBI, COM
Moschenizze Nord (MSN)
Comarie (COM)
Inghiottitoio Sablici (IS1)
Klariči (KLA)
Sardos (SAR)
Moschenizze Sud (MSS)
Timavo 3° Ramo (TIM)
CEST
07/07/2019 02:00
08/07/2019 02:00
09/07/2019 02:00
10/07/2019 02:00
11/07/2019 02:00
12/07/2019 02:00
13/07/2019 02:00
14/07/2019 02:00
15/07/2019 02:00
16/07/2019 02:00

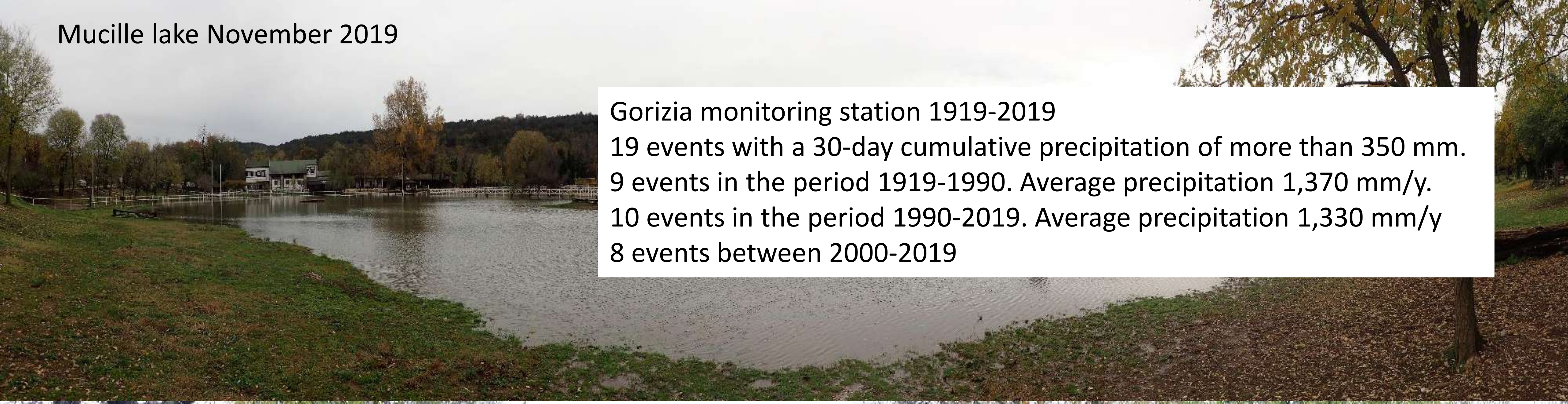
Mucille lake

Mucille lake November 2019

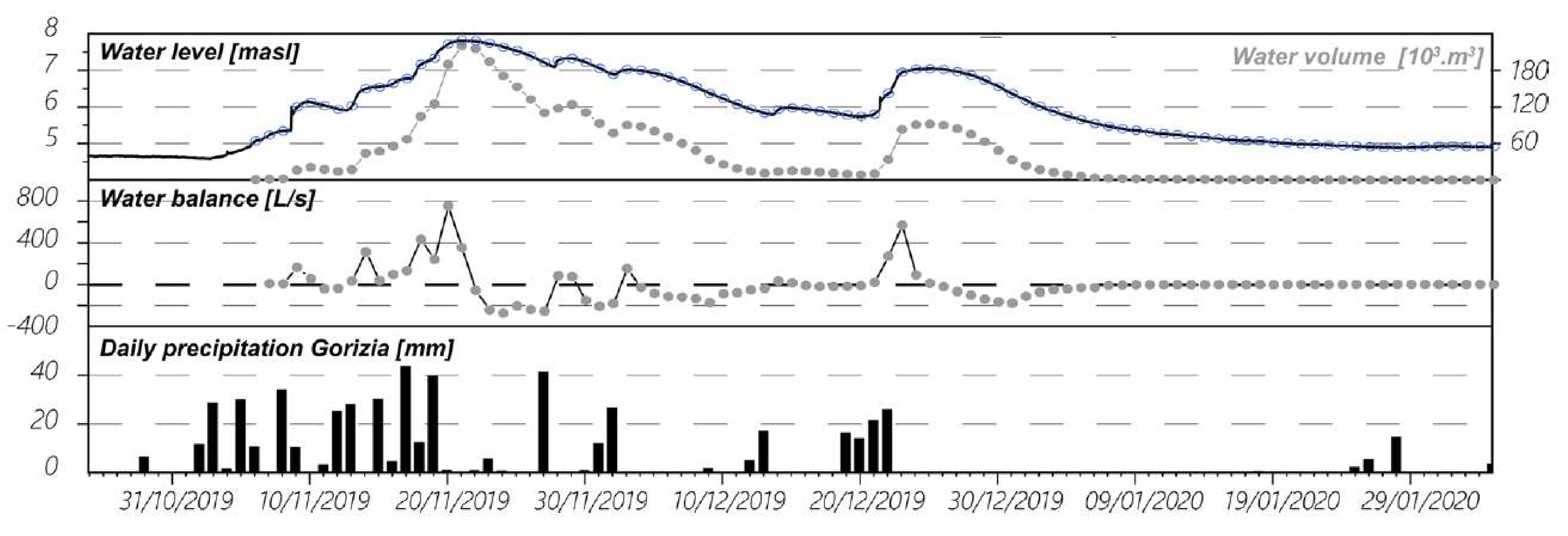


Selz Vil

Mucille lake November 2019



Gorizia monitoring station 1919-2019
19 events with a 30-day cumulative precipitation of more than 350 mm.
9 events in the period 1919-1990. Average precipitation 1,370 mm/y.
10 events in the period 1990-2019. Average precipitation 1,330 mm/y
8 events between 2000-2019



Selz Vil

Doberdò lake

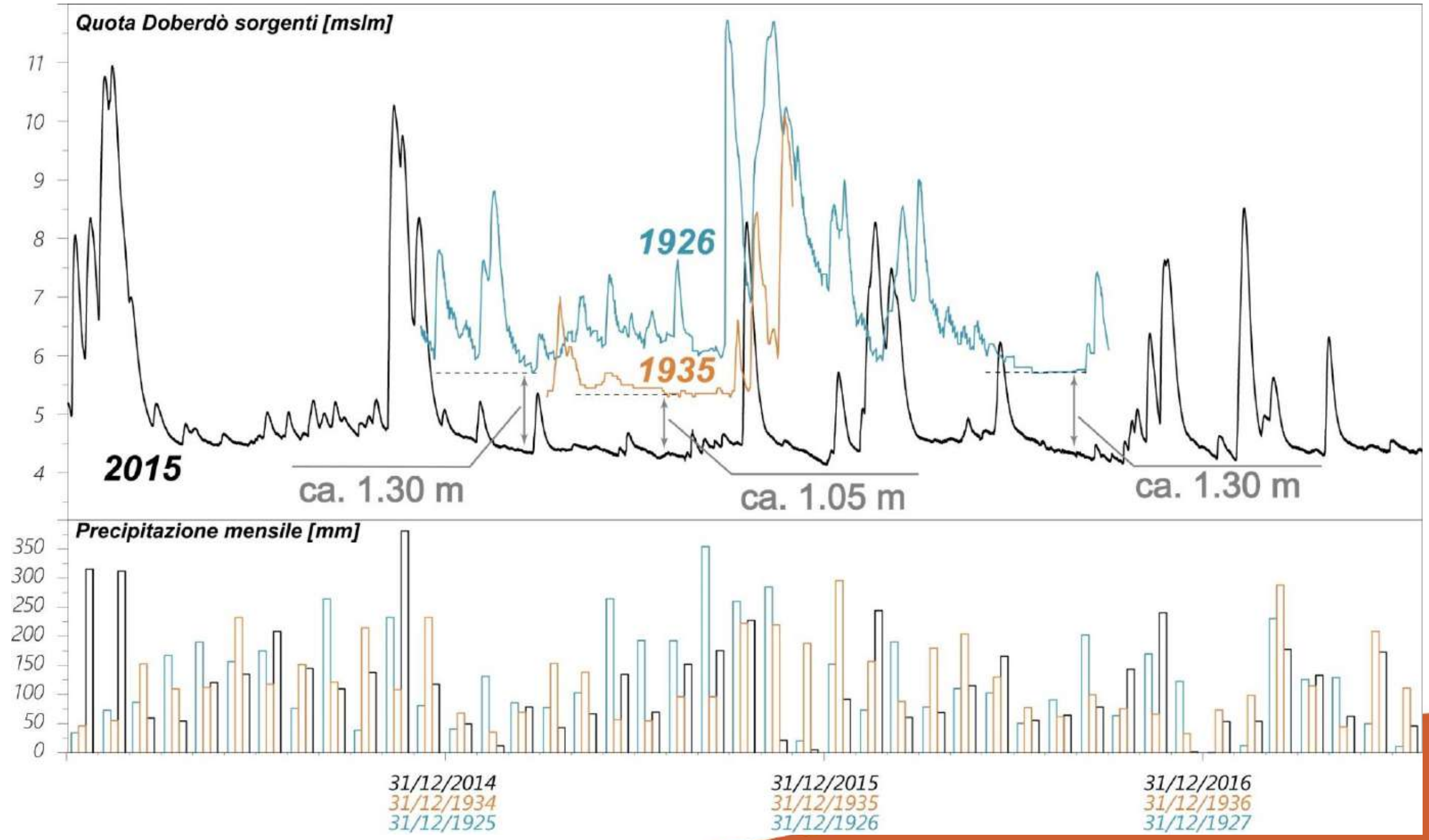

Summer 2022
11 August

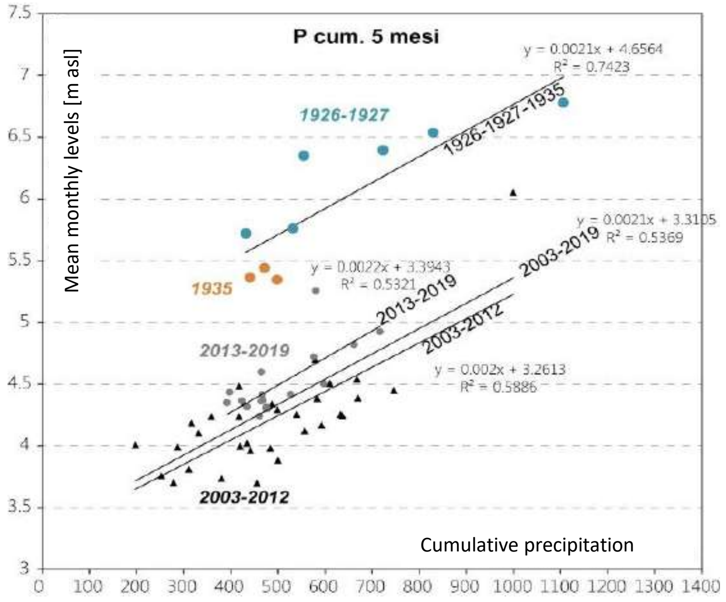

Summer 2022
11 August

What was the condition in the past?

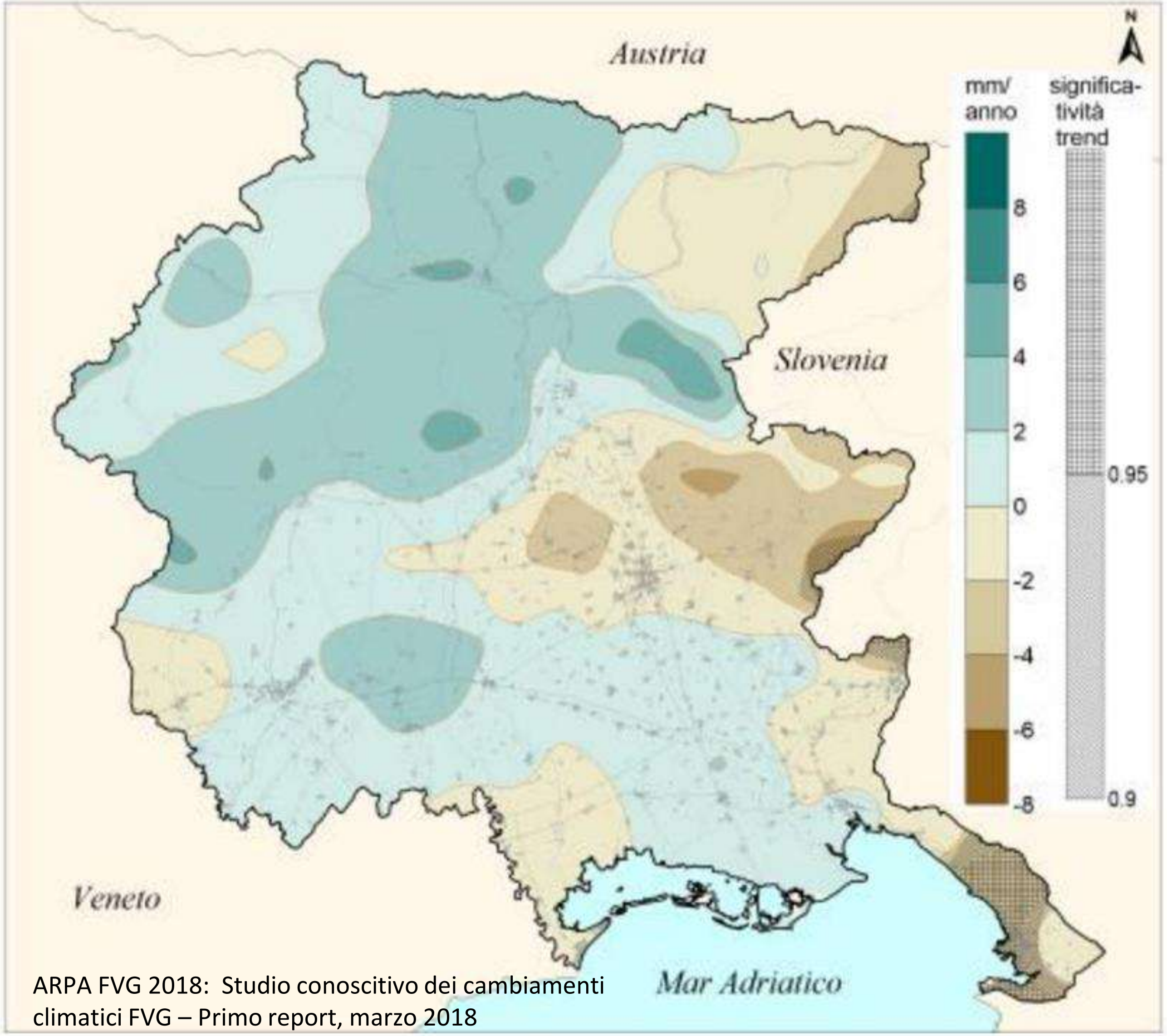
http://www.gofvg.altervista.org/2016/09/28/idrovolanti-cant-a-monfalcone/

The comparison between historical levels



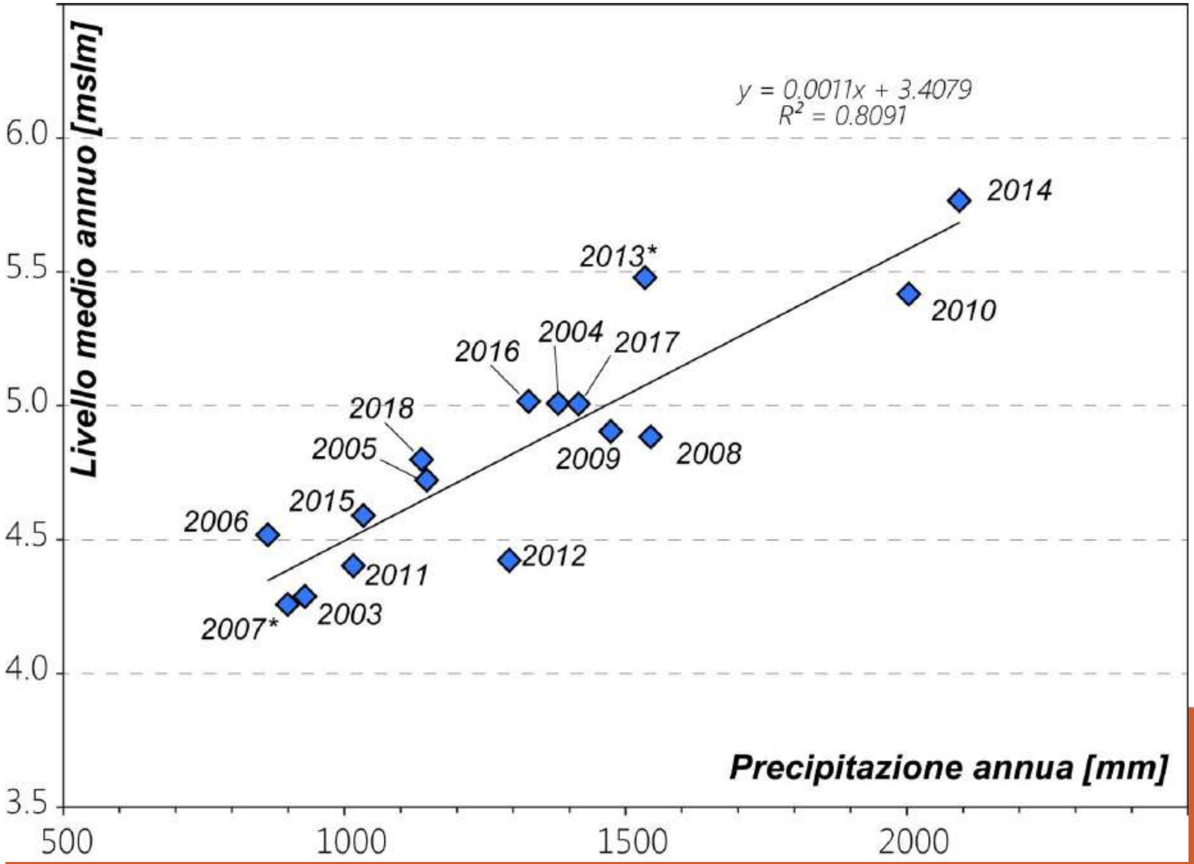


Precipitation trend 1961-2015

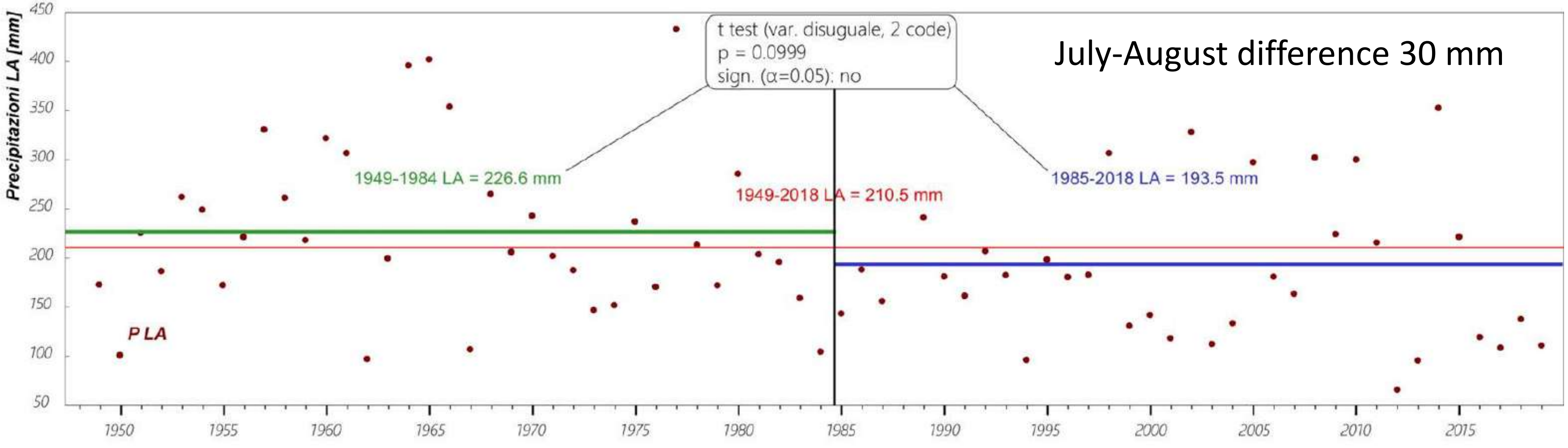


ARPA FVG 2018: Studio conoscitivo dei cambiamenti climatici FVG – Primo report, marzo 2018

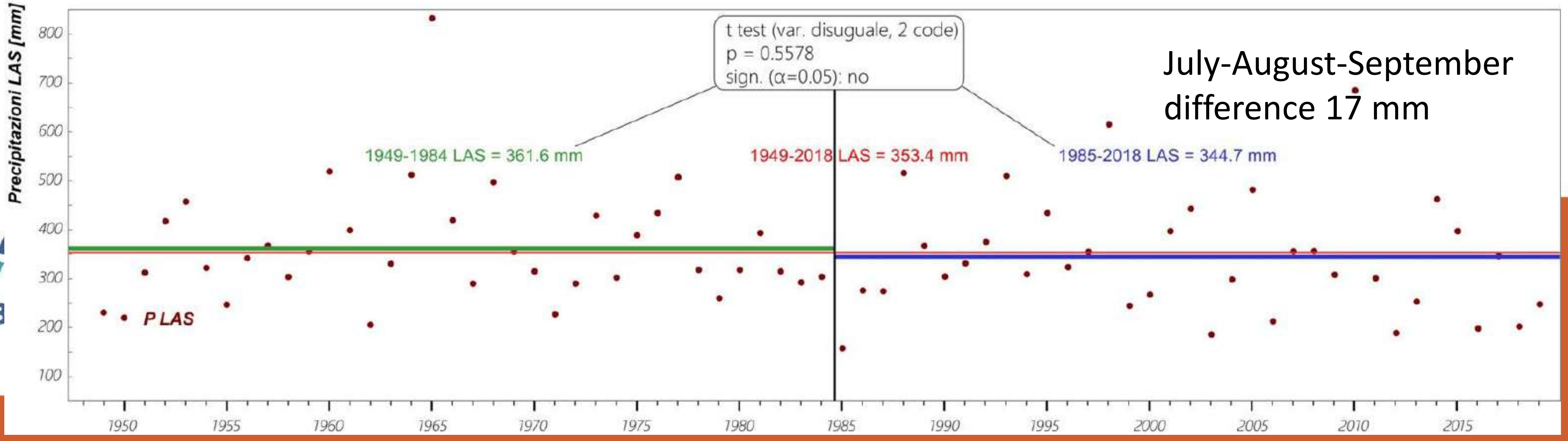
Annual Precipitation – Lake water level



Cumulative precipitation

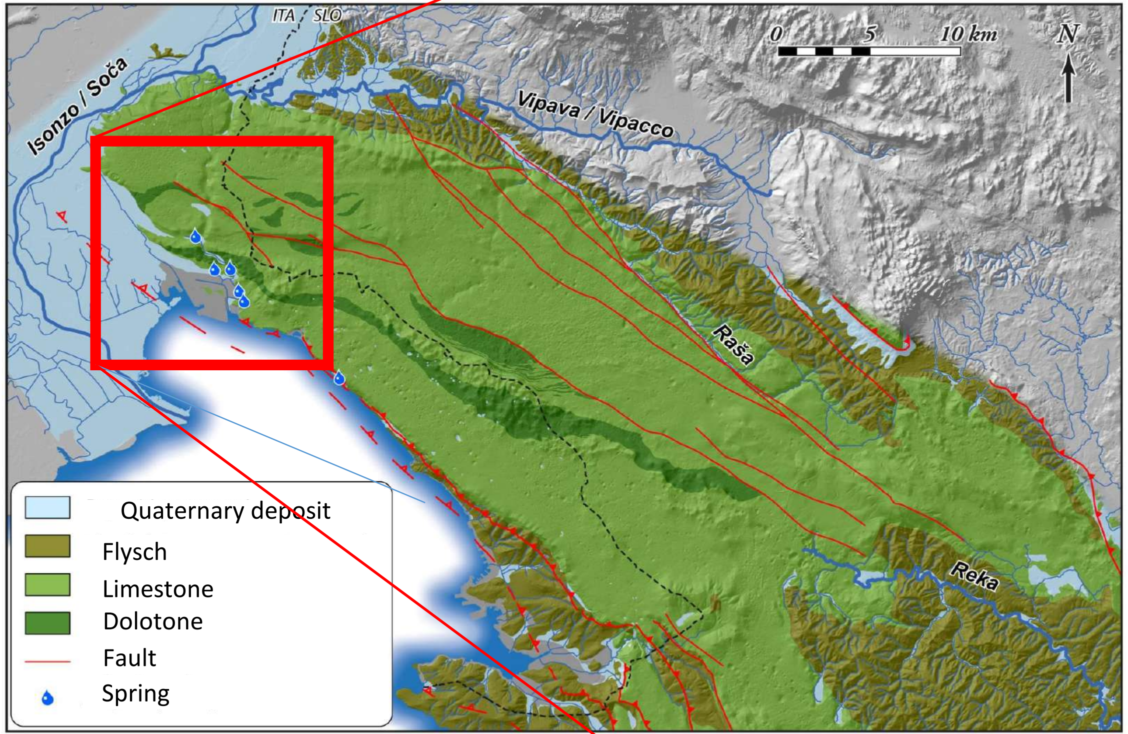


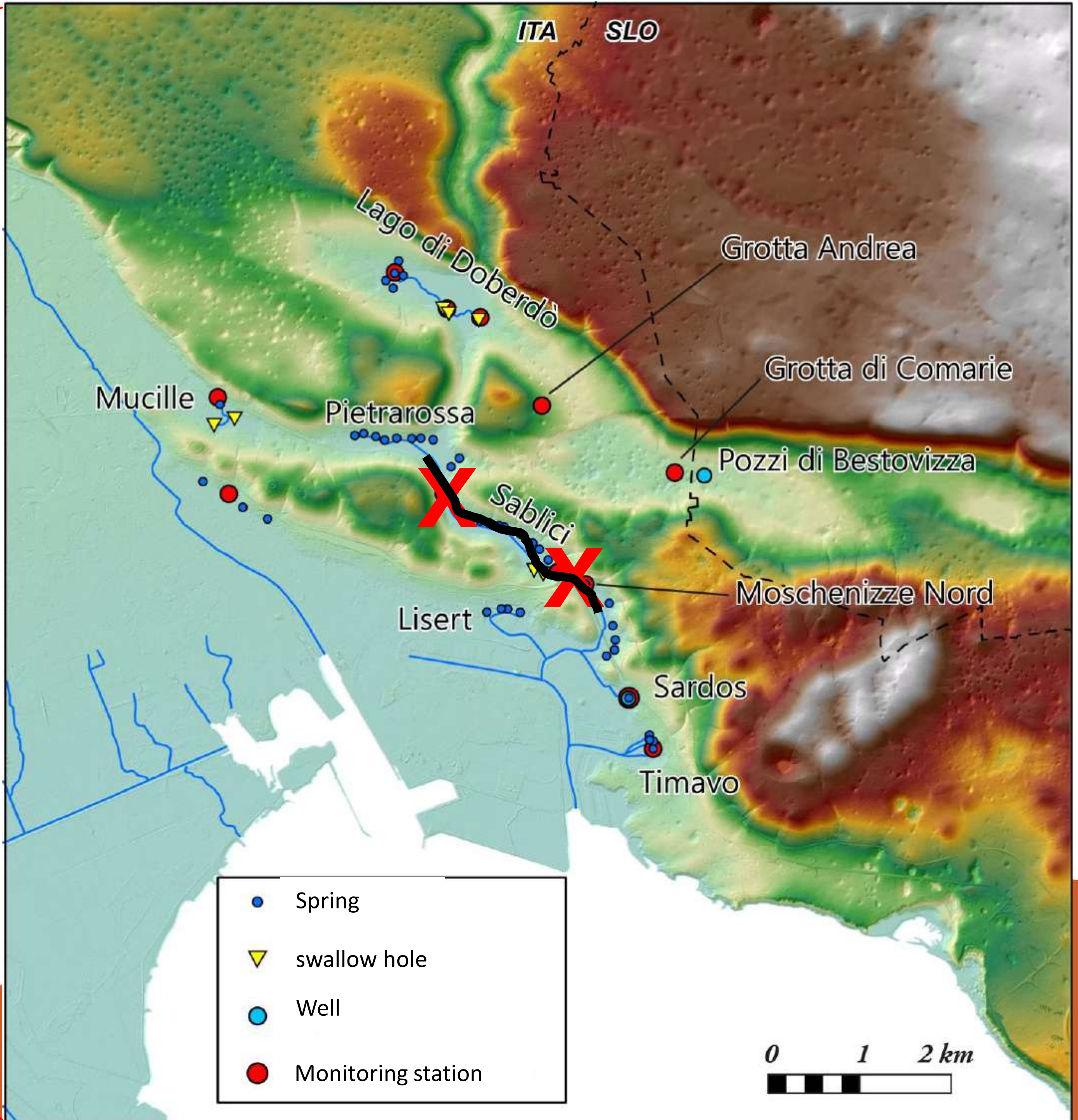
July-August difference 30 mm



July-August-September difference 17 mm

Hydrogeology





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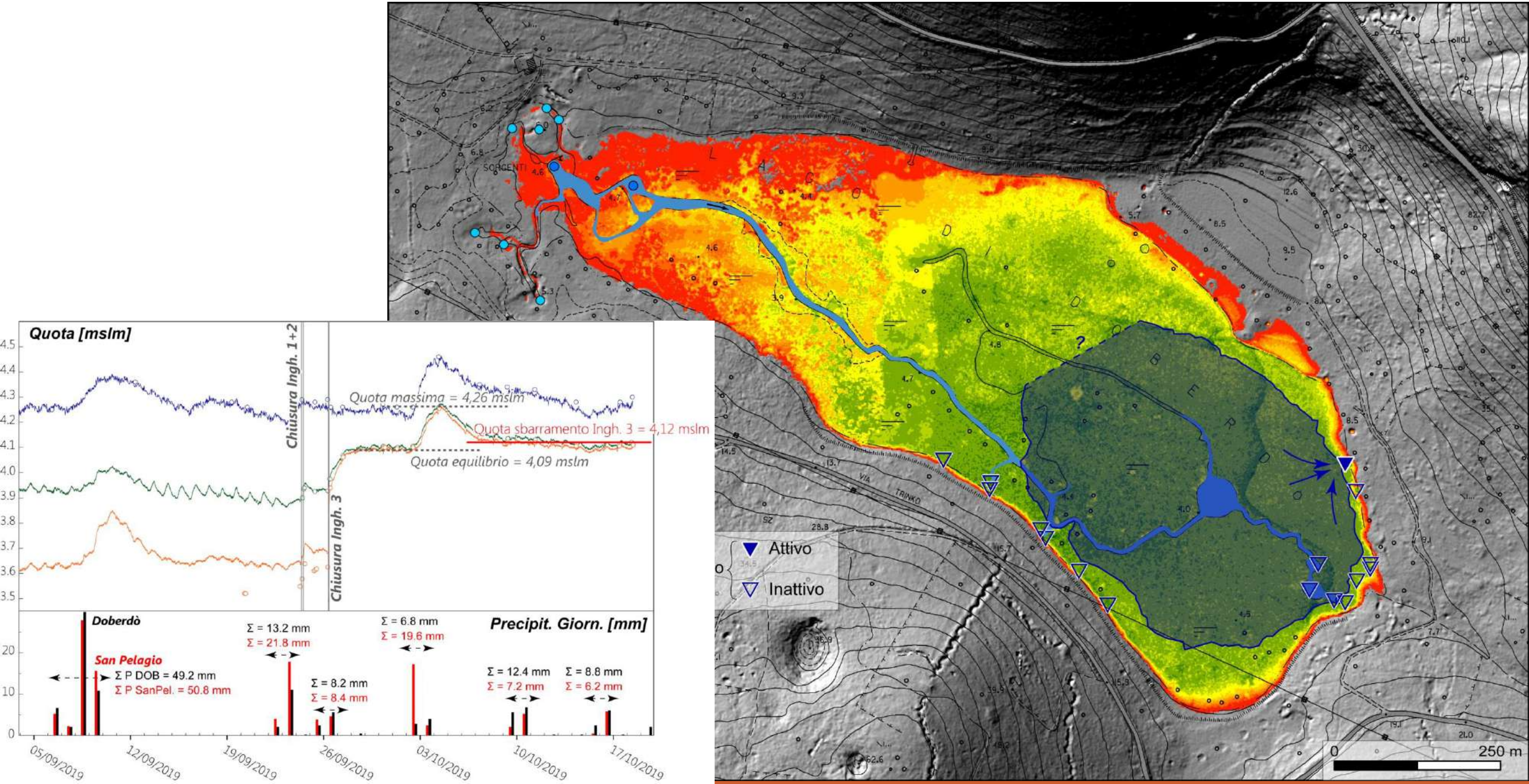
Temporary embankments



Quota [mslm]
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
Chiusura Ingh. 1+2
Chiusura Ingh. 3
Quota massima = 4,26 mslm
Quota sbarramento Ingh. 3 = 4,12 mslm
Quota equilibrio = 4,09 mslm
Precipit. Giorn. [mm]
Doberdò
San Pelagio
Σ P DOB = 49.2 mm
Σ P SanPel. = 50.8 mm
Σ = 13.2 mm
Σ = 21.8 mm
Σ = 8.2 mm
Σ = 8.4 mm
Σ = 6.8 mm
Σ = 19.6 mm
Σ = 12.4 mm
Σ = 7.2 mm
Σ = 8.8 mm
Σ = 6.2 mm
20
10
0
05/09/2019
12/09/2019
19/09/2019
26/09/2019
03/10/2019
10/10/2019
17/10/2019
SORGENTI
LAGO DI DOBERDO
VIA TRINKO
Attivo
Inattivo
0
250 m

Conclusion

In the last 30 years we observe a significant change in the hydrogeological regime of the karst lakes.

The causes of these changes are linked to the reclamation works and the increase in the frequency of intense rainfall and drought periods .

We need to act quickly if we want to preserve these delicate ecosystems.

Only a deep knowledge of the entire hydrodynamics allows to intervene avoiding further damages.

The study was funded by the municipality of Ronchi dei Legionari (Italy) in the framework of the project "Elaborazione del modello idrogeologico del sottosuolo dell'area del Parco delle Mucille di Selz" and its extensions and by Regione Autonoma Friuli Venezia Giuli, Servizio Gestione Risorse Idriche in the framework of project "idrodinamica sotterranea del lago di Doberdò» (Scientific Coordinator: Prof. Luca Zini).

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ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale

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Malta 2023

14th – 16th June
National Meeting on Hydrogeology

JUNE 14-16, 2023

WATER.ORG.MT

The contribution of occult precipitation to karst aquifers recharge in semi-arid zones

Laura Sanna

Istituto di Geologia Ambientale e Geoingegneria

Consiglio Nazionale delle Ricerche

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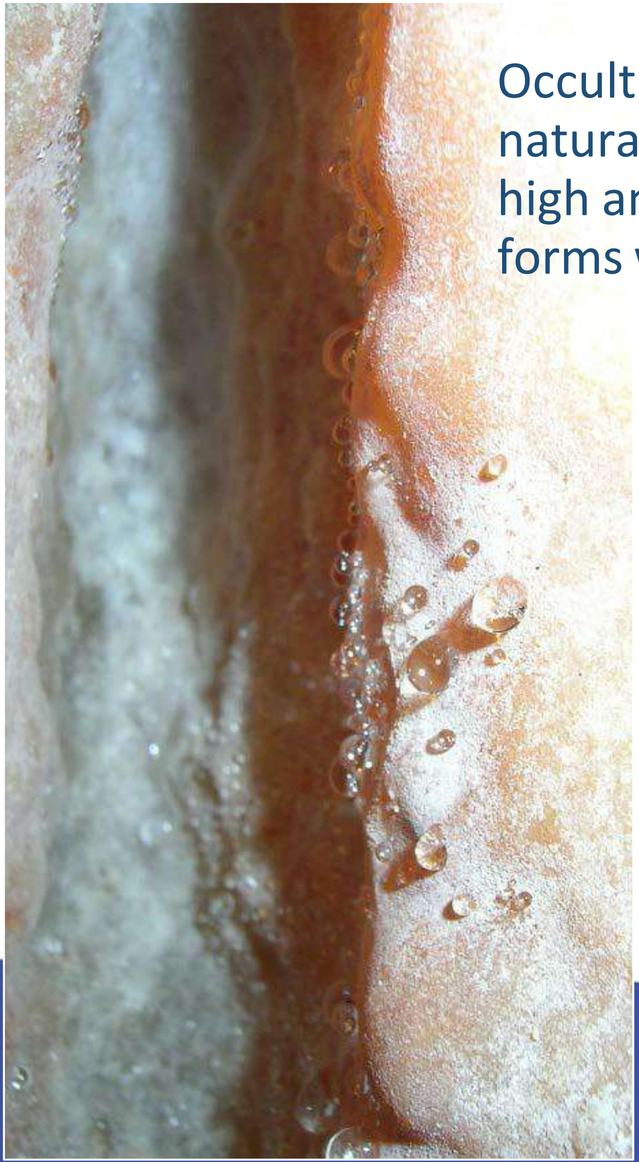
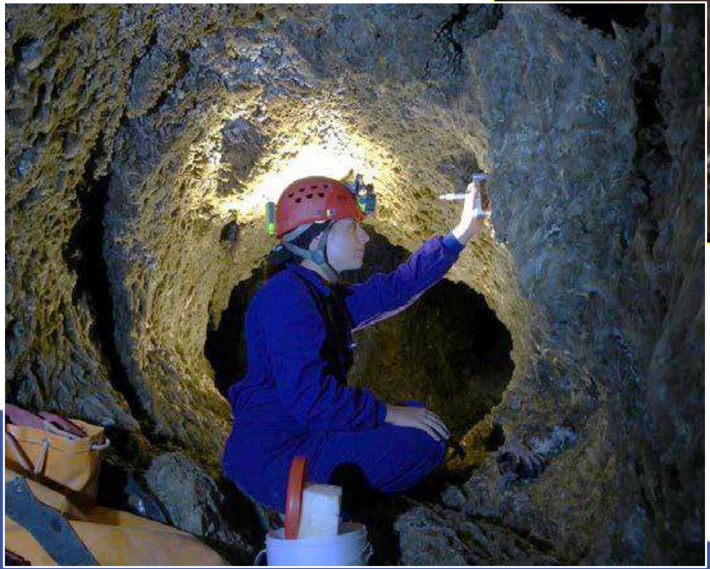
laura.sanna@cnr.it

INTRODUCTION



Occult precipitation occurs naturally when air humidity is high and its condensation forms water droplets.



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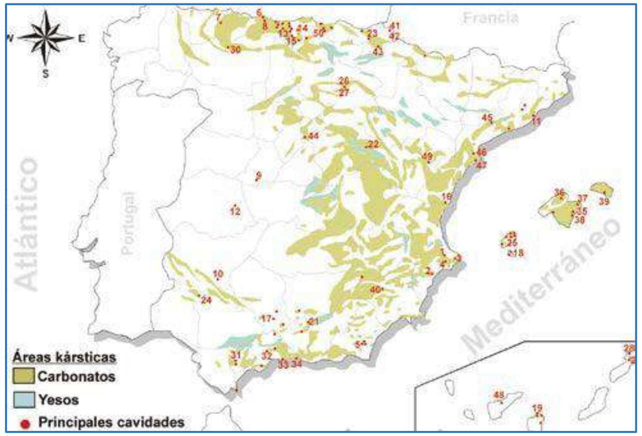
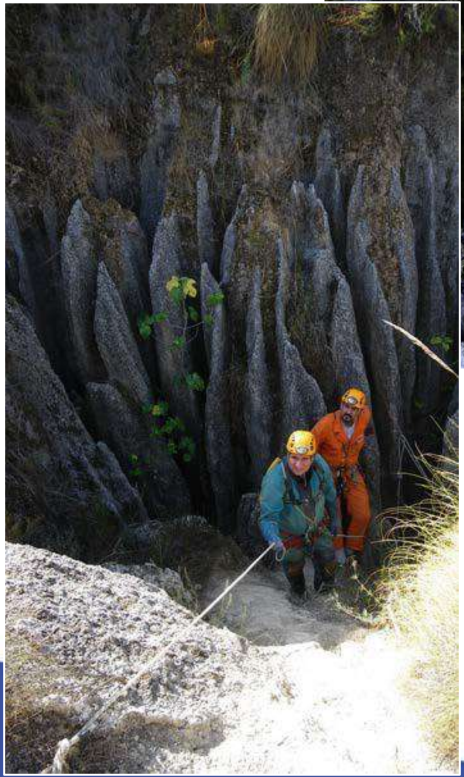
STUDY AREA

The gypsum karst of Sorbas is a protected natural area in the district of Sorbas (Almeria, South-East Spain). In only 12 km^2, this plateau hosts more than 1,000 caves, several of which develop for over 1,000 metres.



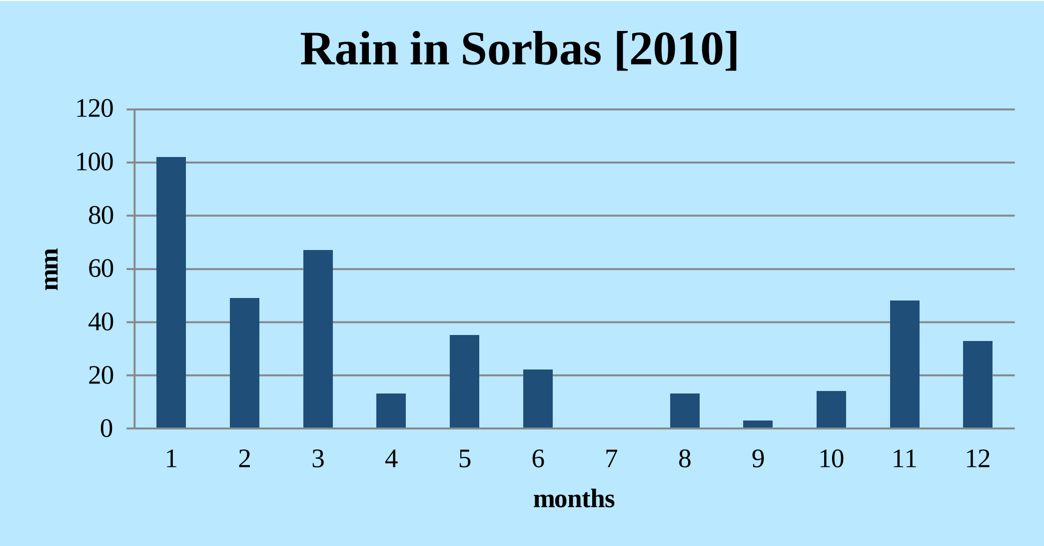


STUDY AREA

The climate in Sorbas is semi-arid mean annual rainfall of 210 mm a^{-1}, 80% distributed in only 3-4 days, 30 rainy days a year. Minimum mean in July, maxima in November. The average annual temperature 19.5 °C, minimum in January (11 °C), maximum in July (30 °C).

High evapotranspiration (1100 mm a^{-1}), useful rain to less than 25% of the total (60 mm a^{-1}).

Mostly exposed to south-western winds.



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GEOMORPHOLOGY

Landscape stands out topographical elevated at about 400 metres above sea level, NE-elongated platform with steep edges looking out on dry valleys.
The epikarst counts dolines, different forms of karren, fields of tumuli.
Characteristic cave morphologies are triangular interbedded galleries.

Photo Riccardo De Luca

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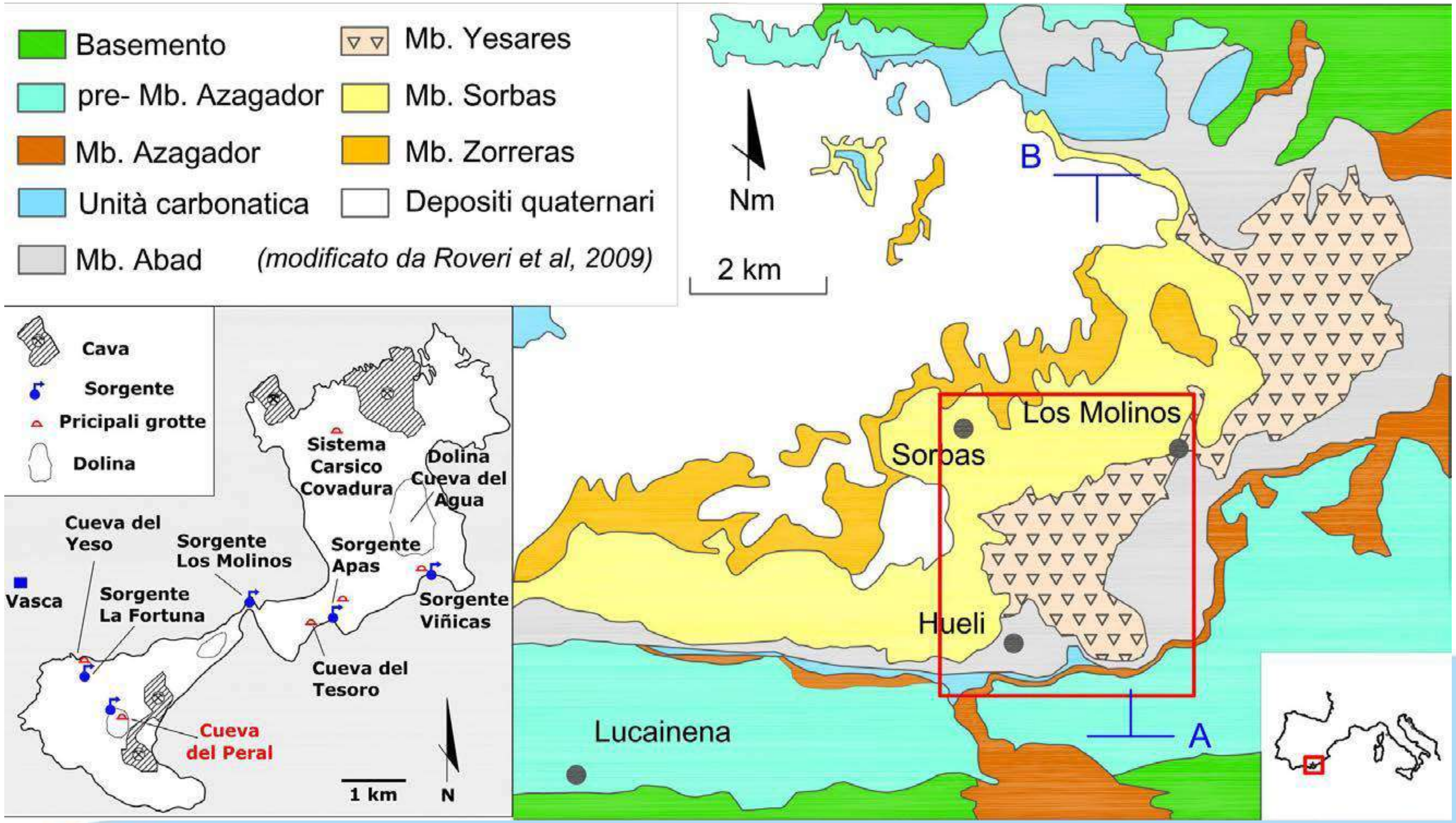
GEOLOGY

This area is located in the Tabernas-Sorbas Basin, a intramontane Neogene depression in the Betic Belt where Messinian evaporite deposition occurred.



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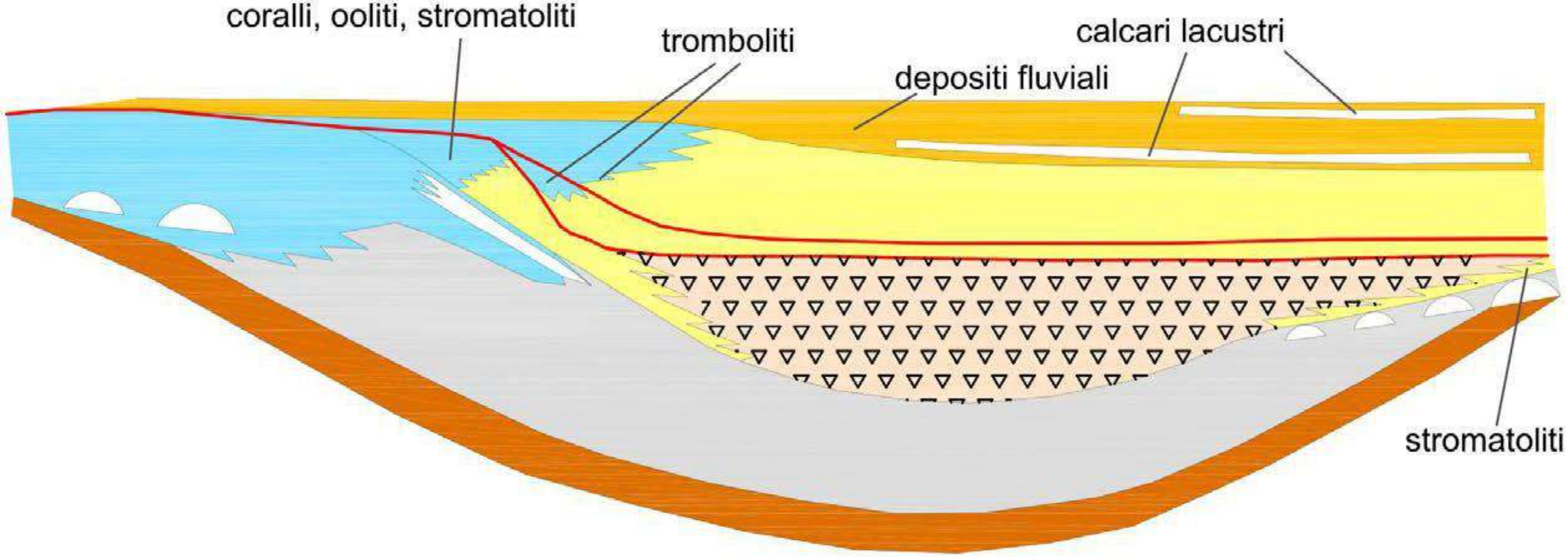
GEOLOGY

The structure is poorly-deformed tabular and stratification slightly inclined



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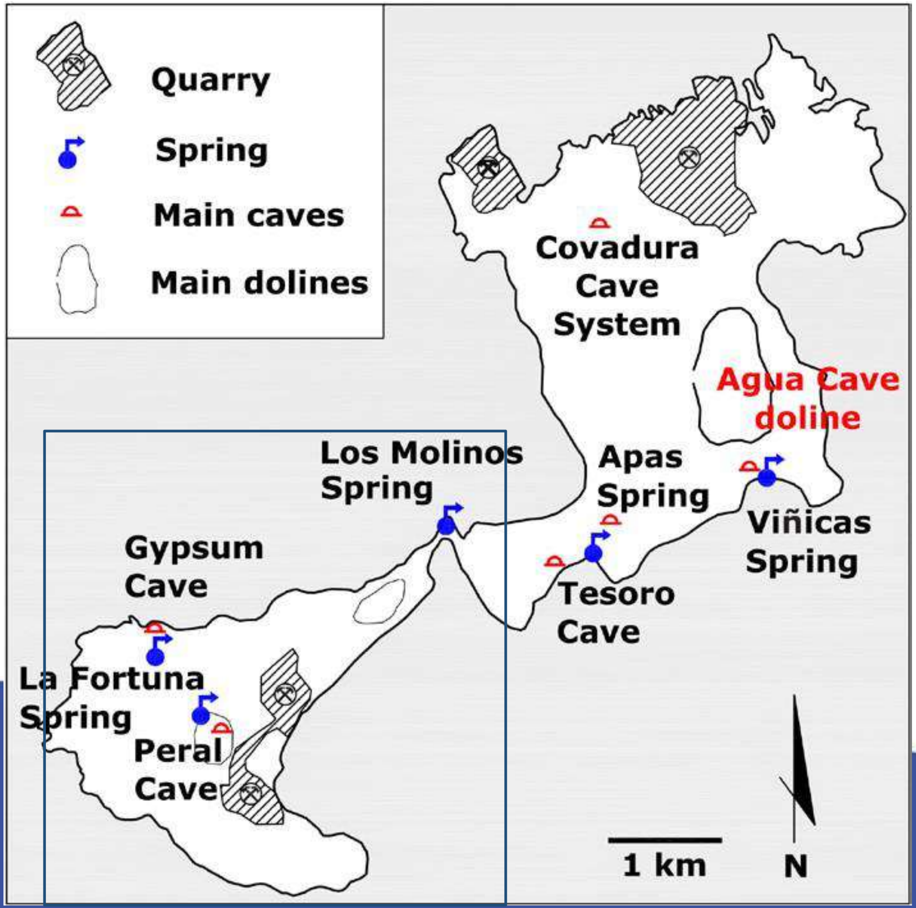
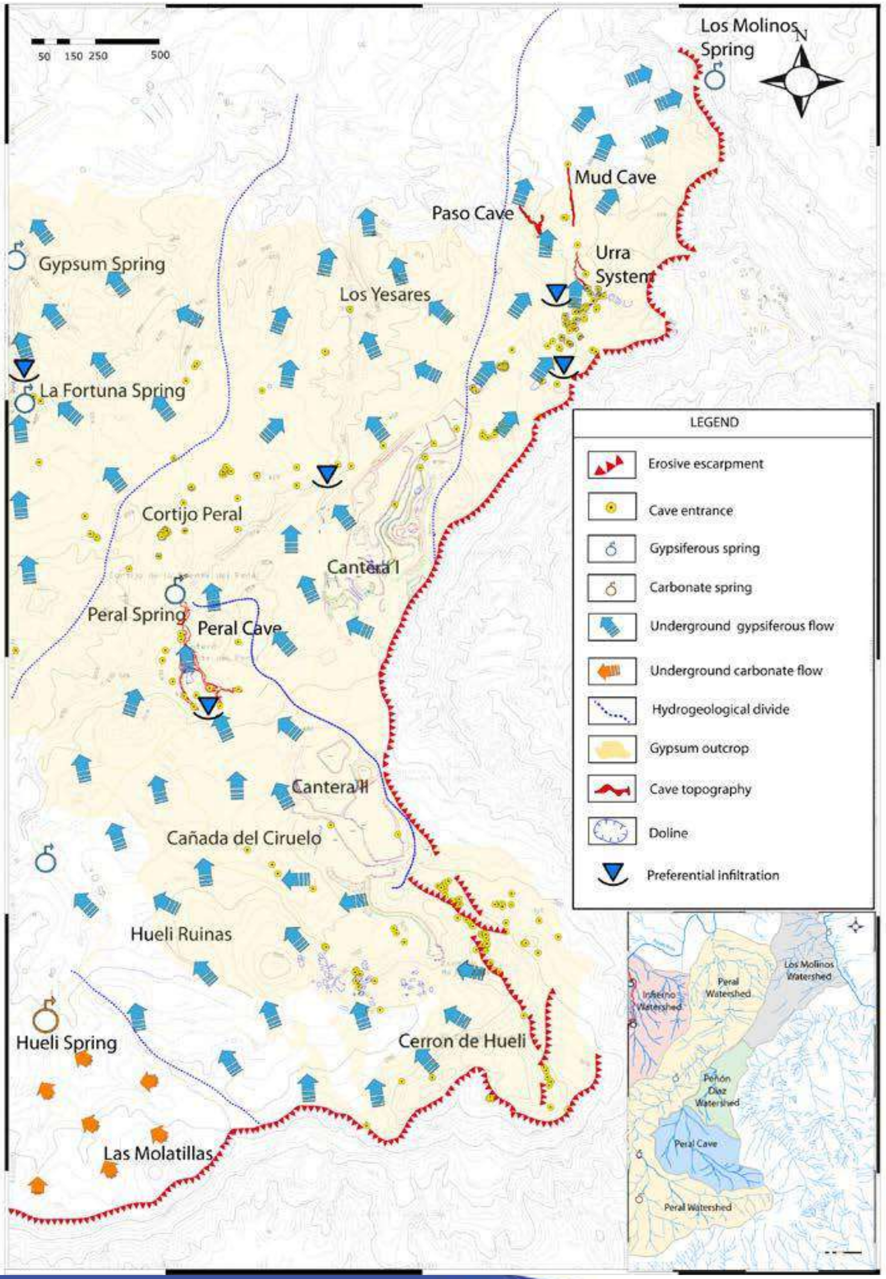
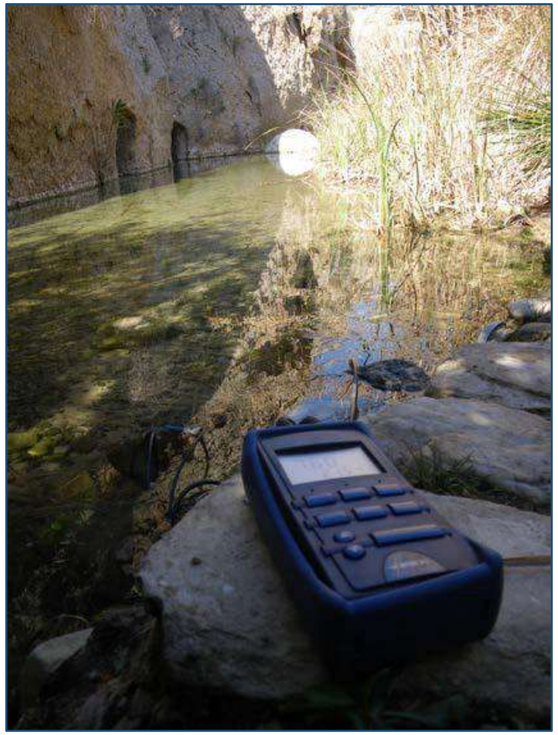
HYDROGEOLOGY

Strong contrasts in lithology;
Gypsum-marls boundary;
6 permanent springs (discharge 26 L/sec).





Sanna et al. 2012



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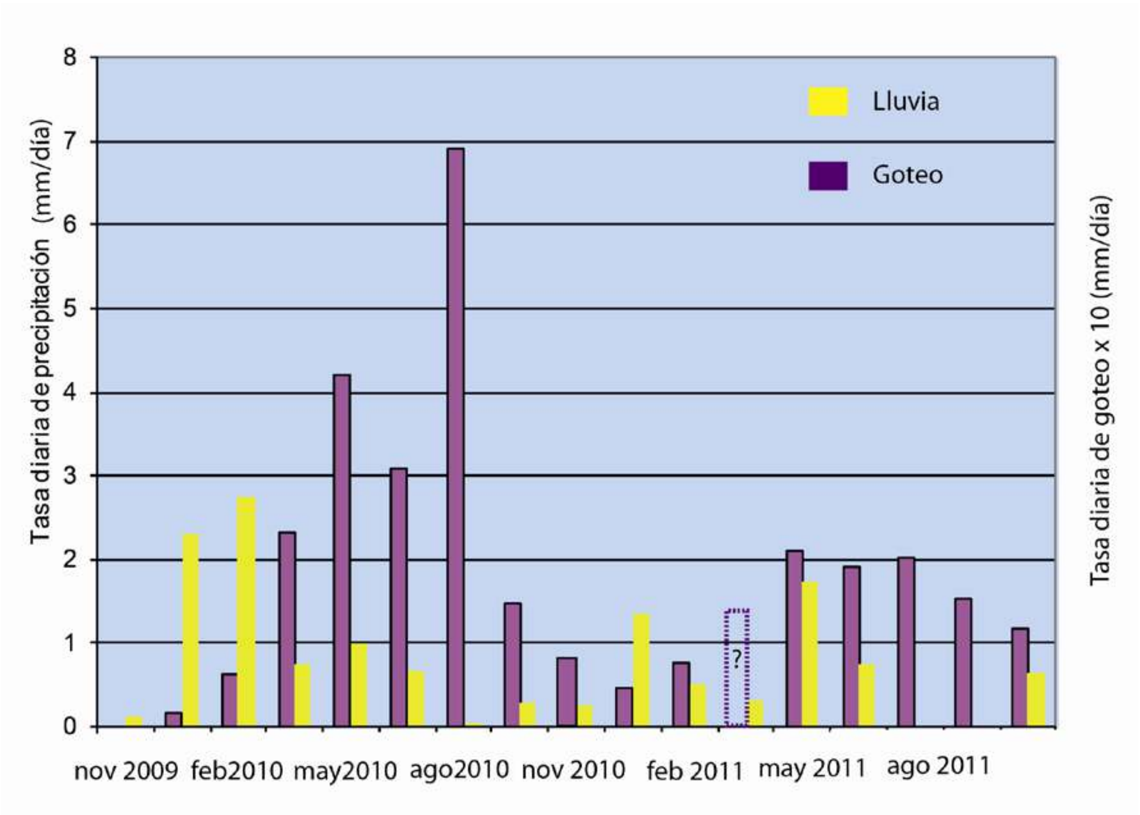
RAINS VS CAVE DRIPPING



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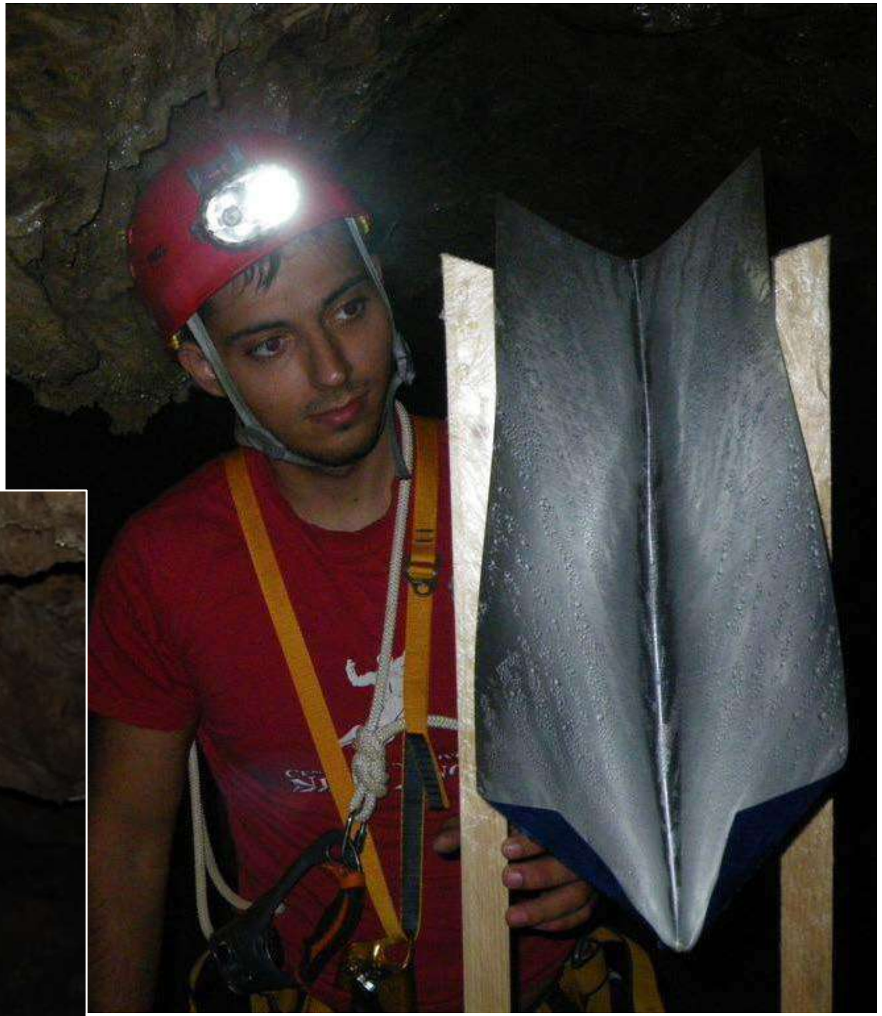
EXPERIMENTAL DESIGN


Photo Maciej Browarny



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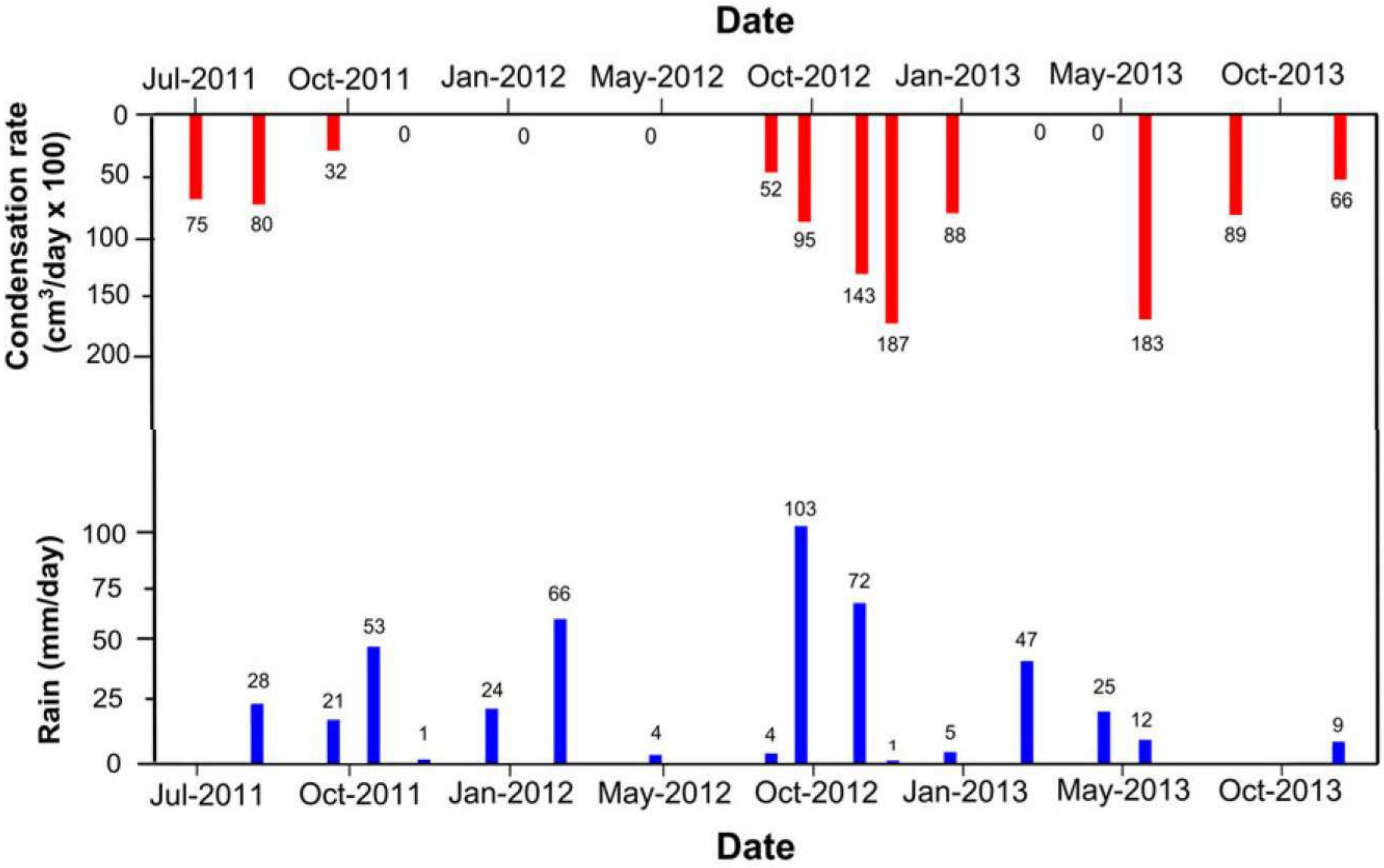
RESULTS



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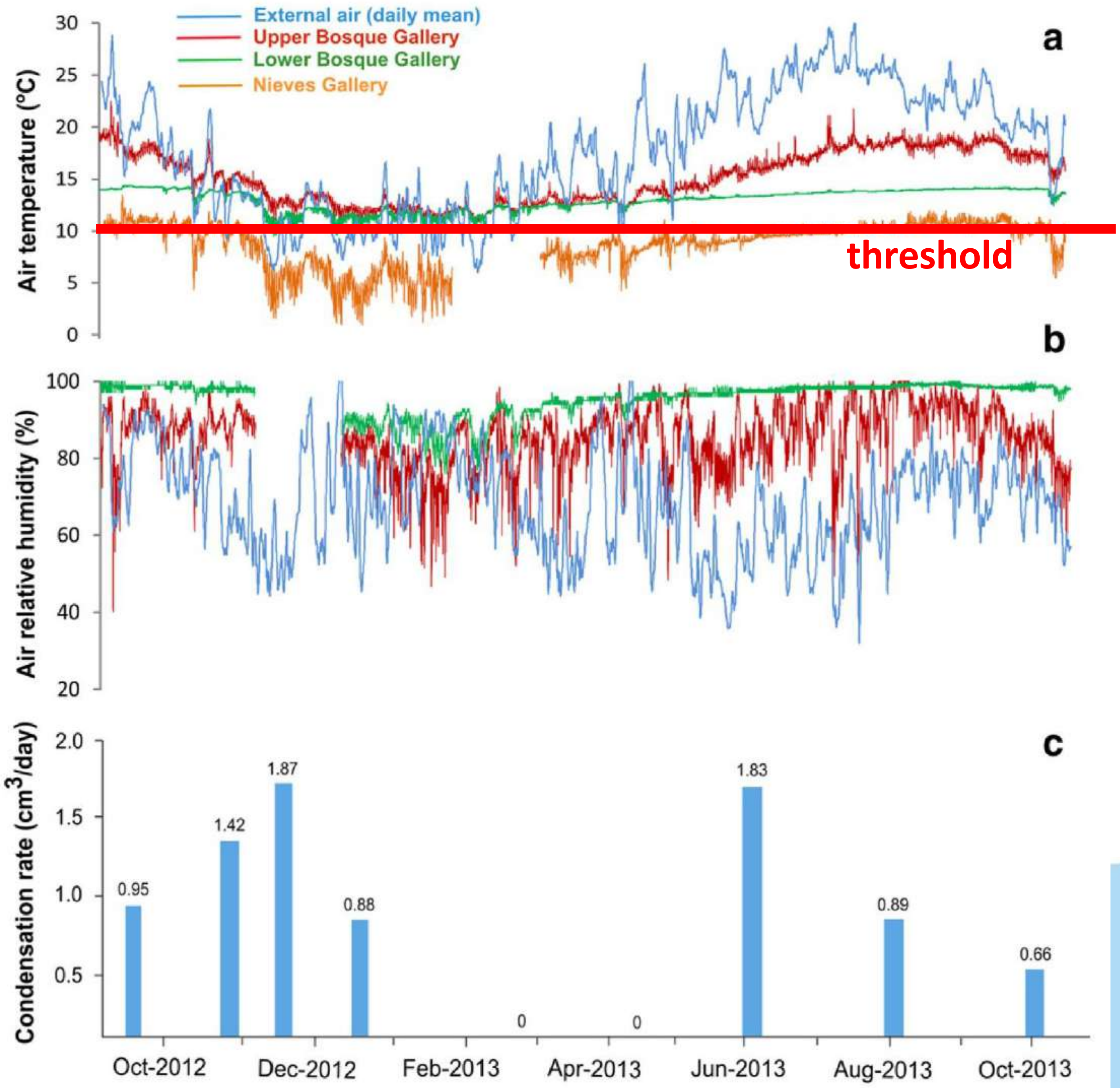
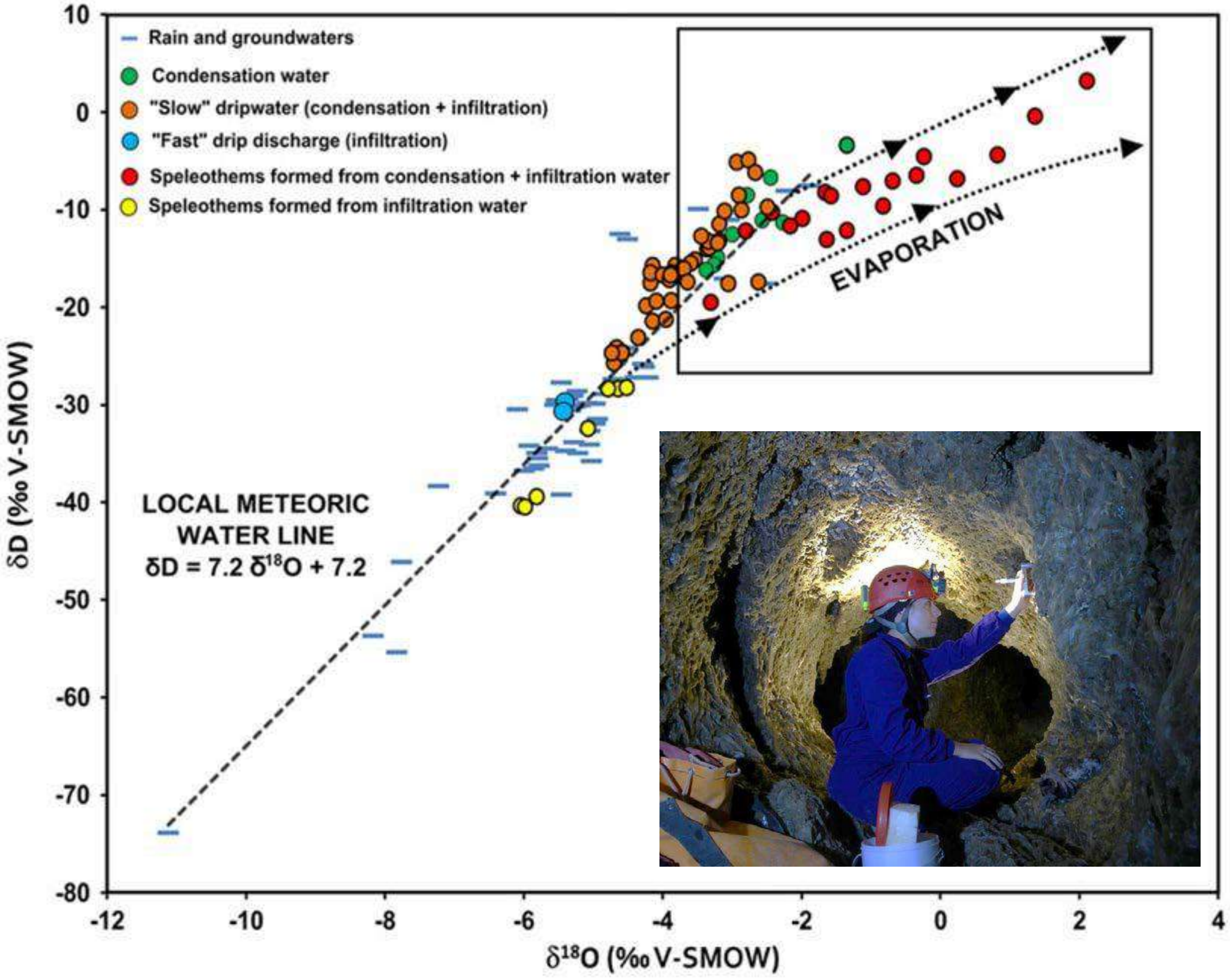
RESULTS



Gazquez et al. 2017

RESULTS



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CONCLUSION

Considering an average 1 m-diameter for karst conduits and a minimum of 100 km of underground cave network, occult precipitation represent 0.1 % of the low water discharge of the main spring.

This volume seems negligible compared to the annual rainfall received by the Sorbas area.

However, it must be taken into account that the obtained condensation rate value is a low estimate, affected by evaporation both on the surface of the instrument and in the container that collects the water, the which has not yet been estimated.

This evaporation effect could be much less in deeper galleries so that the "useful condensation" could increase.

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5. Images

Below one can find a number of images that were taken during the event.

5.1 Registration Desk

A registration desk was provided in order to greet the participants and hand out name tags.

5.2 Speakers

Table and chairs were set up on stage for the speakers during the questions.


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5.3 Attendees

The conference was well attended, by both public and private individuals.

5.4 Moderator

The moderator for this conference was Mr Keith Demicoli.