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5

Implementation Of A Large-Scale Aquifer Recharge Project In A Multi-Screen Coastal Plain Aquifer

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The Sustainable Water Initiative for Tomorrow (SWIFT) is a managed aquifer recharge (MAR) project of Hampton Roads Sanitation District (HRSD) in Virginia, USA, to address groundwater supply challenges facing the Coastal Plain region of Virginia. SWIFT is primarily designed for the rehabilitation of the Potomac Aquifer System (PAS), a deep confined coastal aquifer system, through the advanced treatment of wastewater and subsequent recharge. In 2018, HRSD built the SWIFT Research Center (SWIFTRC), a demonstration facility that recharges approximately 1 million gallons per day (3785 m3/d) into the PAS through a single recharge well (TW-1). The PAS is a primarily fluvial-deltaic coarse-grained sands and gravels with interbedded clays of varying thicknesses. Because of the nature of the interbedded clays, treated "SWIFT Water" is recharged to the PAS at TW-1 through eleven distinct screens ranging from 500 to 1400 feet (152 to 427 m) in depth below ground surface (see figure). The SWIFTRC groundwater recharge monitoring system enables assessment of impacts on the PAS, which includes a depth-discrete sampling system (MW-SAT) to evaluate water quality in each aquifer layer, multiple conventional wells in the Upper, Middle, and Lower Potomac Aquifer (MW-UPA, MW-MPA, and MW-LPA, respectively), and an extensometer on site to measure changes in land subsidence.

Characterizing flow distribution through the 11 screens of TW-1 is paramount to understanding fate and transport of SWIFT Water in the PAS. Multiple methods have been employed at the SWIFTRC to understand flow distribution, including intrinsic and artificial tracers, borehole flowmeters, and water level analyses. SWIFT Water constituents are used as intrinsic tracers in comparison to background groundwater concentration since the start of recharge in May 2018. In October 2020, an artificial tracer test was conducted using sodium bromide. Analytical solute transport models that considered changes in recharge flow (including pumping and shutdown) were employed to simulate tracer concentration breakthrough data. In May 2019, an in-situ flowmeter test was conducted during recharge operations to directly assess flow distribution. Drawdown analysis at the conventional wells was also performed to assess changes in flow distribution over time. Results indicate that flow distribution changes due to both in-situ conditions and recharge operations. This presentation will give an overview of the project, discuss methods and results of aquifer characterization at the SWIFT Research Center, and share lessons learned for project scale up to 100MGD (378,500 m3/d).

6

Monitoring Of Water Quality Impact, And The Incidence Of Human Urolithiasis

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Purpose: To determine relationships between the domestic water and urinary stone formations, and whether the quality of this water influencing stone formation. Materials and Methods: This work was a prospective study that included 87 participants from Aga district in the southern part of Dakahlia governorate, recruited in this study from April 2018 to April 2019. Water samples collected from water sources that are used by these participants. Field measurements of physiochemical parameters were taken at the time of sampling and measured in situ. Other hydro-chemical parameters analyzed for the determination of their major and minor ions. An analytical framework developed to analyze water quality data using statistical analysis to show the significant differences at $p < 0.050$ in values of chemical constituents of samples.

Results: Water quality parameters of patients showed a good trend of increasing concentration with increasing TDS. The anions within the area varied within the order HCO3- Cl-SO42- and cations varied within the order Ca2+Na+Mg2+K+.

Conclusion: The domestic water with high mineral content carries the risk of high incidences of urinary stone formation.

7

Surface And Groundwater Dynamic Modeling Using Weap-Modflow Dynamic Model: A Case Of Middle Awash River Basin, Ethiopia

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The growing population, urbanization, industrialization, and the expansion of new irrigation schemes have increased the depletion of water resources. Climate change exacerbated the situation. Meeting the water supply needs of this fast-growing population requires a new generation tool that considers both demand and supply-side perspectives. This research tries to test and use the WEAP-MODFLOW model linked via an interface created by LinkKitchen for integrated water resources management in the Middle Awash sub-basin. The WEAP model was first configured to describe the surface water resources of the basin. The MODFLOW model was then used to represents the groundwater resources. Finally, the surface water-WEAP and the groundwater-MODFLOW models were linked with the help of an interface created using the LinkKitchen tool.

The coupled model was calibrated (2000-2005) and validated (2006-2010) with river discharge data from five hydrometric stations. A dynamically linked WEAP-MODFLOW model was used to forecast water resources' future trends through scenario development up to the year 2030. The scenario is structured according to ten scenarios to predict possible impacts on the region's water balance and allocation due to varied water demands. The model evaluates projected water demands and unmet water demands for four water sectors: domestic, industry, irrigation, and livestock. The model results show that the population growth will result in a significant shortage of water in 2030(469.56Mm3), resulting in maximum unmet water demands between January to March. The effects of climate change were analyzed under four climate scenarios: temperature, high precipitation, medium precipitation, and low precipitation scenarios. The climate scenario results indicated that huge water deficiency would occur after 2020 under low precipitation scenarios, while water deficiency will be reduced under medium and high precipitation scenarios. As clearly stated by the groundwater abstraction for irrigation scenario, groundwater can supplement surface water irrigate of large irrigation schemes with careful inspection not to affect the groundwater resource potential in the basin. Finally, the META scenario was analyzed to evaluate the combined effects of population growth, precipitation, and groundwater abstraction for irrigation. Water demands increase under the meta scenario, and the unmet water demand was maximum between January to March. The model result can be used as a basis for better water resource water management decision support tools in the basin.

9

Groundwater Contamination And Aquifer Vulnerability From Extreme Drought And Intensive Agricultural Practices In Thailand

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Groundwater levels are measured in many aquifers around the world to monitor the state of the groundwater system. This information is vital to ensure the sustainable use of groundwater resources now and in the future. In the past decades, the use of transfer function noise (TFN) models using impulse response functions has gained popularity to analyze the measured groundwater level time series. Traditionally, the groundwater response to precipitation and evaporation in this approach has been modelled as a linear relationship between these variables. Recent studies explored the application of soil-water balance models in the TFN models, to account for the non-linear processes occurring in the root zone. The results of these studies showed that the simulation of groundwater levels can be improved by the application of such non-linear approaches. While challenges remain, these promising results advocate for a more widespread adoption of non-linear TFN models.

In this presentation we will give an overview of the recent developments in non-linear TFN modeling of groundwater level time series. For this purpose, we modelled ten groundwater level time series measured around Europe (Fig. 1) using precipitation and potential evaporation from the E-OBS database as explanatory time series. The time series were modelled using the open-source software Pastas, which now also includes several non-linear approaches to compute groundwater recharge. Based on these example models we will discuss several opportunities and challenges in the application of non-linear TFN models. Challenges include the estimation of a larger number of model parameters, the modeling of the residuals, and the quantification of uncertainties. Opportunities include the possibility to estimate groundwater recharge and improved groundwater level simulations through a better representation of non-linear root zone processes. The presentation will conclude with possible directions for future research on non-linear TFN modeling.

10

Groundwater Contamination And Aquifer Vulnerability From Extreme Drought And Intensive Agricultural Practices In Thailand

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Thailand receives an average annual rainfall of 1,500 mm nation-wide and relies mainly on its surface water from the new 22 river basin system and groundwater sources. It has seen a marked increase in temperatures and change in rainfall patterns over the past decade, making the country more susceptible to extreme weather and more vulnerable to climate change. Owing to the rising water demand and threatening spatio-temporal changes in climatic patterns, Thailand is nowadays more susceptible to extreme weather and more vulnerable to climate change. Increasing population and urbanization also slowly degrade the quality of surface water. Infiltration of irrigation water in excess of available root zone storage from agricultural lands with degrading water quality may carry both natural and anthropogenic contaminants and naturally recharge to rivers, lakes, and groundwater, leading to progressive aquifer contamination of groundwater recharge by irrigation return flows, which is occurring in major intensive agricultural practices throughout the country. Aquifer vulnerability and risk assessment is a step towards identification, analysis, and classification of vulnerable and risk factors as well as its long-term implications, and thus reduction of the possibility of adverse consequences from extreme drought and agricultural practice, are the primary objective of this present study. An innovative approach for impact of extreme drought and irrigation return flows to groundwater contamination and aquifer vulnerability assessment in Suphanburi (belongs to Tha-Chin river basin) is initiated and applied by combining a novel aquifer vulnerability DRASTIC map with extreme drought intensity, pollution severity, and prioritization based on probability of occurrence of drought and pollution using TOPSIS ranking method. Seven hydro-geological characteristics of the aquifer of interest are overlaid to generate the potential vulnerability map. Comparison of spatial distribution of observed nitrate concentrations in groundwater obtained from ordinary Kriging analysis and aquifer vulnerability degree indicates satisfying model performance based on DRASTIC assessment. TOPSIS ranking methods is additionally applied to estimate the probability of occurrence of extreme drought and aquifer contamination. Aquifer risk map is thus later generated, indicating that around 15% of the total study area is categorized as drought-prone area with very high risk level which needs 1st priority immediate action to cope with this imminent challenge starting with an effective water allocation and management strategies to combat with water scarcity and relief vulnerability as well as aquifer recovery and restoration.

11

Erosion Of Silicate Grouting In Construction Pits, What Are The Effects On Groundwater?

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Injections of silicate grouting are widely used to create low permeable layers for reducing inflow of groundwater at construction sites, in areas with shallow groundwater tables. Silicate grouting forms a horizontal layer of silicate gel in an aquifer. Together with vertical soil-retaining walls and a small dewatering activity, it provides a dry excavation site. Silicate grouting is a technique that competes with large-scale dewatering activities and underwater concrete, because of its low cost and reduced drawdowns in the surrounding aquifer and therefor has a lower environmental impact compared to those often found with large-scale dewatering activities. Especially in urban areas, where construction pits are getting deeper, bigger and are being built in vicinity of buildings, monuments, infrastructure and subsurface energy systems, silicate gels are favourable.

After construction is finished, silicate gels remain in the subsurface and slowly erode into the ambient groundwater. Under normal conditions, the effect of erosion on the groundwater quality is not a topic of interest, but what happens when various ATES systems are located close to the silicate gel or when many construction pits are built closely together? This presentation focusses on the problem definition and reviews relevant processes that need to be considered.

12

An Analytical Methodology To Estimate The Changes In Groundwater Resources With Sea-Level Rise And Coastal Erosion In Strip-Island Unconfined Aquifers: Illustration With Savary Island, Canada

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Damien Marion (Université du Québec à Chicoutimi, Canada); Lamine Boumaiza (Université du Québec à Chicoutimi, Canada); Sandra Richard

Closed-form analytical solutions for assessing the consequences of climate change on fresh groundwater oceanic island lenses have been developed by hydrogeologists during the last decade. Based on existing equations, this study focuses on the case of strip oceanic islands when three combined effects of climate change are observed to affect the freshwater lens volume and its groundwater resource renewal: sea-level rise, erosion, and change in groundwater recharge rates. New equations, integrating these combined effects of climate change on fresh groundwater resources are provided. These equations are solved by a novel methodology based on a Dupuit-Forchheimer groundwater flow model that allows for determination of the hydrogeological parameters included in the equations. The approach is illustrated with the strip island of Savary, which is located along the Pacific coast of Canada in the province of British Columbia. This example illustrates, on the one hand, the volume depletion of the island freshwater lens and, on the other hand, the decrease of the renewal rate of groundwater. The proposed approach can be applied to any strip islands worldwide to assess the cumulative effects of sea-level rise and shore erosion on groundwater resources, depending on the predicted climate change scenarios. The results can then help decision-makers to anticipate the effects of climate change on the groundwater availability in strip oceanic islands and plan future groundwater use accordingly.

16

Multi-Purpose Integrated Water Management Actions On The Surface, Aiming A Climate Resilient Groundwater State In The Campine Basin, Belgium

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The groundwater of the 'Centraal Kempisch Systeem' is one of the main sources of freshwater in Flanders. Approximately 140 Mm³ groundwater is extracted each year from the mainly phreatic aquifer, of which 90 Mm³ is used for the production of drinking water (60 Mm³ by integrated water company Pidpa). In the last 4 dry years (2017-2020) the pressure on the aquifer has increased due to the grown demand for (ground)water. In order to avoid overstress on the aquifer, Pidpa has increased its efforts to implement actions that enhance rainwater infiltration and contribute to an improved surface water quality.

On its own lands, Pidpa maximises opportunities for direct and indirect infiltration by e.g. transforming coniferous forest to deciduous forest, creating/restoring heather landscape. Additional benefits of this policy are an increasing biodiversity and a more robust natural water retention. These actions are taken in close partnerships with nature management organisations, farmers, water boards,

Pidpa is also a sewage infrastructure operator for 41 cities and municipalities. By expanding and transforming sewage system, the surface water and groundwater quality is increased in the short and long term. Sewage system aspects are: constructing and managing sewage and rainwater systems including individual/small scale wastewater treatment plants and revaluing ditch systems for rainwater.

In view of maximising these efforts and to fully integrate state-of-the-art scientific insigths, Pidpa is a partner in the Interreg 2 Seas PROWATER project : "Build resilience against droughts (and water scarcity) by enhancing infiltration and water retention capacity of landscapes in regions of strategic importance for drinking water production". Within this project, the University of Antwerp developed a spatial prioritisation tool for Ecosystem-based Adaptation ('Waterkansenkaart'). Together with the appointed consultancy company, Pidpa is implementing this tool in the rainwater plans of the cities and municipalities of the province of Antwerp. Hereby optimizing the use of rainwater in (future) spatial and infrastructural planning while taking into account potential flood risks. Similarly, Pidpa takes part in the Flemish 'Water-Land-Schap' programme. Actions envisaged are the construction of weirs in water courses, level-driven drainage and adapted land management using buffer areas.

As a final point, Pidpa promotes broad public water awareness with the interactive 'Waterdoecentrum Hidrodoe – a world of water' . Hidrodoe was a SDG ambassador in 2019. By focussing on school programmes it sculpts waterproof future generations.

17

Understanding The Patterns And Processes Underlying Water Quality And Pollution Risk In West Africa Using Self-Organizing Maps Multivariate Analyses

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A good and fast interpretation of river systems quality is an imperative since river is a dynamic ecosystem, influenced along its course by various activities and also influencing, if any, downstream ecosystems. In this study self-organizing map (SOM) combined to multivariate analyses, and quantitative tests (Kruskal-Wallis and Kendall correlation) were used to explore the spatial-longitudinal and seasonal features of water quality along the Sô River Basin (SRB). Twenty-two water quality variables were measured in the surface layer at 12 different sampling sites during twenty-four months. Patterns of water quality variables of the sampling sites, could be classified into three water quality groups with an upstream-downstream

pollution gradient: 1) typical upstream sites with high dissolved oxygen and Secchi disk depth values, more suitable for the aquatic biota; 2) typical middle-lower sites characterized by high concentration of nitrogen and phosphorus compounds especially in wet seasons, reflecting high organic pollution; and 3) common downstream sites characterized by highest heavy metals and organic pollutions.

Even if no significant variation was observed between seasons, the SRB relatively suffered from high risks of heavy metal contamination and organic pollution in wet seasons. Although hydroclimatic processes affect the water quality, anthropogenic inputs of point and non-point sources were identified and discussed as major factor contributing to variation of water quality condition.

Keywords: Eutrophication, heavy metals, artificial neural network, multivariate analyses, West-Africa river systems.

19

Conjunctive Use Of Hydrochemistry And Sparse Groundwater Level Measurements To Characterize Groundwater Flow Of The Ungauged Kano Plains Aquifers In Western Kenya

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Understanding the groundwater flow regime is a key component in most groundwater studies. Traditional methods of measuring groundwater flow characteristics, which are also most explicit, involve making groundwater level maps from measured groundwater levels. The Kano Plains two aquifer system, borders Lake Victoria and like most others sub Saharan Africa, is largely ungauged, and such an approach is not applicable.

The objective of this study is to determine its groundwater flow characteristics which is a requirement for an ongoing groundwater-surface water (gw-sw) interaction study. Recently, groundwater hydrochemistry has been successfully used to determine groundwater types and to define the groundwater flow characteristics by delineating recharge zones in ungauged catchments.

In the Kano Plains, one-time water table measurements spanning a couple of decades are available. These cannot however be independently used to define the needed groundwater flow characteristics. In the top aquifer, some of these measurements have been taken from very close wells (<100 m apart). Further, a hydrochemical dataset of electrical conductivity (EC), alkalinity (CaCO3), Hardness (CaCo3), iron (Fe2+), manganese (Mn2+), Chloride (Cl-), fluoride (F-), Ammonia (NH4+), and nitrate (NO3-) exists. In this study, we use both datasets in a complementary way.

The sufficiently close one-time water table measurements have been clustered to create a basis for temporal comparability, and ultimately generate a groundwater level map through interpolation.

Preliminary results show the groundwater flow is generally towards Lake Victoria but it is not clear whether it discharges there. The map will be validated using a hydrochemical map (EC map) and the groundwater types inferred from the hydrochemical analysis. Using the groundwater types, the spatial connection between the groundwaters can be inferred and hence the groundwater flow regime.

Keywords: Kano Plains, Hydrochemistry, Groundwater types

20

Estimating Spatially Distributed Groundwater Recharge Using Wetspass-M In Equatorial Africa. The Case Of Kano Plains In Western Kenya

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The threat of groundwater mining has necessitated adequate characterization of groundwater recharge, a major input in groundwater modeling studies. Distributed recharge is recommended for large-scale groundwater studies. The purpose of this study is to estimate spatially distributed recharge for a groundwater flow model of the Kano Plains aquifer system, bordering Lake Victoria in Western Kenya, which has an area of 1250 m2. Recharge estimated from groundwater models or inverse groundwater problems is associated with a lot of uncertainty since the other model aspects like hydraulic characteristics and the level of aquifer heterogeneity are usually unknown. A unique solution would require incorporating flux measurements and this is not yet widely applied. Furthermore, such measurements are demanding both technically and economically.

In the current study, we use the fully distributed WetSpass-M, a second-generation model that was originally developed for a temperate humid climate. It is based on a water budget approach. The model has the advantage that it considers the other processes that control the rate of recharge. As a result, the accuracy of the WetSpass model is largely affected by the accuracy with which the other components i.e rainfall, interception, evapotranspiration and, surface runoff, are quantified. In WetSpass-M these components are calculated using analytical techniques, and climate, topography, and geological framework datasets are required. WetSpass-M has been successfully adapted for tropical climate studies but not yet in the Eastern Lake Victoria basin. Applying this data-intensive model in a data-sparse case study like the Kano Plains exacerbates the uncertainty problem. In the current study, a sensitivity analysis will be done to determine the influential parameters.

The parameter space is large, including ten parameters for each land use and ten parameters for each soil type, and the goal is to devise a method to select the most sensitive ones. Preliminary results show a strong influence on the land cover and soil patterns. The model results will be compared to baseflow separated from river discharge data.

Keywords: WetSpass-M, Kano Plains, Sensitivity analysis, Recharge, Baseflow

21

Gadolinium As Anthropogenic Environmental Tracer In Hard Rock Aquifers

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Gadolinium (Gd) is an element of the rare earth element (REE) group. It has been used as an environmental tracer in surface waters since 1996. The method is based on the determination of the enrichment of Gd in the environment compared to geological background values. Gd represents a group of contrast agents in magnetic resonance imaging (MRI), which have been emitted into surface waters since the 1980s. Consequently, an anthropogenic enrichment relates to the patients excreting these contrast agents shortly after ambulant medication in hospitals or at home. Sewage treatment is currently unable to hold back Gd from anthropogenic sources. Therefore, the Gd concentration in the receiving channel increases significantly, and it not only influences surface water but propagates into adjacent groundwater bodies due to its conservative behavior in the environment.

As research focuses on surface water and porous aquifers, however, the anthropogenic Gd-anomaly is a very stable environmental tracer.

The investigation of karst and sandstone aquifers with very different groundwater velocities (125 to ca. 3000 m/d in the karst; 50 m/a in the sandstone) support the usage of Gd as environmental tracer. The karst aquifer study site displays a connection between a river/ponor (input) and three springs (output), which show a Gd anomaly. The sampling of springs and brooks in the vicinity of the karst proved the Gd's anthropogenic origin. Similarly, the anthropogenic Gd-anomaly in the sandstone aquifer originates in a freshwater reservoir filled with river water, leading to the infiltration of the river waters Gd-signature into the aquifer. The anomaly is traced, the geological Gd background quantified, and surface water groundwater interaction evaluated at both sites.

As a result, Gd represents a conservative anthropogenic environmental tracer, that is not interacting with the aquifer matrices and stays stable over long periods (20 years). Furthermore, it is measured directly out of the sample and the Gd-anomaly is much higher in the surface waters (2-25 times) so that it can be measured even with high dilution in groundwater. The geogenic background is calculated for the study sites statistically from anthropogenically influenced and uninfluenced samples. All this taken into account, Gd is a powerful environmental tracer for surface water - groundwater interaction in hard rock aquifers, even for long periods.

23

The Key Role Of Rainfall Variability On The Estimation Of Groundwater Recharge Rates. Implications For Groundwater Management Plans

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Groundwater has been traditionally managed at spatio-temporal scales which not always have the resolution enough to represent local heterogeneities. The need of finding strategies to adapt water management plans to climate change scenarios requires a development of new approaches in the estimation of the water balance of an aquifer. This work quantifies, for the same time interval at various recharge areas within the aquifer, the differences on monthly recharge results, obtained from both daily and monthly rainfall data. The research was conducted in Doñana National Park, a semi-arid area in southern Spain that faces complex groundwater management conflicts. Although there is a high number of studies about the influence of the spatio-temporal scale in precipitation, those which link rainfall and recharge spatio-temporal scales are less common. The aims of this study were to investigate spatio-temporal rainfall variability by means of geoestatistical methods and to evaluate the effect of different spatio-temporal scales on the estimation of groundwater recharge. Daily precipitation data from 1975 to 2016 registered from 113 rainfall gauges were used to estimate spatio-temporal variogram models. Spatio-temporal kriging algorithm provided interpolated values at unsampled times and locations. Thereafter, the time series of groundwater recharge were obtained for different recharge zones of the Doñana aquifer showing homogeneous hydrogeological characteristics.

The results confirmed that monthly recharge values were quite different from daily ones. These disparities were found both spatially -related to soil properties, land uses and spatial heterogeneity of precipitation- and temporally -concerning the occurrence of precipitation events and the variation of the evapotranspiration rates. The main outcome obtained was that monthly recharge estimates were between 21 and 91% of the maximum registered rainfall and were overestimated in some areas. Besides, it was demonstrated that the use of daily recharge values instead of monthly values is more representative of the actual hydrometeorological conditions. Even if annual rainfall averages remain constant, the declining trend observed on the number of recharge days implies that extreme rainfall events are not quantitatively proportional to the recharge of the aquifer.

The findings of this work should be considered in future water plans to increase the efficiency of groundwater resources management. The importance of using finer spatio-temporal scales is even greater if we consider that climate change will cause an increase of the number of extreme rainfall events and evapotranspiration rates, and thus water availability must be better ensured.

24

Biotic And Abiotic Reductive Dechlorination Of Chloroethenes In The Transition Zone Between Aquifers And Fractured Bottom Aquitards

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Chloroethenes are chlorinated solvents denser than water, which are present in many contaminated sites, where they become very recalcitrant, especially in the transition zone from aquifers to the bottom aquitards and into the fine matrix of those aquitards. A major problem arises when remediation of aquifers adjacent to aquitards is conducted, because the back-diffusion of contaminants contaminates the aquifer again. The main objective of our research is to analyze the biogeochemical processes that take place in the transition zone and into the aquitard because these processes could be used for in-situ remediation using combined biostimulation and chemical reduction techniques.

The working hypothesis is that in aquitards, the presence of microorganisms, mineral electron donors and the existence of fairly constant physical-chemical conditions favor biotic and abiotic reductive dechlorination, especially in the matrix adjacent to fractures in the aquitard. In addition, the existence of heterogeneities, such as interstratified levels of coarser grain size and fractures, significantly contributes to the presence of microorganisms that promote chloroethenes biodegradation processes.

For this purpose, a field site contaminated with PCE was selected in an industrial area at Vilafant (Spain). To demonstrate the hypothesis two boreholes were drilled with continuous core recovering. Cores were detailed sampled in the transition zone and aquitard materials and the physicochemical parameters, VOC's concentrations and $\delta^{13}C$ of chloroethenes in the porewater were analyzed. In addition, sampling and analyses of groundwater in the aquitard were carried out.

The main findings of the study were: 1) the existence of sequential reductive dechlorination of PCE to form TCE and cDCE in the matrix adjacent to fractures especially in the presence of Dehalocooides genus, 2) the identification of biodegradation haloes of parental and metabolite compounds (i.e. PCE and TCE), which are useful indicators of the existence of biodegradation in fine materials, 3) the existence of abiotic degradation of PCE and TCE by Fe minerals such as green rust in the transition zones from the aquifer to the aquitard and from a continental to a marine aquitard and 4) that the existence of textural heterogeneities within the aquitard, especially when there are contrasts between coarse and fine grain size, favors microbial development because these zones become ecotones.

The process of reductive dechlorination resulting from the coupling of abiotic and biotic processes in the context of aquitards, though relatively slow and restricted due to a limited presence of electron donors, could be promoted by using combined remediation techniques.

25

Contribution Of Land Use/Land Cover And Climate Factors On Groundwater Recharge And Groundwater Drought In Temperate Context

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Drought is considered an essential natural hazard mainly caused by deficient precipitation for a large area and significant duration that affects both surface and groundwater resources. Natural meteorological variations (climate factor) and human-induced factors, such as land use/land cover (LULC) changes, may play a role in causing or intensifying drought. Drought can be propagated to groundwater recharge, groundwater discharge, and groundwater level.

From these hydrological variables, groundwater recharge forms the primary source for replenishing aquifers. Therefore, reliable groundwater recharge estimation is crucial for the sustainable management of groundwater resources and analyzing groundwater drought propagation in the aquifer.

This research aims to develop a methodology that enables differentiation in space and time between the effects of LULC change and climate factors on groundwater recharge estimation and groundwater drought. A water balance model was used to estimate spatially distributed groundwater recharge, and a variable threshold value method was implemented for groundwater drought analysis. This research is carried out in the Dijle river catchment and parts of the Demer and Zenne basins in central Belgium.

This study result shows that LULC change and the shift of meteorological variables from the long-term "normal" conditions decreased groundwater recharge on a spatial and temporal scale from 1990 to 2013. Besides, drought characteristics such as duration, number, and severity of groundwater drought events are also affected by LULC change and the shift of meteorological variables from the long-term "normal" conditions. The study also reveals the effect of each LULC class on groundwater recharge estimation.

Keywords: Groundwater Recharge, Groundwater drought, Land Use/Land Cover change, Climate factor, Variable threshold method, Dijle river.

26

Groundwater Drought Propagation In The Hydrological Cycle And Its Impact On River Discharge: A Case Study On Dijle River, Belgium

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Drought can be described as a temporary decrease in water availability over a significant period and affects both surface and groundwater resources. In case it concerns groundwater bodies, the term groundwater drought is used. Groundwater droughts propagate through the hydrological cycle and may impact rivers fed by groundwater.

This research investigates drought propagation in the hydrological cycle and assesses its impact on river discharge. Meteorological drought indices were used to analyze meteorological drought severity. Besides, a method for assessing groundwater drought and its propagation in the aquifer was developed and applied. Groundwater drought was analyzed using the variable threshold method. For groundwater drought analysis, time series of the three main groundwater variables, groundwater recharge (R), groundwater level (H), and groundwater discharge (Q), is simulated using a water balance model (WetSpass) in combination with a groundwater flow model (MODFLOW) with a high temporal resolution. Furthermore, meteorological drought and groundwater recharge drought were compared to investigate drought propagation in the hydrological cycle. This research is carried out in the Dijle river catchment and parts of the Demer and Zenne basins in central Belgium.

The results of this research show that droughts are attenuated in the groundwater system. The number and severity of drought events of groundwater discharge to the river were smaller than for groundwater recharge. However, the onset of both drought events occurred with a short delay, indicating a quick response of the groundwater system to hydrological stresses. Besides, drought propagation in the hydrological cycle indicated that not all meteorological droughts result in groundwater drought.

Keywords: Groundwater drought, Numerical modeling, Meteorological drought, Variable threshold method, Dijle river.

27

Characterization Of Emerging Contaminants In Upper And Middle Awash River Basin, Ethiopia

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The issue of emerging contaminants affecting freshwater quality has become a rising concern in the world. Though several pieces of research have been done on emerging contaminants, it has not yet received much attention in Africa. This study aims to develop a database on emerging contaminant status in a rapidly growing region in Ethiopia, namely the Awash River basin. Awash River Basin is a highly urbanized, industrialized, and populated river basin in the country. Eleven reconnaissance samples were collected from tap waters, stream waters, groundwater, and surface water reservoirs. Pesticides (Propiconazone, Trinexapac (plant growth regulator), 2, 4-D/2, 4-Dichlorophenoxyacetic acid, Azoxystrobin, Boscalid (Nicobifen), and Pyroxsulam) were detected in the samples from all sources. Caffeine, Atazanavir, and Carbamazepine were detected in the Awash River sample at Adama town. Pharmaceutical drugs (e.g. Cocaine, Ibuprofen, Amantadine,

Bisphenol S, Triclosan, and Acetaminophen (Paracetamol)) were detected in the tap water samples connected to both surface and groundwater supply sources. Personal care product (D6) was detected in Addis Ababa tap water connected to surface water reservoirs and in the Awash River sample. Artificial sweeteners (Acesulfame (Acesulfame-K), Sucralose, and Saccharin) are detected in a borehole and tap water samples connected with surface & groundwater supply. Additional samples will be collected from the river, groundwater and tap water to complete mapping the emerging contaminant status in the basin.

The spatial and temporal variation in the loading of emerging contaminants in water systems including drinking water resources is being mapped. Since the surface and groundwater systems are interconnected in the Awash River basin, and because the groundwater is the main potable water supply source, the exchange of emerging contaminants between the two systems has been investigated using isotopes (δ^2H and $\delta^{18}O$, Radon-222) and hydro-chemical integrated approach. It appears that groundwater connected to surface water recharge already shows signs of contamination by emerging contaminants.

28

Projections Of Groundwater Nitrate Concentrations – Climate Change Intensifies The Nitrate Problem

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Climate change must be taken into account when investigating future nitrate (NO3-) concentrations in groundwater. Considerable changes in climate are expected, which will have a major impact on the water resource and therefore on NO3-concentrations. In this study, forecasts of water balances are made on the basis of climate projections. The development of NO3- concentration in an aquifer in NW Germany is then simulated based on the expected climate scenarios RCP 2.6, RCP 4.5, and RCP 8.5.

Annual groundwater recharge for the three climate scenarios is calculated by using downscaled data of precipitation and temperature. In a lumped-parameter model, these recharge data are combined with expected fertilization rates and

NO3- concentrations are estimated using the determined NO3- degradation capacity of the aquifer. For better resolution, the study area is divided into 1000 x 1000 m cells. To further improve the model to a more realistic aquifer, each cell is assigned with a specific NO3- input rate and a NO3- degradation capacity. This allows a better reproduction of aquifer and land use heterogeneity in the model. In addition, land use in each individual cell is considered for the calculation of actual evapotranspiration rates (ET).

Results show major differences in the development of NO3- concentrations, using the different climate scenarios. Nitrate increases in the model using RCP 8.5 until the end of the 21st century by 89% compared to 2020. The best result, but still a strong increase in NO3- concentration by 50%, demonstrates the projection with RCP 4.5. Model results indicate that a 20% reduction in agricultural NO3- input reduces groundwater NO3- concentrations, but not sufficiently to reach compliance with the drinking water limit of 50 mg/L.

Projections with only 50% of aquifer NO3- degradation capacity illustrate the immense challenge of increasing NO3- concentrations, as degradation capacity will continue to decline and climate change will further increase NO3- concentrations due to decreasing water resources. Uniform measures for entire regions or countries are therefore not the strategy to solve the NO3- problem. Measures should depend on the characteristics of an aquifer and the expected climate change effects in the region.

29

Lowering Of Groundwater Levels And Their Effect On Water, Sanitation And Hygiene Services In The Savelugu District, Northern Region Of Ghana

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Of all the natural resources available to humankind, water holds a prominent place, particularly because of its importance for human livelihood. Savelugu district in northern Ghana is characterized by unpredictable rainfall patterns with periodic and perennial water shortages. The distance people travel to fetch water and the person-hours spent in search for water affect productivity, economic livelihood, and health and education benefits. Provision of potable water supply to these communities is expected to bring not only health, education benefits but also significant improvement in agricultural productivity/ economic empowerment, increase access to sanitation and hygiene practices. Static water levels (SWLs) of 19 wells in the study area were collected, analyzed and compared to the initial SWLs measured when the wells were immediately drilled and constructed. In addition, rainfall data were collected and analyzed.

The SWL data was subjected to paired samples T-test (with $\alpha = 0.05$). From the results, there was significant difference in the SWL immediately after drilling and construction ($\mu = 12.15$, $\sigma = 7.50$) and SWL after at least 10 years ($\mu = 17.81$, $\sigma = 10.29$); $t(18) = -3.7$, $P = 0.002$. Lowered groundwater levels were recorded in all wells measured. This can lead to drying up of some of the wells whose difference between the current SWL and well depth is close. The lowering of SWLs could be attributed to reducing tree-cover, the harsh harmattan and rampant vegetation removal, which contributes to desertification, increase surface runoffs, less percolation to recharge the underground waters after rainfall in the area.

There must be strong advocacy, development and implementation of IWRM plans to help address the problem of inadequate WASH in the study area, and contribute to achieving the SDG 6 . There is the need to replace existing wells in the area that showed greater potential of drying up with time as revealed by the study findings.

30

Borehole yield estimation from electrical resistivity measurements – a case study of garu

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Electrical resistivity survey has proven to be an effective tool for groundwater exploration and has been widely embraced to help reduce the drilling of unsuccessful wells. Currently, information from electrical resistivity survey is often used in locating points for drilling, but it does not give indication of the yield of the borehole. The lack of this information therefore sometimes results in the drilling of dry and marginal wells. This study therefore looks at the possibility of using resistivity data, which is readily available from electrical resistivity surveys for groundwater exploration, for estimating the yield of yet to be drilled borehole. The study was limited to the Garu Tempane and Bawku West Districts.

Secondary data on Vertical Electrical Sounding (VES) and drill logs for 49 boreholes in the selected districts were used. The thicknesses, apparent resistivities, longitudinal conductance and transverse resistance of the various subsurface layers of the boreholes were determined from drill logs and VES data. Correlations between borehole yields and the third layer apparent resistivity, longitudinal conductance and transverse resistance were then investigated to develop regression models for estimation of the borehole yields.

The results showed that the third layer is fractured and contributes significantly to borehole yields in the area; hence the fractured subsurface layer is of primary interest to be considered in groundwater exploration and estimating potential borehole yield from VES data. The results obtained further indicated that apparent resistivity, longitudinal conductance and transverse resistance had good exponential and positive linear relationships with borehole yield.

31

Supporting the sustainable development of Brussels by modelling and visualizing its subsoil.

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With a surface area of 161.38 km², the Brussels-Capital Region is the largest urban area in Belgium with a growing population of more than 1.2 million inhabitants and a high population density exceeding 7582 inhabitants/km² (2020 data). These demographic and urban pressures in a context of climatic emergency and energy transition encourage the Brussels-Capital Region to lead a proactive and rational subsoil management to:

- ensure a sustainable use of the surface and groundwater resources sustainability;
- support the development of a qualitative geothermal energy sector for building's heating and cooling;
- promote a better environmental integration for buildings and urban infrastructures;
- limit the human activities' environmental impacts and anticipate those related to climate change.

To meet these 21st century challenges, the Brussels agency for environment and energy, called Bruxelles Environnement/ Leefmilieu Brussels (BE/LB), has developed since 2012 a series of numerical models in collaboration with its partners:

- a geological model called Brustrati3D, providing a three-dimensional mapping of the geological layers constituting the Brussels subsoil, from the topographic surface to the top of the Cambrian basement;
- two finite element hydrogeological models, called respectively Brussels Phreatic System Model and Hydroland, allowing to draw up a series of piezometric maps, simulate the quantitative and qualitative pressures exerted on groundwater and constituting useful decision-making tools for supporting the Brussels environmental policies.

In order to ensure a high valorization of these results, BE-LB has released in 2020 a brand new "all-in-one" geoscientific web-application called BrugeoTool, allowing the geology, hydrogeology and geothermal potentialities exploration on the Brussels territory through 1D, 2D and 3D visualization tools. BrugeoTool also supports project managers (architects, facility managers) regarding the feasibility analysis and the predesign of a geothermal system. Finally, BrugeoTool is intended as an educational tool for students or for non-technical profiles interested in understanding the issues related to the georesource exploitations and the subsoil management in Brussels.

This contribution will present an overview regarding the data processing steps, from the development of numerical models to the data valorization within BrugeoTool, including the necessary post-processing steps.

32

Development Of A Water Balance Model For A Massive Limestone Karst Aquifer In The Eastern Rhenish Slate Mountains (North Rhine-Westphalia, Germany)

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The karst aquifer of Warstein, located in the north-eastern part of the Rhenish Slate Mountains, is of regional importance since it is extensively used for local drinking water production and by the limestone quarrying industry. The aquifer consists predominantly of karstified massive limestone. It is surrounded by low-permeable rocks and thus represents an isolated structure.

Previous studies showed a significant excess in discharge from the aquifer at its northern, downstream boundary which cannot be accounted for by groundwater recharge and streams entering the catchment area at its southern, upstream border. Well known from wells and stream sections is the appearance of mineralized waters of >600 µS/cm specific conductance from greater depth. The origin of this water is unknown and different opinions exist about its water type. Possible areas of origin of the so called "extraneous water" are the Münsterland Chalk Basin to the north and a further isolated karst aquifer to the south.

All studies regarding the amount and origin of the extraneous water depend on accurate discharge measurements. The already existing water balance models for the region use discharge measurements which were carried out at 14-day intervals over the course of a year at the beginning of the 1990s. Since then, no comprehensive discharge measurements were performed.

Thus, the aim of this study is to perform continuous discharge measurements over the course of two years with high temporal resolution and to develop a current water balance model to quantify the amount of extraneous water.

In 2019 a total of 11 gauging stations were installed along streams which measure the water level at a 15-minute interval. Monthly discharge measurements are conducted to obtain a water level-discharge-calibration and to compute continuous discharge data. Measurement points upstream and downstream of the karst area allow detecting possible inflows or outflows while the streams traverse the karst aquifer. Conductivity measurements at selected stream sections record the dynamic of effluence from deeper karst water over the year.

Preliminary results show an increase of discharge from approx. 20 to 40 Mio. m^3 per year for the water year 2020. This difference between inflow and outflow of the karst system is higher than values given by the mentioned previous studies. Further measurements are performed regarding this finding.

Besides the water balance model, further investigations, for instance regarding the local groundwater hydrochemistry and isotopes, are planned to allow a sound statement regarding the extraneous water in Warstein.

33

Groundwater Recharge Estimation In Eastern Bolivia Using Remotely-Sensed Hydrometeorological Variables And Its Correlation With Deforestation And Fire

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Water scarcity is a common issue in the municipality of San José de Chiquitos, located in eastern Bolivia. The surface water resources are insufficient to supply the inhabitants yearlong, and the situation is aggravated by populational growth, climate and land use changes. Consequently, the municipality needs to exploit groundwater to expand the water provisions. This context demands a better understanding of the aquifers and their recharge to manage them more sustainably. However, the lack of consistent ground hydrometeorological data entails the use of alternative methodologies. Therefore, this work uses remotely sensed data to (i) estimate groundwater recharge components, (ii) detect areas burned in bushfires, and (iii) analyze land cover change. The use of an open-source cloud-computing platform (Google Earth Engine) allowed straightforward access and processing of data for a 20-year period (2000-2019). Direct vertical groundwater recharge (GWR) was calculated from the FLDAS and TERRACLIMATE datasets by using a simplified version of the water balance equation, which considers GWR as the difference between precipitation, evapotranspiration and runoff. These datasets are models that combine data from various satellite missions and use algorithms to model a range of hydrometeorological variables.

Precipitation was validated against rain gauge measurements provided by the Bolivian Meteorological Service (SENAMHI), resulting in a coefficient of determination (R^2) of 0.62 for FLDAS and 0.48 for TERRACLIMATE. The recharge estimates were validated against results obtained with WetSpa (a GIS-based spatially distributed watershed model). The results indicate a decreasing trend in GWR according to both datasets. The average estimate is of 144 mm/year and 170 mm/year for the 2000-2009 period, and of 110 mm/year and 133 mm/year for the 2010-2019 period, according to FLDAS and TERRACLIMATE, respectively. Nonetheless, the preferential recharge areas differ between the two datasets, suggesting that the spatial resolution (5-10 km pixels) hampers the accurate analysis of local recharge distribution. The analysis of burned area with the MODIS-based MCD64A1v6 NASA's product (500 m resolution) shows a homogeneous occurrence of bushfires in the considered period, with an exception for the year 2008, in which 25% of the study area has burned.

A strong decrease in the naturally vegetated area, from 88% in 2005 to 61% in 2019, is shown by land cover maps obtained by supervised classification of Sentinel 2 imagery. Overall, the results suggest a correlation between decreasing GWR and natural vegetation, but there seems to be no correlation between GWR and bushfires within the study area.

34

Developing A Simple Method For The Evaluation Of Redox Conditions In Superficial Groundwater At Pan Eu Scale

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Denitrification potential is an important information to know for adequate and efficient management and assessment of groundwater vulnerability, chemical status and the fate and migration of different types of contaminants. This parameter is highly variable in space and time.

Different methods exist to evaluate the denitrification potential in groundwater such as i) geological – determined by sediment/rock chemistry i.e. the presence of electron-donor minerals, ii) isotopic using $\delta^{18}NO_3$ and $\delta^{15}NO_3$ tracers, iii) hydrochemical indicators, based on dissolved redox sensitive ions and gases (Eh, O_2, NO_3, NO_2, Fe, Mn, SO_4, CH_4, H_2S or N_2). The methods can be combined and results refined by geochemical modelling.

At the large-scale and using data acquired within various groundwater monitoring networks and for different purposes, data quality and quantity may not be sufficient to allow a strict determination of the presence of denitrification. In the GEOERA HOVER project, the determination of the redox transition from nitrate containing water to iron-reduced water with no nitrate was preferred to a strict delineation of denitrification status due to the need for a pan EU overview of this information using data available in various countries. There was also a need for a simplified approach to map reduction potential in a common way without the need for further extensive data collection.

Based on the existing data in each of the participating countries and previous experiences in mapping nitrate attenuation patterns a classification tree was proposed using a minimum number of parameters. The classification tree is based on nitrate concentration, presence at defined concentrations of Mn, Fe, O2 and NH4. After being tested in some regional scale case studies, the method was applied at national scale in France, Denmark, UK, Ireland, Latvia, Spain, Cyprus and in catchments in the Netherland, Croatia/Slovenia.

After distinguishing between groundwater containing nitrate and groundwater without nitrate, the first step of the method allows for the classification of groundwater with iron or without iron. Water having iron at low concentration or iron but no nitrate is falling into a "mixed" category. The method can either end here or if needed continue in a second step for mixed samples. The second step considers NH4 and O2 concentrations.

After applying the methodology to individual sampling points the results were aggregated to groundwater bodies. Mapping challenges were considering depth and spatial variability.

35

Why there is no evidence saltwater intrusion in the Doñana aquifer despite the groundwater extractions?

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Numerous studies have been carried out on the Almonte-Marismas (Southwestern Spain) aquifer, over which Doñana Natural Space is situated. This heterogeneous detrital aquifer is one of the main concerns of conservationists and ecologists due to the valuable ecological systems that it supports and the overexploitation that it suffers. A significant change in the water table levels could mean a potential disaster for the groundwater dependant ecosystems in this UNESCO Heritage Site. The localized and intense groundwater extractions since 1970 for urban water supply, tourist resorts and irrigation crops, have caused a drop of the piezometric levels in some parts of the Natural Space. Concerning this fact, some studies have warned about the existence of cone depressions in the deepest layers of the aquifer, what entails the possible existence of saltwater intrusion in the near future.

The main objective of this study is to clarify why extending up to the present time, there is no evidence of saltwater intrusion in the Almonte-Marismas aquifer. For this purpose, SUTRA 3.0 code (Voss et al., 2002) has been used to simulate the groundwater flow and saltwater intrusion with a simplified 2D vertical cross-section. This will allow to represent the main flux components in the aquifer. It is important to note that modeling the interaction between saltwater and freshwater remains a challenge due to the heterogeneity of aquifers and the sensitivity to space and time discretization.

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36

Imaging hydraulic conductivity in near-surface aquifers by cross-borehole Induced Polarization

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Precise knowledge about the distribution of hydraulic conductivity (K) in an aquifer is essential for groundwater flow modeling, assessment of contaminant transport and other water resource management issues. In addition to classical hydrological tests, geophysical methods, especially 'Induced Polarization' (IP), are gaining ground in their ability of imaging K heterogeneities. Based on a solid foundation of petrophysical relations between certain IP parameters and K derived from laboratory experiments, this method is capable of retrieving detailed information about the hydraulic conductivity distribution. In our new approach, those empirical laws are directly incorporated into the inversion procedure of IP data, which yields images of K that can have a high resolution (depending on the measurement setup, e.g. electrode spacing) and quantitative accuracy.

While IP measurements are typically carried out from the surface only, cross-borehole setups enhance the sensitivity to heterogeneities in deeper regions and thus improve the resulting K images. This approach is employed within a modelling study, including the forward modelling of IP data from a given K distribution and the subsequent IP inversion. As input datasets, the porosity and hydraulic conductivity distribution of three sedimentary aquifer analogs - namely Herten, Descalvado and Bolstern - are used. In comparison to purely synthetic models, they provide real-world datasets, that are particularly challenging for the inversion due to the complex sedimentary structures and the contrast of decimeter-scale. The IP forward response was computed using a setup combining surface and borehole electrodes with 0.25m spacing. The K image resulting from the IP inversion correctly shows the main features of the analog and the quantitative estimates of K correspond well with the real data. However, some small-scale structures cannot be reconstructed due to the limited resolution resulting from the given electrode spacing.

Since the same petrophysical assumptions are made within the forward modelling and the inversion procedure, their accuracy cannot be tested directly by this modelling study. Thus, the approach was also applied to existing field data that include borehole IP logs as well as measurements of hydraulic properties. We find that the IP-derived K estimates agree very well with the K values gained from grain size analyses and slug tests. In the future, new field experiments are planned to apply this methodology in practice and to compare the results with K images gained from pumping tests (e.g. applying hydraulic tomography) conducted at the same site.

37

Complementarity Of D-Insar And Levelling In Monitoring Ground Deformation Related To The Dewatering Of Urban Construction Sites. A Case Study Of Glòries Square, Barcelona

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In dense urban environments, the construction of underground infrastructures below the water table is becoming more and more frequent. These works usually require the dewatering of the construction site, which entails risks ranging from small ground settlements –which may or may not be differential depending on the geological context– to sinkholes and collapses. Thus, a rigorous monitoring of construction civil works in urban areas is of an increasing importance. Most of the available monitoring techniques are point-like and, consequently, their capacity to describe the deformation in space is limited by the

dilemma of prioritising the spatial density of measurements over the extent of the monitored area or vice versa. In contrast, differential interferometric synthetic aperture radar (D-InSAR) offers the capacity to cover larger areas with a greater spatial density of measurements and a similar or higher frequency of data acquisition. Therefore, an integrated use of levelling and D-InSAR benefits from the complementarity of their strengths, namely, the high accuracy and reliability of levelling and the broad extent and high spatial density of D-InSAR data.

The construction works of a road tunnel beneath Glòries Square in Barcelona, in which D-InSAR is included in the continuous monitoring of the works performed by the Construction Management Office, notably regarding the dewatering of the construction site, illustrates the advantages of a combined use of levelling and D-InSAR.

The study is based mainly on Sentinel-1A SAR data processed following a persistent scatterer interferometry procedure. The spatial distribution of the deformation and its temporal evolution are analysed with detailed hydrogeological and piezometric data. The magnitude of deformation is discussed using levelling data and an analytical estimation based on the hydromechanical parameters of the ground obtained from a pre-existing hydrogeological numerical model and pumping tests.

The D-InSAR results are shown to be essential for identifying the origin of ground deformation and the constraints on its spread. Such observations at the construction site and district (~2 km radius) scales with sub-centimetric deformation are precious contributions of D-InSAR data, whereas levelling offers a more accurate quantification of the deformation –although this remains an open issue to be further investigated. In conclusion, the integration of D-InSAR and levelling improves the monitoring of ground deformation phenomena and enables a more complete understanding of them.

38

Climate-Change And Land Use Adverse Impacts On Vulnerability And Availability Of Groundwater

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Groundwater is an important water source for irrigation, industry, farming, and human consumption. This work's goal was to assess the vulnerability by weighted indices of an aquifer used in agriculture in Chihuahua, Mexico, in current scenarios, as well as immediate and medium future. It was used the DRASTIC model and its modifications to assess vulnerability indices on the aquifer.

Furthermore, scenarios of vulnerability indices were projected to the closest future (2015-2039) and the medium future (2025-2069), through climate change projections, RCP 4.5 and 8.5. Vulnerability maps were validated using water-quality variables; indicating that the southeast and central zones of the aquifer are the most sensitive to pollution of groundwater. Indices with the highest precision of vulnerable zones were those which include land use analysis, DRASTICL and DRSTIL.

The results obtained by the application of climate change scenarios show that the recharge area of the aquifer tend to decrease. Thus, replenishment from recharge to the aquifer remains a deficit problem which has the potential to increase into the future. It is necessary that the general population, water purveyors, agricultural producers, as well as state and federal agencies that oversee water management are making decisions that are informed and aware of these conditions, trends, and vulnerabilities.

39

Transfer Of Tio2 And Al2O3 Nanoparticles Through Saturated Carbonate And Silicate Matrix: Column Experiment And Simulation In Hydrus-1D

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The increasing use of engineered nanoparticles (NP) leads to their release in the environment, i.e. in aquifers. However, their transport through aquifers remains unclear up until now. Nanoparticle's surface charge is sensitive to pH and ionic strength conditions. Consequently, nano-sized TiO2 (nTiO2) and Al2O3 (nAl2O3) may behave differently in silicate and carbonate aquifers. To assess the vulnerability of these types of aquifers to engineered nanoparticles, a transfer experiment was set up and simulated in Hydrus 1D.

The transfer of NP in MQ (150ppm, pH 3.1) was tested through 3 different porous matrixes: glass beads, carbonate and silicate rocks grinded to sand fraction (>500µm). Sands and glass beads were packed in glass columns of 12 cm lengths, saturated with water before the injection of 30ml of NP suspension at 4ml/min. Very low rates were recovered at the outcome of the columns: for nTiO2, recovery rates were 0.25% in glass, 0.006% in carbonates, 0% in silicates; for nAl2O3, those rates were respectively 1.1%, 2% and 0.7%.

Active retention mechanisms were identified by comparing NP aggregates sizes with matrix pore sizes (constriction) and isoelectric points of the minerals and NP (adsorption). Applying the DLVO theory explained the lower recovery rates observed one the one hand for nTiO2 compared to nAl2O3, and on the other hand in "pure" silicate of glass beads compared to carbonate sands. Heterogeneities in natural silicates generated a greater attraction between nanoparticles and sand grains. Detachment is observed when the shear force of the water increases in the column, i.e. when the flow rate increases.

Different retention mechanisms were tested by simulating the transfer of both types of NP through the glass bead columns. The best fit was obtained when Langmuir adsorption mechanisms were simulated. Detachment processes could also be simulated by introducing a detachment coefficient in the model. Since no retention curve was measured in the glass bead columns and as the number of data is limite, data is lacking to validate simulations. However other conditions were also simulated: constant injections at different concentrations to analyse the evolution of the pollution front through a soil profile. The time to cover all adsorption sites was directly proportional to the concentration of the injected solution. This study enlighten that tested NP are strongly sorbed in porous matrix but that condition changes can impact the evolution of the pollution front through a soil profile.

40

Tackling illegal groundwater drilling and abstractions: The IMPEL approach

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Sharing knowledge and good practices on how to manage groundwater drilling and abstractions at an international level is beneficial for good groundwater management and -governance. The European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL) is an international non-profit association of the environmental authorities of the European Union Member States. The Network's objective is to create the necessary impetus in the European Union to make progress on ensuring a more effective application of environmental legislation. Within this network a 2 year project titled 'Tackling illegal groundwater drilling and abstractions (TIGDA)' is launched in April 2021.

Groundwater is and remains a valuable resource for the environment and different human activities. Environmental and anthropogenic pressures on this resource are increasing over time. Water reuse, buffering and infiltration are some of the possible measures to diminish our requirement for fresh groundwater as well as replenish its storage.

Nonetheless groundwater drilling and abstraction will remain necessary for different purposes.

As a tool for reaching a good quantitative and qualitative state of groundwater bodies, a prior authorisation for abstraction and impoundment should be in place in the member states (WFD). The directive does not include any specific requirements on how to successfully enforce these authorisations or other possible impacts they might have on groundwater quantity or quality. This project therefore specifically aims on groundwater drilling and abstractions.

As the different aquifers and aquitards in the member states are drilled (through) it is useful for member states to share knowledge or have guidance on:

1. Specific legislation and requirements in place for groundwater protection
2. Specific methods in use for enforcement of this legislation

Proper regulation and enforcement of groundwater drilling and abstractions are important for reaching a good quantitative and qualitative status of groundwater bodies. Optimal tackling of illegal groundwater drilling & abstraction is therefore an essential instrument. Important to note that by 'illegal' in this sense non-permitted installations as well as permitted but non-compliant installations are meant.

The aim of this project is to collect data from the member states regarding the two topics mentioned above. This will be done via a questionnaire and several online project group meetings. Technical site visits with the project group are planned for the second year. Subsequent drafting of guidance documents on enforceable groundwater regulation and enforcement methods are the main goals of the project after 2 years.

41

Monitoring And Distribution Assessment Of Contaminants Of Emerging Concern And Regulated Pollutants In Surface Water And Groundwater Of A Highly Anthropized River Basin (Southern Spain)

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Contaminants of emerging concern (CECs) have aroused an increasing concern due to their ubiquitous presence in the environment and harmful potential. Both CECs (e.g., pharmaceuticals and personal care products) and regulated organic pollutants pose a serious threat to water quality and their presence and spatial distribution are complicated to address as it can derive from several factors: distribution of point and diffuse sources, environmental conditions, hydrogeological features of the region and inherent properties of the considered contaminants.

Our research is focused on the distribution of a wide range of regulated and non-regulated organic contaminants in surface and groundwater in four anthropized water systems in southern Spain: the Guadalhorce River basin, the Vega de Granada, The Guadiaro River basin and the Fuente de Piedra Lagoon basin. Investigated contaminant groups are: polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), pesticides, personal care products (PCPs), pharmaceutical active compounds (PhACs) and organophosphate esters (OPEs) flame retardants and plasticizers. This is the first time an analysis and evaluation of such a great number of organic pollutants is performed in these areas. In the Guadalhorce River basin, 63 out of 185 target pollutants were detected.

An attempt to understand the importance of different factors governing the distribution of some of the most frequently found pollutants has been made. Contrast in contaminants occurrence is potentially attributed to the way pollutants are released into the environment as well as their physico-chemical properties. In general, hydrophobic CECs (i.e., PCPs and OPEs) presented the highest frequency of detection and concentrations, which can be a consequence of several factors: (1) a higher retardation factor of hydrophobic compounds which results in a widespread distribution.

In contrast, hydrophilic contaminants are more easily transported by water flows towards the lower basin and potentially accumulate as driven by groundwater flow and because of low renewal rates in the detrital aquifers caused by re-pumping and irrigation return flows in agricultural lands; (2) high consumption of hydrophobic CECs studied in this research (PCPs and OPEs); (3) use of biosolids (reclaimed sewer sludge) as fertilizer since these are a potential diffuse source of organic pollutants, especially hydrophobic compounds.

Results highlight the need to better define the potential risk of CECs in water resources as well as the great impact of untreated wastewater discharges.

43

Defining Protection Zones Around Closed And Open Shallow Geothermal Installations In Urban Aquifers

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There is a growing interest in using subsoil and groundwater as a source of geothermal energy to meet heating and cooling demands. The development of these shallow geothermal systems, combined with the presence of multiple urban heat sources leads to thermal stress on urban aquifers and potentially to thermal interference between neighboring geothermal installations, resulting in a deterioration of their efficiency. In France, the mining code requires the definition of a protection zone around shallow geothermal installations extracting more than 500 kW or 80 m3/h.

This protection zone confers an exclusive exploitation right in the area precisely to prevent a geothermal project from being disrupted by other/future installations. Until now, the application of this legal requirement relied on empirical concepts that do not always allow for (1) an equitable distribution of the geothermal potential and for (2) the durability of a project's efficiency. Hence, we developed a novel methodological framework based on the site-specific hydrogeological conditions, defining protection zones around closed and open shallow geothermal installations: small enough to maximize the distribution of the resource, and large enough to protect the installation.

The first step of the methodology consists of determining the appropriate thermal amplitude to maintain the performance of the installation over the duration of the requested license. The second step is mapping the thermal reach of the installation. Analytical and numerical models are used for this purpose. This is done by probabilistic reverse flow-heat transport analysis. The third step is calculating and mapping the maximum acceptable power level for the operation of the installation.

The approach is illustrated in the context of a geothermal project located in Lyon (France), where groundwater flow is influenced by underground structures, and where several geothermal installations are located. The proposed methodology can be applied at different scales, (1) locally to protect the efficiency of a project, and (2) regionally to manage thermal use of urban aquifers by multiple installations.

45

In-Situ Characterization Of Thermal Plume Around Ghe With Groundwater Flows

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Although vertical Ground Heat Exchangers (GHE) is a booming technology for both cooling and heating buildings, several improvements could still be proposed in the dimensioning of such systems. Nowadays, most of the dimensioning methods consider only radial conductive heat flux around GHE using a homogeneous ground thermal conductivity determined from thermal response tests (TRT) or tables. Impacts of groundwater flows on the heat refurbishment around GHE are generally neglected.

Many numerical or analytical studies have investigated and quantified the positive impact of groundwater flows on the efficiency of GHE. However, those results are rarely compared with in-situ temperature measurements around GHE. Such experimental data requires (i) the installation of temperature sensors in the ground around GHE and (ii) the characterization of groundwater flows.

In this work, an experimental platform composed of 4 vertical GHE drilled at depths of 85 m has been exploited. The 4 vertical GHE are located at the 4 corners of a 4-m square and cross a succession of horizontal geological layers. The study focuses on the heat transfers in a 30-m thick sand unconfined aquifer layer, whose 17 m are saturated. Each GHE is equipped with both PT100 (installed at the extremities of the unconfined aquifer and just below the groundwater table level) and optical fibres (OF) along the full borehole. When one GHE is activated, PT100 and OF in the surrounding GHE provide in-situ temperature measurements characterizing heat transfers. In addition, a piezometer has been drilled in this unit and allows the characterization of groundwater flows with advanced hydrogeological tests (Brouyère et al., 2008).

An analytical solution (Erol et al., 2015) considering advective and conductive heat transfers around GHE for intermittent energy demands is used to interpret the temperature and groundwater flows measurements. The contribution provides new insights into the role played by groundwater flows into the refurbishment of the ground heat reservoir around GHE, and its impact on the long-term efficiency of GHE systems. Brouyère S. et al. (2008) A new tracer technique for monitoring groundwater fluxes: The Finite Volume Point Dilution Method. Journal of contaminant hydrology, 95(3-4). Erol S. et al. (2015) Analytical solution of discontinuous heat extraction for sustainability and recovery aspects of borehole heat exchangers. International journal of thermal sciences, 88.

47

Geochemical And Isotopic Study Of Groundwaters In The Mitidja Coastal Plain, North Central Algeria

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The deterioration of the environment and more specifically the aquatic medium has nowadays become progressively an issue of great concern worldwide. In the current context of climate change and demographic / economic growth, Algeria is subjected to an increasing stress on water. Due to its relative poorness in surface water harvesting capabilities, the relatively easier exploitation of aquifers became the preferred source for water allocation both to population and to agriculture/ industry in Algeria. Mitidja plain that is located south of the capital city Algiers, is the country's most expanded sublittoral Mediterranean plain.It occurs in the central-north of Algeria, it is oriented East-West and extends over a length of 80 km and a width of 10-20 km.

It covers a surface-area of 1450 km2 and comprises aquifers that are the main source of drinking water for the whole north-central part of the country. The intensification of industrial and agricultural activities combined with demographic growth and urbanization of the plain, resulted in a clear increase in demand for water accompanied by significant problems of degradation of the groundwater quality. The major ion hydrochemistry and environmental isotope composition (18O, 2H,3H) of Mitidja alluvial groundwaters were investigated to identify the sources and the processes that affect groundwater composition, water origin, and timing of recharge.

Groundwater is classified into 3 water types: Ca SO4 Cl (75.6%), HCO3 Ca (17.09 %) and remaining Na Cl (7.31%). The interpretation of the hydro-geochemical data suggests that groundwater composition is largely controlled by the water rock interactions, particularly the dissolution of evaporate minerals (Halite,Gypsum/Anhydrite) and ion exchange processes. Elevated content of nitrates indicates that agricultural activities are probably the most significant anthropogenic sources of nitrogen contamination.

The concentrations of Fe, Mn, Pb, and Cd in most samples were found higher than the prescribed limits defined by the World Health Organization (WHO). The application of the Principal Component Analysis (PCA) for trace metals identified two sources of pollution- natural and anthropogenic sources. Information inferred from Oxygen-18 and deuterium ratios reflected the existence of recharge through non-evaporated modern rainfall mostly originating from Mediterranean air masses. Measurable tritium concentrations in groundwaters allowed qualitative identification of the present-day component. It is confirmed thus that this component of the alluvial aquifer is supplied by recent rainfall taking place during the rainy season all over the Mitidja plain.

48

Impact On Individual Primary Energy Consumption Due To Subsurface Interactions Between Ates Systems

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Aquifer Thermal Energy Storage (ATES) systems contribute to reducing fossil energy consumption by providing sustainable space heating and cooling for buildings by seasonal storage of heat. ATES is important for the energy transition in many urban areas in North America, Europe and Asia. Despite the modest current ATES adoption level of about 0.2% of all buildings in the Netherlands, ATES subsurface space use has already grown to congestion levels in many Dutch urban areas. This problem is to a large extent caused by the current planning and permitting approach, which uses too spacious safety margins between wells and a 2D rather than 3D perspective.

As a result, the current methods for permitting and planning of ATES do not lead to optimal use of available subsurface space, and, therefore, prevent realization of the expected contribution of the reduction of greenhouse gas (GHG) emissions by ATES. Previous research has already showed that reducing the distance between ATES wells provides better aquifer utilisation and considerably more GHG emissions savings for the area as a whole, due to larger amount of buildings being able to adopt ATES. Up till now it is not yet known to what extent dense well placement policies affect individual performance of ATES wells.

In this research a groundwater model simulating the subsurface interactions of ATES wells is coupled to detailed building climate installation models of many buildings in an area which make use of the ATES wells in the groundwater model. The model keeps track of the energy use of all the facilities in the building climate installations. By simulating different well placement scenario's we compared the energy use of individual ATES systems under dense and spacious well placement.

The results confirm earlier research: denser well placement results in higher ATES adoption, thus more GHG emission savings. The effect on the individual energy use is shown to be limited. The electricity use is not sensitive to mutual interactions, and may be a couple of % more or less under dense setting, compared to spacious, also when applying very dense setting with aquifer utilisation of over 80%. Gas use is the same under 80% utilisation, but at denser setting gas use may increase significantly. This study shows that the current placement policies, generally leading to utilisation levels of about 25-40%, can and must be changed to allow for denser setting, in order to increase ATES adoption and reduce GHG emission.

49

Monitoring Salinity Changes During Tidal Cycles Using Electrical Resistivity Tomography: A Feasibility Study

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Coastal aquifers become increasingly important to ensure potable water for the growing population. A good knowledge of the complex interaction between salt and freshwater is thus imperative. This system comprises two main components, seawater intrusion (SI) in the hinterland and fresh submarine groundwater discharge (FSGD) offshore. In the scope of studying variations of the saline interface on the Belgian coast, we executed a study to assess the feasibility of electrical resistivity tomography (ERT) to monitor the salinity of the intertidal zone during tidal cycles. The study site is nature reserve the Westhoek in Belgium, where the salt distribution is of a unique nature with a salt water lens lying on top of a freshwater tongue, in dynamic equilibrium. The main challenge is that the setup is present in a dynamic environment where the electrodes are both variably and partially covered with seawater.

Due to the high conductivity of seawater, a large fraction of the electrical current is transmitted in the water layer. It is hence important to properly account for the water layer in the inversion to avoid distortions. We approached this problem in two steps. First, a synthetic study was conducted to assess the influence of the water layer on inversion results by inverting the data in different manners. The synthetic model was built to reflect the natural situation. The results show that the best approach to invert this type of data is to use a realistic reference model and that strong distortions of the images at high tide occur because of the overlying seawater layer. Next a field study was executed to verify if fluctuations of the saline interface could be observed. The inversion results confirmed the results of the synthetic case. Nonetheless, we were able to observe saturation and drying on the beach during the tidal cycle, although no clear variation in the saline interface was visible. In the future, we will investigate time-lapse inversion schemes and implement a data correction to resolve the problem of the seawater layer. ERT is a very promising method for future monitoring of SI and FSGD.

50

Groundwater Warming In Central Europe

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The continuous rise of air temperatures as a consequence of climate change also leaves its trace in the subsurface.

The thermal regime of shallow aquifers is strongly coupled with the conditions in the atmosphere, and thus long-term records of groundwater temperature meanwhile reveal significant warming trends at many locations. The focus of our work is on aquifers in Central Europe. We combine different types of measurements and data from wells in rural and urban environments to track thermal changes in shallow groundwater. These include time series of well temperatures logged in-situ over years, repeated temperature-depth profiles, and groundwater quality measurements. Depending on the type of data, time series analysis, analytical heat transport modelling, borehole temperature inversion and heat balance calculations are applied to identify the intensity of shallow subsurface warming.

This site-specific data processing is also needed to distinguish effects from local heat sources that often exist especially in built-up areas, and which often raise groundwater temperature on the local scale. Independent of the data inspected, there is a clear warming trend found at most locations. For example, in southern Germany, repeated temperature profiles over around 30 years indicate slightly delayed and attenuated warming in shallow aquifers in comparison to the trends in the atmosphere. The median value of 32 wells in the state of Bavaria reaches 0.28 K increase per decade for the reference depth of 20 m. In comparison, 227 wells in Austria increased by +0.36±0.44 K per decade, and therefore slightly more than nearby air temperatures (12 weather stations, +0.24±0.13K). Similar rates of increase are found in permanent logs of wells in other regions of Germany and Austria and also Japan, but the trends typically are highly dependent on the conditions at the site, and often elevated temperatures are associated with local anthropogenic impact or land use changes.

51

Modeling The Diffusive Behavior Of Helium And Uranine In A Porous/Fractured Chalk Aquifer

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Informative data is needed to understand transport processes in the heterogeneous subsurface. For example, realistic modeling of transport processes in fractured rocks requires information about the fracture network and possible fracture-matrix exchanges. Field experiments involving the use of tracers with different values for the molecular diffusion coefficient are promising for imaging possible fracture-matrix exchanges more accurately and on different time and spatial scales. This can bring complementary data for modeling and support the reconstruction of the porous/fractured medium.

In this context, dissolved gases (helium, argon, and xenon) and uranine were jointly injected into a saturated and porous/fractured chalk aquifer and recovered at a distance of 7.55 m (convergent test) or in the injection well after a specific 'resting time' (push-pull). For both tests, a sub-horizontal orientated fracture was isolated for injection using an inflatable double packer system. Uranine was measured with a field fluorimeter, and concentrations of the recovered dissolved gases were accurately measured on site with a mobile mass spectrometer.

The diffusion coefficient of the tested tracers varies by one order of magnitude, resulting in significantly different breakthrough curves of uranine and helium during the convergent test. Analytical solutions involving multi-fracture and multi-channel conceptualization were used to simulate the experimental observations and to account for diffusion in the rock matrix. Dispersivity, fractures aperture and number, channels radius and number were manually adjusted using the experimental uranine and helium breakthrough curves in residence time distribution (RTD). The difference between observations and simulations was minimized by giving equal weight to the peak value, peak time, and slope in the RTD.

For the convergent test, the uranine behavior was realistically simulated with the multi-fracture model, while for helium the multi-channel model was required. In contrast, all push-pull results could be simulated with a multi-fracture model as a smaller volume of porous medium was investigated. In addition, the experimental uranine and helium breakthrough curves of the convergent test were numerically simulated using a 3-dimensional model developed with HydroGeoSphere.

Multiple discrete fractures are conceptualized, 3-dimensional diffusion is considered, and parameters are manually calibrated. The experimental data are simulated realistically by considering the contrasted diffusion coefficients of the tracers.

The study demonstrates the potential of higher diffusive tracers and that such informative field data clearly support further modeling of dual media, including the application of innovative predictive approaches with the goal of more robust simulations and predictions.

52

Towards A Hydrogeological Joint Model Inversion: Interpretation And Assessment Of Environmental Tracers For Their Application In Numerical Groundwater Modelling For The Neogene Aquifer, Belgium

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Environmental tracers are naturally occurring, widespread tracers in a hydrogeological system that can be used to identify flow pathways, travel times, groundwater age, and recharge rates. However, these are not typically included during the numerical model inversion process. Recent work has broadened their use in a quantitative way by incorporating them in formal solutions of the inverse problem to estimate hydraulic properties and groundwater fluxes. This is commonly done with numerical codes that at least enable one-way coupling of the different processes, i.e. groundwater flow and solute-transport. Helium-4, carbon-14 and temperature-depth profile measurements represent a valuable source of information which can be exploited to support performance assessment studies.

For the Neogene aquifer in Flanders, groundwater flow and solute transport models have been developed in the framework of safety and feasibility studies for the underlying Boom Clay Formation as potential host rock for geological disposal of radioactive waste. However, the simulated fluxes by these models are still subject to large uncertainties, as they are typically constrained by hydraulic heads only. While the evaluation of candidate host rocks continues, the use of age tracers (i.e. 4He and 14C) as additional state variables for inverse conditioning is being explored. Current methodological developments to integrate such additional observations will allow

i) to test our current understanding and corresponding models of the system, and ii) to potentially decrease the uncertainties associated with model outcomes by a joint inversion approach. In a previous campaign in 2019, a total of 22 piezometers at selected sites across the Nete catchment were sampled and interpreted including major and minor solutes, 4He, 3H, 3He, δ18O, 2H, δ13C and 14C.

As a first step, the 4He concentrations will be further used as observations for the 4He- transport model to test the interpretation based on the full set of additional environmental tracers and hydrochemistry. Furthermore, the inversion of the 4He-transport model and its uncertainty evaluation is performed.

Here, we will present the first interpretations of the gathered environmental data and transport modelling results focusing on helium-4 as potential additional state variable for inverse conditioning. This is a first step in testing the use of 4He as an additional state variable, for constraining groundwater flow and solute transport models at the catchment scale.

53

The Potential Of A Monte Carlo Based Sensitivity Analysis For Transport Using A Heat-Solute Tracer Test In Alluvial Sediments

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For numerical aquifer modeling with uncertainty quantification, a sensitivity analysis is a mandatory process. One-factor-at-a-time procedures, i.e., changing one, calibrated input parameter and keeping the other fixed, are still very popular for hydrogeologists. This show immediately which input parameters have the most influence on the results, but the simultaneous variation of multiple input parameters cannot be taken into consideration. This avoids the detection of interactions between input parameters and makes this procedure uncertain. A sensitivity analysis must quantify the relationship between input and model response uncertainty.

Thus, a Monte Carlo based sensitivity analysis as a distance-based global sensitivity analysis (DGSA), is here performed. This new kind of sensitivity analysis can reveal key information about parameters most influencing the model outcomes. In this study, the basis for DGSA are 250 Monte Carlo realizations, sampled from a prior distribution that was not previously rejected (i.e., not falsified) considering a joint heat-solute tracer experiment in alluvial sediments. In other words, several sets of randomly chosen model parameters were tested for their consistency with the observed data (i.e., prior falsification). In DGSA, the distance between model outcomes is calculated and projected in a low dimensional space. Simulations with a comparable distance to the reference data are a cluster. The parameter cumulative distribution function within k clusters is compared to the reference distribution to deduce the sensitivity. DGSA analyzes both, global parameters (Mean hydraulic conductivity, porosity, etc.) and local high dimensional parameters characterizing the spatial heterogeneity like the complex hydraulic conductivity field generated with sequential Gaussian simulation in the prior. The latter are considered through their principal components replacing multiple statistical parameters with a limited, smaller, and approximated amount of linear combinations.

The results show that the heat tracer seems to be less sensitive to global advective parameters like porosity, indicating the complementary tracer behavior. The principal components describing local spatial heterogeneity are sensitive for the heat and the solute tracer, but heat tends to remain more dominated by conduction. Thus, for robust transport decisions using any stochastic Bayesian inversion, an adequate prior description in conjunction with a global sensitivity analysis considering uncertainty is a prerequisite.

54

Groundwater In Fast-Growing Cities In Western Africa

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The population of Western Africa is booming, as a consequence of the demographic transition. The region was home to 316 million people in 2007, they are now 391 million, and could reach 796 million in 2050. The population is growing more rapidly in the cities than in rural areas, partly due to migration. The rapid growth of urban areas comes with planification and infrastructure challenges that include water supply and waste disposal. As many cities rely on groundwater for water supply, risks of groundwater over-exploitation and/or contamination need to be assessed and addressed.

As part of the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP), the status of groundwater use and management was assessed for the largest cities in the 15 member states of the Economic Community of West African States (ECOWAS). Information was collected on the use of groundwater in public water supply and alternative water supply (e.g. private sellers, private wells), groundwater availability issues, groundwater quality issues (natural and anthropogenic contamination), as well as groundwater management measures. The assessment was carried out using the DPSIR framework to identify linkages between societal changes and groundwater resources. Data and information supporting this assessment were collected during an extended literature review. Because official data were scarce (e.g. water company reports), scientific papers, reports and news items were also consulted. The literature review was completed with the inputs of national experts. The outcomes of this assessment have been presented in a poster containing a regional map, 15 city profiles and summary diagrams. All material and references are also available online.

This assessment was primarily directed toward policy and decision-makers and those involved in regional development and planning, who don't necessarily have a strong knowledge base on groundwater resources and their management. It also calls for further hydrogeological studies to assess the resilience of aquifers in Western Africa, to see how far they can support the increase of anthropogenic pressures.

55

Transboundary Diagnostic Analysis And Strategic Action Plan Of The Eastern Kalahari-Karoo Transboundary Basin Aquifer System (Ekk-Tba)

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A Transboundary Diagnostic Analysis (TDA) of the Eastern Kalahari-Karoo Transboundary Basin Aquifer system (EKK-TBA) was conducted presenting a comprehensive understanding of the state of surface water and groundwater resources, their uses, spatial and temporal variability, interactions, and impacts as well as human benefits derived from ecosystem services and existing infrastructure.

The EKK-TBA is shared between Botswana and Zimbabwe, straddles two river basins: Okavango and Zambezi, and covers an area of about 127,000 km2 (65% in Botswana and 35% in Zimbabwe). The topography is generally flat and the climate is semi-arid. Surface water drainage is mainly through ephemeral rivers towards the Makgadikgadi Pans in the southern part of the Basin and through the Gwayi River system in the northeast towards the Zambezi River. The 2020 Basin human population was estimated at 595,000 (16% in Botswana and 84% in Zimbabwe) and the Basin's economy is mostly driven by diamond mining, ecotourism and agriculture (livestock and cropping).

Groundwater forms the main source of potable water supply within the Basin for both humans and animals. Shallow aquifers are constituted by the Kalahari Group deposits whereas the main aquifers are the deep Ntane/Forest and the Mea Arkose Sandstones. Wellfields have been developed along the south-eastern fringes of the Basin where the sandstone aquifers outcrop and are recharged from rainfall.

Key issues emanating from the TDA included:

- Water insecurity due to increasing water demand given limited groundwater resources
- Data scarcity and inaccessibility and poor quality of data
- Deforestation and poor agricultural practices resulting in land degradation
- Lack of adequate resources for effective and efficient groundwater management including monitoring
- Lack of transboundary groundwater governance and management

The positioning of the EKK-TBA provides a unique opportunity for joint governance and management as the two transboundary river basin organisations (OKACOM and ZAMCOM) have to be involved.

The outcome of the TDA laid the foundation for developing a basin-wide Strategic Action Plan (SAP) through a range of stakeholder engagements across relevant sectors and actors (government, private sector and civil society).

Core elements of the SAP include a long-term vision, mission, objectives and actions. Short-term targets were set and six priority actions formulated based on costs and feasibility:

- Establish institutional arrangements for water resources management (WRM)
- Conduct joint studies to enhance understanding of the water resources
- Develop data sharing arrangements between the two Member States
- Establish joint monitoring systems
- Promote sustainable resources management and livelihood improvement
- Develop capacity for conjunctive WRM

56

A Method To Interpret Coastal Aquifer Pumping Tests: Removing Noise And Natural Groundwater Head Fluctuations

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Interpretation of drawdowns resulting from pumping tests performed in coastal heterogeneous aquifers is problematic. In these areas small drawdowns are superimposed to tidal and other natural head fluctuations that obscured the actual response to pumping, and difficult the identification of the conceptual model behind the response. In this paper a methodology is proposed to interpret pumping test in coastal areas by filtering out natural groundwater head fluctuations and noise, allowing interpretation of resulting drawdowns. The approach consists of five steps: (1) remove natural groundwater head fluctuations from measured heads by reconstructing the natural groundwater heads during the pumping test using a linear multiple correlation approach; (2) define drawdown curves from pumping and recovery phases to compare and test the method; (3) prepare diagnostic plots an remove noise using the smooth log-derivative method; (4) use these plots and geological understanding to define the conceptual model; and (5) estimate hydraulic parameters.

The three initial steps allow to derive drawdowns free of natural trends and noise, while validating the results from the filtering pro-cess. The complete methodology was tested in the interpretation of a long-period pumping test at the Argentona experimental site (NW Barcelona).The methodology allowed us to estimate the hydraulic parameters, identify flow regimens, detect semi-confining layers and deduce a conceptual model. All these results were consistent with pre-existing information about the re-search site, confirming the effectiveness of the method

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57

Reckoning With Eu-Wfd Guidances To Address Transboundary Aquifer Monitoring Strategies. An Application To The Skadar/Shkoder - Buna/Bojana Hydrogeological System.

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Monitoring of the Sustainable Development Goal indicator 6.5.2 on transboundary water resources cooperation, reveals that only 22 countries have all their transboundary basins and aquifers (TBA) covered by cooperation arrangements, showcasing that efforts are still needed to promote cooperation. The assumption is that transboundary cooperation on the shared water resource, based on data and knowledge sharing, is a prerequisite for their sustainable management. The GEF/UNDP/GWP Med Project "Enabling transboundary cooperation and integrated water resources management in the extended Drin River Basin" aspires to promote joint management of the shared water resources of the transboundary Drin River Basin. To meet this objective, the Project includes, amongst others, the design of a monitoring network for the Skadar/Shkoder-Buna/Bojana transboundary aquifer system shared between Albania and Montenegro, and located within the Drin Basin.

As both countries are in an accession process to the European Union, the EU Water Directive (WFD) provides the framework for meeting management goals under a common data gathering program. Facilitating information sharing, should foster joint policies to avoid water use conflicts and enhance cooperation.

The methodology developed for the design of the transboundary groundwater monitoring network, while consistent with the WFD requirements, also draws from lessons learnt in transboundary aquifer management approaches used worldwide.

Such methodology consists of three main steps: first, building a hydrogeological conceptual model including pressure and impact assessment on groundwater resources; second, producing a vulnerability analysis applying the ACVM method that considers the aquifer exposure to diffused and point pollution sources, flooding and seawater intrusion; and finally, designing a transboundary monitoring network proposal, including surveillance and operational approaches, based on the identified priority areas.

The study leds then to the identification of priority monitoring areas and their targets within the TBS framework. Establishing such priority areas rather than specific monitoring locations provides a starting point for both countries to recognise features of transboundary concern, and harmonize monitoring efforts within the context of a common environmental vision. It also provides the necessary flexibility for the riparian states to reconcile both regional and national interests in choosing specific locations that also fulfil the objectives of the transboundary monitoring goals.

58

Interdisciplinary Characterization Of La Garriga-Samalus (Barcelona, Spain) Fault-Controlled Geothermal System

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The first step towards the exploitation of a potential geothermal resource is to perform a comprehensive characterization of the geothermal system. In fault-controlled geothermal sites this means to understand the fault hydrogeology, and how it is integrated with the deep broader regional system feeding the site. This requires answering a complex and diverse set of questions related to the geometry of the reservoir, the permeability and connectivity conditions, the recharge- discharge patterns, the thermal properties, the extension-compression dynamics, among others, in order to built a conceptual model of the geothermal site. Such complexity ideally requires employing tools from different disciplines. However, only recently researchers are trying to fully integrate among them.

In this research we characterised La Garriga -Samalus fault-controlled geothermal system - located 40 km North from Barcelona (Spain) - integrating approaches traditionally used in geophysics, geology, and hydrogeology.

La Garriga -Samalus geothermal anomaly is a historically well-known geothermal site, which, despite its presumable potential, is only exploited by a couple of spa resorts. Several studies have been done since the 70s to characterise the thermal anomaly. In this research we collected, reviewed, and re- interpreted all existing information. To do this, we followed an interdisciplinary approach, using the estimation of permeability as the interdisciplinary cornerstone.

The results update the conceptual model of the geothermal site and serve to discuss the added value of using an interdisciplinary approach when characterising a fault-controlled geothermal system.

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59

Modeling Hot And Cold Water Injections In A Fractured Aquifer: Influence Of The Thermal Gradient Direction On Measured Breakthrough Curves

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Heat tracer tests have shown a high potential to estimate hydraulic and thermal conductivities and heat capacity at the field scale. Most often, such tracer tests are performed in moderately warm aquifers by injecting hot water, compared to the natural background. For aquifers with a high natural background temperature, such as in tropical regions, it is interesting to inject cold water.

Several tracer tests with injection of hot and cold water were conducted in a weathered/fractured aquifer in southern India. The natural background temperature was about 30 °C. In the injection well, a sub-horizontal fracture was isolated by use of a packer system for injection of 1000 L of hot (50 °C) and cold (10 °C) water, respectively. Tracers were recovered by pumping in a well at a distance of 5.4 m and connected by the isolated fracture. The observed temperature breakthrough curves were characterized by their thermal recovery rate and cumulative energy recovery. A plot of logarithmic time against the logarithmic observations translated in residence time distributions allowed to estimate the breakthrough curve tailing slope values close to 1.5 for all temperature tracers, representing a diffusive behavior.

For simulating the observations numerically using HydroGeoSphere, a low-porosity and low- hydraulic conductivity porous medium, intersected by highly transmissive discrete fractures, is defined. The fracture aperture, the effective transport porosity, the hydraulic conductivity and the specific storage coefficient of the porous medium were manually calibrated minimizing the differences between observations and simulations of the drawdown and temperature breakthrough curves. The estimated tailing slope values are well reproduced. The observed and simulated thermal recovery rate and the cumulative energy recovery tend to be lower for a cold water injection. Small differences remain between the simulated hot and cold water tests even when no density-viscosity effect is considered and all calibrated parameters are similar.

These results confirm that heating and cooling the porous medium from an injected highly permeable fracture is influenced by conduction. However, the conduction direction (from the fracture towards the matrix or vice-versa) influences the thermal recovery rate. For the first time, it is evidenced that the difference in results from similar hot and cold water tracer tests is not only due to water density-viscosity changes but induced also by the inversed direction of the thermal gradient between the fracture and the matrix.

60

Determining Relevant Aquifer Factors And Their Relative Importance In The Assessment Of Aquifer Vulnerability

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The vulnerability indices, used to assess the vulnerability of aquifers to contamination, have been subject to various adjustments to make them more adaptative to the particularities of the studied regions. These adjustments include adding and/or eliminating certain aquifer factors and modifying the factor weights. Nonetheless, there is no consensus about which factors, or their respective weights, are most important for assessing aquifer vulnerability.

We propose an operational approach for: (i) selecting the relevant factors when assessing aquifer vulnerability to contamination; and (ii) determining the relative importance of the selected factors. This approach is based on large data set from granular aquifers of Saguenay-Lac-Saint-Jean region of Quebec, Canada. The available data included water table depth, average aquifer hydraulic conductivity, topography, dominant vadose zone soil type, and average annual recharge. We combined these data with information related to groundwater quality and land use. We found topography to be an irrelevant factor for assessing the aquifer vulnerability in our study region. The relevant factors ranked in their relative importance (from highest to lowest) were: (1) water table depth; (2) average aquifer hydraulic conductivity; (3) dominant vadose zone lithology; and (4) average annual recharge.

This study provides an original approach for integrating groundwater quality data and land-use effects with a data set of the characterized factors. This proposed approach can help to adapt indices-based methods of aquifer vulnerability assessment to a range of study regions.

61

Pydov: A Library To Empower Open Geoscience Data In Flanders, Belgium

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The Flemish government collects a wealth of information about the subsoil of its region. These data are made available through webservices provided by (In Dutch) Databank Ondergrond Vlaanderen (DOV). A portal through which data can be selected, viewed and retrieved is available: DOV-explorer [online: https://www.dov.vlaanderen.be/portaal/?module=verkenner].

But this web application does not satisfy all user requests, especially with regard to machine-based and automated queries. A consultation of the stakeholders pointed out that an API combining existing webservices would provide new opportunities to work with the DOV data in this new era of data science with large computing resources. Therefore, a process of co-creation was initiated with interested stakeholders to design, develop, document and publish a Python library on top of the webservices of DOV: pydov.

pydov is a Python package hosted on GitHub [online: https://github.com/DOV-Vlaanderen/pydov]. It provides a convenient wrapper around the metadata, WFS and XML webservices, that also power the DOV explorer. Observations of more than 170 000 boreholes and cone penetrations tests (CPTs) are made available, with interpretations if present. Recently, data from soil samples and groundwater permits became accessible through pydov, in addition to piezometric and groundwater quality measurements. As such, the library provides programmatic access to a large labelled dataset that supports a variety of research topics.

In addition, geospatial functionalities and custom search definitions are included in the library such that data requests can be tuned and automated, paving the way for a more widespread use of the available data. For example, water discharge from drainage at large construction works has gained much attention lately with the increasing water stress in Flanders. People would like to make use of this drained water. The pydov library allows for a screening of the expected water quality for a certain permit. As such, people can be informed about the potential usage of the drained water.

The pydov library gives third parties access to the publicly available data as if they would have access to the backend database. This supports innovation, without putting additional workload on the maintainers of DOV. It is without a doubt the preferred way forward in disclosing open data in this new era of digital native hydrogeologists. A special thanks to all contributors of pydov and to the reviewers of pyOpenSci [online: https://www.pyopensci.org/].

62

The First Known Piezometric Map In The World Was Published In 1856 In Belgium

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To our current knowledge, the first piezometric map ever published in the world is the map of Gustave Dumont in February 1856. Gustave Dumont (1821-1891) was a cousin of the well-known geologist André Dumont (1809-1857). This oldest known piezometric map is showing piezometric levels (heads) in the chalk Hesbaye aquifer of the Geer basin near the city of Liège in Belgium. The map is included in a comprehensive report ordered by the city in 1855 to increase drinking water production with a large extension of drainage galleries in this aquifer. A long tradition of underground coal mining activities in Southern Belgium did lead in the 19th century to new advances in practical hydrogeology. For example, drainage techniques linked to mining activities were developed actively as the mines were going deeper and deeper. This period corresponds also to a first complementary collaboration between engineers and geologists, leading to the early steps of geological engineering. André Dumont was Professor at the University of Liège in Geology and Mineralogy and was the most famous Belgian geologist of that period. He is known for his many detailed and rigorous geological maps.

In 1851, he published a note about the application of the geological regional knowledge for groundwater exploration in Hesbaye. Gustave Dumont was a mining engineer with experience in hydraulic problems. A water commission of the city of Liège provided Gustave Dumont in 1855 with the task to study the feasibility and impact of an optimized network of drainage galleries in this chalk aquifer.

The official report is delivered and published in February 1856 (Dumont 1856) including the first piezometric map entitled: 'Carte hydrographique de la Hesbaye aux environs de Liége' (in French). This map shows the piezometric contours every meter from 57 m until 106 m. These contours were described as 'the intersection between the underground water surface with horizontal planes' (literal translation from French). This study was particularly innovative, as it was not only driven by the required feasibility and efficiency of the project but also by an estimation of the potential impacts of groundwater levels on private wells of farmers.

Dumont G., 1856. Rapport fait à l'administration communale relative aux divers projets qui lui ont été présentés pour procurer à la Ville des eaux alimentaires (in French). Bulletin administratif de la Ville de Liège, Liége, N. Redouté (imprimeur), 109 p.

63

Hydrogeology Of The Eastern Kalahari-Karoo Transboundary Basin Aquifer (Ekk-Tba)

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The Eastern Kalahari-Karoo Transboundary Basin Aquifer (EKK-TBA), straddling semi-arid eastern Botswana and western Zimbabwe, and home to nearly 600,000 people, is facing critical water insecurity challenges. Water insecurity in semi-arid regions of southern Africa provides a major challenge to socio-economic development since close to 70% of the population relies on groundwater for their livelihoods.

The Basin receives a mean annual rainfall of 625mm in the northeast to 325mm in the south. The topography is generally flat, ranging from about 1 400m amsl in the northeast to 880m amsl towards the Makgadikgadi Pans in the southern part of the Basin. Perennial rivers in the eastern section of the Basin drain towards the Zambezi River and few ephemeral rivers drain towards the Makgadikgadi Pans.

Groundwater constitutes the main source of water and humans, the mining sector, agriculture and biodiversity are the main groundwater consumers. There is limited hydrogeological data and information to inform on the sustainability of the groundwater resources on a basin-wide scale. Wellfields developed within the south-eastern fringes of the EKK-TBA (Botswana: Orapa, Letlhakane, Dukwi and Maitengwe; Zimbabwe: Nyamandlovu) provide the main source of hydrogeological data which, in certain instances, is incomplete.

The main aquifers are the shallow Kalahari Group deposits, and the deep Ntane/Forest and Mea Arkose/Wankie Sandstones. Faulting and fracturing have compartmentalised certain sections of the aquifers. Groundwater generally flows towards and discharges into the Makgadikgadi Pans.

Groundwater salinity increases towards the central portions of the Basin and with depth of the aquifers.

Groundwater recharge studies in the region over the last four decades informed the development of a groundwater recharge map of the Basin. Recharge is generally less than 3% of average annual rainfall and 350mm of annual rainfall is the threshold below which hardly any recharge occurs.

Subsequently, a sustainable abstraction map was developed as a first guide for groundwater development for areas where hydrogeological data and information are lacking.

Since current water demand is outstripping supply, any further increase in potable water demand, resulting from population growth and expansion of groundwater irrigated agriculture will exert additional pressure on the groundwater resources. Innovative approaches to sustainably develop and utilise the limited groundwater resources need to be adopted.

It is equally important to establish and capacitate a basin-wide management unit, develop a groundwater monitoring network and a groundwater model, as precursors to balancing demand and supply and ensure sustainability of supply.

65

Estimation Of Surface And Groundwater Interaction Under Arid Climate Conditions Using A Regional Geohydrological Model

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Estimation of surface and groundwater interaction is particularly important in arid regions, where surface water infiltration from ephemeral dryland streams helps to maintain riparian ecosystems. The considered Ejina basin is located in the lower reaches of the Heihe River, a typical intermittent

river of north-western China. The study area is characterized by hyper-arid conditions with high potential evaporation (approximately 1500 mm/year) and extremely low precipitation (less than 50 mm/year). At the Langxinshan hydrological station Heihe River divides into two losing streams, the Donghe and Xihe Rivers, which flow through the Gobi Desert before entering the system of terminal lakes (East and West Juyan lakes, Swan lake). Due to relatively high vertical hydraulic conductivity of streambed, river water is the primary source of groundwater recharge via streambed infiltration, which supports riparian vegetation along the river branches and in the Ejina oasis, located in the delta of Donghe river.

The unsteady geohydrological model of Ejina basin, covering the period the period from 2000 to 2018 year, was created using MODFLOW-2005 (figure 1). The model includes the whole drainless Ejina depression and consideres water exchange processes in the system “surface water (SFR2 and LAK3 packages for modeling rivers and lakes respectively) - groundwater - evapotranspiration (ETS1 package) - groundwater exploitation (WEL package)”. The simulated terminal lakes receive water both from river branches and groundwater, and then this water evaporates. This approach allows considering full water balance of the modeled basin, knowing hydrograph of Heihe river flow at the inlet site - Langxinshan station.

The model was calibrated using a set of observations of groundwater levels, river runoff measuremets (Dongjuyanhai station, figure 2), dynamics of changes in the area of terminal lakes (Landsat-5, Landsat-7, и Landsat-8 images, figure 3 for East Juyan lake) and evaporation from ground surface (MOD16 data). The modeling results made it possible to estimate the proportion of leakage losses from the total river runoff, to identify their dynamics, and to make recommendations for adjusting the flow of the lower part of Heihe River to improve the ecological situation of the Ejina basin.

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66

Nitrates In Groundwater: A Long Term Problem In England

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Rising concentrations of nitrates in groundwater since the 1970s resulted in widespread exceedance of the European drinking water standard of 50 mg/l. The groundwater fails the Water Framework Directive ‘good status’ and requires treatment or blending for public supply. Groundwater provides 30% of the drinking water in England, but up to 100%, in the densely populated South and East.

Thus, supply of compliant quality groundwater requires significant investment by water companies, relying on forecasts of future nitrate concentrations for investment planning. Although nitrate concentrations appear to have stabilized or are declining in many locations, they show a rising trend elsewhere.

The trend in nitrates is linked to intensive fertilizer application since the 1950s. Application rates peaked in the 1980s followed by a downward trend, although the application on arable crops remains high, averaging 142 kg/ha in 2018. A national system of nitrate vulnerable zones covers 58% of England, and water supply companies work with farmers to improve catchment management, with wider environmental benefits and improvements in groundwater quality. Due to the logistics and costs of large-scale catchment management, a targeted approach is essential to identify priority areas. A suite of GIS based approaches was tested to define the areas where catchment management is likely to be most effective. We concluded that the best approach, taking account of uncertainty, is to designate an "expert knowledge" catchment, combining FlowSource modelling of capture zones, conceptual understanding and drinking water Safeguard zone.

Regional scale modelling of nitrate fate and transport in the soil, unsaturated and saturated zones allows prediction of future concentrations, but it is time consuming and significant uncertainties remain despite rigorous calibration. A faster approach of analytical and statistical methods was adopted. Three alternative models performed successfully, each providing different insights into the main drivers of the observed nitrate concentrations. Monte Carlo analysis to generate confidence intervals improved understanding of uncertainty. Therefore, all three models were, using improved estimate of nitrate inputs from NEAP-N and Anglia Defra models. Combining the outputs with vulnerability mapping, expert knowledge catchments, comparison of nearby groundwater sources, and observed trends in surface waters with high baseflow, improves conceptual understanding and optimises prediction of future changes in nitrate concentrations.

This presentation updates previous nitrate talks at the IAH congresses in 2012 and 2016, showing the advances in conceptual understanding and more effective methods for identifying priority areas and predicting future nitrate concentrations.

67

Modelling Framework To Estimate Fresh Groundwater Occurrences And Volumes Below Atolls

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Freshwater lenses are important fresh groundwater resources at Small Islands Developing States (SIDS), especially during droughts. During the last decades, sustainable groundwater management has become a pressing issue due to a changing climate, population growth, and unsustainable groundwater extraction. Furthermore, sea level rise will have an irreversible impact on these lenses and their ability to supply enough fresh water for domestic and agricultural use. Previous studies show that the occurrence of fresh groundwater at small islands depends on many factors like hydrogeological composition and permeability, topography, size and shape of the island, drainage characteristics, vegetation, land use, and meteorology. The way these factors interact and determine the fresh groundwater volumes at small islands over time can be estimated by groundwater modelling. The accuracy of the estimation depends on model conceptualization, accuracy of the parameter values and scenarios for climate change, sea-level rise and socioeconomic developments/human activities. We used a MODFLOW/SEAWAT based toolbox, iMOD-WQ, to set up a detailed variable-density groundwater flow and coupled salt transport model of the Laura freshwater lens on Majuro atoll (Marshal Islands) to explore which factors are the most sensitive in controlling the volume of the freshwater lens over time.

Based on the findings of this Laura lens modelling as well as previous studies, we set up a generalized conceptual modelling framework using global datasets which contain the most important factors determining the freshwater lens occurrence. Although data for most SIDS is scarce, the geological characteristics of atolls show large similarities which helps to schematize a general hydrogeological composition of an atoll. Within this modelling framework, the key factors that determine the freshwater lens volume can easily be adapted once actual local data is available (e.g. thickness of the Holocene layers, hydraulic conductivities, recharge, shape of the island). The modelling framework is set up using python and uses the python package Snakemake as a workflow manager. It applies the extensive capabilities for pre- and postprocessing of data and model building of the iMOD-python package and has version control (using Git).

The robust and flexible modelling framework provides a quick estimate of the freshwater lens occurrence and volume while it can be easily adapted to the local situation with new data. The modelling framework opens a wide range of possibilities for both site specific and general estimations of freshwater lens volumes. This framework forms the base towards more effective and sustainable fresh groundwater management.

68

Hydro-Mechanical Modelling Of The Compaction Of A Multi-Layer Aquifer System In West- And East-Flanders (Belgium) Based On D-Insar And Field Data

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The overexploitation of the deep aquifers in the western half of Flanders, Belgium (provinces of West- and East-Flanders) is causing ground deformation at the regional scale, first detected in the 1980s by levelling. From the hydrogeological point of view, the compaction of these aquifers would cause a permanent loss of water resources that, in a context of climate change, will become even more precious than they are today. From the hydrographical point of view, this deformation may alter the flooding risk areas –in a region of flat and low topography. And from the geomechanical point of view, in case of differential ground movements, the ground deformation can lead to damages to overlying structures.

The deformation is primarily due to the compaction of two aquitards that confine the two main aquifers of the region. Until now, the displacements of the ground surface were described by means of point-like measurements, mainly levelling but also GPS data. However, optimal management of the issue requires determining the weight of each of the two aquitards in the total ground surface movement, in order to adapt the exploitation of the aquifers accordingly.

To this end, a series of 1-D ground columns simulating the subsurface in different locations around the region is numerically modelled to calibrate the hydraulic and mechanical parameters of each hydrogeological unit for a future regional 3-D hydro-mechanical model. Here, thanks to their great extent and high spatial density as well as the existence of a historical archive, differential interferometric synthetic aperture radar (D-InSAR) data have provided maps of displacements of the ground surface from 1992. The columns are based on an existing geological 3-D model. Each ground column is subject to variations of the piezometric level based on field measurements. The comparison between D-InSAR time series of displacements of the ground surface and the response of the 1-D hydro-mechanical models allows to calibrate the hydraulic and mechanical parameters of each aquifer and aquitard. D-InSAR data have also been essential in determining the number and location of the 1-D models. The study highlights that, at the regional scale, homogeneous hydraulic and mechanical parameters lead to satisfactory results. In addition, the calibrated values are in good agreement with geotechnical maps and other laboratory and field tests available in the literature. Finally, the interpretation of 1-D ground columns provides in-depth insights into the relative importance of each hydrogeological unit in the total ground deformation.

69

Fresh Submarine Groundwater Discharge In The Western Belgian Coast

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The Belgian coastal phreatic aquifer mainly consists of salty/brackish pore water at shallow depth. One of the few locations where freshwater can be found are the eolian dunes which delimit the sandy beach.

The drinking water demand of the coastal region is putting high pressure on these water resources, especially during the touristic summer season. Also, the recent, drier summers increase the need for solutions. A good understanding of the hydrogeological situation is needed to allow a sustainable management of the potable water.

The Intercommunale Waterleidingsmaatschappij van Veurne-Ambacht (IWVA) has two exploitation facilities in the most western part of the 65 km coastline, where the dunes are up to 2.5 km wide. The company pumps yearly around 300,000 m^3 freshwater in the dunes of De Panne, while the pumping of groundwater in St-André (over 2 million m^3) is combined with managed aquifer recharge (MAR) at the surface (since 2002) and underground (since 2014) for more sustainable exploitation.

Part of the potable water, found underneath the dunes, is flowing towards the North Sea. The freshwater discharging zone is assessed by means of electromagnetic (EM) induction mapping, electrical resistivity tomography (ERT) on land, and marine continuous resistivity profiling (CRP). The combination of these geophysical methods allows to assess the lateral variation of the salt- freshwater distribution in the aquifer and the efficiency of the MAR project at St-André.

We identify a correlation between the strength of outflow and the extraction activity. The groundwater discharge zone is positioned more landward in front of the De Panne exploitation site, indicating a relatively weak outflow. The zone of discharge moves seaward towards the West, with decreasing influence of the groundwater extraction. In contrast, in front of the artificial recharge site, the discharge zone is located below the low water line. This outflow zone is situated more seaward compared to the area in front of Koksijde (to the West) which has a larger hydraulic gradient between land and sea, due to the presence of a shallow clay layer, and where no pumping or MAR occurs. Also to the East of the St-André exploitation site, we find fresh groundwater outflow located more landward. The data shows a clear influence of the extraction sites and MAR on freshwater discharge in the area. The geophysical observations are in some areas in contradiction with existing groundwater models, which should be updated to account for the actual location of the discharge zone.

70

Estimating The Effect Of Wildfires On Groundwater Recharge Rates Through Soil Water Balance Models

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Wildfires are a threat to life, property and natural resources, including water. Forest basins are important sources of groundwater for communities around the world due to good infiltration conditions and because they are often associated with good water quality. However, the damage or loss of vegetation and litter cover after a wildfire have implications for the interception, evapotranspiration, runoff and consequently for groundwater recharge rates with possible consequences on the water security of a region. A better understanding of these processes will lead to improved predictive capabilities of post-wildfire recharge models, and with it, a higher probability of anticipating water shortage scenarios in burn-prone areas.

The aim of this work was to assemble information to provide a coherent knowledge base about how to include the effects of different forest fire regimes into numerical models of groundwater recharge. Although there are a number of reviews dealing with aspects of fire impacts on hydrology, most of them are focused on either soil erosion by water or post-fire peak-flows. This last one has received more attention than changes in total flow at catchment scale, reflecting better understanding of the runoff processes and easier measurement.

Published material was organized in order to synthesize functional relations between a wide range of wildfire responses of the most sensitive hydrological components, into post-wildfire response domains composed of fire regimes. Among the most important qualitative results, the decrease in soil permeability caused by soil–water repellency, soil-sealing and air entrapment stands out, and would lead to significant changes in the monthly recharge rates even for low recurrence wild-fires.

Simulations of groundwater recharge were carried out on "El Sutó" spring's catchment, located in San José de Chiquitos municipality (Bolivia) which is part of the Amazon region.

For the simulations, a monthly soil-water balance model called WetSpaSS-M was used, which was developed by the Department of hydrology and hydraulic engineering (HYDR) of the Vrije Universiteit Brussel (VUB, Belgium). Among the first set of outputs, the model estimations showed a general decrease in recharge rates in the whole catchment. It could be seen that under the worst-case scenario conditions, in some parts the recharge decreased by one third of its average value. These estimations will be validated and refined through coupling the WetSpaSS-M model with a MODFLOW groundwater flow model of the region.

71

Land Subsidence As Revealed By Ps-Insar Observations In The Antwerp Area (Belgium): First Steps Towards The Understanding And Modelling

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PS-InSAR observations using multi-sensor radar data acquired by ERS 1-2, ENVISAT ASAR, and Sentinel-1A satellite sensors operating in C-band, have shown various land subsidence rates in different zones of the Antwerp area along the Scheldt River and in the harbour zone during the 1992 to 2021 period (Declercq et al. 2021). The LOS velocity values calculated from different radar datasets collected over Antwerp City Centre are ranged between -0.96 - +1.14 mm/year (ERS 1-2), - 2.21 - +1.11 mm/year (ENVISAT), and -3.31 - +3.87 mm/year (Sentinel-1A). Moreover, the LOS velocity values for Antwerp Harbour are -4.38 - +1.02, -4.06 - +1.65, and -9.46 - +3.86 which are more significant than their corresponding ranges in the Antwerp City Centre.

Groundwater is intensively pumped from the sandy Vlaanderen Formation (Holocene), Lillo and Poederlee Formations (Pliocene), and Berchem Formation (Miocene). However, in this area, land subsidence can be attributed to four potentially complementary consolidation processes:

- natural consolidation of the Holocene estuarine sediments,
- additional consolidation in the saturated Holocene estuarine sediments due to the backfill overload (8 m thick embankments) along the harbour docks,
- saturated-unsaturated consolidation of the backfill materials,
- consolidation of the most compressible layers, probably in the Boom Formation (Paleocene) and in the Asse clay of the Maldegem Formation (Eocene) due to pore pressure decrease induced by groundwater pumping in the different Cenozoic aquifers.

Indeed, several of these processes could be added to produce the actual observed land subsidence. Geomechanical and hydrogeological data were being collected in the frame of the BESLSPO BRAIN project: “monitoring LAnd SUbsidence caused by Groundwater exploitation through gEOdetic measurements (LASUGEO)”.

For consolidation of estuarine sediments induced by the backfill overload, the rapid increase of total stress should be equilibrated by an increase of both water pore pressure and effective stress. This later, inducing land subsidence, will progressively increase as the water overpressure can be dissipated mostly laterally through groundwater flow. A coupled approach including a 3D groundwater flow model and 1D geomechanical models will be needed for a detailed analysis. First, local models will probably be needed in specific zones to understand in detail the ongoing consolidation processes. Then a large 3D groundwater flow model will be considered over the Antwerp area including all the complex boundary conditions with the Scheldt River and the harbor docks to provide realistic transient water pressure conditions to numerous 1D geomechanical models in the area.

72

Pretashkent Transboundary Aquifer: Interim Results Of The Ggreta Project In Central Asia

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Keywords: Pretashkent Transboundary Aquifer, Ggreta Project In Central Asia

The GGRETA Project, funded by the Swiss Agency for Development Cooperation (SDC) and implemented by UNESCO-IHP Secretariat, includes as a case study The Pretashkent transboundary aquifer (PTBA). PTBA is a unique source of deep fresh groundwater in Central Asia, located on the territory of Kazakhstan and Uzbekistan. The PTBA groundwater is widely used for drinking, SPA and bottling in Kazakhstan and Uzbekistan. According to approaches of GGRETA' guidelines for transboundary aquifers assessment, in the Kazakhstan part of TBA the interdisciplinary assessment of the PTBA was carried out. The diagnostic analysis of the main problems and risks for the Kazakhstani part of the PTBA was carried out in accordance with the methodology of the GGRETA project based on the DPSIR assessment. The assessment identified two main transboundary issues, both of them relate to the groundwater levels drawdown of the PTBA: 1. Storage depletion of the PTBA groundwater; 2. Potential deterioration in the quality of the PTBA groundwater. As a result of the diagnostic analysis, recommendations were prepared for optimizing the further exploitation of groundwater resources of the PTBA (for Kazakhstani part).

The results of the assessment and diagnostic analysis of the PTBA showed that the joint interstate governance and management of groundwater resources of the aquifer should be based on modern hydrogeological information and predictive estimates of the possibility of groundwater extraction. Such estimates can be given only on the basis of mathematical modeling in the environment of modern software.

From 2020 activities on the Phase 3 of GGRETA project carried out by coordinated team of experts from Kazakhstan and Uzbekistan. Harmonization of maps and databases for the Kazakhstan and Uzbekistan parts of the PTBA made it possible to create a digital basis to fulfill mathematical simulation for the whole Pretashkent TBA. The generated model is in the stage of calibration. The model is being developed in parallel by the Kazakh and Uzbek parties with the obligatory coordination of the results of each stage of modeling.

73

Hydro-Economic Modeling For Integrated Management Of The North-Western Sahara Aquifer System

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Groundwater use in irrigation has highly increased throughout the world, especially in many arid and semiarid areas. In the North-Western Sahara, the population is highly dependent on the huge multi- layer groundwater reserve beneath the desert, and the use of such water source has intensively increased over the last 30 years, mainly for irrigation purposes. The intensive exploitation of this common-pool resource has caused severe water table declines, outlet depletion, and salt intrusion. Accounting for population growth and climate change, this abstraction might still continue to increase, such that assessing possible trends of the North-Western Sahara groundwater is a challenging research. This paper aims to study the behavior of myopic water users who share two superposed aquifers in order to investigate pumping rates in the North-Western Sahara Aquifer System (NWSAS).

For this purpose, we developed a hydro-economic model based on the well-known and largely debated hydro-economic model of Gisser-Sánchez for the two interconnected aquifers of the North-Western Sahara, with accounting for the natural drainages and the vertical flow between the two aquifers. Following hydrologic and economic parameters calibration, simulations using the proposed model were carried out to examine the economic behavior of water users who can withdraw groundwater from both aquifers. This allowed to analyze what drive individual pumping decisions, but also to investigate these decisions impacts on the protection of natural drainages (environmental flows).

74

Solid Data Sets Are Essential To Provide Reliable Solutions. A Practical Example Of Improved Insights By A High Resolution Site Characterization Approach

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Chlorinated solvents are known to pose major challenges in terms of both investigation as well as remediation of soil and groundwater contaminations. The distribution of these dense non aqueous phase liquids (DNAPL's) is controlled by subtle variations of geohydrological properties of the subsurface. As a result the architecture of source and plume is often very complex and unpredictable. Traditional investigations with drilling and sampling of soil and groundwater cannot deliver the necessary data density to describe those complex contaminations. Conceptual site model (CSM) are flawed by data gaps and uncertainties; soil and remediation experts are required to make considerable generalizations and assumptions.

Present work describes how a revised historical investigation and a High Resolution Site Characterization approach shed a new light on the contaminant situation and remediation strategy.

The investigated site is situated in a highly urbanized area. Activities of a former printing office have lead to extensive contaminations with chlorinated ethenes and ethanes. The main conclusions of the detailed soil investigation campaign, executed in the period 1998 – 2002 with conventional drilling and sampling techniques, were the following:

- Only one source zone was localized, originated on the site itself by discharging waste water directly into the groundwater via clarifiers;
- The chlorinated solvents plume, consisting mainly of TCE, stretches over a distance of 500 m;

Enhanced anaerobic bioremediation is a suitable remediation approach in the source zone since no pure phase is present.

During the design of a groundwater remediation strategy, 2020, a supplementary survey campaign was needed to have a better understanding of the distribution of the contaminations Therefore the EnISSA technique ,an on-site soil screening tool, was selected.

The survey campaign was based on the results of additional historical research. The main conclusions of this supplementary assessment can be summarized as follow:

- The initial source zone area may contain residual pure product which makes enhanced anaerobic bioremediation less suitable;
- It is not a single plume originating from a single source zone but two different overlapping plumes caused by the two secondary source zones, identified at the level of (former) sewer lines;
- The preferential distribution horizons were clearly delineated and the plumes of chlorinated solvents dissolved in groundwater are sinking;
- The degradation sequence of the chlorinated solvents in the plumes was clearly demonstrated.
- Based on the supplementary data the CSM was redefined. A re-evaluation of the groundwater contamination risk assessment is necessary.

75

An Integrated Hydrological Model For The Restoration Of Ecosystems And Flood Control: A Case Study In Mangelbeek Valley In Flanders, Province Of Limburg Belgium

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The Mangelbeek Valley is located in the province of Limburg NE Belgium. The valley is a part of the European project "Green WIN" (Interreg NWE Green WIN) which focuses on lowering the energy consumption and carbon emissions from water managers (Waterway Management Organizations WMOs) in NW Europe. The subject of the study in the Mangelbeek are pumps used for water management in the mining subsidence areas, among some other issues. The Mangelbeek valley is also home to six major sites. The sites have important groundwater dependent ecosystems (GDE), including peat areas. The sites are experiencing pressure by the water management. An improvement of these GDE is asked for. The province of Limburg and the Flemisch Land Agency (VLM) work together with Antea Group and several other stakeholders in this project.

Project phases:

- Inventarisation phase
- Simulating the present geohydrological situation with a groundwater model
- Describing the ecohydrological situation in the present situation
- Defining and simulating measures to improve the situation

The groundwater model consists of 3 model layers, reflecting the geological situation. The transient modeling of a three-year period with time steps of 14 days allows the calculation of summer and winter values. The groundwater model has been calibrated for the present situation and is also used to predict the effects of measures.

Using the results of the inventory of ground- and surface water, of the groundwater model, and of available descriptions of habitats, the present ecohydrological situation is described. In general, the groundwater table in dry situations drops too low for the most precious GDE. Also, the streams do not offer enough variation and shelter for aquatic ecology.

Investigating measures and scenarios for each Natura 2000 site are developed together with specialists in hydrology and ecology of the water managers. The measures include adjustment of pumping regimes, interventions in the water system including a revaluation of the Mangelbeek and removal of ditches and construction of pools for reptiles such as toads and frogs. Water system restoration changes the interaction between groundwater and surface water, resulting in wetter conditions. Changes in the streams also improve the habitats for aquatic ecology. The effects of the measures on the GDE are investigated using NICHE-modelling. The other effects are described qualitatively.

The last step includes the decision which measures and scenarios will be effected to reach the goals of the study, while limiting negative effects on other parties.

76

Groundwater In The Area Of The Copper Mine Tailing Pond In Żelazny Most (South-Western Poland)

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Copper mines belonging to KGHM Polska Miedź Corporation are the largest in Europe and constitute one of the biggest copper industry complexes in the world. Like most such industrial facilities, they leave their mark on the environment, including groundwater resources. since 1977. The waste stored at the site is not particularly hazardous to the environment, but its delivery in the form of a suspension containing highly mineralized water results in a build-up of 630 million cubic

metres of mineral phase and highly mineralized water in an area of 1532 ha; primarily water containing chlorides and sulphates, which affect the quality of the first aquifer and surface runoff in the area surrounding the tailing pond. Saline water delivery affects both groundwater and surface water in the ŻM TP area. Horizontal and vertical drainage systems are used both at the storage site and in front of the facility in order to reduce the negative impact of saline water from the tailing pond on the surrounding area and aquifers.

Changes in water composition are monitored at hundreds of monitoring points. The article presents the results of observations of the range and rate of saline water migration in the 41 years of the facility's operation. Currently, drawing on the data from 452 water quality monitoring stations, it can safely be concluded that groundwater salinity is increasing in a small area of approximately 322 hectares. The irregular range of water stains containing high levels of mineralisation ranging from 40.6 Cl/l (1988) to 6087 mg Cl/l (2018) is related to permeable preferential flow zones in the tailing pond substrate. The maximum vertical range of the saline water front is 1500-2000 m from the dam. The rate of movement of chloride-containing water is variable and equals on average 29-73 m/year. Increased chloride ion concentration in surface water has been reported. Analyses carried out between 2001 and 2019 showed a significant impact on groundwater resources both in the reservoir and less on the groundwater in front of the facility. The changes in the dynamics and quality of groundwater found in the area surrounding the storage site have forced the mine administration to employ active preventive measures, including innovative technologies which reduce the impact of the site on the local aquatic environment.

77

Characterization Of The Nitrate Contamination In The Chalk Aquifer Of The Mons Basin (Belgium) Using Hydrochemical And Isotopic Analyses.

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Whether it concerns the management of drinking water reserves or the preservation of natural ecosystems, a good understanding of the nitrate groundwater contamination is crucial. In particular, identifying its origin is often difficult, due to the variety and combinations of nitrate sources. This task is nevertheless decisive for mitigating the pollution and predicting its spatial and time evolution.

The chalk aquifer of the Mons sedimentary Basin, which is part of the South Belgium strategic groundwater reserves, is affected by nitrate contamination. Composed of Mesozoic chalk, it covers an area of more than 400 km², characterized by mixed land use activities including fields, pastures, urban areas and industrial sites. The aquifer is intensively exploited for water public distribution (50 million m³/year), to answer the local demand but also with significant volume transfers to Brussels city and other regions. Some parts of the aquifers are highly contaminated by nitrate, with suspicion of denitrification processes along specific interfaces such as confined – unconfined limits.

To characterize the pollution and related nitrate sources, sampling campaigns have been performed throughout the aquifer, covering the different land use areas and the confined/unconfined compartments. Classical hydrochemical analyses were performed to define the extent of the nitrate pollution, to locate potential denitrification zones and to highlight correlations with other major ions. In parallel, analyses of the $\delta^{15}N$ and $\delta^{18}O$ isotopes in nitrate were carried out. These isotopic ratios differ according to the chemical processes in which they were involved and allow to differentiate different sources of nitrate, including mineral or organic fertilisers, household waste degradation in landfills and possible leakage from sewer systems in urban areas. In addition, the amount of $\delta^{11}B$ in each sample is measured as it allows to better distinguish sewage, fertilizers or manure.

First results show significant variations in nitrate concentration at the scale of the aquifer, mainly explained by land use activities and the presence of confining units above the chalk aquifer.

The spatial distribution of the nitrate concentration and differences between nearby sampling points suggests the presence of spontaneous denitrification zones. Correlations between nitrate, iron and organic carbon concentrations are emerging and are interpreted to characterise denitrification processes.

Planned numerical modelling, based on those field results, intend supporting the management of groundwater resources in this type of aquifer.

78

Hydrogeological Model Of The Riga Old Town

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This study presents initial steps for development of an integrated 3D hydrogeological model of the Riga Old town. The goal of the study is protection of infrastructure and historical monuments from groundwater induced subsidence and exploration of water resources. The research area is located in the city centre at the Daugava River, approximately 14 km downstream from estuary in the Riga Gulf.

Down to 10 - 15 m of depth, Quaternary sediments are present. The Quaternary sequence mainly consists of anthropogenic deposits followed by loose sandy layers and glacial till in the lowermost part. Quaternary deposits are underlain by bedrock composed of marl, dolomite or clay.

Hydrogeological conditions are constrained by high groundwater heads, conductive sandy deposits and human impacts such as anthropogenic deposits, street pavement, drainage systems and underground parts of buildings.

Riga is a UNESCO World heritage site where the old-town represents medieval core of the city. Hydrogeological conditions are crucial for the urban environment because location of groundwater table affects health of wooden piles of the historical buildings. Degradation of wooden piles can occur when they are exposed to the atmosphere due to decrease of the groundwater table.

Moreover, alternations of groundwater heads and intense flowrate can cause settlement of land surface and foundations. Impact of climate change on groundwater conditions, induced through water level change in the Baltic is a relevant research topic as well.

Integrated groundwater modelling programme will be extended to detailed-scale geomechanical simulations is separated locations. Initial groundwater monitoring network in the yard of Riga Dom church was installed for obtainment of sufficiently long tine-series of groundwater observations.

Different scenarios of land-cover and drainage of rainwater will be implemented in later stages of the project for detailed investigation of groundwater recharge.

In this study we are presenting first steps of the model's building. Modelling data such as LiDAR surveys, historical drillcore records, cone penetration tests and observation of groundwater heads in piezometer wells are systematised. Public and private cooperation partners – city council and construction companies working on actual construction projects in the Old town are addressed to provide geological investigation and monitoring data for this project.

Preliminary results will include stratigraphical model of the Old town, evolution of the site's topographical and sedimentary conditions within context of 800 years settlement history. Governing boundary conditions such as Daugava river and City channel will be applied for the preliminary groundwater simulation.

79

Geochemical Characterization Of Groundwater And Saltwater Intrusion Processes Along The Luy River, Binh Thuan, Vietnam

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With an average annual rainfall of 800-1150 mm/year, the Binh Thuan province is one of the driest places in Vietnam. The quantity and quality of groundwater play a significant role in the agriculture, aquaculture development, and daily life of the local communities. Recently, prolonged droughts combined with sea level rise and over-extraction of groundwater increased dramatically the seawater intrusion process. In 2012, the national center for water resources delineated the seawater intrusion extent in Binh Thuan based on water samples taken from shallow boreholes. The salinity thresholds of 3g/L and 1.5g/L were exceeded in the estuaries of the Luy, Long Song, and Ca Ty rivers.

The geochemistry of groundwater in the Luy River catchment was studied to investigate the contamination of the aquifers. From 1991 to 2015, 98 water samples had been taken mostly from the shallow (< 10 m) wells in the area in both dry and rainy seasons. 71% of the water samples were fresh while 21% and 5% were lightly saline and moderately saline respectively. In summer 2020, 110 new water samples from both shallow and deep wells were collected in the Luy river catchment in wells from 3m to 40m. The TDS values are ranging from 105 to 23080 mg/L among which 48% are fresh (mostly at depth < 10 m), 40% slightly saline, 8% moderately saline, and 4% very saline. The samples show that the seawater intrusion expands not only horizontally at shallow depth along the river but also deeper down the aquifer in most of the study area, with some strong variations at short distance, which is confirmed by geophysical data. The chemical composition of water samples was analyzed showing evidence of seawater intrusion, but also the occurrence of freshening processes within the study area.

The sediments in the Luy's river catchment consist of sand, clay, marine fossils, gravel, and pebble and are quite heterogeneously distributed. They also underwent cyclic transgressive and regressive events from the Pleistocene to the Holocene. Therefore, the presence of fossil seawater trapped in the heterogeneous sediments in the Luy's river delta is a possible hypothesis. Together with the presence of saltwater at larger depths, this points towards a situation more complex than previously thought. Saltwater intrusions are likely not only related to interaction with the river estuary, but also to the presence of fossil saltwater in the aquifer, and groundwater pumping and irrigation practices.

80

Simulation Of A Geothermal Aquifer Storage In Brussels Showing The Need For A Better Balanced System With Regards To The Local Hydrogeological Conditions

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An Aquifer Thermal Energy Storage (ATES) system was started in 2014 in the center of Brussels using the Landenian confined aquifer for heat and cold needs of an administrative building. Unfortunately, imbalance between the injection of warm and cold water combined to the local hydrogeological conditions, have led rapidly to thermal interferences between the heat plume and the cold wells. A second ATES system located nearby started to operate around August 2017 for the heat and cold needs of another large administrative building. In the scope of the MUSE project (GeoERA/ERA-NET program), a numerical model was built using FEFLOW® to simulate groundwater flow and heat transport in the confined aquifer. After calibration on the available piezometric and temperature data, realistic scenarios were simulated to determine possible interferences and to image the year after year persisting and growing heat plume in the aquifer.

Results show that even if the heat plumes of the two systems had come into contact, the influence of the second system on the first one was negligible during the first two years of joint operation.

Indeed, for a longer period, simulated results pointed out that due to the thermal imbalance and the limited advection in the aquifer, the groundwater temperature would rise inexorably in the warm and cold wells of both systems. A business as usual scenario will lead to a decrease in efficiency for both systems. This case- study is showing how it could be difficult to find an optimum with regards to the local hydrogeological conditions. If advection is very important, thermal energy cannot actually be stored locally as heat and cold plumes are transported far away from the wells. On the contrary, if advection is limited, a global thermal balance is required for hot and cold injections.

If advection is moderate (as in this case study), a detailed simulation of the groundwater flow and heat transport in the aquifer is required to find out if the annual imbalance can be managed in relation with the specific local hydrogeological conditions.

81

Biomonitoring (Honey Bees, Earthworms And Aquatic Vegetation) As An Early Warning Of Groundwater Pesticides Vulnerability

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The study takes place in the Néblon watershed which is located in the BERWM021 limestones aquifer. The main outfall of the limestone basin is exploited by several catchment galleries. It produces around 10 million cubic meters of drinking water per year, which makes it one of the biggest catchments in Wallonia. It supplies a large part of the Liège conurbation, and constitute one of the major resources of the future Master Plan for water production in Wallonia.

The water produced in these galleries is of high quality. However, there are traces of some pesticides in the water.

Underground and surface karst phenomena take place at numerous sites within the basin. Several swallow holes are well known. These sites are direct contact points of contact between the surface and the groundwater and play a major role in terms of groundwater vulnerability.

We have been using honey bee, earthworms and aquatic vegetation as bioindicators to assess the quality of the air, soil and water ecosystems. In parallel, we have been collecting samples in air, soil and groundwater in search for pesticides content during 2 sampling campaigns, summer and autumn 2020. Herbicides are at major concerns in the first results.

82

The Treated Wastewater Effluent Impact On Contamination Of Water Supply Aquifer During One Decade Of Water Exploitation (Tursko Well Field, Poland)

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The studied recharge zone of the water supply aquifer (Tursko well-field, Poland) is located in an area of sparse water resources, where groundwater contamination was discovered, manifested by high nitrate concentrations and pharmaceuticals occurrence. The main objective of the presented study is documentation of steady deterioration of groundwater chemistry during one decade of groundwater exploitation and the trace of the wastewater impact on groundwater using pharmaceuticals as an anthropogenic tracer. This study presents an anthropogenic impact on groundwater chemistry caused by the influence of treated wastewater and drainage water. These waters infiltrate into groundwater from losing drainage ditch located in the water supply aquifer's recharge zone. It was determined that strongly contaminated water could deliver organic matter and nutrients to groundwater, what is the factor activated/intensified denitrification. As a result, the nitrate concentration decreases in groundwater, but concentrations of denitrification products (mainly sulphate and total hardness) increase. The oxidation of organic matter overlaps and causes periodical exceeding of the upper permissible limits for drinking water. The investigation of treated wastewater impact on groundwater chemistry was supported by pharmaceuticals as an anthropogenic tracer, indicating that infiltration of wastewater is a significant factor that influences groundwater drinking-water quality.

84

Hydrogeochemical Assessment And Geothermal Modeling Of Some Thermomineral Waters: Case Of Northern Algeria

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A thermal or thermo-mineral water is defined as a deep water whose temperature at emergence is higher than the average annual temperature of the region where it is located. It has constant physico-chemical characteristics for each spring (flow, temperature, mineral and gas concentration) and this, independently of climatic and environmental conditions (seasons, rainfall amount, drought periods).There exist on the Algerian territory more than 200 thermal springs that are mainly located in its Northern tectonically-active part.Their number regularly increases in the Eastern part of the country. Northern Algeria's thermalismis characterized by a great number of hot springs that are generally linked to a large number of geological fractures deeply affecting the sedimentary formations and sometimes even the crystalline basement. These fractures are often filled with Triassic evaporites. These fractures are mainly oriented NE-SW, NW-SE or E-W, limiting the large geo-structural settings.In this context, forty-seven hot spots spread over the North of Algeria have been measured and sampled for physicochemical and isotopic analyses in order to proceed with their characterizationas well as to estimate theirreservoirtemperatures. The results show that temperatures measured at the northeast emergences vary from 38.6°C (Beni Haroun, Mila) to 93.0°C (Hammam Debagh, Guelma).In the northwestern part, the measured temperatures vary from 20°C (Ain-Bagra, Aïn Temouchent) to 67.2°C (Sidi-Boussaid, Mascara). The calculated geothermal gradientswererespectively:4.0°C/100m in the eastern part, 4.3°C/100m in the western part while it is 4.2°C/100m in the central part.Hydrochemistry shows that these warm waters are characterized by the presence of three chemical facies.

The firstone fallsinto theNa Cl in the Eastern part, the secondone is classifiedas the Ca SO4type for the central partwhile the thirdone falls into the

HCO3 Na Ca type in the Western part. Hydrogeochemistry also shows that the salinity that characterizes these thermal waters is mainly due to the circulation of water at great depth in the gypso-saline formations of the Triassic.Saturation indices show that for the evaporite elements, halite is in under-saturated state which causes its dissolution and the presence of high concentration of bothsodium and chloride.Waters are also saturated with respect to quartz, calcite and aragonite. The δ18O and δ2H compositions vary respectivelybetween -6.3 to -9.6 ‰ and from 37.3 to 64.6‰ vs VSMOW2.Chemical geothermometry tools (silica and cationic geothermometer) allowed one to calculate the temperature reached by the hot springs after they infiltrated along the fractures and travelled undergroundtowards the basement before ascending again.

85

Induced Denitrification - Effect Of Temperature On Reaction Rate And Microbiology

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It will become increasingly necessary to treat nitrate-polluted water in the future, because the geogenic nitrate (NO3-) degradation capacity of aquifers is decreasing and finite. Without countermeasures, NO3- concentrations are expected to continue to rise. One of the most effective treatment methods is biological denitrification enhanced by organic carbon. To apply this method on the field scale and to increase its effectiveness, a better understanding of the reactions under real aquifer conditions is necessary.

This project aims at exploring and comparing the impact of temperature on the effectiveness of induced denitrification. Four organic substances (acetate, glucose, ascorbic acid and ethanol) are added as electron donors to circulation columns using sediment without degradation capacity. To evaluate the temperature dependency of denitrification rates, each series of experiments is conducted at room temperature (ca. 21°C) and typical groundwater temperature in Germany (10°C).

Results show a substantial temperature effect on denitrification. Besides a wide range of reaction rates induced by the different C substrates, denitrification rates at 10 °C differ considerably from those at room temperature. Contrary to many previous studies, reaction kinetics here does not increase with rising temperature for all electron donors. Ethanol is clearly the most effective electron donor for biodenitrification in groundwater with temperatures of 10 °C used in this study. With ethanol, a stronger and more effective NO3- degradation occurs at 10 °C than at room temperature, while glucose appears to be highly effective in regions with higher groundwater temperatures. With the addition of ascorbic acid, only a very low NO3- degradation can be achieved at both temperatures.

Additionally, there is a large production of biomass, which leads to clogging. Results of microbial community characterization show a strongly modified denitrifying microbiocenosis influenced by the choice of added organic substance. Also the temperature effect is clearly visible in microbial community composition with microbiocenosis changing considerably between denitrification at room temperature and 10°C.

86

Numerical Modelling Of The Ezousa Mar Site In Cyprus Using A Web-Based Approach

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The need to implement novel and environmentally sustainable technologies to mitigate water- related issues, such as escalating population growth and contamination of water sources, has become noticeable on a global scale. An elegant option to address these issues is to apply Manage Aquifer Recharge (MAR) schemes. These schemes are processes that intentionally recharge water into aquifers for future recovery or environmental benefits.

The MAR site of Ezousa, located at the south-western part of Cyprus, has been operational since 2003 based on Soil Aquifer Treatment (SAT) with the aim of providing a water supply mainly for irrigation purposes. Due to the semi-arid conditions and the groundwater overexploitation though, Ezousa MAR system is vulnerable to specific hazards, such as seawater intrusion and nitrate pollution due to intense agricultural activities.

An efficient way to evaluate these risks is by using numerical models to predict the response of the system under different conditions. Moreover, recent technological advancements in terms of computational capacity and internet accessibility have pushed towards the development of web- based tools for optimizing water resource management. These tools possess a number of advantages compared to conventional, desktop-based tools, such as locations and device independence, easy maintenance, as well as resource pooling. One such example is the INOWAS platform, which is a free web-service that focuses on groundwater-related issues. Particularly, this platform contains various analytical and numerical tools that can be used to improve the management and operation of groundwater systems, especially with relation to MAR. Accordingly, the present study focuses on using INOWAS platform for the development of a numerical groundwater flow model and its evaluation under different scenarios to assess the Ezousa aquifer.

Steady computations are first performed to calibrate the aquifer hydraulic properties (e.g. the spatial distribution of hydraulic conductivity) prior to the installation of the MAR facility in the aquifer. As a second step, a transient flow model for the period 2014-2018 was setup to analyze the impact of the MAR system on the groundwater flow system. Subsequently, the influence of increased water demand due to the agricultural development of the region as well as reduced water availability caused by climate change is analyzed through the simulation of various scenarios.

Preliminary results suggest that the web-based INOWAS tools are helpful to evaluate the influence of MAR on the local groundwater system under different scenarios.

87

Water Stewardship, A Transdisciplinary Approach For Sustainable Groundwater Management And Locally Addressing Water Related Sdgs : Joint Initiatives In Rejoso Watershed, Java Island, Indonesia

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Water Stewardship, defined as using water in a way that is socially equitable, environmentally sustainable, and economically beneficial, requires a transdisciplinary and integrated approach. This is achieved through a stakeholder-inclusive process that includes factory-and watershed-based actions, collectively defined and implemented with regional and local authorities,

small holders, grassroots non-governmental organizations, and academic institutions. It aims at guarantying long term water security for all uses and even beyond, for the nature's sake. And when groundwater is the main resource, hydrogeology is more than ever intertwined with social sciences.

A Water Stewardship Journey starts with the mapping of both water availability and demand e.g. water balance of the aquifer and water users, including ecosystems' needs, as well as all stakeholders with interest in managing water use, tapping both social and hydrogeological science data. Social sciences focus on how water resources are used and perceived by stakeholders. Various methodologies are used, starting with defining theory of change, then conducting surveys and focus group discussions with local community to identify barriers and leverages, as well as setting-up a local water forum and monitoring the impact of implemented solutions. Hydrogeological sciences lead to creating conceptual model and decision support tool design for stakeholders. When combined, these two data sets, results will be more credible and salient. Evidence-based information as the basis for decision-making leads to building the joint vision and collective responses of a multi- stakeholder forum. Awareness raising and dissemination targeting behavioral changes are applied by translating and presenting scientific results by using short videos, or games, and simple languages that are more appealing to wider audiences.

This socio-hydrogeology approach is illustrated with the case study of Rejoso watershed. The landscape has a volcanic hydrogeological setting, where collective responses have been implemented to face a decrease of groundwater hydraulic head of a confined aquifer. A full hydrogeological study allows determining the reason for the decline of water outflow at the major spring and of the piezometric level (Toulier, 2019). The implemented solutions focus on free-flowing wells management and rice cultivation practices with water efficiency optimization downstream as well as agroforestry with payment for ecosystem services upstream. The contribution of hydrogeology and socio-economic sciences will be presented, along with challenges and opportunities. Changing and practices require time, piloting solutions are influenced not only by human behavior and existing policy and regulations, but also naturally by climatic drivers. Many challenges still must be addressed and discussed.

89

Vulnerability Assessment Of A Tropical Cone Karst Area In Gunung Kidul (Java) As Resource For A Water Supply Improvement In A Changing Climate

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Developing countries in tropical areas are particularly affected by climate change. Gunung Kidul is a region in Indonesia which has suffered from water scarcity for a long time. In the past years, a shift in seasons with an increase in extreme weather phenomena was observed.

Gunung Kidul is geologically dominated by a tropical cone karst. This karst aquifer system is prone to water scarcity close to the surface but has high potential for underground water storage. Water supply and wastewater management in this area are poorly developed which leads to weak economic development and poverty. In 2011, an integrated water management system (IWRM) was installed including a hydro power plant in a karst cave to use the stored karst water to improve the regional water supply in some areas.

In order to design a sustainable strategy for water supply from karst water with respect to the whole region, it is necessary to develop a vulnerability map of possible recharge areas. Extreme weather phenomena can lead to high infiltration rates which exceed the karst system's capacity and lead to local flooding. Quick infiltration and flood events can result in a decrease of water quality and is therefore a risk for sufficient water supply. Furthermore, very dry periods also give the potential of enhanced groundwater vulnerability.

Former studies about underground karst rivers, recharge areas, and flood events are combined with recent remote sensing data first time of the whole karst area. This set of data is evaluated by using a geographic information system (GIS) to identify recharge areas of low vulnerability and to detect possible access points to related karst storages. This study will build the foundation for a concept of a sufficient and sustainable water supply for the future in Gunung Kidul.

90

Impact Of Climate Changes On Water Supply In Wallonia

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Wallonia presents favorable water resources. Groundwater withdrawals provide 75% of pipe-borne water and surface water the other 25%. They are amply sufficient to answer to the needs of population, industry and agriculture. Furthermore, the water network allows the large export towards Brussels and Flanders.

Water reserves rely closely on the local geological structure ; limestone and chalk formations provide around 75% of the groundwater production, the remaining comes from less productive aquifers. Therefore, water stress can locally and temporaly appear, resulting from a high water demand added to limited storage capacity of the aquifer.

Regular rains refill aquifers essentially during winter, when water is not used by vegetation. More the winter refill is good, lower the risks for water supply will be during the rest of the year. This refill also defines the water availablily in the reservoir dams, although these can still take advantage of later precipitations.

Nowadays, water use during dry periods is not always in adequacy with water production, particularly as a result of climate change. Indeed, first the available water is becoming lower due to winter recharges less long and more intense precipitations and secondly summers becoming longer and warmer. Moreover, dimensions of the current distribution network can't follow consumption peaks due to heat waves. Drought is closely monitored for several years in Wallonia. All water stakeholders periodically gather in the CRC-W to discuss about the evolution of water ressources and make decisions about management and communication towards the public. Dealing with recurring droughts in Belgium is part of the Regional Scheme of Water Ressources, mission mandated by the Government to the SWDE to distribute quality water in abundance across the country. Thus, research is undertaken to lead wisely the territorial development, highly depending of the local available water ressource and to increase the performance of the public infrastructure by reducing water leaks and connecting public operators networks. Moreover solutions are studied to help the agricultural sector to face drought by finding alternative water ressources.

Alongside, drought has led the Government and water producers to study by modelisation the evolution of the Walloon groundwater bodies in order to predict the measures to carry in order to preserve them. Regularisation of boreholes and water uses prioritisation have to be established to avoid overexploitation of aquifers during low-water periods. Finally, cooperation between neighbouring states for a sustainable management of the cross-border groundwater bodies is required.

91

Hydrogeological Characterization Of Crystalline Bedrock Using Borehole Magnetic Resonance At A Mining Development Site, Northern Finland

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The Borehole Magnetic Resonance (BMR) method was tested for measuring porosity and estimating groundwater flow

parameters required for hydrogeological modelling in a crystalline rock setting at the Sakatti Ni-Cu-PGE mining project site in Northern Finland. The characterization of hydraulic properties of deep bedrock, shallow fractured bedrock, surficial deposits as well as groundwater and surface water flow patterns and interactions between them is informative already during ore prospecting phase. Although BMR is widely used for determining storage and flow properties in sedimentary rocks forming hydrocarbon reservoirs, there have been few studies in basement rocks as described here.

The BMR method allows the detection of water in the subsurface by applied electromagnetic fields in a continuous manner with decimetre-scale measurements along the boreholes. The measured response is inverted to give a continuous distribution of relaxation time T2 which is a direct measure of the amount of water, or pore volume. This can further be divided into bound water and free water using specific cut-off values for each lithology, which can then be used to calculate estimates of hydraulic conductivity.

The Sakatti Cu-Ni-PGE deposit, located several hundred meters below the Natura2000-protected Viiankiaapa mire, displays complex and heterogeneous subsurface geology, hydrogeology and deformational history. The BMR data was acquired from six drillholes in order to obtain specific information about the structural heterogeneity and free water content within the depth interval of 50 to 360m, and thus estimations of the local flow parameters. Other available survey data, such as natural gamma ray, acoustic image data, core logging and packer tests were compared with the BMR data in order to compare and calibrate the groundwater flow parameters calculated based on these measurements. The initial results indicate that BMR is a suitable tool for studying lithologically and hydrogeologically heterogeneous fractured crystalline rocks. Flow parameters derived from the measured T2 distributions vary significantly throughout the intervals. In this crystalline bedrock setting, independently from the lithological composition, the measured intervals locally display relatively high hydraulic conductivities, and may be correlated to the more intensely fractured and/or brecciated zones. In addition, BMR may reduce more time-consuming methods such as packer tests or replace them altogether in regions where borehole conditions prevent the likelihood of successful testing. Furthermore, the BMR log provides continuous data over fractured crystalline basement rocks. This will include questions dealing with interactions between surface water, shallow groundwater as well as groundwater in fractured and weathered bedrock.

92

Coping With The Risk Of Salinisation In The Zwin Area

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The Zwin area is a nature reserve on the Dutch-Belgian border. The area is a remnant of a tidal inlet through which the medieval city of Bruges was connected. However, from the late 13th century onwards, the channel was affected by silting up progressively which led to the decline of the thriving city economy.

The silting up of the Zwin area remains a problem. To counteract this, the area has been enlarged in 2016-2019 with an extra 110 hectares surrounded by a new dyke. However, the flooding of the enlarged area with seawater would almost certainly cause saline seepage in the adjacent polder area. To cope with this risk of salinisation, a dual barrier system was designed just behind the dyke. It consists of two ditches with different purposes: the ditch closest to the dyke serves as a drainage channel and captures saline seepage coming from the tidal area. This “saline ditch” is pumped to lower the water level and the pumped water is discharged in the nature area. The second ditch, further away from the dike, serves the purpose of infiltrating fresh water into the aquifer. This “freshwater ditch” is fed by the upstream Polder drainage system and maintained at a higher water level. The combination of both ditches forms a hydrological barrier and prevents salinisation of the agricultural land surrounding the Zwin area.

However, due to the heterogeneity of the aquifer, this shallow barrier isn’t sufficient to counter deeper saline groundwater flow.

Several solutions to capture the deeper saline flow such as gravel drains underneath the ditch or deep wells were compared. Field tests showed that saline seepage in the deeper part of the aquifer could be passively drained by vertical wells overflowing in the saline ditch. The use of wells delivers multiple benefits such as controlling of the flow rate and drainage level, accessibility for monitoring and maintenance, and the possibility to close off the well. The robustness of the final design has been extensively tested with 2D and 3D groundwater models.

Important factors are the distance between the wells, the filter screen interval, the heterogeneity of the aquifer and the hydraulic resistance between the groundwater and the ditches. The system will be tested in a field trial with four wells and extensively monitored. The combination of ditches and vertical wells will eventually enable us to fully control the risk of salinisation in the Zwin area.

93

Groundwater Availability And Management In Mexico: Case Of Study “Toluca, Mexico”, Water Stewardship Project.

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Groundwater is a major resource for Mexico as a country, contributing to 39% of the water needs, water supply and water for irrigation. Groundwater supplies 58% of the water demand in cities where 60 million inhabitants are living. In addition, it contributes to cover 36% of the water for irrigation at a national level and satisfies a large part of the industrial demand (CONAGUA, 2018). The groundwater resources are under pressure, threatened by overexploitation and contamination due to anthropic activities. 16% of aquifers at national level (i.e. 104 major aquifers) are overexploited. Northern and central Mexico areas have low water availability, in contrast of the southern region that has the highest availability. Thus, due to the concentration of large urban areas in the central part, 66% of population and 85% of gross domestic product are in water stressed zones.

Intensive groundwater extraction puts at risk the sustainability of aquifers resource. To address this, Mexico is improving its water policy, with some measures concerning over allocation of water rights. However, as water counts for everyone, collective responses at the watershed level must be implemented in the framework of Water Stewardship (WS) to address those important water issues, building on existing water governance set up by the authority, such as local technical committee of groundwater management (COTAS). COTAS is responsible for enabling participatory groundwater management and producing a groundwater management plan including all water users.

DANONE Waters Mexico (BONAFONT) is operating, extracting groundwater from aquifers.,. We illustrate the approach of WS that is carried out, considering the case study of Toluca’s aquifer. This aquifer is located in the central part of Mexico, where water supply for industrial and urban area is almost exclusively met by groundwater; the intensive groundwater exploitation has caused an average decline in groundwater level (1m/year) with some subsidence problems. Major water and environmental shared challenges are analyzed based on available data from COTAS/CONAGUA and scientific literature, as well as existing initiatives are mapped. From this analysis, a first theory of change map is drawn to determine actions to be further designed with partners such as water efficiency in agriculture practices, nature-based solutions to reduce erosion and restore surface water quality, as well as aquifer modeling update. Toluca’s case will highlight the importance to develop a water stewardship actions in such areas, in partnership with local authorities, academic institutions, and major stakeholders.

94

Water Bottling Industry And Sustainable Water Resource Management Under Global Change: How Water Stewardship Interacts With Iwrm At Watershed Level?

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Groundwater resources under development for domestic, industrial, and agricultural purposes, are threatened with both quality and quantity issues from anthropogenic and natural causes. Without a sustainable water management, water use conflicts may arise with drastic economic, environmental, and social consequences.

Various companies are today concerned about the sustainability of water resources, in particular groundwater, especially the water bottling industry that is operating on Natural Mineral Water or spring water from groundwater origins. Several drought events, with serious consequences in the agriculture sector, namely in Australia and also in other parts of the world - Africa and in less extent in Europe-, back to early 2000, are at the root of the Water Stewardship (WS) concept. In 2007, CEO Water Mandate (UN) was launched with the aim to engage CEOs of leading companies in committing to develop collective solutions in response to such growing water crisis. Unlike the concept of Integrated Water Resources Management (1977), where the focus is on institutional arrangements at country level with setting planning frame, the WS embarks public and private stakeholders at territory level. Although their end goal is similar, i.e. to ensure a water resources management that satisfies both economic and social welfare with equity and above all, without compromising the sustainability of vital ecosystem (Hassing et al., 2009), their scope of intervention differs as WS sets collective field responses out through landscape approach. These collective responses are co- designed with bankable features to enable co-funding from private sector, local and internationals NGOs. At watershed level, initial steps to start WS journey could be to carry out an hydrogeological study that would define the recharge area and the water balance, the groundwater and surface water interactions, and to gather socio-economic data in order to complement any IWRM knowledge already available e.g aquifer delineation, boreholes database and water allocation.... As such, preservation solutions can be co-built targeting specific issues (e.g. water supply reliability with reduction of water losses, efficient irrigation techniques, wetland conservation...).

Several examples will illustrate how the Danone WS Journey interacts with IWRM at watershed level and what the joint benefits are, in Europe, Asia and Latin America, for confined and unconfined aquifers. In addition, how also Water Stewardship challenges, such as implementing a project with balancing stakeholders points of view on water issues, improving governance to overcome institutional barriers, or communication issues about technical topics towards communities, among others, are tackled will be discussed.

95

Transient Electromagnetic Sounding And Electrical Resistivity Tomography As Tools For Improving Hydrogeological Knowledge In Regions With Scarce Data

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Semiarid regions are constantly in search of fresh water sources for their daily social and economic activities. This task might become more complex when comprehensive information is not available (e.g. geological, hydrogeological and hydrological information). The western and central regions of Bolivia are characterized by a fast growth of population, a growing agricultural activity, and scarce surface water offer. As a consequence, groundwater becomes an important source of freshwater.

However, the lacking and/or limited information in terms of hydrogeology and geology makes it difficult to plan a sustainable groundwater management and extraction within several regions of Bolivia. The aim of this paper is to summarize the most important findings in terms of hydrogeology and geology. These findings were possible after performing six years of geophysical campaigns in five pilot areas (Punata, Toco, Chocaya, Challapampa and Pucarani) located in the western and central parts of Bolivia. The main used geophysical methods were ERT and TEM.

The geophysical results and interpretation allowed to detect areas where thermal intrusions occur in the Challapampa fan. The geophysical information retrieved in this project was also very useful for refining the hydrogeological conceptual models. For instance, in the Toco and Punata alluvial fans the refined model has an extension of 20 km and reach a depth of about 150 m below the surface. Some complementary results highlight a very saline layer in the bottom of the Punata aquifer system, hence new regulations about the maximum drilling depth of new well must be elaborated in order to prevent salt water intrusion. The results in this project evidence that the applied geophysical methods are highly suitable for retrieving key information. The resistivity models from ERT and TEM complement each other very well. This project is a milestone in Bolivia as regards the large amount of geophysical information produced.

96

Development Of A Participatory Methodology For The Identification Of Water Recharge Zones In The Inter-Andean Valleys Of Tiraque, Bolivia

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Achieving effective water management under scenarios of misuse of natural resources, rapid and excessive population growth and the ever-widening climatic variability is an intricate sustainability problem that requires integrated solutions. In this sense, groundwater is especially fragile due to the fact is often ignored in comparison to other water bodies, despite its vital importance for diverse ecosystems and communities around the world. The vulnerability of an aquifer system is also relaying on the lack of protection of recharge and discharge areas and pollution from human activities. Hence, it is necessary to develop regulations that promote the protection of water taking into account actions that allow its rational use. This also requires a change in the attitude and customs of users in order to improve their relationship with water and its territory, and as well to adapt agricultural practices towards greater efficiency on water use. The case study presented here deals with the implementation of a water-related policy in Tiraque (Bolivia), which aims to protect water recharge zones in the upper part of the local basins. For the policy to be applied effectively, science and engineering must serve as tools that lay the foundations, for example, to identify precisely the areas that should be protected with the policy. For this purpose, numerous methodologies have been developed, though most of them need numerous hydrogeological parameters as inputs, which are usually not available in developing countries.

Therefore, this study proposes a participatory-simplified multi-criteria decision method that uses categorical values and variables with significant influence on water infiltration. The proposed methodology was developed and adjusted to the specific conditions of the basin, taking into account specially the different local vegetation communities and their influence on infiltration processes. With the intention that local communities can use this tool for the sovereign management of their water resources independently in the future, technical knowledge was complemented with knowledge of the local communities about their territory.

The results obtained by using the proposed methodology are congruent with water infiltration field measurements and, likewise, the initial application by the community show potential to be used in the framework of the proposed policies. Therefore, the proposed methodology can be of special interest when protecting and managing groundwater is pursuit, where there is restricted hydrogeological data.

99

Modelling The Effect Of The Roer Valley Graben Border Faults On Groundwater Flow: The Case Of The Grote Brogel Fault

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The border faults of the Roer Valley Graben (RVG) have been reported to act as barriers to groundwater flow and altering its regional behaviour. At the location of these faults, high hydraulic gradients have been observed due to the low permeability of the fault zone. This affects the flow patterns and travel time and is of high importance for characterizing the protection zones around groundwater extraction wells. This study focuses on the Grote Brogel Fault (GBF), which is a major WNW-ESE striking normal fault in Belgium. Previous studies at two sites along the GBF, Maarlo and Bree, have integrated Electrical Resistivity Tomography (ERT), Cone Penetration Test (CPT) and borehole data. Monitoring data of the groundwater levels, showing large hydraulic head differences of up to 13 m as a result of the GBF acting as a flow barrier, is available for both sites. In one of the sites (Bree), a local stepover in the shallow subsurface was observed, affecting the groundwater levels in the different fault blocks.

The aim of the present study is to investigate the role of the GBF on the local hydrogeological conditions, considering local fault complexities observed along this border fault. To achieve the main objective, numerical groundwater models were built. A preliminary sensitivity analysis was performed to determine the parameters controlling the fault zone hydrogeological behaviour. The monitoring data from Maarlo was used for calibration and further validation of the model. Finally, a model was set up for the Bree site to test different fault linking scenarios and observe their response to groundwater flow.

The results of the sensitivity analysis showed that the thickness and hydraulic conductivity (K) of the fault zone are the most crucial parameter controlling its behaviour. Moreover, the ratio between the formation K and the fault K and the dip of the fault control the steepness of the hydraulic gradient across the fault. After calibration, the model was able to simulate the trends of the hydraulic head in the footwall and the hangingwall which are largely controlled by the recharge rates. For the Bree site, the defined scenarios for the stepover pointed out differences in groundwater flow, specially between soft-link and hard-link scenarios. These differences could be observed in the field by installing a monitoring network with several piezometers. Some guidelines are given for the installation of a larger monitoring network.

100

Groundwater Head Time Series Analysis With Non-Linear Recharge Models - Msc Thesis

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Time series analysis with transfer function noise (TFN) modelling (using predefined response functions) is becoming a more popular method to analyse groundwater head measurements. To do this successfully the response function of each stress has to be estimated, including the uncertainty. The most commonly used stress for these models is the recharge flux which can be approximated by a linear combination of the precipitation and the (potential) evaporation. This is a big simplification given that soil water flow is highly non-linear.

Some research has already been done to implement non-linear recharge models in time series analysis. For instance the model of Berendrecht which introduced non-linearity by modelling the degree of water saturation of the root zone. Collenteur recently used a non-linear bucket recharge model based on the Flex modelling concept. This abstract describes the results of a new research, which is focused on the general applicability of non-linear recharge models under different hydro- geological settings.

To test the applicability of non-linear recharge models, HYDRUS-1D is used to model the unsaturated zone and groundwater

head. This way synthetic time series are generated for different hydro- geological settings. The results of using non-linear recharge models for time series analysis are promising. When time series analysis is done on the synthetic time series, the fit improves significantly with the use of non-linear recharge models compared to the linear recharge model.

The performance is better especially during dry periods, when no more water can be evaporated from the root zone due to the low saturation. The linear model cannot correct for this situation, maintaining a negative recharge flux, estimating a too low groundwater head. This is a common problem with the linear recharge model which is also observed when using measured time series.

The assumption that the response of the groundwater head is the same for a precipitation (or evaporation) flux of equal magnitude is also found to be wrong when using TFN modelling in time series analysis. The predefined (gamma) response function assumes that the response to a precipitation event is always the same and not dependent on the state of the system. It is seen that the block response of the groundwater head can be quite different, depending on the depth of the groundwater head and the soil moisture content in the unsaturated zone.

101

Local And Large Scale Climate Forcing On Groundwater Management Of Tropical Islands

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In Indonesia, and more particularly on the island of Java, anthropogenic development causes significant pressure on water resources, especially on groundwater. At the base of andesitic volcanoes, important artesian springs and wells are used to supply drinking water to the population. Their recharge occurs along the volcanoes' slopes inducing seasonal variations, which are notable in springs' discharge time series. To understand their hydrogeological functioning and to set up a sustainable management for water resources, it is necessary to correctly estimate the recharge of these aquifers. This quantification requires an accurate and continuous monitoring of rainfall and potential evapotranspiration highly variable along the slopes of volcanoes.

In such mountainous tropical setting, each year is characterized by a dry season from April to October under Asian monsoon regime, while the dry season is impacted by the Australian monsoon from November to March. Locally, steep topography of young volcanoes strongly impacts the circulation of the hot and humid air masses generated by the Indo-Pacific Warm Pool leading to a strong spatial and temporal rainfall variability. At larger temporal and spatial scales, El Ninõ- Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) are irregular climatic variations above the Pacific and Indian Ocean respectively. They both induce teleconnections impacting South Asian atmospheric circulations and temperature.

The first part of the study is a spatially high-resolution analysis of the spatial and temporal dynamics of rainfall over three andesitic volcanoes (Gede, Pangrango, Salak) located south of Jakarta. The objective is to analyze the strengths and weaknesses of three high spatial resolution global products (CHELSA, CHIRPS and TerraClimate) with respect to ground rain gauges monitoring. Our study used statistical and spatial analysis of both datasets to demonstrate that only ground data are currently adapted for an accurate water management of volcanic slopes under tropical climate. Nevertheless, TerraClimate demonstrates overall good performances to qualitatively understand temporal trends as well as an ability to catch coarse local orographic effects.

The second part consists on a statistical analysis of Terraclimate time series highlighting a significant mean temperature increase while rainfall variability appears to be more complex. In addition, both rainfall and potential evapotranspiration anomalies are correlated with ENSO/IOD climate indices. These regional phenomena particularly impact dry season climate increasing the intensity of droughts in some conditions. After the integration of the global product uncertainties, this climatic forcing analysis can reliably be used for local water resources management and forecast springs' discharge.

102

How To Set Up An Operational Lumped Model For Groundwater Management Of A Volcanic Artesian Aquifer

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In andesitic volcanic setting, geological formations display important longitudinal and lateral lithological variations, leading to complex aquifers. Along the volcanoes' slopes, effective rainfall infiltrates to recharge local perched aquifers or percolates deeper down to larger basal aquifers. At the bottom of the slopes of these volcanoes, the accumulation at the surface of weathered volcanic- detritic and laharic formations locally confines the basal aquifer, which often becomes artesian.

Previous studies demonstrated that recharge occurs along the slope of the volcanoes. Recharge is therefore controlled by the spatial and temporal variability of climatic forcing on the volcano slopes and geological structures controlling groundwater flow. Moreover, the spatial heterogeneity of the surface low permeability formations can induce various spring typologies. The main outlet can be concentrated in a major spring or diffuse in an emergence zone where the aquifer supports several dozen springs and/or supply streams. These complexities make it difficult to quantify groundwater flows and thus to implement a sustainable management of the resource.

On the slopes of the Salak volcano, south of Jakarta (Indonesia), our study aims at characterizing the structure and functioning of an important artesian aquifer in order to support the sustainable management of the groundwater resource. For this purpose, we developed a reservoir model which structure is conceived to integrate various processes such as climatic forcing and groundwater flows stratification. The model is composed of three reservoirs in series which tends to represent soil moisture dynamics, perched aquifers and deeper aquifers, respectively. The recharge area was defined by coupling a water balance approach with isotopic measurements. It is thus possible to integrate the evolution of climatic forcing along the recharge slope. Finally, the model parameterization is validated by a sensitivity analysis in order to reproduce accurately both aquifer discharge monitored at an artesian spring and its seasonal and interannual dynamics. The obtained model allows a better understanding of the functioning of the underground hydrosystem while providing an adapted and efficient operational management tool for the water resource. Finally, we coupled these results with an assessment of climate forcing for the short and medium term in order to provide operational information to local operators.

103

Quality And Vulnerability Of Groundwater In The Zaccar Karst System

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The objective of this investigation is the application of geochemical and isotopic techniques for determining the quality of groundwater for a system of a karst in a semi-arid environment.

For the case study, Zaccar, which is a karstic system of primary and secondary age, is affected by a network of very dense faults, which favors the infiltration of water at the expense of runoff. Mount Zaccar with its 1554 meters of altitude is the culmination of the Dahra Mountains' chain in Algeria. It represents a geographical entity of an area, which is close to 90 km2. The populations of Miliana and the neighboring towns have always relied on those Limestone aquifer reserves occurring in the region for the drinking water supply. The stratigraphic series of Jebel Zaccar is quite complete, with at the base a Palaeozoic basement overlain by secondary to Quaternary age formations. A rainfall approaching 700 mm, and a fissuration density favoring good infiltration characterizes the study area. These two key-features make the reserve exploitable. On the other side, it makes the resource very vulnerable to different types of pollution. Through this research work, a contribution was made to the hydrogeological study of the mineral waters of the Zaccar karst system. The survey highlights the qualitative characteristics of groundwater using hydrochemical and isotopic tools. More than 40 water points (boreholes and springs) were sampled in order to implement such a research work. The waters have a calcium, magnesium and bicarbonate dominant chemical facies that is typical to a carbonate reservoir. The hydrochemical analysis made it possible to highlight the relationship that exists between the host environment and the infiltrated water. all water points study respect the drinkability standard except some springs are marked by nitrate pollution with figures exceeding the standards of drinkability. This confirms the vulnerable aspect of karst aquifers especially in urban areas where sanitation networks are poorly designed.

104

Stakeholder Perspective Analysis To Improve The Sustainable Groundwater Management In Four Water-Stressed Mediterranean Areas

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In the Mediterranean, the proper management of groundwater resources is assuming an even larger importance in the context of climate changes. As a result, the challenge for the water planners is to adopt more efficient aquifer management plans to avoid undesirable effects, such as land subsidence or salinization, that limit the farmland productivity.

The RESERVOIR project (sustainable groundwater RESources managEment by integrating eaRth observation deriVed monitoring and fl0w modelIng Results), funded by the Partnership for Research and Innovation in the Mediterranean Area (PRIMA) programme supported by the European Union, is aimed at providing a new approach for the sustainable management of groundwater using low-cost and non-intrusive tools such as satellite-based Earth Observation (EO) data. The approach will be developed in four water-stressed Mediterranean areas: the coastal aquifer of Comacchio in Italy; the Alto Guadalentín aquifer in Spain; the alluvial aquifer of the Gediz River Basin in Turkey; the Azraq Aquifer (Azraq Wetland Reserve) in Jordan.

Current groundwater management problems in the four pilot sites were evaluated taking advantage of stakeholder participation. A number from 13 up to 31 stakeholders were engaged for each pilot site. The stakeholders represent public organizations at the municipal, regional, and country levels, national and local authorities responsible for water and land use management, environmental agencies, water supply companies, non-profit relief organizations, private companies, farmers, irrigators associations, civil society organizations, industrial consumers, research and academic organizations.

The identified stakeholders have been mainly engaged via a questionnaire translated into the native languages of the countries of each pilot site.

RESERVOIR questionnaire results show that the main problems related to the groundwater management are different in the four pilot sites. From the stakeholder perspective, the main issue in all the pilot sites is the over-exploitation of groundwater, except for the coastal aquifer of Comacchio, in Italy. In this coastal aquifer the problems are land subsidence due to natural and anthropogenic processes and saltwater intrusion in the phreatic aquifer. The majority of the participants consider that the groundwater level and groundwater quality monitoring network is insufficient, even though the quality level of a monitoring system is quite subjective, changing from group to group and site to site. The results highlight the need to define objective parameters to evaluate the adequacy of a groundwater monitoring system considering both the spatial and temporal sampling strategies.

106

Antibiotics And Args In Natural Springs: Are They Predictable As Subsurface Groundwater Pollutants? Insights Based On Natural Spring Data

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Pharmaceuticals and antibiotics (PhACs) occur in groundwater because of the use of organic fertilizers in agriculture, such as livestock waste, or the impact of human sources. Livestock waste can be an important reservoir of veterinary antibiotics (ABs) and bacteria carrying antibiotic resistance genes (ARGs), due to the large amounts of pharmaceuticals used in animal husbandry. The fate of ABs in the subsurface is governed by hydrogeological and geochemical processes, which depend on the aquifer nature and the compound behaviour along the flow path. Natural springs stand as locations where flow paths outcrop and, provide information about pollutant transport processes. A seasonal survey of pharmaceutical compounds at 11 natural springs in Osona (Barcelona) was conducted to describe their fate in the uppermost parts of a hydrogeological system. Neither changes in chemistry nor in stable isotope content, which describe the spring hydrogeology, seem to influence nitrate concentration, as nitrate content stays uniform despite geological variations. A steady hydrological regime can thus be defined for each spring based on chemical data. Just a few PhACs are regularly found in springs, being the most common doxycycline, ofloxacin, sulfamethazine, and sulfamethoxazole. Where found, concentrations are usually about the same order of magnitude. The large seasonal variability of their occurrence in the spring flow is attributed to hydrological factors and reactive transport processes. Nevertheless, given the steadiness of the chemical and isotopic parameters and the high reactiveness of PhACs in soils, we postulate that their appearance could be linked to past strong recharge events.

ARGs conferring resistance to sulfonamides (sul1) were the most abundant and widespread genes in natural springs. Sul2, which also confer resistance to sulfonamides, were detected in some sites at similar concentrations. tetW, conferring resistance to tetracyclines, were detected in some springs. In general, ARGs copy numbers were lower in winter samples.

In synthesis, some PhACs are usually present in the spring flow, and subsequently in streams and aquifer recharge; yet the predictability of their appearance in springs is low. Seasonal variability hinders the assessment of spring water quality for public uses, and the execution of efficient monitoring strategies.

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107

Seasonal Recharge Vs Regional Flow Effects On Antibiotic Occurrence In Groundwater

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Antibiotics and antibiotic resistance (AR) in the subsurface, derived from manure fertilization, are considered as contaminants of emerging concern. Their fate depends on complex geochemical processes and conditions; whose detailed dynamics is still far from being properly understood.

This research addresses the hydrological behavior of these pollutants in groundwater under seasonally changing hydrological conditions so monitoring and prevention strategies can be efficiently delineated. It links two relevant issues that determine our capability to deal with such type of pollution; first, the effect of hydrological variability on their occurrence, and second, how to adequately include them in the groundwater quality management plans.

Based on a detailed monitoring survey in the Baix Fluvià alluvial aquifer (NE Catalonia), the spatial occurrence and temporal distribution of antibiotics is analyzed and interpreted within the regional hydrogeological context.

Antibiotic data indicate that seasonal recharge has a strong influence on their occurrence. Given the high adsorption and degradation rates, some antibiotics can only be found when intense infiltration occurs, and their usual low concentration is the result of mixing (dilution) with the regional groundwater flow, explaining the sparsity of their occurrence. Notice that groundwater withdrawal rates also stay as an important factor of their identification in groundwater samples. Only a few compounds (i.e., those with large input loads and lower reaction conditions) are considered to be uniformly distributed along the aquifer, and define a background level.

The outcome of this research provides and explanation for the sparse spatial and temporal distribution of antibiotics in aquifers, as observed in the Baix Fluvià area. Results indicate that the identification of these pollutants will largely be influenced by the hydrological regime, which will vary seasonally as well as with the newwith climate change scenarios. This is paramount to establish trustable monitoring strategies upon which develop management plans.

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109

Preliminary Assessment Of Local Water Shared Challenge As First Step Of Water Stewardship Journey: Study Case Pandaan Watershed, East Java, Indonesia

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Understanding local shared challenges is instrumental to start a Water Stewardship (WS) journey. As company, we illustrate the preliminary assessment of local water shared challenges on Pandaan watershed where we operate, in East Java, Indonesia, focusing on land use and water uses as well as on preliminary hydrogeological conceptual model that will be necessary to elaborate a precise diagnosis of the water resource status and propose sustainable management scenarios.

This watershed situated on North-eastern part of Arjuno-Welirang Volcano covers around ±372 km², groundwater takes place within the volcanic aquifer complex with shallow (unconfined) and deep aquifers (confined to semi-confined). Water is mainly extracted for agriculture, domestic, industrial (mostly manufacturing, textiles, tourism, bottling water industry, and refill station). Based on a Water Risk Assessment analysis (WWF methodology), this watershed is under a high physical risk.

Recent land use changes at the watershed level is one contributed factor for this risk. Based on land use change analysis, the forest cover has reduced by 26% for the past 25 years in favor of settlements and tourism areas, in the upstream part of the watershed. In the downstream area, agriculture and dry land area is decreasing around 8% of agriculture and dry lands have been lost in favor of settlements and industrial area. This trend has serious consequences on water demand and water sources. Total domestic needs increased around 1.5 Mm3/year over the last 10 years mostly abstracted from shallow aquifer. The deep aquifer has been expanded for industrial uses around 33.8 Mm3/year 1,072 L/s thus turning groundwater into challenging and critical water shared resource. The impact on the groundwater showed on depression cone of dug wells and deep piezometers. Moreover, the first geological and hydrogeological analysis of volcanic and sedimentary layers of this watershed (Baud et al. 2021) based on available geological and hydrogeological data of the Arjuno-Welirang Volcanic Formation, Middle Quaternary Volcanic, and the Volcano Sedimentary Plain highlights the need of setting a detailed conceptual model. The recharge area needs to be more accurately defined as well as all the compounds of the water budget. It will allow to set up also a numerical model to test some water management scenarios. All this preliminary information is presented in a synthetic approach, to make it easy to share water understanding among stakeholders and define collective responses to implement to guarantee a long-term sustainable water resources management.

110

Impact Of Subirrigation With Treated Domestic Wastewater On Groundwater: A Field Experiment In Kinrooi, Belgium

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Climate change is projected to increase evaporation, intense precipitation and the intensity and frequency of droughts. The importance of evolving to a circular water economy has grown over the years. In 2020, the legislation on minimum requirements for water reuse in agriculture was approved by the European Parliament and Council of the European Union. Thoroughly monitored experiments with treated wastewater are essential for the risk assessments needed to translate these regulations into law. The Vrije Universiteit Brussel, Soil Service of Belgium and Aquafin initiated a case study where secondary treated domestic wastewater is used for subirrigation in agriculture.

The study started in 2019. Subsurface drainage pipes are installed and used to infiltrate effluent into the soil. The subirrigation system has four blocks which are controlled independently and online in real time.

From January 2020 to March 2021, before the subirrigation system was in operation, various water quality parameters were monitored in the groundwater, effluent and surface water, to infer the background concentrations in the groundwater, to characterize the effluent and to infer the quality of the river water. Parameters measured are basic physicochemical parameters (pH, electrical conductivity, total dissolved solids, salinity), nutrients, trace metals, phenols, pesticides, volatile organic compounds, microbial parameters (E. Coli, Salmonella) and bioassay measurements for estrogenic activity and polycyclic aromatic hydrocarbon activity (ER-CALUX and AhR-CALUX). Oxygen concentration, deuterium stable isotopes and the Br:Cl ratio are measured to trace the advance of the effluent in the groundwater. Continuation of these measurements allows to infer the influence on the groundwater quality while infiltrating the effluent in the soil.

Groundwater levels are monitored in 15 locations at various depths to conclude the influence on the groundwater quantity. Cone penetration tests with pore water pressure measurements were carried out to characterize the subsurface.

The influence of the subirrigation on the quantity and quality of soil water and groundwater will be reproduced with a groundwater flow and transport models with MODFLOW and with unsaturated flow and transport models (HYDRUS 2D). These models will allow to make predictions for the long term effects of subirrigation with WWTP effluent waters.

111

Delineating Groundwater Occurrence And Patterns Within The Free State Province, South Africa

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Climate change and its attendant consequences are one of the most devastating environmental issues facing countries all over the world. In South Africa, the persistence of drought conditions has resulted in various water-adjustment policies in different provinces. The prolonged drought condition has created water stress environments affecting both crop and man. Within the agricultural space, adjustments in terms of improved irrigation have been one of the promising solutions while for human sustainable livelihood, it has been water rationing. Across most provinces and municipalities, the provision of water has largely rested on groundwater. Water for drinking is purchased as commodities in bottled water while other conjunctive use of water rested on what the groundwater can offer. The distribution of groundwater across space is a natural resource is expected to be highly variable. For a country like South Africa, considering her physiography and geology, the occurrence and distribution of groundwater are expected to follow defined associations or affected by some parameters. Based on the above hypothesis, this study aims at delineating groundwater occurrence in the Free State Province, South Africa. The study uses Geographic Information Systems and Remote Sensing Techniques to identify the occurrence of groundwater within the Free State Province. The dataset includes soil, geology, lineaments, slopes, rainfall, land use pattern, geomorphology and drainage. Geomorphology, drainage, slopes and lineaments were derived from Shuttle Radar Topography Mission (SRTM). Landsat series TM, ETM+, and OLI satellite imageries of Free State were obtained from the US Geological Survey (USGS) Landsat series of Earth Observation satellites accessible on the Google Earth Engine (GEE) platform. Supervised classification was done using a random forest (RF) machine learning classifier in the GEE platform.

Rainfall, geology and soil are already available in needed formats. An overlay technique to identify zones of groundwater occurrence and abundance was performed using machine learning algorithms and these were compared with groundwater data obtained from groundwater institutes and journal articles for cross-validation. The groundwater cluster zones were in close proximity to groundwater occurrence data. The importance of GIS and RS techniques cannot be overemphasized in the management of disasters and disaster reduction. For more improved planning and water-adjustment policies, there is the need to incorporate the spatial dimension using GIS and RS techniques.

112

Overexploitation Of The Maastrichtian Aquifer In Senegal.

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The transboundary Maastrichtian aquifer, which extends over almost the entire SenegaleseMauritanian basin, is shared by Senegal, Gambia, Mauritania and Guinea-Bissau. It contains considerable groundwater resources estimated at 35 billion m3. This deep, confined water table is the main source of water supply in Senegal. It is exploited intensively with more than 1000 boreholes listed delivering from 60 to more than 200 m3/h.

In this article, we evaluate the quantitative and qualitative evolution of the aquifer based on government databases on boreholes characteristics, their flow rates and piezometric and hydrochemical monitoring. If the exploitation of the aquifer began in the 1930s, it accelerated during the drought of the 1970s and by industrial and private investments since the 1980s. Boreholes are distributed over the entire sedimentary basin, but with a higher density in the western part of the territory in the Ndiass horst, where the aquifer outcrops and is subject to significant withdrawals for the drinking water supply of large urban centers such as Dakar and Thies.

Our analysis of the data shows that these high withdrawals since the 1970s have led to a significant drop in the water table level accompanied by an increase in salinity. Since 1970, decreases of about 0.1 m/yr have been observed on the piezometers in the east and southeast of the basin, while in the center and west they vary on average from 0.1 to 0.7 m/yr. From 1988 to 2020, the hydrochemical study shows an increase in conductivity values recorded on several piezometers.

Keywords: Maastrichtian transboundary aquifer, overexploitation, piezometry, hydrochemistry

113

Multidisciplinary Approach To Conceptual Modelling Of Hydrothermal Systems In Croatia

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Hydrothermal resources have been used for tourism and energy purposes in Pannonian part of Croatia for decades. Due to favourable geothermal and structural characteristics, natural thermal water springs emerge at two dozen localities, with temperatures up to 65 °C. Thermal springs are part of hydrothermal systems (HTS) which include: recharge areas in the mountainous hinterlands of the springs; geothermal aquifers (in Croatia mostly Mesozoic carbonate rocks) in which water resides and gets heated due to heat flow from the Earth; and discharge areas in places with favourable structural characteristics of higher permeability. The continuous functioning of such systems depends on a delicate balance between groundwater flow velocities, precipitation/dissolution processes and structural framework. The increase in thermal water utilisation is foreseen by many European and Croatian strategic documents regulating energetics, tourism, environmental protection and sustainable development. Sustainable utilisation of thermal water resource from natural springs demands understanding on a system level. It is necessary to investigate the whole cycle - from recharge to discharge of the systems. Multidisciplinary methodology (structural geology, hydrogeology, geothermal, hydrogeochemical and geophysical research and remote sensing) will be used to develop and physically validate the conceptual models of HTSs, perform 3D geological modelling, hydrogeological and thermal parametrisation of the geological units involved in the thermal fluid flow, and conduct numerical simulations of system functioning in undisturbed conditions and with different extraction scenarios. The aim is to delineate geothermal resources, locate aquifers or structures that may control aquifers, or assess the general properties of the HTS. Methodology will be applied to three HTS pilot areas in the Pannonian part of Croatia, all of which are well known for the utilisation of their thermal water resources: Daruvar, Hrvatsko zagorje and Topusko. These three systems have a different level of initial data availability and it shall therefore be determined which methodology and order of application of different methods should be applied while researching the systems with considerable existing data, medium amount of data and very scarce data, respectively.

114

Improving The Snmr Signal-To-Noise Ratio Using Cost-Effective Em Shielding

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Surface Nuclear Magnetic Resonance (sNMR) is a geophysical method suited for hydrogeologists, due to its unique ability to directly sound groundwater. Nevertheless, its use is highly limited in urbanized areas due to the ubiquitous ambient electromagnetic noise that perturb the signal originating from the groundwater response to the sNMR excitation.

In this study, we investigate the efficiency of a cost-effective shielding made of cattle fences to reduce the noise impact on sNMR measurements. The main issue with EM shielding in sNMR is the size of the antennas required to acquire signal

from deep aquifers, since the depth of investigation is roughly equal to the diameter of the transmitting antenna. Therefore, classical shielding methods are very difficult to implement at a reduced cost. We emit the hypothesis that using a cattle grid lying above the antenna should reduce the noise impact on the measurements. A proof of concept field experiment was first conducted on the University of Liège Campus, showing that using a simple 25mm grid reduced the noise by 40%. Further experiments were held inside the walls of the Orval abbey. There, multiple shapes of shielding where tested: domes and tunnels.

Several aspects were investigated: the ease of installation and the efficiency of the used setup in filtering the noise. Building a tunnel above the cable of the receiving loop was the easiest to achieve, whereas the construction of a dome covering the full antenna revealed complex to set in place.

Shielding proved more efficient with tunnels above the receiving antenna cable than a full dome covering the whole loop. Using tunnels-like shields, we were able to reduce the noise measured on the receiving loop by 80%, using superposed tunnels with different grid sizes.

Those experiments show that an efficient and easy shielding could be achieved to reduce the noise impact on measurements by as much as 80%. Such approach is promising to enable the use of sNMR in more diverse environments. Nevertheless, demonstrating that the shielding does not perturb the NMR signal transmission and reception remains to be investigated. The sNMR signal-to-noise ratio could also be improved using the central-loop configuration with a shielding only on the (small) central antenna loop.

115

Interpreting Salinization Phenomena In The Coastal Groundwater Of The Murgia Aquifer (Apulia, Southern Italy) By Means Of B, Sr, O, And H Isotopes.

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Salinization is the main responsible for groundwater quality degradation in coastal aquifers. This process is often amplified by the aquifer over-exploitation, being the coastal areas densely populated and commonly hosting important tourist settlements and industrial sites. It comes that coastal aquifers are characterized by the fragile freshwater-saltwater equilibrium. Paleo-seawater trapped in sedimentary rocks can also affect the hydrologic cycle. Chemical and isotopic tools, in particular boron, strontium, oxygen, and hydrogen, could support discriminating the different sources of salinity, water-rock/ interaction process, and the origin of the water molecule.

This work aims to investigate groundwater from the coastal sector of the Murgia aquifer located in the Apulia region (southern Italy) and bounded by the estimated 1.0 g/L isoaline borrowed from the Regional Water Protection Plan (Figure 1). The Murgia aquifer is made up of several hundred-meter- thick of Cretaceous fissured and karstified carbonate rocks and constitute one of the larger coastal karst Italian aquifers. From a hydrogeological standpoint, the Murgia aquifer is characterized by the main SW-NE flow direction from a wide recharging area, located on its most elevated inner side, towards the Adriatic Sea coastline. Paleo-seawater as an additional source of salinity has been suggested by previous studies. 87Sr/86Sr, δ11B, δ18O, and δ2H, measured with overall chemistry in about 50 samples collected during autumn 2019 in Murgia groundwater, range from 0.70768 to 0.70884, from +15.3‰ to +43.0‰, from -7.78‰ to -3.40‰ and from -49.50‰ to -23.30‰, respectively. The coupled chemical and isotopic approach allowed us to evidence that different mixing processes concur in the studied waters, highlighting hydro-geologic zoning and different and complex groundwater circulation patterns.

Some samples reveal strontium and boron isotopic compositions that are typical of the local Cretaceous carbonate rocks. These isotopic features imply a prolonged water-rock interaction. A significant contribution from modern seawater is evidenced by chemistry and isotopes in 6 samples where chlorine ranges from 3162 to 9684 mg/L. A different mixing degree of known "endmembers", such as meteoric, marine, and rock-interacting water is suggested to explain intermediate compositions. δ11B values, and Cl, B, and Sr contents seem to exclude a main contribution from fossil seawater in the studied groundwater. Further studies on higher conductivity samples are ongoing to better detail the zoning based on the isotopic and hydrogeological characteristics and to confirm or deny the occurrence of fossil marine waters.

116

Geogenic Arsenic In Groundwater Flow Systems, In A Semi-Arid Area: Graben Of Villa De Reyes, Mexico

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The Graben of Villa de Reyes (GVR) is an area of volcanic rocks, ignimbrites, lava flows, and tuffs with a total thickness of 500-700 m, as well as basin fill sediments (200-300 m) in a NE-SW graben structure. It has been the subject of many investigations related to hydrochemistry, groundwater dating, and dissolved arsenic (As) in groundwater. The main geological units of the GVR are fractured rhyolites, with ages ranging between 32 to 28 Ma, and volcanoclastic sediments hosting groundwater. Irrigation is the main use; additional uses are water supply for local population and industry. Groundwater flow is controlled by the surrounding volcanic highlands, drawdown of wells in the graben and regional faults and fractures.

For this study, groundwater chemical composition have been determined at 121 sampling sites. Even though 100% of the sampled sites are within the Mexican critical value (25 µg/L) for As, 63% of the sites are above the World Health Organization guidelines (10 µg/L) becoming a concern to the public health. In the GVR the source of As are rocks and the sediments derived from those rocks. Groundwater has an important thermal (42.4°C) component.

Values of the pH range between 5.8 and 8.6, but most of the sampled waters are circum-neutral (average 7.40), the specific conductance values are in the range of 105 to 1,233 µS/cm and 86% of the samples are Na-HCO3 water type. Warm waters were analyzed for 14C and 13C. Corrected Libby ages of 12,300 to 17,500 B.P. indicate groundwaters of Pleistocene age. The statistical analysis of the main ions and trace elements reflected five factors that explain 61% of the total variance. One factor that links Li, B, Ge, Na, and Cs is spatially correlated to an area where a NW-SE trending regional fault system crosses the GRV, there the groundwaters are younger, have lower temperatures and As concentrations. A further factor that groups As and Na is spatially related to the center of the GVR where the older groundwaters, higher temperatures and As values are placed.

The area influenced with the Li factor indicates shallow groundwaters and the As factor implies that the wells tapping this area are deeper, however, both factors shows affinity to the regional major fault system. Understanding the As sources, mechanisms, and mobility contributes to sustainable groundwater exploitation in the future as in some areas old groundwater is being mined.

117

Groundwater Potential Recharge Areas Delineation Using Groundwater Potential Recharge Index (Gpri) Within Arid Areas: Ghomrassen, South Tunisia

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Groundwater is the main drinking source in Ghomrassen in South Tunisia. As an arid area, the annual precipitation in Ghomrassen is practically less than 150 mm/year.

This area suffers from drawdown of water table and surface water scarcity. The concept of groundwater recharge is one of the best solutions to increase the reservoir capacity in these areas.

This study aims to delineate the groundwater potential recharge areas. To achieve this objective, a groundwater potential recharge index (GPRI) was computed using five parameters such as soil lithology, land use land cover, lineament density, slope density and drainage density. For each parameter a score and a weight were assigned and thematic maps were developed using GIS analysis (ArcGIS). A global potential recharge map was produced and highlighting three recharge zones from the total area (35% high, 18% medium and 47% low). Under the use of the GPRI, the groundwater potential recharge was estimated to 5.4 Mm3/y. Results are significantly matching to groundwater potential recharge areas according to numerous worldwide study areas. The presented methodology can be helpful for planning various water projects in this location using the artificial recharge structures and wells establishment.

Keywords: Groundwater, Potential recharge, GPRI, Maps, Tunisia, GIS

118

Geochemical And Salinization Processes In The Sedimentary Basin In Mauritania: A Study Case Of Benichab Coastal Area

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The study area is located in the South of city of Nouadhibou and belongs to the Senegalo- Mauritanian sedimentary basin precisely. The Benichab aquifer has been influenced by the saline water occurred during Quaternary transgressions (Inchirian 30000 years BP and Nouakchottian 5500 Years BP). It is a confined aquifer layer under a thick calcrete/sand/clay/ sandstone aquiclude bordered by the saline water except in its eastern part where it pinches out at the basement rock contact. The objective of this study is to evaluate the water quality and the source of the salinity using geochemical and isotopic indicators in order to increase our knowledge in the system functioning. In total, 91 boreholes and 6 dug wells were investigated and in situ parameters measured such as temperature, electrical conductivity (EC), pH and alkalinity. 119 groundwater samples are collected for analysis of major and some minor ions and isotopes (δ18O, δ2H, 3H, δ13C and 14C).

The Results show two types of water: saline and low to moderate mineralized water bodies. The EC values in the saline water range from 2000 to 45,200 µS/cm with a medium of 3,503 µS/cm. While in the low to moderate mineralized water part, EC range from 227 to 2000µS/cm. Major ions contents vary and depend on the two identified groups with main water type namely Na-Cl, mixed-HCO3, mixed-Cl and Na-HCO3. Seawater mixing ratio computed from Chloride content varies from 0 to 100% with a mean value of 9.4%. Values of δ18O and δ2H range from -6.97 to -1.86 ‰ and -47.59 to -23.72‰, respectively.

Plotted again the GMWL, data cluster along an evaporative line (slope of 4.6) confirming the 2 groups in which the saline groundwater exhibits two sub-groups located in the encroached saline water body between Bennichab and Boulanoir aquifers; and in the transition zone bordering the lower mineralized water body, respectively. Using 3H and 14C dating isotopes, the system is marked by ancient water without any component of modern to recent water since it exhibits low 3H contents (below detection limit) and 14C contents ranging between 22 and 63 pmC.

Computed uncorrected age using 13C values renormalized to-25‰ span from 4,178 to 11,902 yrs BP evidencing palaeowater infiltrated during the last wet period of the Holocene.

119

Imaging The Extent Of Salt Water Intrusion In The Luy River Coastal Aquifer (Binh Thuan) Using Electrical Resistivity Tomography (Ert)

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Seawater intrusion (SI) has been one of the most concerning issues of the Vietnam South Central provinces in recent years, especially in the Binh Thuan province which is characterized by a hyper- arid climate. During the dry season, seawater intrudes through estuaries and threatens groundwater resources. Moreover, the latter are under increasing pressure due to water extraction for agri-, aquaculture, and industrial production. To evaluate the current state of salinity in the shallow coastal aquifer of the Luy River, an optimum choice used for estimating because of the extreme sensitivity to the electrical conductivity of the pore fluid, 21 electrical resistivity tomography (ERT) profiles were collected along the downstream part of the river. ERT data clearly reveals the depth of the rock basement and the thickness of the coastal aquifer.

The interpretation of low bulk resistivity in terms of salinity is partly impeded by the presence of abundant clay deposits. Nevertheless, petrophysical laboratory analyses combining with existing water salinity measurement show that resistivity zones lower than 6.5 Ohm.m are corresponding to saltwater. On the left bank, saltwater is present in lowland areas with almost the entire thickness of the aquifer filled with brackish to saltwater. On the right bank of the river, the presence of higher elevation dune area contains a freshwater aquifer which limits the intrusion of saltwater. At a larger distance from the sea, the aquifer often displays a complex distribution of fresh and saline lenses.

Those variations are probably the results of complex interactions between natural recharge sources and irrigation practices. The geophysical observations show that the extension of saltwater intrusions is much larger than expected from existing borehole data and is not limited to interaction with the river.

120

Impact Of Spatial Heterogeneity On Flow And Heat Transfers For A Deep Well Doublet In The Breccia Layer Of The Hainaut Limestone Geothermal Reservoir, Belgium

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In the South-West of Belgium, the Hainaut limestone geothermal reservoir is exploited since the eighties. The geothermal reservoir is mainly composed of limestone from the Carboniferous period, with highly permeable breccia evaporites levels. Three single wells currently extract warm groundwater from this transmissive breccia layer and provide energy for the heat production to two hospitals, schools, station, housings and an economic area. The depth of the exploited layers is around 2000 meters and the pumping groundwater temperature is about 70°C.

This paper focusses on a new geothermal doublet to be drilled in Mons city (Belgium). A numerical model has been developed at the scale of the future geothermal doublet. Numerical models are implemented using HydroGeoSphere to simulate fluid flow and heat transport in the geothermal reservoir. Simulations aim at analysing the conditions of the exploitation regarding pressure and temperature variations at the scale of the doublet and to assess the longevity of geothermal operations according to hydrogeological conditions.

Results analyse the sensitivity of the pressure and temperature fields as a function of the hydraulic and thermal parameters and their spatial variability in the breccia layer. To account for uncertainties related to the reservoir geology, different patterns and types of heterogeneity are studied, using Gaussian distributions and multiple-point geostatistics. Multiple-point geostatistics uses training images to characterize the geological heterogeneity. Training images are representations of the expected geology. Multiple-point geostatistics simulations allow reproducing the occurrence of permeable channels within the reservoir. Indeed, the dissolution of the anhydrite layers in the Carboniferous is not contiguous. Heterogeneity results in preferential flowpaths inside the breccia layer. They show the importance of the permeability distribution in the life expectancy of the geothermal well doublet. The life expectancy corresponds to the period between the start of the pumping and the start of decrease of temperature at the pumping well (>2°C). This spatial heterogeneity increases or affects the life expectancy of the doublet by isolating the extraction and injections wells, or conversely by inducing thermal shortcuts between the two wells.

121

A Multi-Parameter Geochemical Approach To Identify Blind Hydrothermal Systems In Ocean Island Volcanos: Looking For A Diluted Hydrothermal Component In Groundwaters At A Regional Scale

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Ocean island volcanoes sometimes host hydrothermal systems with little to no surface evidence such as thermal springs or fumaroles. These so-called blind hydrothermal systems may be diluted in a wider hydrogeological network, with strong lateral groundwater flows concealing the rise of hot fluids. Such blind hydrothermal systems are known to exist in Mauna Kea and Kilauea volcanos in Hawaii. The purpose of this study is to develop a geochemical approach to identify blind hydrothermal systems in the groundwaters at a regional scale in ocean island volcanoes. The selected target is the active volcano of Reunion Island (Piton de la Fournaise) with huge water infiltration under tropical climate but no surface indicators of hydrothermal activity.

We sampled 75 groundwater boreholes, rivers and cold springs and analyzed them for major and trace elements and C and B isotopic ratios in search of a hydrothermal signature. Some samples, even with electrical conductivities as low as <80µS/cm, have high amounts of B, Li, Na and SO4 compared to other trace or major elements and relative to other springs. A subset of them also display high concentrations of F, Mo, P, V, As and K. All these elements can originate from magmatic degassing or the dissolution of fumarolic deposits. In addition, these samples show anomalously low δ13C and δ11B ratios, consistent with a magmatic/hydrothermal contribution.

For other samples also enriched in Na, SO4, B, Br, and Cl, the hydrothermal component is not clearly identified, as they also have either (1) high NO3 concentrations and high δ11B values that could characterize an anthropogenic contribution, or (2) elemental ratios distinctive of a seawater contribution.

These findings reveal the probable presence of a blind hydrothermal system in Reunion Island. Hence, our study shows that combining major/trace elemental and isotopic analyses enables the identification of a hydrothermal contribution in groundwater among many other mineralization processes, even at extreme dilution.

122

The Impact Of Different Heat Transfer Processes On Energy Losses Of Ht-Ates Wells Under Varying Storage Conditions

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Heating and cooling is responsible for about 50% of the European total energy use and is therefore of importance for reducing GHG emissions. Due to a temporal and spatial mismatch between availability and demand of heat, large scale heat storage facilities are needed. Moreover, this need increases the coming decades because of the transition to more renewable sources of heat (e.g. geothermal, waste heat). High Temperature Aquifer Thermal Energy Storage (HT-ATES) systems are potentially one of the cheapest and most adequate ways to store large amounts of sensible heat.

Also, a worldwide potential exists for these kind of systems. Regular/Low temperature ATES systems are considered a proven technology with currently more than 3 000 systems operable globally.

However, at higher storage temperatures (e.g. 40-100 °C) temperature dependent water properties (density, viscosity) more strongly affect heat transfer processes, resulting in higher and more unpredictable heat losses. Unfortunately it is currently not well understood how these heat transfer processes interact and under which storage conditions the heat losses can be minimized. In this research we provide insight in the behaviour and interaction between heat transfer processes during storage.

We do this by analysing the results of a detailed sensitivity analysis where the storage conditions (aquifer thickness, hydraulic conductivity, anisotropy) and HT-ATES design parameters (storage volume, storage temperature) are varied. A numerical model is used taking into account the variable viscosity and density of water at different temperature. By doing this we obtain generic insights in the effect of these storage conditions on the performance of HT-ATES systems. These insights allow to identify which heat transport processes dominate in contribution to heat losses.

The following three main insights are provided: Firstly, we show that losses due to conduction and buoyancy flow are the main heat transfer processes leading to energy losses during storage. These processes are interlinked and dependent on each other, making the prediction of these processes complex. Secondly, conduction always contributes to heat losses for HT-ATES systems and acts as the minimum losses for a given storage geometry. Finally, we show that buoyancy flow can have a relatively large impact on heat losses, but that this only happens under specific conditions.

Moreover, the magnitude of buoyancy flow losses are also, like conduction, influenced by the storage volume geometry.

123

Improving Flanders' Salinization Map: Applying A Scale-Dependent Wavelet-Based Regularization Scheme On Time-Domain Electromagnetic Inversion

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The salinization map of the region of Flanders, Belgium shows the depth of the interface between fresh and salt groundwater in the coastal and polder area. It serves as an exploratory tool to examine the potential of groundwater projects that improve freshwater availability in the shallow subsurface. Flanders environment agency published an updated map in 2019, based on airborne time-domain electromagnetic induction data. The result of the inversion is, however, overly smooth, which potentially conceals interesting features.

Via an inverse problem, the electromagnetic induction data can be mapped onto a conductivity profile, which serves as a proxy for salinity via petrophysical laws. The inverse problem is ill-posed and regularization improves the stability of the inversion. Based on Occam's razor principle, a smoothing constraint is typically used with a very large number of thin layers. However, the salinity profiles in the Belgian coastal plains are sometimes sharp, impeding the correct estimation of the fresh-saltwater interface. An alternative is to use a predefined number of layers and to invert for their conductivity and thickness. This can yield sharp contrasts in conductivity. In practice, however, the real underground might be either blocky or smooth, or somewhere in between. Those standard constraints are thus not always appropriate.

With a novel wavelet-based inversion scheme, the original data can be re-interpreted in a flexible fashion. In simple terms, a wavelet function can be seen as a building block and a simple model is one that can be built with few building blocks of various sizes. Our proposed inversion scheme adds a regularization term that limits the number of building blocks in the wavelet-domain to make sure only the necessary complexity is retrieved. The scheme is tuned by only one additional parameter (which determines the wavelet basis function) and is able to recover blocky, intermediate and smooth structures. It is also capable to recover high amplitude anomalies in combination with globally smooth profiles, a common problem for smooth inversion, and an essential feature to accurately predict the salinity.

We first demonstrated this alternative inversion scheme on 1D data and now extend it to two dimensions. We apply it to the data of the salinization map to validate our inversion model with ground-truth data collected in boreholes. Our approach yields an improved estimation of the fresh- saltwater interface and can thus be used to update the salinity map.

124

Pesteaux-Rw : Modeling Of Pesticide Transfer To Water Resources At Watershed Scale For Walloon Region

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Pesticide losses after application, from field to water resources, can result in serious water quality deterioration. The PESTEAUX-RW project aims at assessing the risks of water pollution due to plant protection products (PPP) in the Walloon region from an existing hydrological model. As a first step, the model will estimate the PPP run-off to surface water based on multiple hydrological processes. It will allow the evaluation of the most suitable agricultural practices to mitigate the risk of water contamination by a comparison of usual crop productions at the watershed scale.

Moreover, it will highlight for each parcel, the crop rotations and the active substances inducing the highest risks of water pollution. A review of multiple hydrological models has been carried out and has resulted in the selection of the Soil and Water Assessment Tool: SWAT+. In comparison to conceptual models such as Clark, TANK and AWBM, the semi-distributed physical model SWAT+ is able to consider the spatial variability of land use, slope, soil and climate to deal with the hydrological regime corresponding to the watershed; for example through mass, momentum and energy conservation equations (1). SWAT+ is considered as one of the most efficient applied models for addressing hydrologic and environmental issues (2). It has been widely used for multidisciplinary studies, from regular events to hydro-climatic extreme conditions. For each of these studies, a performance assessment was undertaken using the Nash-Sutcliffe Efficiency. In most cases, the model presents performances ranging from good (> 0.65) to very good (> 0.75) for calibration and validation on a daily and monthly basis (2,3). SWAT+ relies on the concept of hydrological response unit (HRU), which consists into a watershed sub-area characterized by homogeneous properties related to soil composition, land use and slope classes. The use of these HRU makes the model SWAT+ less demanding in terms of data and computational time. To facilitate data management and the parameterization of the model, an automation process will be developed using Python language due to its compatibility with SWAT+ and GIS software. The collection of water samples and analysis is foreseen to improve the calibration and the validation of SWAT+ for estimating the dynamic of PPP transfers at the watershed scale.

- 1. doi:10.1007/s13201-019-1122-6
- 2. doi:10.3390/w11050914
- 3. doi:10.1016/0022-1694(70)90255-6

125

The Catchment Pesticide Diagnosis Unit: A Tool For Drinking Water Protection

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In the Walloon Region of Belgium, the agricultural system is characterized by intensives productions that lead to large use of fertilizers and Plant Protection Products (PPP). Consequently, drinking water standards defined by the Walloon Water Code concerning PPP as 0,1 µg/L for an active substance or some metabolites and 0,5 µg/L for the total of PPP quantified (1) are sometimes exceeded for water catchments. Therefore, the protection of groundwater catchments from agricultural activities is essential to ensure a good quality of drinking water. The Catchment Pesticide Diagnosis Unit (CDPU) aims to determine the contamination sources of catchments by PPPs to target solutions at the field scale. This level of scale is necessary to ensure a good management of the contamination risk in the considered area. The CDPU was set up in 2005, as part of a collaboration between the Public Water Management Company (SPGE) and the Walloon Agricultural Research Centre (CRA-W) to provide to the water producers a scientific frame and expertise in agronomic and hydrogeological matters.

Since 2018, the CDPU has been part of the Protect'eau framework whose mission is to preserve water quality due to a sustainable management of nitrogen and PPPs for farming sector. To evaluate the contamination, the diagnosis performed by the CDPU can be described in three different steps. The first one consists of the documentary work to gather relevant information related to the studied site. This important step allows us to make assumptions on putative contamination paths. At the second step, field visits as well as a survey of PPP users are performed to validate the first hypothesis. Finally, the last step consists of the diagnosis itself and the proposal of solutions.

Since its beginning, the CDPU has handled more than thirty cases. The majority of studied cases (80 %) often involves spot localized pollution, constituting a point-source contamination. Diffuse pollutions (drift and leaching) are complementary to the point-source pollution. Root herbicides are the most frequently found as for example S-metolachlore. Some contact products are also present such as bentazone, particularly worrying in karstic sites.

Moreover, since 2018, the CDPU diagnosis is part of catchment agreements that aim to draw up an action plan with the stakeholders and invite farmers to co-design solutions that will be implemented in the field.

(1) Code de l'Eau coordonné – Partie réglementaire (Livre II du Code de l'Environnement) (http://environnement.wallonie.be/legis/Codeenvironnement/codeeaucoordonneR.html, consulted on the 18th of March 2021)

126

Long-Term Groundwater Temperature Trends In Cologne, Germany

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Shallow ground and groundwater temperature in urban areas exhibit large scale temperature anomalies compared to rural settings. These typically elevated temperatures have been traced back to numerous anthropogenic heat sources, that accumulate especially in urban areas into large-scale heat carpets in the shallow subsurface. These subsurface urban heat islands are typically described in steady-state for a respective point in time.

This is due to the low number of reliable observations in urban areas and to the general data scarcity in the subsurface. In our contribution we present an approach that fuses data from the past five decades from groundwater quality measurements, level- logger temperature and temperature-depth profiles for the urban aquifer beneath Cologne, Germany. Even though temperature is recorded nearly for all groundwater and surface water quality measurements, these data are typically treated as a side product and rarely analysed. In addition, modern groundwater level loggers also record temperature which resolves in single-depth timeseries typically 1 to 3 m below groundwater level.

Temperature-depth profiling has been the go- to method for most studies of urban subsurface temperatures, because of the high-precision and information residing in the depth resolution. However, profiling is almost exclusively performed by academic institutions and therefore these data are very scarce both in time and space. Preliminary results of the fused temperature data reveal a general warming trend in the same magnitude as atmospheric temperature change between 0.3 and 0.4 K per decade (data from 1970 to 2020). In addition, the rates of temperature change indicate a moderate correlation to the rate of urbanization. Using ordinary least-square regression we were able to build a basic statistical model of the temperature distribution from 1973 onwards. This is probably one of, if not the richest temperature archive of city-wide subsurface temperature records world-wide and a unique opportunity to study urban subsurface temperature variations in response to local anthropogenic overprinting and regional climate change.

128

The Distribution Of Saline And Fresh Groundwater And Factors Affecting Water Quality In The Coastal Aquifers Of Southwest Bangladesh

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People in the southwest coastal areas of Bangladesh are suffering from a potable water crisis. The groundwater development in this area is challenged by some natural processes. For the purposes of this research, emphasis is placed on revealing the factors controlling the water quality, and distribution of saline and fresh groundwater using hydrochemical, geophysical and geostatistical analyses. Three aquifers have been identified in this area (Sarker et al., 2018): upper shallow aquifer (USA) (<100 m depth), lower shallow aquifer (LSA) (100-200 m depth) and deep aquifer (DA) (>200 m depth). The groundwater type based on Stuyfzand's (1989) classification shows that the water in USA is mostly of brackish saline NaCl- type. The water in LSA has similar characteristics like USA but is brackish. The presence of some CaCl and CaMix water types in shallow aquifers indicates reverse ion exchange process during saltwater intrusion. The water in shallow aquifers is derived from the dissolution of evaporite on the ground surface by monsoon precipitation as is confirmed by Cl-/Br- ratio and stable isotopes. DA comprises mostly fresh NaHCO3+ type water and is formed by cation exchange process from infiltrating freshwater from the recharge area (Sarker et al., 2021). Direct seawater intrusion by lateral flow from the Bay of Bengal has no contribution to salinization in the shallow aquifers. Electrical resistivity tomography (ERT) and vertical electrical soundings (VES) show no evidence of seawater intrusion in the coastal plain. The groundwater level data also illustrate north-south flow. A geostatistical analysis on selected ions of all the groundwaters allows identification of three major clusters that are hydrochemically comparable with the USA, LSA and DA. Factor analysis also shows that the groundwater is affected by evaporite dissolution, fresh saline water mixing, ion exchange and anthropogenic pollutants. The DA could be a good option for sustainable use of the groundwater resource in the coastal region of Bangladesh.

Keywords: Hydrochemistry, evaporite, environmental geophysics, coastal aquifers.

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130

Limitation Of Applying The Dupuit-Ghijben-Herzberg Analytical Model For Quantifying The Volume Of Freshwater Lens In Extremely Highly Permeable Aquifer

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A hat-shaped freshwater lens was observed in Tarama Island, Japan, of which hydraulic conductivity

(K) is on the order of 10-2 m s-1, and is quite different from that predicted from the Dupuit-Ghijben- Herzberg analytical model. This observation has posed a question whether the analytical model is applicable to assess freshwater resources in extremely highly permeable aquifers. In this study, we compared the freshwater lens shapes predicted by both the analytical model and numerical simulation with various K values. Numerical simulations that consider the density-driven flow and dispersive mass transport well reproduced both the hat-shaped nature and the volume of freshwater lens in Tarama Island. In contrast, the analytical model overestimated the lens volume at around 14 times larger than that from the numerical simulation. This discrepancy increased with an increase in K because the analytical model assumes a sharp interface between freshwater and saltwater and does not include a transverse dispersion process, which was enhanced with the increase of K. These findings suggest that the analytical model may not be suitable to apply for freshwater lenses in extremely highly permeable aquifers.

131

Improved Representation Of Groundwater-Surface Water Interaction In Swat+ For Wetland And Drought Simulations

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Surface water models are weak or mostly apply a simplistic approach for representing groundwater hydrology. This often leads to an unrealistic hydrological water balance and unreliable low flow simulations. Hence, it is vital to integrate groundwater models and surface water models as the interaction between the different processes is inevitable. Recent attempts to integrate SWAT and MODFLOW were successful, however, the memory and computation time requirement was high. Moreover, this also creates additional problems such as a more complex and expensive parameter estimation, sensitivity and uncertainty analysis procedure. Therefore, there is still a strong need to find a compromising point among computation time, memory requirement and realistic representation of the groundwater-surface water interaction.

In this paper we evaluate/apply a new method (gwflow module) to replace the simplified representation of the groundwater processes in SWAT+ by a physically based and spatially distributed manner that is easily integrable into SWAT+. The module uses a single layer to represent a given aquifer and is based on the Dupuit–Forchheimer assumption of horizontal flow in unconfined aquifers, and therefore ignores any vertical gradients in groundwater head. This new approach will be tested for the River Dijle catchment (Belgium). The aquifer in this catchment is unconfined, and the latter increases its vulnerability during drought periods. Besides, the catchment has wetlands whose existence partly relies on the surface water – groundwater interaction, especially during drought periods. Hence, the application of the new proposed approach on this catchment can also enhance our understanding of the hydrology in wetlands. In addition, hydrological drought analysis will be performed using several drought indices. Finally, a comparison will be made among the model outputs of SWAT+, MODFLOW and SWAT+ modified with the gwflow module. The study will also indicate to what extent the new 'gwmod' module improves hydrological process representations for wetland and drought simulations in the River Dijle catchment.

132

Mapping Of Aquifer Productivity And Assessment Of Groundwater Vulnerability To Pollution In The Lower Chari-Logone River Basin, Southern Lake Chad Basin

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The lower Chari-Logone River Basin is situated south of Lake Chad in the transboundary region between Nigeria, Cameroon and Chad. It is characterised by vast wetlands flooding up to 9400 km² and significantly contributing to the groundwater recharge in this arid and semi-arid region. Wetland loss, climate variations and increased human pressure on water resources influence agriculture, livelihoods and the functionality of the ecosystem. The impact of these major changes on groundwater resources is still poorly understood due to the lack of monitoring data and transboundary maps summarising the status quo of hydrogeological knowledge in this region.

To bring together existing dispersed data and to establish regional planning tools, BGR in collaboration with the Lake Chad Basin Commission (LCBC) develops an aquifer productivity map using the Krásný classification and evaluates the aquifer vulnerability to pollution based on the GLA method. Associated side maps were elaborated together with the LCBC member states, including a harmonized transboundary lithological map and a map of potentially polluting land uses. The combination of these maps represents a tool for strategic decision making in spatial planning and gathers basic information to design an effective groundwater monitoring network. The project is funded by the German Federal Ministry of Cooperation and Development.

133

Eliminating The Risk From Pfas Contamination: Low Cost In-Situ Remediation With Colloidal Activated Carbon

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Per- and polyfluoroalkyl substances (PFAS) are a class of man-made fluorinated organic chemicals that were common within a variety of consumer and industrial products. These chemicals are now being detected in the groundwater, drinking water and soils of sites worldwide and pose serious threats to human health, leaving contaminated sites in need of environmental action to reduce risk to human health.

PFAS compounds are presently considered to be resistant to biological degradation. Other destructive methods are still in early developmental stages. Presently, this means that when treatment of PFAS impacted groundwater is required, hydraulic containment systems using GAC filters are often installed, resulting in ongoing operation costs, waste production...

This presentation discusses an alternative remedial approach. Colloidal activated carbon (CAC) is a proven in-situ method to eliminate the risk associated with PFAS compounds in groundwater. It has been developed and applied on a number of sites worldwide. The approach is to eliminate the environmental risk by removing the exposure of the receptor from the environmental hazard.

Upon low-pressure injection, the CAC permanently coats the aquifer matrix and a permeable sorption barrier is created in-situ, purifying groundwater as it passively migrates. PFAS constituents are rapidly sorbed to the carbon and removed from the mobile dissolved phase, by which the downgradient public health risk associated with PFAS is eliminated.

The PFAS is not permanently attached to the CAC; instead, the PFAS is retarded from further progression. A typical Retardation Factor for PFAS in a natural aquifer would be 3-20. A CAC-coated aquifer can achieve a retardation factor of around 10,000 –meaning that the contamination can be sequestered for decades from a single application. The sequestration time is modeled prior to application and has been verified by an independent study (Carey, G., McGregor, R., Pham, A., Sleep, B, Hakimabadi, S. Evaluating the Longevity of a PFAS in situ colloidal activated carbon remedy.

Remediation. 2019;29:17-31).

Data will be presented from multiple sites where a single application of colloidal activated carbon resulted in reduction in PFAS groundwater concentrations to below target levels. Our understanding of PFAS continues to develop. While this is ongoing, the in-situ sorption approach with CAC provides a presently available and immediately effective solution for risk management of PFAS plumes.

134

“Water 4 Later” – Collective Rainwater Storage Coupled To Asr, Located Within A Business Park In Keiberg-Vossem (Belgium)

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Greenfield business park Keiberg-Vossem is being developed as a future-proof example. Total area of the site is approximately 80'000 m², of which 45'000 m² of roads and roof surface. It is situated within drinking water protection area, which means that water falling on pavement is not allowed to infiltrate into the groundwater due to possible pollution.

As part of a subsidized project under the call “Living Labs Drought”, rainwater will be stored centrally in a watertight storage basin, which is accessible as a blue-green recreation area for business park workers.

The storage basin has three functional layers for water management (from bottom up): a permanent volume as a natural element, a part reserved for further treatment and reuse, and the largest share for stormwater storage (with controlled discharge towards downstream system).

The collected water is treated and made available to local businesses in a parallel "household water network" (next to drinking water). This water can be used for applications that do not require drinking water quality.

Surplus of (treated) rainwater will be stored in the subsoil (Aquifer Storage). As a result, the risk of flooding is mitigated and the sewerage system is not addressed when it is already overloaded. This concept makes it possible during persistent dry periods to address the volume of rainwater in the aquifer which was harvested and stored in the wet season, for household use (Aquifer Recovery). Under the expected patterns of precipitation and household water consumption (25,000 vs 3,500 m^3 per year respectively), there will be a clear net replenishment of the groundwater. The filter of the ASR-well is installed in the oxidized water layer to avoid well clogging.

To allow infiltration of surface water to the aquifer, the quality of the treated water must always meet the environmental quality standards for groundwater. To meet this requirement, a treatment will be provided with ultrafiltration and activated carbon filtration. In addition, a qualitative and quantitative monitoring program is set up.

A subsidized demo project "RainBrain" is currently being set up to optimize the functioning of the basin. Using the RainBrain software, the volume reserved for further treatment can be expanded by intelligently controlling the swirl valve. In concrete terms, the valve can be closed (i.e. extend storage for reuse) if no major rain events are expected, so more water can be treated and infiltrated in the aquifer (resulting in potentially 3,000 m^3 extra infiltration per annum).

135

Simulation Of Water Flows In A Tailings Pile At The Former Uranium Mine Le Cellier (Lozère, France)

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Water flow is an essential aspect in the long-term management of mine tailings. Flows through tailings piles deposited on the surface influence chemical reactions and pollutants migration into the environment. This study is focused on one of the piles from the former Cellier mining site (Lozère- France) resulting from heap leaching. Tailings are characterised by a dominance of coarse particles and mainly consists of clay, sands and leucogranite blocks. This site is now decommissioned, and all waters are collected and treated before release in the environment with a daily and monthly basis monitoring since 1991. The environmental monitoring includes discharge rates and chemistry of the drains located below the pile. The analysis of the available hydrological data allows to evaluate the actual evapotranspiration and to carry out water balance calculation, auto-correlations and cross- correlations between available parameters. From the calculated water balance, it is noted that evapotranspiration, which corresponds to 45% of the precipitation affects strongly the hydrological behavior of the pile in summer and autumn. June, July and August are nonetheless marked by a weak flow of the drains despite the negative balance (P-ETR < 0), which persists in early autumn. The hydrological response time of the pile to rainfall is one month. Auto-correlations suggest that drains discharges have a low inertia with a memory effect of 2 to 3 months. The cross-correlations between rainfall and observed drain discharges indicate that there is a cyclical pattern (quarterly to semi- annual) in which flows react to rainfall and influence chemical parameters such as pH and sulphate concentrations. We developed a hydrodynamic model with Hydrus that describes the expected average hydrologic behaviour of the pile according to the observed discharge data (monthly data 2010-2018). Both homogeneous and stochastic distribution of hydraulic conductivity give simulations showing that water distribution in the pile varies seasonally according to wet and dry periods. However, water content (2.9 - 3.8%) remains low throughout the simulation period, which is susceptible to promote acid drainage in the environment and its subsequent neutralisation by the water treatment plant.

137

Hydroclimatic Approach To Evidence A Past Severe Droughts And Its Consequences On Water Resource: Application On The Kara River Basin And Its Aquifers (Togo)

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In the 70s a severe drought has been recorded in Sub-Saharan Africa and in Gulf of Guinea countries. This large spatial scale phenomenon had consequences on water table and on groundwater dependant river flows in these regions where the water resource is precious.

This study aims at evidencing this drought in the Kara River Watershed (KRW - northern Togo) and to characterize the consequences of this event on hard rock aquifers of the studied region and on the flow regime of the groundwater dependant Kara River. To reach this goal, the daily rainfall and temperature data covering the period from 1961 to 2018 from four meteorological stations distributed on the KRW were collected from the National Office of Meteorology as well as the stream flow of the Kara River, at the city of Kara, from the Office of Water Resources.

Calculations of Nicholson indices and second order low-pass filter of Hanning allowed to highlight a significant temporal variability of the rainfall at the four studied stations with an alternation of dry, normal and wet periods. The use of statistical rupture detection tests (Pettit, Lee and Heghinian and Hubert's segmentation) showed ruptures in the probability law of the precipitation regime in 1972, 1970 and 1965 for the Niamtougou, Sokodé and Pagouda stations, respectively.

The calculation of the hydrological balance on the stations of Niamtougou and Sokodé using the Thornthwaite water balance method showed that in the years after the rupture, a significant decrease of groundwater recharge is observed. This drop is about 31 % for Niamtougou and about 28 % for Sokodé. The flow of the Kara River fell by 34 % after the rupture (74s). The recession coefficients estimated average between 2.8.10-2 j-1 and 3.5.10-2 j-1 either side 1974, whether an average increase of 25%. At last, the volumes of groundwater mobilized from the studied aquifers also decreased from 0.32 km3/y before the 74s to 0.25 km3/y after the rupture, i.e. a decrease about 22%.

The KRW has clearly been submitted to the effects of 70s climate variability, like other basins of the Sub-Saharan regions. From a socio-economic point of view, this rapid decrease of river and groundwater flow could affect the productivity of agricultural activities, especially market gardening on which a large part of the population depends. Future socio-hydrological studies could allow to better characterize the consequences of this 70s droughts on populations.

138

Enhancing Of The Hydrodynamic Knowledge Of Hard Rock Aquifers Of The Kara Watershed (Northern Togo) To Improve The Productivity Of Future Boreholes

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In the Kara Region (Northern Togo), the entire population is not served with potable water. To respond these water needs, groundwater is the major resource. It is extracted from wells and boreholes which are mostly less productive during low water periods. Numerous boreholes were drilled during the last decades to address this problem but often poorly successful. Furthermore, the hydrogeological properties of exploited aquifers are not always well investigated and when they are, they are never crossed to produce a better understanding of the global functioning of these hydrosystems.

This study aims at assessing the hydrogeological properties of hard rock aquifers of the Kara river watershed (KRW) developed in fractured metamorphic rocks. Since 1970, the PROGRESS program targets to record dataset from any new borehole on the Togolese territory (static water level, borehole depth and diameter, and sometimes pumping test data). We used the data of 610 boreholes distributed all over the KRW to propose a first piezometric map of this area and to highlight the better conditions to obtain consistent and durable flow rates.

The piezometric map of the KRW shows that water table morphology is strongly influenced by topography. Piezometric domes are observed in the South of the watershed close to the cities of Kpéwa and Alédjo, to the East in the Kabyè massif and to the North in Kadjala. The lowest piezometric levels are located in the western part of the basin where the Kara River flows into the Volta one. The flowpaths converge toward the Kara River that clearly drains the groundwater.

Analyses of boreholes properties show that the most productive depth for all lithologies is between 31 and 87 m. As it has already been described elsewhere, we observe a weathered profile with a capacitive reservoir in the weathered surface layer and a transmissive function in the underlying fractured part of the aquifer. The better flows rates are met when a weathered layer is present with a thickness between 1.8 m and 15 m with the first water flows at 10 m depth, mostly at the base of the weathered materials.

Nowadays, at the KRW scale, 47 % of the boreholes show a flow rate less than 2.5 m3/h mainly because of a lack of preliminary investigations before drilling. Our main goal in coming years is to propose a conceptual model to improve the identification of future boreholes points and therefore their productivity.

140

Thermal Groundwater Flow And Temperature Evolution In El Hamma Geothermal Aquifer, Southeastern Tunisia

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The region of El-Hamma in southeastern Tunisia is characterized by shallow warm groundwater. The El-Hamma shallow aquifer is the main source of water to meet agricultural and industrial needs and the traditional baths needs. To date, groundwater circulation in the aquifer system and the origin of the thermal anomaly has been poorly studied. In this contribution, we develop a more detailed conceptual model of the temperature distribution in the aquifer in the study area. Groundwater temperature data were collected area from 91 wells and implemented in a database. Thermal waters are found between 30 and 80 m below ground level at temperatures between 25 and 65 degrees Celsius. The temperature remains constant during the year, regardless of external climatic conditions.

Based on those new measurements, a conceptual temperature-to-depth model in the shallow aquifer of the El Hamma geothermal system is developed. This model shows the lateral and vertical communication between the Continental Intercalaire aquifer (CI) and the El Hamma geothermal aquifer system across the El Hamma threshold.

The groundwater cooling trend shows that lateral groundwater flows from west to east in the study area and the vertical geothermal groundwater flow, indicates a vertical flow from bottom to top from continental intercalaire aquifer to shallow aquifer via vertical fault system. This numerical groundwater model is going to be built to reproduce the observed hydraulic head and temperature observations.

141

The Deep Geothermal Energy Research Project At Balmatt: A Fractured Carboniferous Limestone Reservoir In Mol, Northern Belgium.

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Since 2010 VITO has been investigating the potential of deep geothermal energy in Flanders. To gain in-depth knowledge of this source of energy VITO developed his own geothermal pilot installation located on a brownfield site, Balmatt, in Mol (Belgium) nearby VITO's headquarter. The goal is to assess the technical and economical viability of geothermal co-production of heat and electricity.

Between 2015 and 2018 three wells with true vertical depths between 3.6 km and 4.2 km were drilled into the Lower Carboniferous Limestone reservoir. Well tests on the first vertical well indicated favorable transmissivities, at least in the vicinity of the well, with bottom hole temperature (BHT) of 138°C and production temperature up to 128 °C. The second well, aimed as the injection well, is deviated to the northeast, away from known faults to minimize the risk of fault reactivation. At final depth of 3.8 km (length 4.3 km) BHT was 142°C. The third well targeted the same fractured and faulted zone as the first well, about 1.6 km to the Southeast. For the first time the entire Carboniferous sequence was drilled in the Mol area. Unfortunately, well tests did not reveal significant permeability.

Beside geological and energy production related expertise, this pilot installation allows VITO to investigate various topics related to the use of deep geothermal energy:

- Corrosion and scaling: The formation water is a Na(Ca)Cl brine with 165 g/l TDS. Sodium and chlorine sign for 90% of the dissolved ions. The combination with high temperature and high pressure results in an aggressive fluid for both dissolution of metals and precipitation of minerals in the casing and surface installation. VITO tests the use of different materials.
- NORM (Natural Occurring Radioactive Materials): These elements are the result of the decay of natural 238U and 232Th which are found everywhere in the Earth's crust. As the geothermal water is reinjected, most of these elements go back into the reservoir. Samples are taken periodically from the filter elements, scalings and the geothermal water to determine the activity level.
- Microseismicity: The reinjection of cooled water into the deep reservoir can cause small artificially induced earthquakes. To monitor this microseismicity VITO has developed a dense seismometer network, which allows to locate the events by tens of meters accuracy. By monitoring the injection pressure and temperature, VITO can operate the plant as safely as possible.

142

Role Of Basin Interplay In Geothermal System Operations

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The undulation of topography and the groundwater table serves as a driving force of fluid flow not only in mountainous or volcanic regions but also in sedimentary basins. Since topographical variations do exist at any part of the continental lithosphere, the existence of regional-scale groundwater flow systems and their role in the formation of heat accumulations need to be considered.

A numerical simulation series was performed on a wide range of synthetic groundwater basins with topographical driving forces of groundwater flow to reveal the effects of various geometric and geologic parameters and agents, such as anisotropy of hydraulic conductivity, surface undulation, sedimentary basin fill and temperature gradient.

Our results showed that in identical basin-halves, exactly the same flow pattern develops and there is no flow from one part to the other. However, this ideal situation is not the case in real groundwater basins. Groundwater flows from one basin(–part) to another described as interbasin flow, a general form of basin interplay. This process is a direct consequence of basin geometry since waters enter a territory of another flow system due to the differences in driving forces and/or geographic position. At the convergence of opposing flow systems under a discharge area, quasi- stagnant zones and hydraulic traps may develop and support heat accumulation.

Furthermore, groundwater flow systems and their carrier fluids provide a continuous natural replenishment of geothermal systems. Mountain-block recharge (a form of basin interplay) is essentially the subsurface groundwater contribution from a topographically elevated area to the adjoining lowland sedimentary aquifers. The role of mountain-block recharge is relevant and important in maintaining groundwater flow systems and related heat accumulation in the basin fill part of an area. Thus, the rejuvenation of a geothermal system is provided by natural topography- driven regional groundwater flow both on a human and a geological time scale. If the production of a geothermal system exceeds the rate of replenishment, reinjection of carrier fluids might be a solution for long-term sustainable operation.

The possibilities of utilisation and reinjection are determined by hydrogeological processes, the vertical component of groundwater flow and fluid dynamic parameters. Analysis of the basin-scale flow patterns, heat accumulation and natural recharge could also be implemented during the reconnaissance phase of exploration for sustainable energy production.

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143

Rising Groundwater Tables In Semi-Arid Contexts : An Overview

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Groundwater resources in semi-arid areas are highly solicited and are often associated with decreasing water tables due to overexploitation. Such scenarios are frequent and threaten the sustainability of the groundwater resource, since users are forced to deepen their wells or to resort to an external water source that can cause a variety of environmental effects (increasing salinity, regional subsidence, etc.).

Alternatively, and more surprisingly, semi-arid areas also host situations of long-term rising groundwater tables, due to anthropization. Deforestation, changes in land use and land cover, irrigation from surface water or from deeper aquifers, inflow of external resources are all actions that may generate a rise in water levels. Consequences may not be less dramatic than those of overexploitation, as in the medium term they can compromise i) agriculture, via soil waterlogging and dryland salinity, ii) urban development, via the saturation of drainage systems and water networks and iii) the environment, via the increase in groundwater discharges towards low- topography areas or surface water bodies.

Illustrated by lessons learnt from Mauritania, Niger, Algeria, Tunisia, Australia and Spain, this paper proposes a typology of contexts, associated consequences, and potential remediation measures. It also illustrates the need to anticipate anthropogenic and climatic impacts on groundwater evolution at long-term scales.

144

Impact Of Climate Forcing On The Hydrogeological Functioning Of A Small Anthropogenic Mining Catchment

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We studied the groundwater flows in a small catchment (240 ha) located in Aveyron (France) where tailings, covered by waste rock, are stored in a valley behind a waste rock dam. Mining waters, coming from both tailing drainage and old mine facilities (galleries and open pit mine), are collected to a water treatment plant before being released in the environment, meeting the environmental standards. The objective of this study is to provide a better understanding of the functioning of this hydrological system and its evolution in the context of climate change.

Meteoric recharge through waste rocks and tailings creates acid mining drainage, a phenomenon that will continue for at least several decades on site. Climate change is likely to modify precipitations and temperatures in the next 50 to 100 years, as well as frequency and intensity of extreme events, which could affect the water balance at the catchment scale. These changes could impact groundwater table and surface water discharge. Taking into account the impact of climate change on the hydrogeological functioning of these mining sites will ensure sustainable management of water and environment.

We analysed hydrogeological data acquired on site using auto-correlations, cross-correlations and water balance calculations. These data come from long-term monitoring (20 years) on 13 piezometers and 4 discharge points. Recent two-year daily monitoring of water tables completes the dataset and provides a better understanding of the hydro(geo)logic system response after precipitations. The results show that: 1) there is a 5 to 10 days' time lag between precipitations and increase of water table and flow rates, and 2) flows in the tailings occur only under unsaturated conditions.

Climate change impacts on the hydrologic functioning of the catchment were investigated with the daily precipitations and temperature coming from the Coupled Model Intercomparison Project (CMIP5) for three climatic scenarios (RCP2.6, RCP4.5 and RCP8.5) and computed by several French institutes involved in climate modelling (http://www.drias-climat.fr/). The evolution of the water balance as well as the frequency and intensity of extreme events over the next 100 years were evaluated. The analysis shows a rise of the temperature that will affect the water balance and the recharge. In the meantime, no statistical trend is observed for the annual precipitation but extreme events will be more intense even if no more frequent. Our hydrogeological study combined with this climate change analysis will help providing the most accurate water management for the next years.

145

Comprehensive Study Of The Groundwater Resource In The Bacchiglione Basin (Italy): Statistical Analysis, Monitoring Network Optimization And Flow Model

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The study investigates the groundwater flow system of the hydrogeological basin of the Bacchiglione river for planning a sustainable use of the resource. This aquifer system is increasingly exploited, and it is already characterized by few monitoring points with decreasing groundwater heads. Its current exploitation level appears unsustainable. The groundwater resource is concealed underground, and its investigation is often based on few punctual field data.

Numerical modeling reproduces the groundwater flow, but it can lead to misleading conclusions if it is implemented and calibrated on little field data or on few longitudinal observations. This study proposes an analytical framework that overcomes this problem by merging statistical techniques and numerical modeling. The statistical analyses improve the modeler's understanding of the groundwater system behavior, giving insights on how to set the model. The model takes the information of the preliminary statistical analyses, developing a more realistic representation of the system and enabling more accurate sustainability scenarios.

The present study extends and integrates a 3D groundwater flow model of the Bacchiglione basin owing to new stratigraphic logs and years-long timeseries of local hydraulic heads. First, several statistical analyses are run on longitudinal observations to yield more insights on the system. This, in turn, enables the development of a statistical procedure able to improve the quality of future data by optimizing the existing groundwater level monitoring network. Following, the study undertakes a major update of the existing regional flow model using FEFLOW. This is done by first revising the conceptual model by means of stratigraphic logs and geological sections. Then, the flow model is calibrated in FEPEST based on the measured hydraulic heads and by testing several alternatives for a few arbitrarily selected parameters.

As expected, to run statistical analyses before implementing a flow model yields a deeper understanding of the hydrogeological system, which enables the modeler to make informed decisions when setting the model. As a consequence, the updated regional 3D model is found to reasonably simulate groundwater flow, and it is effective in establishing causal relationships between inflows/outflows and the variations of hydraulic heads. It also identifies critical areas in a scenario analysis proving itself to be an essential tool for managing water resources within the Bacchiglione basin. Overall, the present study proposes a general approach deemed applicable to any hydrogeological basin: first extract information from hydraulic head timeseries through statistical analyses, then implement a flow model adopting more insightful modeling choices.

146

Managed Aquifer Recharge As A Solution For An Over-Exploited Aquifer In South Portugal: Development Of A Decision-Support Groundwater Model

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The Campina de Faro (Vale do Lobo sector) aquifer system in South Portugal is set within a meso- cenozoic basin, comprising thick sequences of calcareous sandstones and limestones. The aquifer has been extensively exploited for agriculture, leisure and tourism purposes, with over 300 extraction points within an area of 32 km2. Groundwater levels have been declining since the 1980's, and a large depression now exists with groundwater levels well below sea level. As a result, the aquifer is not meeting the requirements for 'good' quantitative status under the Water Framework Directive, and measures are required to improve the status by 2027 and prevent further deterioration.

Managed Aquifer Recharge (MAR) by capture of ephemeral river flows is proposed as a potential solution. Groundwater modelling is being undertaken to assess whether such a scheme has the potential to achieve 'good' quantitative status and/or prevent further deterioration in quality as a result of saline intrusion. Although there are extensive records of hydraulic heads in the area, there are significant unknowns regarding the water budget components and hydraulic properties of the system. Given that the outcome of the proposed MAR scheme is highly dependent on these components, their contribution to predictive uncertainty needs to be quantified. This model is designed to have a fast run time, incorporating complexity only where it is important for the prediction, and with "process abstraction" where possible. This facilitates the use of highly parameterized approaches which enhance the assimilation of available data and the ability to quantify and reduce model predictive uncertainty.

We present details of the model development and preliminary outcomes of this ongoing study that show that a combination of MAR measures can be employed to improve the situation, but due to the variability in ephemeral river flows, re-use of treated waste-water for MAR should also be considered, subject to appropriate risk assessment. Whilst there is currently no legal framework available to licence MAR in Portugal, the situation in the Vale do Lobo aquifer remains critical, and should significant saline intrusion start to occur, this remains a potential mitigation measure. Further assessment of the environmental impacts of using waste-water for MAR would be needed before these options could be included in the Program of Measures designed to invert the poor quantitative and qualitative status of groundwater in the study area.

147

Evaluation Of The Groundwater Quality In The Ghallil Quaternary Basin (Todgha Downstream, South-Eastern Morocco)

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The Ghallil basin is located in the Todgha lower valley (South-Eastern Morocco). The quaternary unconfined aquifer is dominated by wady alluvium, water samples (5 water points in total) were taken; the analyzed chemical elements are Chlorides, Nitrates, Sulfates, Sodium, Potassium, Calcium and Magnesium.

The aim of this study is to assess the groundwater quality of the Ghallil, and to provide information on the origin of their provenance, and their behavior through geological formations.

The results also made it possible to determine the physico-chemical characteristics of groundwater in the Ghallil basin. The groundwater temperature varies between 15.1 and 49°C. The pH is close to neutral; and varies from 6 to 8. The electrical conductivity (EC) of the water points vary between 500 and 1600µm/cm, these EC values result from the leaching out of the reservoir rock in which the water was staying.

The analysis of the groundwater quality revealed that 40% of the points checked are of good quality, 20% are of average quality, and 40% are of poor quality. The chemical analysis showed that the groundwater of the basin belong to two chemical facies a chlorinated and sulphated calcium and magnesium facies and a sodium and potassium chloride facies.

The deterioration of the groundwater quality in the Ghallil basin could have geological and anthropic origins. The relationship between conductivity and sodium absorption indicates that there is no risk of alkalization while the risk of salinization remains.

148

Coastar As A Subsurface Solution To Improve Water Availability, In Areas Around The World With Water Scarcity And Salinization Issues

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Climate change including sea-level rise and the growing world population put enormous pressure on the (fresh) water resources in coastal zones and deltaic areas. Increasing water demand, decreasing fresh water availability in combination with higher waterquality demands pressurize the water resources.

This results often in increasing (groundwater) extraction, salination and serious land subsidence, which combined with sea level rise, leads to additional stress on future freshwater use. This complexity of issues needs an integral approach of various solutions.

We propose the COASTAR strategy that uses the subsurface as part of the solution to mitigate drought and salinization problems leading to a robust and sustainable water management. The overall aim is to close the (time) gap between water demand and supply using the subsurface. Large- scale coastal Managed Aquifer Recharge (MAR) can be used to store surpluses of freshwater until the demands peak. Our COASTAR cases combine different concepts in an integral approach, that incorporates environmental, societal and economic impact. For example: intercepting the intrusion of brackish to saline groundwater prevents salinization of the groundwater system in low-lying areas near the coast and groundwater extraction fields, while at the same time the brackish groundwater itself can be used as a source of freshwater after desalination.

In field pilots we translate our theoretical knowledge into a strategy with realistic and feasible solutions. Therefore, we combine numerical models and hydrogeological data in order to understand the system and identify possible solutions. In the Netherlands, the COASTAR strategy is already part of water resources planning executed by water authorities, water companies and the (food) industry. In 2019-2020, we performed studies in a low-lying area, a dune area (drinking water company Dunea near The Hague), the city of Rotterdam, the Westland horticulture area and on a national level for the Dutch coastal provinces. We believe that the integral COASTAR approach can be successfully applied in many areas around the world. For instance, a new project is running in Chili, but similar concepts are applicable in many coastal areas worldwide – from urban delta's to small islands. In all these potential COASTAR cases, we opt for regional scale implementation of water resources management strategies to secure freshwater supply in coastal areas for agricultural, industrial and domestic use. See for more information: coastar.nl.

149

50 Years Of Groundwater Management And Observations In Louvain-La-Neuve: A Review And Outlook For Sustainable And Resilient Groundwater Management.

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In 1968, a political and cultural crisis in Belgium led to the split of the Catholic University of Leuven, between the Dutch (currently KULeuven) and French-speaking (currently UCLouvain) twin universities. A new urban university city was designed and built from scratch in Louvain-la-Neuve to host part of the French-speaking UCLouvain. Louvain-la-Neuve is the most recent urban center created in Belgium since the creation of Charleroi in the late 17th century. The first academic year of UCLouvain in Louvain-la-Neuve was organized in 1972. Louvain-la-Neuve situates in a formerly rural area that had only seen farms, fields, and woodland before. It is located in the central loamy belt of Belgium and it is underlain by the unconfined aquifer of the tertiary Brusselean sands.

From the onset onwards, the urban planners and university authorities considered the local exploitation of the local groundwater body for drinking water provision. They also implemented innovative urban planning methods limiting the impact of the construction of the new university on the water resource. These planning methods aimed at i) promoting rainfall infiltration in the city by selecting permeable surfaces for the many pavements, roads, parking, and other public spaces between the newly created buildings; ii) optimizing water conservation and treatment by using a completely separated sewage network for rainfall and wastewater evacuation; iii) the creation of an artificial lake allowing artificial groundwater recharge.

For supporting water management, long-term monitoring of the different components of the hydrological cycle in Louvain-la-Neuve was initiated by the technicians and local scientists. Notwithstanding the willingness of former urban planners and university authorities to implement sustainable water management strategies, different pressures and groundwater

management problems appeared. On the eve of the 50th birthday of the UCLouvain at Louvain-la-Neuve, we review the groundwater management strategies and management problems that occurred in the city of Louvain-la-Neuve. We also illustrate the potential and limitations of the monitoring program and present new pathways for supporting long-term resilient and sustainable groundwater management in this unique context of a newly created university city.

150

Multi-Isotopic Screening At Regional Scale In Northern Italy: Implication On Groundwater Management For "Water Alliance" Drinking Water Suppliers

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Groundwater represents the main and safest source of water that supply, for drinking purposes, numerous urban and rural communities all over the world. For this reason, a deep knowledge of groundwater flow system in terms of quality, vulnerability and renewability of this precious resource is fundamental for a responsible use and management by different stakeholders. Thanks to the contribution of different members of Water Alliance in synergy with the Hydrogeology lab of Sapienza University, a multi-isotopic analysis at regional scale for a wide area of Lombardy region, aimed to improve knowledge about groundwater flowpath, aquifer vulnerability and renewable rate has been carried out.

Starting from a previous isotopic characterization performed at regional scale during 2017, each Water Alliance supplier selected wells and springs tapped for drinking purposes, for a total of 121 samples , intercepting different aquifer levels and distributed along a possible regional N-S flowpath. Groundwater stable isotopes analyses were performed on all the monitoring points, instead tritium, nitrogen isotopes (15N and 18O in nitrates), sulfates isotopes (34S and18O) and 13C isotope in Dissolved Inorganic Carbon (DIC), were analyzed in selected monitoring wells basing on previous data and major ions concentrations results. Groundwater isotopes and tritium highlighted the direct influence of meteoric recharge and infiltration of surface water on different portions of the regional aquifer system. Nitrogen results point out the possible anthropogenic origin of nitrate in groundwater and occurring degradation processes, while sulfates origin was ascribed both to marine origin and oxidation processes, partially influenced by human activities. Through the analyses of 13C in DIC, a clear distinction between shallow and aquifers was not confirmed, suggesting a possible interaction among different aquifer levels. Therefore, results confirmed the key role of multi-isotopic approach in defining origin, ages, vulnerability and renewability of groundwater resources, offering an useful tool for improving the sustainable management and the protection of tapped groundwater resources used by different water suppliers.

151

Combined Effects Of 2016 Seismic Sequence And Recharge Variability On Groundwater Storage And Discharge Regime Of Pescara And Capodacqua Springs (Sibillini Mts. Aquifer, Central Italy)

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The long-term effects of the 2016 seismic sequence, that strongly affected the groundwater flow of the regional aquifer in the Mts. Sibillini area [1,2], have been investigated for the aquifer feeding the tapped springs of Pescara and Capodacqua del Tronto, host in the calcareous fractured aquifers, namely Scaglia and Maiolica complexes (southern sector of the Sibillini Mts).

The water budget analysis, implemented starting from the discharge data and the evaluation of seasonal and annual variability of the aquifer recharge, revealed that the progressive shortening of the discharge of the tapped springs is a result of overlapping causes, attributable both to the seismic sequence and to the recharge variability. Additional stresses on the aquifer are related to the increased seasonal withdrawals from wells, due to the shortening of available spring discharge.

The baseflow recession analysis confirmed a transient enhancement in hydraulic conductivity after the seismic sequence, although the latest data support the assumption of a gradual recovery of the depletion coefficient δto the pre-seismic values. The main seismic events, by pore pressure propagation, triggered a short-term general increase of the discharge of the studied springs resulted in a water surplus of about 6 millions m3, zeroing the dynamic reserves and requiring a contribution from the static deep reserves too.

In conjunction, the study highlighted since 2017 a reduction of snow cover permanence, triggering a decrease the meteoric recharge of the aquifer, which hinders the recovery of the spring discharge to pre-seismic values. Further, as a result of the earthquakes, part of the groundwater previously drained by the tapped springs, is now flowing out at lower altitudes.

Through the analysis of the recession coefficient δand of the recharge variability, future scenarios have been carried out, previewing the recharge return to the pre-seismic conditions in a limited number of years. Different transient conditions have been recognized for the two tapped springs, where Pescara seems gradually recovering the pre-sismic hydrodynamic conditions, while Capodacqua fractured system, less affected by hydrodynamic changes, suffered for a strong consumptions of groundwater reserves. Consequently, in the immediate future it would be recommended to limit well withdrawals for facilitating the aquifer reserves, and to use additional sources (e.g. the new ones located at lower elevation), to ensure the requested drinking water amount.

152

Recharge Assessment And Water Table Variation Over Time In Groundwater Dependent Ecosystem: Possible Implication On Forest Health In Castelporziano Presidential Estate, Rome, Italy

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The piezometric monitoring of the aquifer of the Castelporziano Presidential Estate, a Natural Reserve clearly identified as Groundwater Dependent Ecosystem, is based on a network measuring the water table and the main chemical-physical parameters, of about 40 monitoring wells. Water table changes recorded during last 25 years are limited, but different trends have been recognized in different areas of the coastal sandy aquifer, due to the distribution of rainfall and infiltration and to the soil permeability. On coastal area seasonal changes of the water table are limited and time trend shows a depletion. On central area oscillations with time are evident and a negative trend is also affecting the aquifer. On the northern and eastern areas, the recharge periods are able to hinder the depletion, resulting in a positive trend of water table, probably enhanced by groundwater flow coming from the regional volcanic aquifer of Alban Hills.

A winter semester of aquifer recharge is usually followed by a summer period of groundwater exhaustion. Increase of occurrence of drought years (like 2016-2017) caused an extension of the exhaustion phase, which both decreases the water table and causes stress and water scarcity in soil and unsaturated zone, in the so-called “Critical Zone”. Soils act as link among the rainfall, the forest having an high ecological value and the groundwater table. The water content in the first meter of soil has been monitored by CREA Institute, recording different responses of outcropping sediments. In different periods of the year, the soils have a fundamental role in capturing rainfall water in unsaturated zone, in allowing deep recharge of the water table, but also in feeding the forest roots. These different conditions with time and space can obviously influence the forest health and consequently changes in recharge regime of the aquifer are to be considered one of the possible causes of critical stress shown by the forest during last years in the Castelporziano Presidential Estate.

153

Mapping The Susceptibility Of Groundwater To Drought Across The Republic Of Ireland Using A Machine Learning Model

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Climate change appears to modify hydrological processes across different spatial (>local) and temporal (event, seasonal, multi-annual) scales. In order to improve the understanding of how changes to processes affect groundwater resources, the Groundwater Climate project of the Geological Survey Ireland is upgrading the existing Irish groundwater monitoring network by developing additional monitoring sites to specifically record relevant hydrological processes with regards to: 1) groundwater-surface water interaction along streams; 2) coastal and tidal dynamics linked to flooding and sea water intrusion; 3) groundwater flooding; and 4) groundwater drought, which is the content of this paper.

Identifying suitable monitoring locations is challenging, as there is no a priori information of the prevailing groundwater dynamics in place. Hence, this paper proposes a machine learning model (Random Forest) to map the susceptibility of shallow (<~100 m depth) groundwater to drought across the Republic of Ireland. Groundwater drought is linked to: a) effective precipitation available for recharge, and b) surface and subsurface properties allowing recharge and transmission and providing storage. The presented method is concerned with b), the potential of the surface and subsurface to allow for recharge and groundwater storage.

Here, groundwater storage is expressed in terms of linearity of well or borehole hydrographs using the autocorrelation function (ACF). The increasing linearity (and decreasing rate of memory loss) of a time series expresses increasing storage of an associated system, and vice versa. Hence, the method quantifies the susceptibility to drought in terms of subsurface storage via the rate of memory loss.

The ACF was applied on daily groundwater level time series of 119 wells across Ireland. A Random Forest model was trained to predict the memory loss (lag times for ACF <0.05) based on the relative importance of available vectorised maps for Ireland, namely (in decreasing order of importance) the surface elevation (mOD), Height Above Nearest Drainage (HAND) (Rennó et al., 2008), groundwater vulnerability, depth to bedrock, presence of peat and subsoil permeability.

The model achieves an accuracy of 80.0% and a mean absolute error of 17.6 days (lag). The next steps will include an independent model evaluation using additional borehole hydrographs, and defining classes of groundwater drought susceptibility by linking the predicted memory loss with the Standardised Groundwater Index (SGI) (Bloomfield and Marchant, 2013).

The final product will inform site selection for drought-specific groundwater monitoring and provide a basis for climate change adaption measures.

155

Evaluation Of Groundwater Quality In The Senegal Deep Maastrichtian Aquifer: Multivariate Statistics And Water Quality Index-Based Gis Approaches

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The deep Maastrichtian confined aquifer constitutes the largest groundwater reservoir in Senegal, with an estimated reserve ranging from 300 to 500 Billion m3. It is the main exploited aquifer with around 1,300 operating boreholes pumping approximately 4.6 Million m3/year. However, the aquifer bears fossil groundwater featured in the mid-western part by a brackish water along a South- North band with high mineralization content, high chloride and Fluoride exceeding drinking water standard. Previous studies on the hydrochemistry, isotopes and groundwater flow modelling of the aquifer have been carried out, but no systematic and updated publication of a regional study of groundwater quality assessment was available.

In this regional study, Multivariate Statistical Analysis (MSA) and Multicriteria Decision Analysis were used to (1) evaluate the water type and composition (2) identify the probable factors controlling the hydrochemistry (3) and map the suitability of groundwater for human consumption and irrigation purpose through groundwater quality index (WQI). The quality data of 232 boreholes covering the overall country used in this present research were obtained from the Water Management Department of Hydraulic Ministry by compiling physicochemical and chemical analyses from 2013 to 2019 (TDS, EC, HCO3-, Cl-, NO3-, SO42-, Na+, K+, Ca2+, Mg2+, F-).

Results shows that major ions, TDS and fluoride are globally under WHO standards except in a meridian band (brackish band) globally oriented North-South where a strong increase in mineral loads is sharply noted. The Pearson correlation matrix used on EC and major ions indicates a correlation degree ranging from moderate, high and strong correlations. The Principal Component Analysis (PCA) exhibits rock interaction, ion exchange, carbonate dissolution minerals and, to a lesser extent, anthropogenic effects. The Hierarchical Cluster Analysis approach coupled with the Piper Diagram define mixed-HCO3 and Na-mixed water types in one hand; and brackish groundwater with very high fluoride contents in another hand. The rock interaction between fluoride minerals (apatite fluoride) with groundwater can explain the increase of fluoride and residual sea water and/or current marine influence Na+ and Cl-; and dissolution of gypsum minerals. The WQI based on GIS indicates excellent to acceptable groundwater and suitable for drinking usages representing 69% of the total area and. However, there is a high concentration of ions in the brackish band and its surroundings leading to poor (11%) and unsuitable (20%) groundwater for both domestic and irrigation purpose.

157

Groundwater Potential Mapping By Means Of Multilayer Supervised Classification: An Application To The Abéché Region, Eastern Chad

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Groundwater supply for drinking and agricultural purposes has an important role in the Abéché area, which is the economic center of Ouaddaï region (eastern Chad), where more than 200.000 people live. The geological settings along with scarce precipitation limit the storage capacities and recharge to the aquifers. However, productive wells in some specific areas encourage the identification of promising hydrogeological targets.

To improve the identification of these areas, a machine learning approach was first applied to an area of 20.000 km2. The area is characterized by the Precambrian basement in the eastern part, and by quaternary deposits in the central and western areas. The national database SITEAU includes more than 500 boreholes for this region; the location, operational status and, whenever possible, flow rate and depth of groundwater have been verified during a dedicated fieldwork. A spatially-distributed set of explanatory variables for groundwater occurrence was then compiled into a geographic information system and linked to the borehole database.

Explanatory variables were generated from multiple remote sensing data and geological/hydrogeological surveys. They include parameters such as geology, soil, land use, distance to major channels, moisture-related indices and rainfall, among others. Twenty supervised classification algorithms were then used to find patterns of explanatory variables leading to the presence of groundwater. A sample of the borehole database was used to train the algorithms, while the rest was used to check how well the algorithms were able to predict groundwater occurrence. After performing cross-validation, recursive feature elimination and parameter fitting routines, classifier performance was assessed as a function of number of successful predictions relative to the total number of attempts. The classifiers able to predict the target variable were extrapolated to develop a groundwater potential map.

Decision trees, random forest and K-nearest neighbors algorithms predicted the presence of groundwater to an acceptable extent (>85% test score). Geology, landforms, NDVI, lineament density and distance to major channels were found to be appropriate explanatory variables in most cases. The resulting groundwater potential map shows that wadis and the piedmont area are the most suitable for groundwater development. Moreover, the combination of best fitting parameters can be upscaled to cover larger areas where observation points are not available.

This study proves that groundwater potential maps issued by a multiple approach, combining remote sensing data processing, field work and machine learning may be considered a valuable tool for the development and exploitation of groundwater resources in arid region

158

Combined Isotopic And Dissolved Gases Approach For The Assessment Of Co2-Rich Mineral Groundwater Origin – Application In The Ardennes Region, South-East Of Belgium

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Naturally CO2-rich mineral groundwaters have been exploited for centuries for bottling and thermal activities and nowadays constitute a dynamic economic market. In the eastern Belgium, the city of Spa is known worldwide for its ferruginous and naturally sparkling groundwater springs that gave their name to the bathing tradition commonly called 'spa'. However the origin of the CO2-rich waters, and specifically the origin of the dissolved CO2 is still a matter of debate (Barros et al., 2021), with three main competing theories: (1) the in depth dissolution of carbonate rocks by slightly acidic groundwater (2) a volcanic origin, with a direct input of mantellic gas produced by the neighboring plumes of the Eifel region (distant of about 50 km) (3) a combination of both theories explained above.

The aims of this study is to evaluate these theories in the light of new analysis results including especially carbon and helium isotopes together with dissolved gases. A first step consisted in the analysis of δ13CCO2 in groundwater. However, without taking into account the potential fractionation of δ13CCO2 that would result from formation of a free-phase CO2 during carbonates dissolution, the obtained values fall into the overlapping zone between the sedimentary range of values and the magmatic range of values. The origin cannot thus be clearly attributed to either carbonate dissolution or magmatic degassing.

In a second step other dissolved gases were considered, particularly He, N2 and Ne that are powerful tracers of CO2, particularly to identify mantle contributions. First results show that the studied samples are indeed oversaturated in CO2, but also in He, which is often a signature of a magmatic origin. To confirm this, 3He/4He ratios will be studied soon to detect whether combining CO2/3He with13CCO2 will allow to distinguish limestone-derived CO2 from mantle CO2. This method has proven to be conclusive in many different contexts and should therefore respond to a long-standing uncertainty in the studied area. Barros R., Defourny A., Collignon A., Jobé P., Dassargues A., Piessens K. and K. Welkenhuysen. 2021. A review of the geology and origin of CO2 in mineral water springs in southeast Belgium. Geologica Belgica 24 (1-2): 17-31 https://doi.org/10.20341/gb.2020.023

159

Historical Pathways To Water Insecurity And The Future Risks On The Water Supply Of Addis Ababa City

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Stable isotopes in water (e.g., δ2H and δ18O) have been used as important indicators of natural hydrological processes. Recent studies have documented tap water isotope patterns can reflect interactions of human activities with hydrological processes. This study presents stable isotopic ratios (δ2H and δ18O) of more than 200 tap water samples collected and analyzed at ten Addis Ababa sub-cities. The geographic location information of the sample collection sites including latitude, longitude, and elevation was recorded. The isotope results were used to map the tap to its sources- namely, surface water, groundwater, mixed surface water groundwater sources. To augment the mapping of the tap to its sources, electrical Conductivity measurements have been carried out. Water interruption patterns were recorded for both dry (May) and wet (August) seasons and linked to the different sources so as to see if shifting to groundwater has helped increase the reliability of uninterrupted daily supply. The historical contribution of the different water supply sources to the Addis Ababa city water demand has been outlined. The pathways to water security and improvement in the water supply services of Addis Ababa city due to a shift from surface water- dominated to groundwater-dominated water supply sources have been analyzed. This study promotes applications of isotopes as a tool to generate important information to map water supply risks to urban residents.

160

Developing A Methodology For Deep Groundwater Suitability Mapping: Towards Increased Boreholes Success Rates For Wash Programs In Arid And Semi-Arid Areas

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The dryland areas of eastern Africa show distinct characteristics when compared to other arid regions in Africa. Unlike the arid regions in northern Africa, which are known to hold large aquifers with good quality groundwaters, eastern Africa benefit from few such aquifers. The groundwaters in the multi-layered sedimentary rocks of eastern Africa are characterized by a very deep water table and often saline water conditions. The region is underlain by thick succession of volcanic rocks forming extensive to narrow plateaus, isolated peaks, usually truncated by the tectonic basins along the active East African Rift. The rugged highlands create a rain shadow effect that reduces moisture availability in the leeward side. The arid climate, the volcanic and geothermal activities led to high- salinity groundwaters with abundant geogenic contaminants in groundwater.

Drilling success rates are generally very low, in some sub regions up to 80% of newly drilled wells turn dry or return poor quality waters. UNICEF in collaboration with Acacia Water and local hydrogeologists developed an integrated methodology to increase drilling success rate in the region. The method builds on and applies an existing III phase approach developed by UNICEF Ethiopia (Godfrey and Hailemichael, 2016) and tested to be successful by Josephs-Afoko et al (2019). The current method employs a two-stage process whereby firstly the regions are classified by the likelihood of encountering groundwater using an overlay analysis combining remote sensing data and GIS-layers to develop groundwater suitability maps. The input layers get their own weighting score in the analyses and includes information such as lithology, lineaments, topographic wetness index, soil type, etc. The second stage of the investigation involves detailed survey of the regions using remote sensing, geophysics, field inventory of wells, geological and hydrogeological ground truthing assessment, isotope and geochemical investigation, etc. The objective of this presentation is to showcase the hydrological difficulties, the methodology

employed and the results achieved by employing the two-stage hydrogeological mapping methodology. The project has been funded by the EU RESET II programme in Ethiopia and implemented by UNICEF Ethiopia.

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161

Assessment Of Groundwater Quality Using The Water Quality Index And Microbiological Parameters In Thiaroye Shallow Aquifer – Dakar/Senegal

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Thiaroye, the study area, is the densely populated suburban of Dakar in Senegal and is under the assessment of groundwater quality for drinking purpose and irrigation using a GIS approach based on Water Quality Index (WQI) and microbiological assessment. It is a part of the Quaternary sand system extending along the northern coastal zone and covers an estimated area of 300 km2.

However, the main problem reative to groundwater is nitrate pollution which highly depleted water quality.

To assess the quality of this groundwater, 57 groundwater samples were collected from dug-wells and boreholes with 27 samples collected in the wet season and 33 in the dry season for physic- chemica and chemical analysis (TDS, EC, pH, Na+, Mg2+, Ca2+, K+, Cl-, HCO3-, NO3-, SO42-).

Furthermore, 30 additional samples for microbiological analysis were also collected.

The results show that in the dry season 1% of groundwater represents good quality, 56% poor quality, 37% very poor quality, and 6% is extremely poor for drinking. However, their suitability for irrigation indicates that the sodium percentage (Na%) is acceptable. In contrast during the wet season, 20% of samples show poor quality, 56% very poor quality, and 23% extremely poor for drinking. Their suitability for irrigation indicates that the percentage of sodium (Na%) is 75% acceptable.

The microbiological analysis in the dry season indicate that 56.7% of the samples are infected by Total Coliforms and 43.3% by Echerichia. Coli while in the wet season, 71.4% of the samples are contaminated with Total Coliforms and 17.65% with E. coli. In addition, By this, most of the dug- wells samples exceed the WHO limit for drinking water. These pathogens as an indicator of microbial quality indirectly indicate faecal pollution. The number of Total Coliforms and E. coli found in some of the dug-wells show that poor groundwater protection coupled to poor sanitation conditions remain the potential source of the high microorganisms content in the groundwater.

Keywords: Groundwater – GIS - Water Quality Index - Microbiological quality - Thiaroye aquifer.

162

Qmra For Setting Health-Based Performance Targets During Soil-Aquifer Treatment: Application To The Ezousa Site In Cyprus

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A quantitative microbial risk analysis of Ezousa (Cyprus) MAR site is presented to evaluate the health risks associated with three pathogenic micro-organisms: pathogenic fraction of Escherichia Coli (E. Coli) , Rotavirus and Giardia duodenalis. At Ezousa, raw wastewater is collected from the urban area and subject to technical treatment (primary, secondary and chlorine dioxide) and soil-aquifer treatment prior reaching the end-users, who are mainly farmers. A schematic overview of the MAR facility is shown in Figure 1 (Annex).

The removal efficiency of these processes is determined according to World Health Organization reports, whereas two extreme exposure scenarios are considered. The first scenario refers to the situation commonly encountered in industrial countries, where farmers use tractors and associated equipment and are expected to wear protective gloves during their activities. The second scenario describes farming practices in developing countries, in which tractors and gloves are rarely used. The results suggest that all three pathogens are likely to infect individuals for both exposure scenarios.

Regarding Scenario 1, around 25 % of the samples for E. Coli exceed the target values, whereas highest health risks are found for Rotavirus and Giardia, in accordance with existing reports. As expected, the risk analysis for Scenario 2 provides much higher values for the health parameters compared to Scenario 1, suggesting that all pathogens possess a high risk for human health under the “worst-case” scenario. The statistical results for different health indicators for each pathogen regarding Scenario 1 are shown in Table 1 (Annex).

Finally, the QMRA was used to predict the required microbial removal of the subsurface in order to meet health based targets. The health-based objective for E. Coli (bacteria) is met after a Log Removal Value (LRV) of soil-aquifer passage for Scenario 1 and Scenario 2 at approximately 2.5 log(10) and approximately 4 log(10), respectively (Figure 2, Annex).

For E. Coli, the total performance requirement (combined with the microbial removal of the engineered pre-treatment) for Scenario 1 and Scenario 2 is found to be 5.5 log(10) and 7 log(10) units, respectively. These values are consistent with the findings of existing reports, suggesting that the removal efficiency of the soil-aquifer passage plays a crucial role under circumstances such as a heavy microbial load or technical failures.

163

Impact Of Sustainable Land Management On Water Availability In Aba Gerima Watershed

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In the highlands of Ethiopia Sustainable Land Management (SLM) has been practiced and recently promoted by the Ethiopian government to tackle problems related to land degradation. However, the impact of SLM practice on water avalablity has not been well demonstrated with evidence. Here, an integrated monitoring study was conducted from Aug-2019 to Sep-2020 in the Aba Gerima watershed, in the upper reaches of the Blue Nile basin, to assess the impact of SLM practice on stream discharge and, in particular, on groundwater flow on two adjacent sub-watersheds: one where the SLM practice had been implemented (treated watershed); and the other a control watershed without SLM (untreated watershed). In the treated sub-watershed integrated soil and water conservation (physical and biological measures) had been introduced to the area since 2015. Shallow groundwater levels, stream discharge and water stable isotopes (18O and 2H) signatures were monitored.

Results show a shallower groundwater levels, delayed recession, higher base flow, lower surface runoff and higher stream residence times in the treated watershed as compared to the untreated watershed. It can be concluded that the SLM practices have resulted in higher infiltration rates and a reduction of direct surface runoff which has had a positive influence on water storage within the catchment.

164

Identification Of Potential Sites Of Groundwater / Surface Water Interaction At The Artois-Picardie Basin Scale

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To facilitate the assessment of the effects of "groundwater / surface water" interactions on water quality, within the framework of the Water Framework Directive (WFD), the Artois-Picardie Water Agency and BRGM have joined forces to develop an innovative multi-criteria approach, to better characterize these exchanges at basin level.

To meet the needs of the WFD aimed at verifying the non-degradation of surface water due to groundwater, it is necessary to have a good prior knowledge of the areas potentially favoring exchanges between groundwater and surface water. In Artois-Picardie, numerous studies carried out in recent years have made it possible to acquire knowledge, often local, but no capitalization or valorization has so far been really undertaken.

Different approaches have been carried out as part of this knowledge synthesis:

- a bibliographic inventory and the construction of a georeferenced database leading to the characterization of "groundwater/surface water", observed or supposed, interactions on more than 2000 hydrographic segments;
- the development and implementation of an innovative multicriteria approach combining geomatics and geostatistics to determine the areas with the greatest potential for interaction;
- the identification of the most relevant hydrogeochemical indicators to target the hydrographic segments benefiting from the strongest support by groundwater.

In the end, several areas were identified as very favorable to "groundwater / surface water" interactions, in particular the chalky valleys, the Marquenterre coastal aquifer on the western coastline, the pissard sands crisscrossed by watergangs on the northern coastline and the thanetian sands (only the outcropping parts outside the Orchies basin and outside the area undercover by the Flanders overconsolidated clays).

These conclusions were compared with the results of the work of the Water Agency on the ecological and chemical state of surface water, with the aim of locating the so-called "high-stake" areas. Several rivers, with degraded water quality and apparently fed by groundwater, have been identified: the upstream and middle Lys, the Souchez, the Scarpe river upstream, the Selle / Escaut and the Scardon. These areas will be the subject of additional investigations in order to characterize more precisely these "groundwater / surface water" interactions.

166

Some Best Practices In Condition And Performance Tracking For Wellfield Asset Management For Sustainable Groundwater Supply

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Wells are a distinctive part of groundwater-source water facilities, such as (but not exclusive to) municipal or industrial water supplies. Water supply and other wells (e.g., recharge, monitoring, and geothermal wells) are in close contact with

the nonengineered "wild" environment. There can be numerous formation changes over depth, and water chemistry and microbiological gradients.

Aquifers and even confining units are known to harbor notable natural microbiological communities with their geochemical, corrosion, and depositional influences. Human contamination and aquifer alteration factor into planning.

Besides the distinction of being at the "wild"-engineered system interface, water supply wells are typically relied on to produce raw water that is consistent in water quality, safe chemically, and free of harmful microbiological constituents. Water wells are impaired if at risk of pumping contaminated groundwater, even if they are otherwise high-performing. Taken together, a total life-cycle asset management program for these "wild" wells ideally involves planning, design, baseline documentation of performance, environmental assessment, and performance tracking. These actions facilitate the establishment of trends and making decisions over time, such as planning service events proactively based on that tracking, or correcting environmental impairments.

Current or potential environmental, hydrologic, well condition and performance problem causes can be detected and tracked with available (not exotic) methods, permitting preventive maintenance actions and treatment, and predictive planning and budgeting.

This presentation will concisely discuss biological, physicochemical, inspection, and hydrogeologic methods found to be useful in well/wellfield condition and performance assessment based on some decades of experience in various aquifer settings the USA.

168

Conjugated Approach To Model Aquifer Drainage And Land Subsidence Induced By Underground Mining

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One of the most serious direct consequences of underground mining is land subsidence, which can damage both surface and underground infrastructure and even put surface users' safety at risk.

Nonetheless, extensive pumping operations are necessary to carry out mining activity. Thus, the effect of coal extraction is attributed not only to land subsidence, but also to an increase in fracturation degree and, as a result, rock mass permeability. As a result, underground stress is redistributed. This can result in the depletion of regional aquifer systems and land subsidence caused by groundwater head drop. Typically, the spatial extent of the phenomenon exceeds the direct impact of the exploitation.

Notably, a variety of models are capable of forecasting mining-induced ground movements with reasonable accuracy. As a result, its adverse effects can be evaluated and mitigated successfully. Nonetheless, assessing rock mass drainage caused by mining operations remains a challenging research problem. Thus, the study presented aimed to ascertain the extent of land subsidence caused by the depletion of aquifer systems as a result of underground mining.

The research was conducted in the area of underground hard coal exploitation in the Bogdanka mine, Poland. To begin, using conventional groundwater flow theory, a 3-D finite-difference hydrogeological model of induced aquifer drainage was constructed. The values for the model's hydrogeological parameters were determined using literature and empirical data. Second, an influence function (IF) model was used to estimate the groundwater-related land subsidence. Finally, the calculated results were compared to the field data with success.

According to the research findings, underground mining's indirect effects are significantly greater than its direct impacts. The numerical modelling results indicate that between 1976 and 2020, the main aquifer was significantly drained. The groundwater head decreased by approximately 550 m in the mining exploitation field.

In 2020, the depression cone covers an area of about 548 km2.

Additionally, the determined subsidence bowl is extremely similar to the observed depression cone. However, land subsidence covers approximately 410 km2, with maximum values of about 0.36 m in 2020.

The methods described can be used to develop effective plans for controlling and regulating land subsidence. Thus, when underground mining is considered, the findings may pave the way for more efficient groundwater management.

169

An Improved Drastic Framework For Urban Groundwater Vulnerability Assessment Using Statistical, Metaheuristic And Parameter Superimposing Approach

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Groundwater is a precious resource that is available at the ready-to-drink form in most of the region. Groundwater contamination is an inevitable problem in the course of urbanization and to rejuvenate the polluted aquifers to the original state is prohibitively expensive. To protect this precious natural resource from pollution, a proper assessment tool is required to demarcate the groundwater vulnerable zone. DRASTIC is the extensively used index-based groundwater vulnerability assessment model. However, the DRASTIC model has certain limitations in terms of subjectivity associated with the rates and weights. To overcome such limitations a combinatory statistical, metaheuristic, and parameter superimposing approach was proposed in this study to improve the generic DRASTIC model. The Wilcoxon rank-sum non-parametric test was used to optimize rates of DRASTIC parameters and weights were optimized using the biogeography-based optimization (BBO) algorithm. In addition, the landuse parameter was superimposed with the DRASTIC model to evaluate its influence in groundwater vulnerability assessment. The performance of the generic DRASTIC model was compared with the optimized DRASTIC model (Wilcoxon-BBO-DRASTIC) and in turn optimized DRASTIC model encompassed with landuse parameter (Wilcoxon-BBO-DRASTIC-L) for Chennai mega city, India. The correlation coefficient between the nitrate concentration of wells and the vulnerability index were used for validation of developed models. The generic DRASTIC model result depicts very poor correlation (R = 0.055), whereas Wilcoxon-BBO-DRASTIC model produces a good vulnerability accuracy (R = 0.725). The Wilcoxon-BBO-DRASTIC-L yield the better vulnerability assessment among the other developed models (R = 0.758). The resultant vulnerability map from the optimized model were classified as very low, low, moderate, high, and very high vulnerability with 13.69 %, 24.84%, 24.20%, 24.78%, and 12.49% respectively. The developed Wilcoxon-BBO- DRASTIC-L model demarcates the north-eastern region of the study area as very high vulnerable zone and to avoid further exploitation. The proposed optimization DRASTIC framework coupled the hydrogeological parameter with the existing landuse to increases the performance of the vulnerability assessment model in an urban region. Hence, the developed optimized framework is a robust one and can be adopted for vulnerability assessment globally.

171

Implementation Of A New Framework For Real-Time Monitoring And Modelling Of Subsurface Processes At A Pilot Managed Aquifer Recharge Site In Pirna, Germany

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Managed aquifer recharge (MAR) represents a viable technique for sustainable groundwater management. Nevertheless, the absence of proper monitoring and the lack of data on associated risks at some MAR facilities, reduces the public trust and raises questions about the impact of MAR on the affected ecosystem as well as hinders the optimal operation.

Thus, an efficient control of the recharge and recovery processes incorporating real-time data while reducing the environmental and economic risks could optimize the performance of MAR systems. The main objective of the EU- funded WaterJPI project SMART-Control is hence to reduce the risks in the application of sustainable groundwater management techniques through the development and implementation of an innovative web-based, real-time monitoring and control system (RMCS) in combination with risk assessment and management tools.

As a first step, the RMCS at the pilot MAR site in Pirna, Germany was installed and setup. The monitoring sensors measuring e.g. electrical conductivity, water level and temperature in the groundwater, were connected to a webserver (SensoWeb, UIT company). From there, the data is send to the web-based INOWAS platform (www.inowas.com), a free online service where various empirical, analytical and numerical tools are compiled for MAR assessment. On the INOWAS platform, new features and tools have been developed and implemented including data pre- processing, time series manipulation, value processing and visualization that foster the real-time monitoring and help to assess operational risks of MAR schemes such as high electrical conductivities (saline intrusion) or water level fluctuations.

As a second step, the processed time series can be further used, e.g. to analyze the hydraulic residence time in the aquifer or as input for a (real-time) numerical groundwater flow model. The incorporation of real-time monitoring data into the web-based numerical modelling scheme was subsequently tested. Although the numerical model run is currently manually started by visiting the INOWAS website, the automated incorporation of new monitoring data as boundary conditions or observation points is promising to evaluate the underground processes in almost real-time. This could foster the actualization of numerical models which are frequently only updated on an irregular basis.

The results indicate that the developed tools help to analyze the relevant processes occurring during MAR operation reducing the risks associated with MAR and enables the up-to-date diagnostic for operators, regulators and water managers. The developed tools are currently tested and enhanced at five additional pilot and full-scale MAR schemes in Germany, France, Brazil and Cyprus.

172

Study Of The Hydrological Functioning Of Two Coastal Ponds In A Unesco World Heritage Site In Southern Spain

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Doñana National Park (southern Spain) has a high bio-geological value, in which groundwater plays a fundamental role, as it provides a great deal of resilience to the numerous groundwater-dependant ecosystems, such as ponds, springs and water courses that exist in the Park. Despite the efforts to conserve it, anthropogenic activities, such as groundwater extraction, are one of the main threats menacing this ecosystem. Hydrogeological monitoring of water bodies is crucial to understand the surface water-groundwater interaction and prevent its degradation or even its disappearance. In this study, the hydrological functioning of two nearby coastal ponds has been analysed by means of hydrochemical transects and continuous surface water and groundwater level measurements, made along a flow path in the wet season of hydrological year 2020-21. The coastal ponds selected for this study were Santa Olalla pond, the only permanent pond and the largest in this area, and Dulce pond, a semi-permanent pond located at a higher altitude. The transects have been made in a horizontal path from the shore towards the centre of each of the ponds. In these transects, conductivity, pH, and temperature have been measured. The water level measurements have been made with sensors programmed to take three-hourly data located in the centre of both ponds, and in piezometers near to the shore of these. Both hydrochemical results and water level measurements indicate that minor surface water-groundwater exchange is expected in the upper pond (Dulce pond), whereas a net groundwater discharge was detected in the lower pond (Santa Olalla pond).

173

Current Risk Assessment Approaches Applied For Managed Aquifer Recharge (Mar) – An Overview

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Managed aquifer recharge (MAR) is increasingly being used worldwide for drinking and irrigation water supply, aimed at a sustainable and resilient groundwater management. Excess water e.g. from rainfall/flooding, water treatment plants, rivers or desalinated seawater can be infiltrated into an aquifer to store and recharge groundwater. Planning, implementation and operation of MAR schemes require appropriate risk management to allow a resilient and safe water supply and use. In this work we have reviewed currently existing and applied risk assessment methods and guidelines (published within the last 20 years) as well as summarizing possible potential hazards. This review may support MAR planners and operators within the risk management processes, such as for selecting appropriate approaches.

Five main risk types can be identified: (i) human health and environmental risks, (ii) technical, (iii) social and (iv) economic risks as well as (v) risks related to legislation and governance. Human health and environmental risks have most widely been addressed in the considered literature. Currently, few approaches are reported that consider a holistic risk assessment (including all five main risk types). Financial concerns might often hamper the application of a holistic risk assessment approach for which e.g. detailed and expensive hydrological and water quality-related models might be needed. However, the use of a holistic risk assessment approach could also contribute to a higher economic efficiency. To date, apart from Australia, a lack of legally binding MAR frameworks (including risk assessment approaches) can be seen. Summarizing our findings, barriers for implementing MAR are not only related to geological/hydrogeological conditions or technical and economic feasibility but also to lacking acceptance by the public and policymakers. The latter issue could be addressed by using a holistic and transparent risk management approach that includes the assessment of a wide range of potential hazards related to MAR and the development of a risk treatment plan.

174

Evaluation Of Transfer Function Noise Modelling And Dimensionality Reduction Techniques For Karst Systems

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Though karst aquifers are important sources of drinking water on a global scale, these systems are still insufficiently understood regarding adequate model representation. Time Series Analysis (TSA), as a data-driven approach, has been demonstrated to be useful for the characterization of karst system hydrodynamics with sparse data. Recently, transfer function noise (TFN) modelling with predefined impulse response functions, as a linear TSA-method, has been applied to analyze and manage groundwater systems. In this approach, impulse response functions in continuous time are used to describe the system response (e.g., spring discharge) to independent stress input time series (e.g., precipitation).

Depending on the TFN model complexity and the kind of response functions used, the model could have a large number of parameters, potentially causing ambiguity of the calibration.

This is further aggravated if the physical meaning of model parameters is unclear such that parameter values cannot be constrained or verified by field measurements.

Dimensionality reduction (DR) techniques can be used to study the model parameter space, identify most important parameters, and potentially lower the total number of model dimensions. Previous applications in karst hydrology employ the linear DR method of active subspaces. A broad variety of linear and non-linear DR techniques exist in statistics and computer science, which were not yet adopted for karst or other water resources.

The goal of this study is to evaluate the suitability of TFN models and DR techniques to simulate karst systems. To reach this objective, the following steps are carried out. First, we develop synthetic karst systems using the distributed numerical flow code MODFLOW-CFP. With these models we generate data to be in turn modeled by the TFN approach. After fitting the TFN models to the synthetic data, the corresponding parameter spaces are explored and studied using DR methods. In combination with statistical model diagnostics, all results are used to evaluate the applicability of TFN models for karst systems. Lastly, we study a real karst system with the proposed framework.

Preliminary results show that the TFN approach may be used to model karst spring discharge, as evaluated according to fit metrics. When using complex TFN models, though, the initial solutions were found not to be unique. Lower dimensional structures could be identified independently of general TFN model structure or defined response function. Preliminarily, linear DR may be insufficient in capturing the lower dimensional structures, however giving the most useful results for further applications.

175

Variability Of Interactions Between Groundwater, Rivers And Gravel Pit Lakes In The Seine Alluvial Plain Of La Bassée, France

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Hydrological time series analysis is a key asset for understanding hydrosystems' behaviour and characterising their dynamics in response to forcings, wether natural or anthropogenic. It allows the identification of the preponderant factors leading water level fluctuations in each surface and underground water compartments. It relies on in situ and high frequency data acquisition. Such a water level monitoring network has been deployed for around 6 years along the alluvial corridor of the upper Seine River. In this lowland wet area, the landscape has been shaped by human activities since the mid nineteenth century and is marked by the river channelisation and the exploitation of sand and gravel. Rivers, oxbow and gravel pit lakes interact with the chalk and alluvial aquifers. The variability of their interactions is here interpreted through the prism of available water level time series. Special emphasis is placed on understanding the dynamics of the numerous gravel pit lakes that are present in the alluvial plain and whose fluctuations will soon be accessible for SWOT satellite observation.

176

How To Efficiently Clog Groundwater Wells: Lessons Learned About Well Aging From An Extraction Site In The Brussels Sands, Belgium

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At the Vlierbeek site near Leuven, Belgium, De Watergroep extracts groundwater from the phreatic part of the Brussels sands. 14 siphon wells have screens between 13 and 37 m below surface level and are sensitive to clogging by the precipitation of iron(III) hydroxides. Well rehabilitation occurs every two or three years.

The site's design dates from the early 1970s when little attention was given to well clogging. Consequently, there are a number of issues in the well design as well as operational issues that favor clogging. The upper part of the screen interval is for instance located in the transition zone between the aerobic and anaerobic part of the aquifer. Dissolved oxygen and iron(II) are thus mixed in this transition zone and clog the gravel pack and the borehole wall by iron(III) hydroxide precipitation. Further, there are frequent periods when the extraction is not used for a number of hours. During these stand-stills, iron(III) hydroxide can precipitate in the well and clog the screen.

But that is not the whole story. Time series of hydraulic head in the wells show that there is a clear relation with the extraction rate up to a certain point in time. Afterwards, the head drops rapidly not related to the extraction rate and this instigates the frequent rehabilitation. When the change happened, extended periods of no extraction occurred for a total of 23 months. With a model simulating in detail the groundwater flow in the vicinity of the wells, it can be shown that the well forms a connection between the upper and lower part of the aquifer. Oxygen rich water enters the upper part of the screen. It flows downward where it mixes with iron(II) rich water and leaves the well via the lower part of the screen. There, iron(III) hydroxide precipitates and clogs the well. And especially the prolonged period of stand-still led to an aging of the well to a point of no return: the main part of the flow channels was cemented with incrustrations causing well rehabilitation to increase only temporally well capacity.

Remedial actions could be to minimize screen length to the lower part of the aquifer, although possibly limiting extraction capacity. Alternatively, the application of subsurface iron removal was investigated and proven feasible. To conclude, the Vlierbeek site illustrates some important issues of what not to do trying to minimize the rate of well aging.

177

Hydrocycles For The Intensification Processes Of Groundwater Treatment From Hexavalent Chromium Using In Situ Technology

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The results of groundwater treatment from hexavalent chromium on Ilek industrial site, Aktobe, Kazakhstan are represented in the following article. Specific techniques, practices and methodologies employed on sites with chromium contamination using in situ technology are described. The aim of this technology is to reduce Cr (VI) in groundwater and contaminated soil to the thermodynamically stable Cr (III) by creation reactive zones in the aquifer. Therefore, migrating contaminants are intercepted and get permanently immobilized or degraded into harmless end products.

The main difference from the standard in situ treatment technology was in creating so-called hydrocycles. For a one hydrocycle a period of reagent injection changes to the water injection for pressurization and enlargement the area of reagent delivery and after that take turns to a period of re-injecting for the further prolongation of treatment process. The intensification of treatment process is effected by numerical model controlled to add or exclude injection dots from the pumping net.

The results of chromium reduction on pilot site shown a considerable decrease of hexavalent chromium from 53 mg/L to 0.05 mg/L, indicating that in situ treatment using hydrocycles may be an effective approach when deployed at the field scale. The results of successful treatment are proved by the absence of secondary contamination during three-year monitoring on a site after a period of work performed.

180

Fast Mg-Na Exchange During Salinization-Freshening Processes In Coastal Aquifers

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Marine intrusion is a problem that affects many coastal aquifers, especially in arid and semi-arid areas. Various solutions have been proposed to remedy this problem, among them the development of negative hydrodynamic barriers. These consist of the extraction of water from the saline wedge that penetrates the aquifer (SGW). This type of strategy against seawater intrusion is especially advisable in places where a desalination plant is installed that is supplied by SGW.

The Almería desalination plant (SE Spain) captures 4000 m3/h of SGW through a coastal detrital aquifer. As a consequence of the periods of extraction and stops by the desalination plant, the variations in the salinity and chemistry of the aquifer water are notable, reaching drops of 40 m at the interface. The cyclical variations of salinization and freshening that the aquifer undergoes cause a series of cation exchange modifying processes to also act cyclically. Thus, at pumping times, when there is a freshening in the aquifer waters, an excess of sodium ions is registered, while at the moments of shutdown and salinization, an excess of magnesium ions is observed. This Na-Mg exchange does not conform to the cation exchange processes that are generally attributed to salinization-freshing processes in coastal aquifers.

On the other hand, regardless of the pumping regime, there is a clear excess of calcium ions that would be attributed to Holocene marine intrusion. 14C dating of the most saline waters of the aquifer register ages between 8-10 Ky. All this indicates that while the exchange processes in which Ca is involved are long-lasting processes, the Na-Mg exchange occurs rapidly when the conditions of the environment change.

181

The Contribution Of Weather Radar In The Evaluation Of Meteoric Recharge In Hydrogeology: A Case Study In Central Italy

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The measurement of precipitation, based on traditional rain gauges, exhibits many limitations due to the spatial and temporal high variability of atmospheric precipitation. In the past decades, the use of ground-based microwave weather radar has greatly improved the quantitative rainfall estimation by providing spatially continuous estimates of rainfall, at high temporal (i.e., few minutes) and spatial resolution (i.e., hundreds of meters). Furthermore, weather radar data have also proved to be relatively reliable in mountainous areas. These paramount features of radar-derived precipitation data could definitely improve the estimation of recharge of aquifers, which generally rely on geospatializations (e.g., Thiessen polygons) of rainfall data, collected by a sparse rain gauge network. In regional aquifers, the rain gauge network is often lacking at high altitude (i.e., recharge areas), introducing additional uncertainty in the inflow volumes. Indeed, weather radar rainfall estimation is also affected by various sources of error, comprehensively discussed in literature, that can be reduced by proper post-processing; however, uncertainties still remain, especially for surface rain rate estimations.

Beyond the currently necessary complex numerical processing, the purpose of the study is to evaluate the use of the weather radar data as an alternative or in addition to meteorological data. Based on the above considerations, this study is aimed at evaluating the feasibility of using radar- based precipitation data to estimate aquifer recharge and calculate a detailed water balance in the areas characterized by high elevations, such as the Majella massif in central Apennines. To address this objective, the Majella aquifer water balance has been calculated in the 2017-2018 period using both radar-based precipitation data and rain gauge data as well as adopting different methods (i.e., Turc, and Thornthwaite). Although intrinsically uncertain, the radar-based precipitation data provided robust results, pointed out by the comparison with water balance, obtained by rain gauge data, and the Majella aquifer total discharge. This interdisciplinary work may pave the way for continuous monitoring of aquifer recharge at very high temporal and spatial resolution

182

Multidisciplinary Approach Of A "Free-Flowing" Groundwater Resource For Its Sustainable Management: The Case Study Of Pasuruan Artesian Plain, Java Island, Indonesia

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The issue of groundwater management is multidimensional, related to reliable assessment of available water from the recharge to the aquifer's outflows through successive atmosphere- vegetation-rock reservoirs. Therefore, notably in complex aquifers, only a multidisciplinary approach can efficiently provide robust scientific knowledge to enable adequate integrated groundwater management.

In some artesian basins, the access to groundwater is facilitated by the natural "free-flowing" conditions of wells and springs. However, this "free-flowing" groundwater resource is challenging to control and may lead to over exploitation trends. In addition, all water users would not behave in the same way towards them. Whilst some would consider the outflow from the aquifer "natural and perennial", others would carefully pay attention to the decreasing of groundwater levels or of the discharge itself.

In East Java, Indonesia, the groundwater abstraction in the volcanic confined aquifer of the Pasuruan Artesian Plain (PAP) has been intensified over the last two decades, due to the development of low cost agricultural "free-flowing" wells (> 600 in 2018). In addition, the major artesian spring (Umbulan) is being used since 2021 to supply drinking water to the Surabaya city (~3 million inhabitants), therefore generating an additional pressure onto the resource.

In such circumstances and with low data at hand, the PAP hydrogeological study performed in 2019 considered insights from different field surveys combining geology, geophysics, hydro-climatic monitoring, hydrodynamic and isotopes-hydrochemistry analyses to build both conceptual and numerical models of functioning. The results make it possible to estimate the current water balance, precise the quality and age of groundwater, identify the recharge zone and make a first assessment of the artesian conditions. The numerical model has been developed using 2018 hydrogeological data and further used to provide predictive scenarios. Results underline the critical situation of the groundwater resource, which is highlighted with the example of Umbulan spring that could cease to flow in about 40 years, thus putting at risk the Surabaya water supply.

Such results allow improving management schemes of free-flowing wells and springs, in the frame of the Rejoso Kita program.

183

Switching Between Open And Subsurface Infiltration According To Temperature

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In July 2002 the Intermunicipal Water Company of the Veurne region (IWVA) started reusing wastewater effluent at WPC Torreele for infiltration of its unconfined dune aquifer (St-André catchment, Koksijde). Groundwater extraction reduced by over 50% resulting in higher groundwater levels and enhanced natural and ecological values. Typically around the infiltration pond wet grasslands emerged and consequently typical plants like orchids and Parnassia reappeared.

An evolution of infiltration capacity was observed since the start-up in 2002. In the first years the infiltration was better compared to the designed ratio between extraction and infiltration (1,4). Since 2009, on three exceptions, the yearly ratio exceeded 1,4. The loss of infiltration capacity was more obvious during the first 4 months of the year. Temperature was identified as the dominant factor. Temperature causes variation of kinematic viscosity and influences the hydraulic conductivity in the soil.

To increase the infiltration capacity IWVA added 'subterranean' or 'subsurface' infiltration to the scheme. Infiltration boxes; 0,60 m heigh and 4,8 m wide, were placed at a depth of approximately 1,6 m under ground level and recovered with 1 m of dune sand. The initial length of 50 m, realized in November 2014, was expanded to a total of 300 m early 2016. Since then, the subsurface infiltration was used according to the temperature of the infiltration water: as infiltration capacity in the open infiltration decreases in Autumn, the feed to the subsurface infiltration is then gradually increased. The opposite is done once the temperature of the infiltration water increases again.

The part of subsurface infiltration into the total capacity of the initial infiltration varied between 12,68 and 15,74% between 2017 and 2020. 36,76% of it was infiltrated in the coldest quarter, being the first and 26,78% in the last quarter of the year. During the summer only 13,51% of the total amount of subsurface capacity was infiltrated.

Subsurface infiltration proved the ability to enhance infiltration capacity and is mainly used during the colder periods. The advantage of subsurface infiltration is the constant temperature, contrary to open air where the temperature can substantially drop during colder periods, and the absence of clogging as it is protected from open air. The increased infiltration capacity was a major asset during the past years where in Flanders, and broader in Europe, periods of longer draught were observed. The combination of water reuse and MAR proved a robust combination to cope with these).

184

Uncertainty Quantification Of Salinity In Costal Aquifer (Binah Thuan Province, Vietnam) Using Bel1D Inversion Of Transient Electromagnetic Data

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Vietnam south central provinces have been facing saltwater intrusions problems for many years, particularly in Binah Thuan province. Binah Thuan has a hyper-arid climate and during the dry season, seawater penetrates the river estuaries and contaminates the fresh groundwater reservoirs. Recent hydrogeological and geophysical data have shown that saltwater intrusion was not limited to river but was likely the results of a complex situation involving fossil saline water heterogeneous sediments and anthropogenic activities. To determine the state of salinity transient electromagnetic (TDEM) soundings were collected along the Luy River, where the situation is most problematic.

TDEM data can reveal the vertical variation in electrical conductivity. An inversion was carried out with SimPEG, an open-source Python package for solving the electromagnetic forward and inverse problem. It revealed the conductivity transition of different layers from the surface until about 40 meters depth, with a gradual increase in electrical conductivity showing the encroachment of salt- water in the shallow aquifer. Deeper, a decrease in conductivity shows the presence of bedrock.

However, SimPEG's inverse solution is deterministic and, thus, provides only one possible solution among many others.

For an uncertainty quantification of the salinity, we apply a new stochastic inversion approach named Bayesian Evidential Learning 1D imaging (BEL1D). BEL1D is combined with SimPEG to solve the forward problem. BEL1D bypasses the inversion step by generating random samples from the prior model distribution (with predefined ranges for thickness, electrical conductivity and salinity for the different layers). It then directly generates the corresponding data in order to learn a direct statistical relationship between data and model parameters. From this relationship, BEL1D can generate posterior models fitting the field observed data, without additional forward model computations, making it a very efficient way to stochastically solve the inverse problem. The output of BEL1D shows the range of uncertainty for subsurface models. It enables to identify which model parameters are sensitive and can thus be accurately estimated from TDEM data. In our case, it reveals the uncertainty on the depth of fresh saline interface as well as the total dissolved solid content of groundwater.

The application of BELID together with SimPEG for stochastic TDEM inversion is a very efficient approach as it allows to estimate the uncertainty at a limited cost. We thus expect our approach to be also valuable for the inversion of airborne data sets.

Keyword: saltwater intrusion, groundwater, Luy River, transient electro-magnetic data, SimPEG, uncertainty, BEL1D

185

Installation Of An Iot System For The Real Time Monitoring Of Hydraulic Heads In The Vicinity Of Groundwater Extraction Sites

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The groundwater of the 'Centraal Kempisch Systeem' is one of the main sources of freshwater in Flanders. Approximately 140 Mm^3 groundwater is extracted each year from the aquifer of which 90 Mm^3 is used for the production of drinking water. The aquifer, which is for the largest part phreatic, is mainly formed by the Miocene sands of the Diest and Berchem Formations. In the last 4 dry years (2017-2020), the pressure on the aquifer has increased due to the grown demand on (ground)water. Pidpa, has started to roll out an internet of things (iot) monitoring system in 2021 to ensure sustainable extraction of the aquifer combined with real time monitoring data.

For the iot monitoring system a careful selection of about 150 monitoring wells has been made. The selected monitoring wells are situated at different distances from the production sites as to include both the influence from the extraction as well as from drought/climate.

In the monitoring wells the hydraulic heads will be recorded hourly and transmitted once a day to a central location. The median value of the recorded values will be used for long term analysis and put into our ERP. The hourly records are kept for ad-hoc analyses and quality control.

Currently most of the selected monitoring wells are finished just below ground-level in (partially metallic) road boxes. By using recent NB-iot technology and absolute pressure sensors Pidpa tries to prevent bringing them above ground in protective sleeves to avoid visual pollution in natural environments. To ensure reliable communication and vandalism protection the road boxes are however changed to a synthetic version with locks. By using absolute pressure sensors the issue of damp within the road boxes should be overcome. In the rare cases where transmission (or other) issues are expected the monitoring wells are above ground-level and covered with a protective sleeve.

The barometric pressure compensation for the acquired records is done by using meteorological data from different meteorological observing stations around the wells. By using inverse distance weighted calculations a local barometric pressure compensation can be calculated for each location. Simulations with historic data show good results with expected errors below 0.5 hPa (= 0.5 cm water column).

As the roll out has started this year the first results are expected in the second half of this year with the system fully up and running in the spring of 2022.

186

Socio-Hydrogeology And Environmental History - Groundwater Levels Mirroring Urban Development In Berlin, 1870-2020

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Although it is self-evident that today's groundwater issues have a history that frames both problems and responses, these histories have received scant attention in socio-hydrogeological literature to date. This paper aims to enrich the field of socio-hydrogeology with a novel, historical perspective on groundwater assessment and management by analyzing a case study of urban groundwater management over a 150-year period.

Berlin's groundwater levels have been monitored continuously since 1869. In the German capital, local aquifers have always been central to its water supply. Furthermore, the water table of the shallow aquifer is, in many locations, very close to the surface, making for intricate interactions between urban development and groundwater levels. This close relationship was observed by early hydrogeologists, who saw groundwater levels as a proxy indicator for the economic performance of the city, falling in periods of high production and rising during periods of crisis or restructuring.

Berlin's turbulent history of the last 150 years, marked by frequent regime changes and disruptive events, provides a rich tableau on which to map oscillations in groundwater levels and the meanings attached to them.

Only through close collaboration is it possible here for a hydrogeologist and an historian to investigate and understand how and why groundwater levels have fluctuated, what explanations have been provided by hydrogeologists of the time and what responses have been invoked to address the problems resulting from both falling and rising groundwater levels. By taking the narrative up to the present day, they demonstrate how the current challenges to urban development of high groundwater levels have powerful echoes in the past.

The core objective is to use the Berlin case to inspire greater sensitivity towards history in hydrogeology in general and in socio-hydrogeology in particular and to show how both could benefit from extending their temporal range to consider histories of groundwater politics, debates and patterns of use.

188

Monitoring Landfill Impact On Groundwater Using Environmental Isotopes

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Modern urban landfills are useful instruments for the safe disposal of everyday waste, especially when associated to a separate waste collection and circular economy best practices. Nevertheless, environmental pollution in the surrounding of the disposal area is always a major threat. The leachate and gas produced during the waste maturation must be carefully collected and conveyed to appropriate treatments or uses e.g. for energy production, in order to avoid harmful pollutants from migrating to groundwater or other natural matrices.

Appropriate monitoring practices are required to intervene promptly at the first sign of failure of the protective barriers or leachate/gas collection systems. As regards groundwater, the parameters to be analyzed, required by the legislation, aim at detecting the passage of specific contaminants or indicators of pollution, including inorganic elements and organic contaminants.

Very often, reducing conditions are observed in the groundwater underlying landfills, which trigger the reductive dissolution of iron and manganese (hydro)oxides. Reasons for this include: natural conditions of the aquifer, leachate pollution, the interaction of groundwater with landfill gas migrating from the plant.

Groundwater monitoring campaigns have been conducted for several years for the characterization of landfill impact on groundwater in central Italy and several case studies have been analyzed.

Natural background levels have been applied to distinguish the presence of metals due to natural conditions from exceedances related to anthropogenic impact. Traditional groundwater monitoring has been complemented with the analysis of environmental isotopes including tritium and 13- carbon. Tritium is an excellent tracer of landfill pollution because its concentration is particularly high in both leachate and landfill gas.

The aim of this communication is to present some successful examples of isotope application to resolve doubts about the origin of high levels of inorganic compounds in groundwater, as well as traces of organic compounds, which are of concern as a possible sign of failure of the protective barriers of the plant.

In particular, we compare the results of the monitoring activities at two landfills, one currently active and one that has been operating in the past and is now completely dismissed. The adopted holistic approach allowed to distinguish a slow and modest contamination that is taking place in the old plant while in the active plant some anomalous data regarding sulfur and chloride were provisionally ascribed to a geogenic origin.

189

Modelling The Thermal Efficiency Of Low Temperatre Aquifer Thermal Energy Storage For A District Energy Scheme In The Chalk Aquifer Of The London Basin

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The UK Government has set ambitious decarbonisation targets requiring the rapid development and deployment of technologies that adopt efficient use of resources and re-use of waste heat sources. District heating and cooling networks will have an essential role in helping meeting those targets.

In the London Basin, the Environment Agency limits the maximum injection temperature to around 25°C. This raises challenges for optimising the operation of ATES in terms of thermal and hydraulic efficiency, due to the lower temperature bubble and higher pumping rates required of such systems.

This presentation provides the numerical groundwater modelling outcomes undertaken in Feflow for Feasibility Study purposes for GreenSCIES; the Green Smart Community Integrated Energy Systems in the London Borough of Islington. This is a fifth-generation (5G) low temperature network, which offers a more direct opportunity to capture renewable, low-grade waste streams. The 5G approach requires a means of balancing the heat and coolth in the DES headers. ATES is proposed as an optimal solution to balancing heating and cooling for 5G temperature networks and the integration of the DES into the ATES is discussed.

An overview of the six Ground Heat Exchanger reversible boreholes will be given along with discussion of the options and impacts on borehole spacing and orientation in a real-life situation, where alternative and conflicting aquifer uses are present.

It will demonstrate how the efficiency evolves as quasi-steady state conditions are established such that thermal losses reduce to 20% by year 15. The effects of grouping cold and warm wells will also be presented whereby thermal efficiency improvements are achieved by capturing plume migration when aligned down-hydraulic gradient within the aquifer. The spacing of these GHX boreholes are critical and our findings are corroborated against work undertaken by Bloemendal et.al (Delft University of Technology and Hartog et. al. at the KWR Watercycle Research Institute (The Netherlands) in that increasing spacing between grouped boreholes decreases efficiency. Additional comment will be provided on mitigating the adverse impacts of other conflicting groundwater uses within the zone of influence of the ATES boreholes.

190

Implementation Of Water Safety Plan For Drinking Water Supply System Supplied From Groundwater Sources In The Municipality Of Empoli, Italy

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The adoption of the Water Safety Plan (WSP) approach, as recommended by the World Health Organization (WHO), represents the most effective means to guarantee public health protection and improve drinking water safety. WSP is a risk assessment and management approach applied to all phases of the water supply chain. In this study, the development and implementation of the WSP for the municipality of Empoli are presented.

The Empoli's drinking water supply system (DWSS) is supplied from groundwater sources and consists of several wells, water treatment plants, storage tanks and 388 km of the water supply network. This infrastructure system is located in an area crossed by the Arno river and the Pesa torrent and was the subject of a strong process of industrial and urban development since 1960.

A methodological approach for the risk assessment and management was adopted, focusing on the vulnerability assessment of the groundwater sources and the engagement of key stakeholders. For the risk management, an analytical model based on the D.P.S.I.R. model (Determinants, Pressures, State, Impact, Response) was developed to describe the water supply system and its relations with environmental and socio-economic aspects adopting indicators. Afterwards, the most critical events, to be evaluated in the risk assessment phase, were identified using a vulnerability rating for each of the indicators. Most of the identified risks resulted to be "low" in all the phases of the water supply chain; to lessen the remaining risks, appropriate control measures were identified and implemented.

High natural levels of Fe, Mn, NH4, Ba and chemical contamination by MTBE and VCM were detected in some wells. Several successful control measures were immediately implemented, such as the optimization of sand filtration to remove Fe, Mn, NH4 and of air stripping to remove VCM, the disconnection of wells containing high MTBE concentrations, the mixing of barium-contaminated water with high-quality water. An additional monitoring activity plan for Ba, MTBE, and VCM was also defined and applied regularly.

The following long-term control measures were also identified and applied:

- statistical study of the correlation between rainfall indexes and microbiological and chemical contaminants detected in groundwater samples;
- development of a mathematical model for the vulnerability assessment of the aquifer including the impact of the anthropized area.

The implemented WSP based on DWSS assessment proved to be a suitable tool to regularly improve system management and control, increase consumer confidence and reduce the risk of water contamination.

191

The Voluntary Groundwater Watch List – A New Tool For Ensuring Long-Term Quality Of Groundwater Across Europe

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The EU Water Framework Directive (WFD) 2000/60/EC, is an overarching legislation that aims to protect the quality and quantity of water resources across Europe. It is complemented by 'daughter Directives', such as the European Groundwater Directive (GWD), 2006/118/EC which adds details on how to assess chemical status and reduce levels of pollutants in groundwater. The review of the GWD annexes that took place in 2014, included the request for a Watch List for groundwater pollutants to facilitate the identification of substances, including emerging pollutants which were not in the legislation and were putting groundwater bodies at risk. The collection of already existing monitoring data and the voluntary monitoring of substances of emerging concern via the Groundwater Watch List (GWWL) by EU Member States is the first step to support any future decision to include new pollutants of European-wide concern in Annex I or II of the GWD.

The present paper describes the work done under the voluntary GWWL activity within the EU's WFD Common Implementation Strategy (CIS).

The proposed GWWL prioritization and selection process involves several steps, and relies upon aggregate data from national entities across Europe on substance occurrence in groundwater, as well as available data on substance persistence, mobility, toxicity, and bioaccumulation behaviour.

The approach has been supported by three pilot data collections in European Member States and Associated countries on pharmaceuticals, per- and polyfluoroalkyl substances (PFAS) and non- relevant pesticide metabolites (nrM) all chosen due to their growing concern regarding their persistence in the environment, and potential impact on human health and ecosystem.

Up to 17 countries reported monitoring data and additional information for these studies.

A total of 28 substances (10 PFAS, 2 pharmaceuticals and 16 nrM) were found to be widely detected in groundwater sites and were therefore presented in the 'List Facilitating the Annex I/II review process of the GWD', as a recommendation for the European Commission for the next GWD annexes review. Two PFAS and 9 pharmaceutical compounds, posing a potential risk to groundwater, have been selected for a first Groundwater Watch List to gain more evidence and to better understand

their occurrence in groundwater. These lists will be regularly updated based on new data collected for different groups of chemical substances.

*Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any of the entities they represent.

192

Climate Indices Teleconnection Pattern On Groundwater Level Prediction Of The Urban Region Using Narx And Lstm Networks

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Urban cities are exposed to huge water stress in recent years due to erratic climate events and urbanization especially in cities lying in the coastal zone. These factors increase the stress of an urban aquifer by overexploitation and leave the stakeholders in a crisis during the non-monsoon period. Understanding the past climatic events and their impact on groundwater level, the future hydrological extremes can be avoided in turn it helps the planning authorities for proper water management. The teleconnection between the climate indices and its effect on urban groundwater level fluctuation is a complex phenomenon, to overarch this problem two neural network-based models such as nonlinear autoregressive network with exogenous inputs (NARX) and Long Short- Term Memory (LSTM) were employed to predict the groundwater level. The developed neural network architecture was applied to predict the groundwater level of the urban aquifer, Chennai city, India. The input time series considered for this study are rainfall, temperature, groundwater level, NINO3.4, NOI, SOI, and IOD. The input datasets were pre-processed with singular spectrum analysis followed by normalization. The normalized dataset was used as input for four permutation combinations of seven parameters to found optimally performing one. Twelve years of datasets were considered for model training and testing which splits into eight years for training and four years for testing. The results obtained from the training and testing phase inferred that the LSTM model performs better than the NARX model. The performance of model for groundwater level prediction 12 month ahead, results with R = 0.7565 and RMSE = 0.9558 m for LSTM model, whereas NARX model results with R = 0.6481 and RMSE = 1.3167 m. The better performance of the LSTM model is due to the deep learning capability of its own. Hence, the developed models with the employed pre-processing technique improve the groundwater level prediction and aids in understanding the teleconnection between climate indices and groundwater level of the coastal urban aquifer and also assist the city planner for sustainable groundwater management.

193

Assessing The Quantity And Quality Controls Of The Freshwater Lens On A Semi-Arid Coral- Limestone Island In Sri Lanka

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The processes governing the quality and distribution of shallow groundwater in the semi-arid coral- limestone Delft Island, Sri Lanka were investigated in this study. Groundwater plays a major role in attaining the island's water security for present and expected future domestic demand. However, uncertainties in the freshwater lens (FWL) salinization mechanisms coupled with anthropogenic pressures such as groundwater contamination threaten the already low availability of freshwater. Hydrochemical analysis was combined with recharge assessment and geophysical data, taking into account the hydrogeological settings, to understand the processes driving the quality and thickness of the FWL. We identified a spatial heterogeneity of potential groundwater recharge zones linked to differences in land use/land cover and geological units in the island. A root zone water balance model was built which revealed the spatiotemporal variability of potential groundwater recharge occurring mostly during the wet season (October to January), and high potential recharge in coastal dune areas. Classification of five water facies, varying from fresh to brackish, was done by hierarchical clustering of physicochemical and hydrochemical data. Geochemical modelling using PHREEQC combined with (Gibbs, Piper, Stiff) diagrams and scatter plots, including stable water isotopes, revealed the origin of groundwater, water-carbonate rock interaction, seawater intrusion, and anthropogenic impacts.

Findings suggest that: 1) groundwater has meteoric origin with salinization mainly caused by seawater mixing and slight evaporation; and 2) salinization is driven by the island's low-lying nature, the low hydraulic heads, the shallow depth of the marine water, the presence of lagoons in the center which are in hydraulic continuity with the ocean, and to some extent by unregulated abstraction of groundwater through shallow hand-dug wells. Infiltration of saline water through the root zone possibly due to storm inundations was revealed by high alkalinity combined with high salinity in groundwater samples. Cation exchange also showed indications of salinization of wells mostly in low lying areas, and freshening in areas near the coast with high potential groundwater recharge. Elevated nitrate concentrations in groundwater revealed anthropogenic inputs further threatening the FWL quality. A detailed conceptual model was proposed accordingly to visualize the present condition of the FWL. The results of this study, mainly the current condition of the aquifer in terms of water quality, and the natural and anthropogenic causes of saltwater intrusion, are expected to provide a valuable contribution to the sustainable fresh water management of the island by providing the necessary baseline data and bridging the existing knowledge gap.

195

Modelling Land Subsidence Caused By Groundwater Exploitation And Revealed By Geodetic Insar Measurements In The Leuven Area

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Synthetic Aperture Radar (SAR) is used since the late 1990s to measure slow-moving ground deformations. The SAR Interferometry (InSAR) technique provides high-density measurements of changes in land surface altitude over large-scale areas. In Belgium, most of the identified subsidence areas have been related to piezometric fluctuations in aquifers. Using data acquired by satellite ERS and ENVISAT, from 1992 to 2001 and from 2003 to 2010 respectively, two areas of significant subsidence have been detected in the north of Leuven. In these specific locations, there are also many historical and currently active pumping wells. The problem of land subsidence induced by changes in the groundwater conditions is significant locally and a link between pumping or drainage and subsidence had been clearly shown in many locations. For the area north of Leuven, data collection showed that the most important pumping wells are screened in the Brussels Formation and the Hannut Formation. Then, a 3D regional groundwater flow model of 5 layers have been developed using Modflow. Transient simulations are performed starting in the 1990s for the next 30 years. This numerical groundwater flow simulation is coupled to a 1D geomechanical model for consolidation and rebound calculation. Even if the aquifer drawdowns are generally well reproduced by the model, it is less easy to obtain simulated subsidence in agreement with InSAR measurements during the corresponding periods. The subsidence observed by the InSAR measurements is the result of a delayed consolidation process as the pore pressure variations propagate slowly in the compressible low permeability aquitards of the Ieperian. Results comparison to the InSAR measurements can also be used to constrain (calibrate) better the geomechanical model. The coupled models could probably then be used as predictive tools for future groundwater management in relation with local land subsidence risks.

This research work is performed in the framework of the BESLSPO BRAIN project: "monitoring LAnd SUbsidence caused by Groundwater exploitation through gEOdetic measurements (LASUGEO)".

196

What Drives Cities To Adopt Groundwater Banking? A Cross-Case Analysis Of U.S. Cities

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As climate change continues to increase the variability and decrease the reliability of water supplies, urban water utilities must adopt and implement innovative strategies to enhance water security and promote system resilience. Groundwater banking, which includes managed aquifer recharge and in- lieu recharge methods, is becoming an increasingly common water management strategy in response to these challenges. As more states and cities turn to groundwater banking, there is a need to better understand factors contributing to the adoption and implementation of groundwater banking as a long-term water management strategy, as well as its impacts on broader urban water sustainability.

Using a two-stage comparative case study design, this research investigates 16 large-scale urban water systems in the United States to understand various drivers of and barriers to groundwater banking. Then, a longitudinal comparison of two cases of water-stressed cities in the southwestern

U.S. is conducted to identify patterns in groundwater banking development and assess the variables that enable sustainable groundwater banking. Data was collected from utility planning documents, archival reports, and interviews with water managers, among other sources. By systematically analyzing the drivers underlying groundwater banking and comparing the implementation and impacts across cases, this research will elucidate critical factors, and the relationships between factors, that promote or hinder a utility's use of groundwater banking.

198

Groundwater Age And Travel Time Distributions In European Aquifers

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Estimating and understanding groundwater travel time and age distributions in aquifers is important for assessing the evolution of groundwater quality and quantity, and e.g. the history and fate of contaminants in the subsurface, globally.

Here we present 1) a database structure for groundwater dating tracers suitable for storing dating tracers and the required parameters for calculation of mean travel times and simulation of groundwater age distributions 2) More than 20 pilot studies on the application of groundwater dating for water resources research and management across Europe 3) Application of groundwater age distributions for design and assessment of monitoring programs and trend assessment and 4) Application of new tracer and modelling techniques for estimation of groundwater age distributions in the age range 10-1000 years in water supply wells.

Summaries, reports, papers and cross sections etc. showing selected results from the European groundwater dating studies and applications is made available via overview maps and search functions in a new groundwater information platform developed by the four GeoERA groundwater projects in close collaboration with the data scientists developing a digital subsurface information platform for Europe, the European Geological Data Infrastructure, http://www.europe-geology.eu.

199

Integrated And Sustainable Management Of Subsurface Resources - Introducing The Contributions Of The Four Geoera Groundwater Projects To The European Geological Data Infrastructure

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UN and EU policies such as the sustainable development goals of the United Nations and the European Green Deal emphasize the strong need for integrated and sustainable management of subsurface resources to protect society and nature. The four GeoERA groundwater projects contribute to this by preparing information on European groundwater quantity and quality for a European subsurface information platform. The quantity and quality issues related to natural processes, human activities and climate change are investigated to improve our basis for informed decision making e.g. for climate change mitigation and adaptation. The four projects provide new and important data for further development of the European Geological Data Infrastructure (EGDI) as a leading information platform for sustainable and integrated management of subsurface resources in Europe and one of the leading platforms, globally.

The four groundwater projects deliver "FAIR" (Findable, Accessible, Interoperable and Reusable) data easily accessible for all relevant end users via EGDI. This will improve our understanding of the subsurface and support common efforts to meet EU and UN sustainable development goals and to develop efficient tools for climate change impact assessment, mitigation and adaptation. Here we briefly present some main objectives and deliverables of the four groundwater projects: 1) HOVER – "Hydrogeological processes and geological settings over Europe controlling dissolved geogenic and anthropogenic elements in groundwater.." – studies e.g. I) geogenic (natural) groundwater quality issues affecting human health, II) polluted groundwater focusing on nitrate, pesticides and emerging contaminants and III) groundwater age and vulnerability of European aquifers 2) RESOURCE – "Resources of groundwater, harmonized at cross-border and Pan-European Scale" – studies I) two transboundary aquifers II) Karst and Chalk aquifers across Europe and III) Develops a new Pan European groundwater resources map that include information on volumes, age and quality (salinity) 3) TACTIC – "Tools for assessment of climate change impact on groundwater and adaptation strategies" – compiles and studies climate change impact assessment and adaptation tools within more than 40 pilot areas distributed across Europe and develops a European groundwater recharge map 4) VoGERA – "Vulnerability of shallow groundwater resources to deep sub-surface energy-related activities" – studies groundwater vulnerability to energy-related activities in the UK, the Netherlands, Belgium and Hungary.

200

Airborne Electromagnetics Detects New Groundwater Potable Resources For Future Generations: A Case Study From Brescia, Italy

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Since the 1980s, many parts of the Brescia area (Northern Italy) have been characterized by pollution of groundwater, due to the presence of Nitrates. A further increase of the values was experienced in the 1990s, so that the public authorities requested a specific exception from Lombardia Region, allowing the temporary drinking water use, although with content of Nitrates higher than the legal limit concentrations. Therefore, in the last years, it has been necessary to search for aquifers which are better protected against anthropogenic surface pollution. In June 2020, the Ufficio d'Ambito di Brescia, water supply regulator for the province, started a technical board with the water companies A2A Ciclo Idrico and Acque Bresciane to carry out a pilot study over an area of about 150 km2 by means of the Airborne Electromagnetic (AEM) Method.

Thanks to the advanced modelling of the geophysical data that returned 3D resistivity of the subsurface, it was possible to achieve a detailed geological-hydrogeological model, from suface down to 300 m depth and more. The data were acquired in 2 weeks, covering about 2.000 linear Km (Figure 1). Despite the severe urbanization of the area, that led to substantial variations of the planned flights, we were able to draw interesting and useful results, often confirmed by the known hydrogeological-stratigraphic info (Figures 2 and 3). The resistivity models allowed resolving the main aquifers (gravels, fractured conglomerates and sands), in spite of the complicated geological setting, due to significant glacial processes that severely involved the study area. These aquifers are characterized by high resistivity (> 100 ohm-m), while the impermeable clay layers show a low resistivity (< 30 ohm-m). Furthermore, the capability to resolve deep resistive structures, below conductive clays (as shown in Figure 3 between distance 3500 and 5400 m), could suggest the presence of unexploited and protected new aquifers that can assume a strategic role for any future demands.

Thus, the new subsurface modeling contributed to:

1. Implement the available information about the hydrostructures of the study area, up to depths of 400 m of depths
2. Identify deep aquifers protected by clay impermeable layers, that are able to reduce risk of pollution from the surface
3. Check the vulnerability of the currently exploited aquifers
4. Contribute to a more efficient management of groundwater use: the next step will be in fact the building of a detailed hydrogeological model and 3D flow models.

201

Groundwater Head Trends And Precipitation Response Patterns In A Cross-Border Aquifer System

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The Roer Valley Graben contains a transboundary multi-aquifer system spread over Germany, Belgium and the Netherlands. This system is the subject of work package 3, H3O-PLUS, of the RESOURCE project, which in turn is part of the GeoERA programme of the joint European geological surveys. One of the objectives of WP3 is to create information that is useful and relevant for improving cross-border groundwater management. The evaluation of groundwater heads, their evolution over time and potential human influences across the individual state boundaries is crucial in this aspect.

Therefore, an extensive set of groundwater head time series and meteorological data have been collected for the project area parts in the Netherlands, Germany, and Belgium. Trends have been determined on the raw head time series using, amongst others, the Theil-Sen procedure. In addition, time series models have been created using different transfer function-noise modelling approaches with precipitation and either evaporation or temperature as explaining variables, depending on data availability. The fitted transfer/impulse response functions illustrate how the multi-aquifer system responds in space and time to impulses of these explaining variables. Using the models for time series imputation furthermore enables classic time series decomposition, and access to seasonal and trend components, while the remainder may reveal clear human influences on the system.

The results show clear effects of the meteorological forcing and other influences, that vary laterally and vertically. Also, the response to precipitation varies both laterally and vertically. This seems to be related to the spatially varying properties of the transboundary multi-aquifer system.

Furthermore, it could be verified that the use of temperature and precipitation as explaining variables produced results similar to using evaporation and precipitation. Thus, a consistent analysis could be carried out with the transfer-noise modelling, even including parts of the transboundary system where no evaporation data was available.

Finally, the methods applied to the cross-border dataset have been compared to the methods currently used in the individual countries. The cross-border results and the comparison of methods can be used to improve cross boundary monitoring of groundwater heads in order to support management of transboundary water resources.

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202

Comparing Time Series Analysis Methods For Identification Of Groundwater Impacts From Construction Projects In Urban Areas

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Construction of underground facilities often impacts groundwater levels, which may lead to subsidence-related damage, effect of objects with high nature-values, impact of groundwater and geothermal heat wells and mobilization of pollutants. These negative effects are in turn associated with potentially high costs. Effects on groundwater levels are generally difficult to identify in aquifers in urban areas that are highly perturbed by known and unknown human activity. Here, we compare the suitability of time series analysis methods to make traceable the extent to which a certain infrastructure project perturbs the groundwater in time and space. Among these methods are Transfer function noise models (TFN), as well as machine learning methods Long short-term memory (LSTM) and Nonlinear autoregressive exogenous models (NARX). Results of these models are combined with cluster analysis to map groundwater impact in time and space to attribute magnitude of perturbations to different constructions sites. We show examples on how this approach can be used to reduce uncertainties associated with the cause of an effect which allows for timely mitigation measures at the correct location and time before high costs arise.

203

Earthquake-Induced Groundwater Flow Modification Revealed By A Hydro-Structural Study In The Sibillini Mts (Central Italy)

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Keywords: seismic-induced groundwater change, hydraulic barrier breaching, extensional earthquakes, spring discharge, Central Italy

We analyze the effects of the 2016-17 Central Italy extensional seismic sequence (Mmax=6.5) on the Campiano stream system in the Sibillini Mts., Central Italy.

By combining structural geological and hydrogeological data we explain the constant discharge decrease of the Campiano stream, observed since one year after the earthquake, in contrast with a co-seismic and early post-seismic increase in discharge.

Similar effects were simultaneously observed in the Nera River and Torbidone springs, respectively NW and SW of the study area (Petitta et al., 2018; Valigi et al., 2019; Mastrorillo et al., 2020).

We suggest that the Campiano discharge increase in the co-seismic and early post-seismic is due to groundwater transfer from aquifers located South East of the study area.

Our hypothesis is supported by subsurface geology reconstructions, which show that the main normal fault of the area (Nottoria-Preci) allows a contact among the basal aquifers located SSE of the Campiano stream, at higher elevation, with the shallow aquifer of the Campiano stream area.

As opposed to inter-seismic conditions, when the normal faults behavior is a barrier to flow, during the co-seismic and early post-seismic periods the hydraulic conductivity increased due to fracturing, hence allowing a transfer of groundwater through the fault zone. The earthquake-induced intense fracturing also caused a subsequent rapid draining of the shallow aquifers, triggering the present- day low discharge.

Tracer tests performed in 2018 and 2019 confirm the early post-seismic connection between the Campiano area, at the Nottoria-Preci fault hanging-wall, and the basal aquifer at the fault foot-wall SE of the study area.

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204

Scientific Legislation Approach To Promote Sustainable Low Enthalpy Geothermal Energy Utilization

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The use of geothermal energy resources to support anthropogenic activities has a long-lasting tradition, renewed in recent decades with the increasing use of low enthalpy geothermal energy (LEG) with combined systems of heat pumps and geothermal exchange, exploiting the enormous thermal capacity and very low-temperature variability of subsoil. LEG is already the main renewable energy sources in Europe, contributing significantly to reach 2030 UN sustainable development goals (SDGs) on renewable energy resources. This research pursues LEG spreading improving knowledge on limitations of guidelines, technical regulations, laws, rules, especially in terms of potential risks or limitations due to environmental constraints or natural phenomena. The global documentary research included quality and duplications; 161 documents were selected. The system of rules resulted worldwide inhomogeneous and complex, with high differences from countries, nations or regions, also at the local scale. The low quality or the absence of simple and careful “rules” emerged as an important obstacle to LEG diffusion that can guarantee sustainability and the absence of natural risks. Main virtuous systems of rules were recognized as very useful to promote LEG spreading but these are still uncommon. Given the many differences in regulations, both at the international and national level, there is a general need to revise, update, and/or provide a more complete geographical coverage of regulations, more exhaustive for types and classes of installations.

Regulations should be locally and globally operative, easy to apply, and useful to guide LEG characteristic selection respecting local environmental characteristics and geo-hydrological potential risks. The regulation should consider LEG hazard contribution during installation, utilization, and/or decommissioning, because the optimal sustainable development of LEG requires careful assessments of impacts, consequent limitations or prescriptions, according to geological, hydrogeological, and environmental site-specific characteristics of the area. For these reasons, a specific study of natural risks connected with LEG installation was made, considering the main geological, hydrogeological, and environmental Apulian peculiarities. The mapping activity is integrated by the lithological conceptualization, at the regional scale, with the definition of 21 lithostratigraphic models that represents all the possible combination of the six lithological groups presents in the Apulian Region. Using this conceptualization, together with specific environmental risk layers defined, the region was distinguished into three zone types with different degrees of LEG- related hazards: green, orange, and red. Green zone without relevant restriction, orange zone with a restriction due to specific hazard, and red zone, where LEG-installation is not permitted.

205

Groundwater And Salinisation Risk: Management Experience In The Mediterranean Area

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The increasing use of groundwater and the effect of seawater intrusion makes the study of coastal aquifers extremely relevant. There are various measures, practices, and actions throughout the world for managing groundwater when this natural resource is subject to salinization risk.

This research, focusing on the effect of seawater intrusion, classifies the different practical solutions protecting groundwater through salinization mitigation across the Mediterranean Area with a literature review. The literature review was based on the study of about 300 papers, which are mainly international journal articles (76%). The remaining papers include conference papers (11.8%), reports and theses (7%), and books or chapters of a book (25%).

Three main schematic groundwater management approaches can be distinguished for the use of groundwater resources at risk of salinization.

The engineering approaches optimize the quality and quantity of the discharged fresh groundwater. The most recent experiences of tapping submarine springs have been realized in the Mediterranean Sea using underground concrete dams, tools shaped like a parachute or tulip (including flexible tubes and a plexiglass dome), or a fiberglass telescopic tube-bell, especially in the case of karstic aquifers. The current widespread form of the engineering approach is to address the issue of groundwater exploitation by wells. More complex solutions use subhorizontal designs. These works include horizontal drains or radial tunnels bored inside the saturated aquifer, shafts excavated down to the sea level with radial galleries. These solutions have been successfully applied in Malta Islands.

The discharge management approach encompasses at least an entire coastal aquifer and defines rules concerning groundwater utilisation and well discharge. A multi-methodological approach based on monitoring networks, spatiotemporal analysis of groundwater quality changes, and multiparameter well logging is described in Apulian karstic coastal aquifers (Italy). The core is the definition of the salinity threshold value between pure fresh groundwater and saline groundwater mixture.

The water and land management approach should be applied on a regional scale. The main choice for this approach is pursuing water-saving measures and water demand adaptation. In Guyennon et al. 2017 a multiple-users and multiple-resources-Water Supply System model is implemented to evaluate the effectiveness of Increasing the Maximum Capacity of the surface reservoir and Managed Aquifer Recharge in the Puglia, a semi-arid region of South Italy characterized by a conspicuous water demand for irrigation.

206

Improving Groundwater Dynamics In Restored Tidal Marshes: An Explorative Field And Modelling Study

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Along estuaries and coasts, tidal marsh restoration projects are increasingly executed on formerly embanked land to regain the ecosystem services provided by tidal wetlands. There are, however, more and more indications that restored tidal marshes do not deliver these ecosystem services to the same extent as natural tidal marshes. We found that marsh restoration on a compacted agricultural soil (which has a very low porosity and hydraulic conductivity) leads to reduced groundwater fluxes and soil aeration, which may imply decreased soil-water interactions, reduced biogeochemical cycling and impaired vegetation development.

We studied the subsurface hydrology in the restored marsh Lippenbroek (Scheldt estuary, Belgium). To investigate spatial and temporal variation of groundwater fluxes in the restored tidal marsh, we developed a real-time groundwater flux sensor (iFLUX sensor) that enables us to measure both the groundwater flow velocity and flow direction in real-time. With these instruments installed at multiple locations and depths in the marsh soil, we were able to capture the effects of the tidal regime and soil stratigraphy on groundwater flow in high detail.

Furthermore, we set up a 2D vertical model with a domain representing a creek and marsh cross- section. The model enables variably saturated flow calculations for groundwater and solute transport in dual porosity soils. Input parameters for the model were obtained by soil sampling and laboratory measurements. Simulated results are in good agreement with in situ measured groundwater levels.

With a scenario analysis, we showed that in a scenario in which the compact subsoil is absent, 6 times more water passes through the marsh soil during a spring tide – neap tide cycle compared to the reference scenario in which the compact soil starts at a depth of 60 cm. In the compact layer, which is always saturated, flow rates are so low that this layer is expected not to contribute to nutrient cycling.

We then simulated the effect of (i) creek excavation and (ii) soil amendments on groundwater flow in newly restored tidal marshes. We found that increasing the creek density from 1 creek to 2 creeks per 50 m marsh, or changing the depth to the compact layer from 20 cm to 40 cm, both more than doubles the volume of water processed by the marsh soil. As such , our study demonstrates that groundwater modelling is a useful tool in support of designing marsh restoration measures aiming to optimize groundwater fluxes and related ecosystem services.

207

Evaluation Of Groundwater Resources In Plio-Pleistocene Arenaceous Aquifers In Central Italy

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The Periadriatic area in Central Italy is well-known for its hilly landscapes, which have been modeled on foredeep basin deposits (Plio-Pleistocene age). These deposits mainly consist of marly clays, with an average thickness that is above 500 meters. Although these lithotypes, if compared with the regional limestone aquifers of Apennines, are usually considered aquicludes, their upper portion is characterized by a coarsening upward trend. As a matter of fact, the corresponding stratigraphic sequence has at its top arenaceous deposits and even conglomerates.

These geological features as expected influenced the morphological evolution of the landscapes, which are characterized by peculiar landforms. In fact, the areas with coarser outcrops show a flat shape and sub-vertical slopes, as boundaries. At the base of these scarps, springs can be found at the interface between coarse and fine deposits, accounting for the fact that these arenaceous bodies are actual aquifers.

A combination of regular landscape, high position over the sea, and natural springs are the main reasons for settlement in these plain areas since pre-historic times. Until the middle of the last century, contact springs were the only water resource for both potable and agricultural purposes. Groundwater was exploited by historical complex systems of wells and drainage tunnels, which are nowadays abandoned.

Since these aquifers have not been considered worthy water resources by local authorities, their hydrodynamics and hydrochemical features of this kind of water body have not been investigated in detail. Nevertheless, they could play a crucial role in integrated water management, especially to cope with climate changes and ever-increasing drought periods.

Based on this consideration, this study is aimed at investigating this kind of aquifer from a hydrogeological point of view and assessing the quantity and quality of groundwater. Five examples throughout the Abruzzo region have been considered. For each of them, wells and springs have been monitored seasonally (i.e. hydraulic heads or discharge, and physico-chemical parameters), pumping tests have been carried out, and water balance has been calculated.

The first results indicate that groundwater quantity and quality proved to be suitable for multi- purpose utilization and to represent a valid contribution for an integrated and sustainable water resource management system.

209

Geology And Norm In Groundwater In South Korea

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This study aims to figure out the concentration levels of the N.O.R.M. (Naturally Occurring Radioactive Materials) in groundwaters from CWSs (Community Water Systems) in South Korea, 2) to evaluate the relationship between the geological formations of the CWSs and N.O.R.M. levels in groundwater. A total of 4,980 CWSs using groundwater for drinking were examined to know the concentrations of the N.O.R.M. Uranium-238 values in groundwater range from N.D. to 1,757.00 μg/L (median value; 0.78 μg/L) in wells, and 176 CWSs (3.5%) among 4,980 CWSs exceeding the 30 μg/L (Maximum Contaminant Level) of the drinking water standard of South Korea for the uranium. Radon-222 values in pumped groundwater range from 0 to 1,218 Bq/L (median value; 52 Bq/L) with 876 CWSs (17.3%) exceeding the 148 Bq/L of the monitored item of drinking water. Gross alpha levels in pumped wells range from N.D. to 8.33 Bq/L (median value; 0.04 Bq/L) with 23 CWSs (0.5%) exceeding the 0.56 Bq/L M.C.L. of the US EPA. Groundwaters from the regions of the igneous rock including the granitic rock areas have relatively higher concentrations of radon and uranium values in general.

210

Using Reactive Transport Modeling And Fractionation Isotope Analysis To Evaluate Chlorinated Hydrocarbons Plume Remediation Time-Frame

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Chlorinated hydrocarbons pollute groundwater resources in many aquifers worldwide, representing a serious threat to human health when the groundwater is used as freshwater. Therefore, these compounds pose important challenges in remediation processes. Due to high costs of water cleanup and remediation actions, it is needed to find effective and economically sustainable techniques to reach the prescribed goals, for example by using innovative methodologies such as in-situ bioremediation techniques. In this work, the application of the Monitored Natural Attenuation (MNA) technique is evaluated through the implementation of two different codes able to produce Reactive Transport Models (RTM) together with Isotopic Fractionation (IF) simulations, BIOCHLOR and PHREEQC. Due to the relatively simple geologic conditions, the model was chosen to be one- dimensional. First, the two codes were compared in a synthetic case to test PHREEQC goodness compared to an analytic solution.

Then, the two codes were applied to a real field case study (i.e. a dismissed site located in southern Italy polluted by chlorinated ethenes) and an assisted calibration was performed to assess the values of degradation rates and enrichment factors using PEST. Finally, PHREEQC was used to forecast the remediation time frame by MNA in hypothesis of complete source cleanup: a remediation time frame of about 10-11 years was achieved by means of natural attenuation processes. This application study shows the potential of the reactive transport-isotope fractionation modeling approach, which can be relevant for many chlorinated hydrocarbons contaminated sites.

This study provides a stepwise methodology that can be applied to evaluate the feasibility of the MNA approach application and could be also extended to design enhanced bioremediation applications. For this case, the model is also able to provide an estimation of the remediation time frame that can be helpful to site owners and Public Authorities in the process of selecting a suitable remediation strategy that is both effective in reasonable time frames and as low- cost as possible.

211

Forensic Hydrology Through Time Series Modeling Of Groundwater Levels: A Case Study Of The Grazer Feld, Austria

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Groundwater from alluvial aquifers and springs is the main source of drinking water in Austria. One of the bigger alluvial aquifers in southeast Austria is the Grazer Feld Aquifer, a groundwater system that plays an important role in regional agriculture, industry, and drinking water supply. Secured availability of future groundwater resources, with increasing populations and urban development under climate change, is a vital need for the city of Graz and its surroundings. It is, therefore, crucial to understand how the aquifer may respond to changing climatic conditions and human groundwater use.

Such knowledge can contribute to better-informed groundwater management decisions, often supported by numerical groundwater models. An important initial step in the development of these models is to obtain a good understanding of the local hydrogeology, the aquifer boundary conditions, and the most important stresses. It has recently been advocated to apply time series modeling as an additional step in the development of a numerical groundwater model (Bakker and Schaars, 2019).

The objective of this study is to show how time series models can be used to improve groundwater system understanding prior to the development of numerical groundwater models. In this case, the identification of (anthropogenic) stresses and their change through time is particularly challenging, as the Grazer Feld Aquifer is potentially affected by both agricultural and urban land use. Thus, the following approach was adopted. First, time series models were set up and calibrated for each monitoring well in the aquifer, using the stresses identified in the initial hydrogeological assessment (e.g., precipitation, evapotranspiration, river levels). Second, we conduct a targeted search into previously unknown stresses and processes causing groundwater level fluctuations, by focusing on the models with a bad model fit. With this approach, we were able to quickly identify previously unknown driving forces and processes that were often local.

For all of these causes, it was determined if data is available such that it can be incorporated in a future groundwater model. If this was not the case, for example when the abstraction rates at a construction site some years ago were unknown, the period with unexplained fluctuations is flagged. These flags were used to create a cleaned data set for calibration of a future groundwater model. The results from this study will be used in the future development of a numerical groundwater model for the city.

212

Urban Groundwaters: Transforming The Resilience Of Towns And Cities.

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Groundwater is fundamental to the water security of towns and cities around the world. It provides a foundation for economic growth, as well as providing the means to supply urban populations with the water they need for drinking, sanitation and general domestic use. Groundwater is also increasingly regarded as a resilient resource that will in turn contribute to the resilience of towns and cities, particularly in the face of changing climatic conditions.

Both the concept of resilience and the role of groundwater in promoting urban water resilience are highly contested despite, or because of, their rising profile. In this paper I seek to unpack different repertoires of resilience and consider the role of groundwater in supporting urban resilience outcomes. Drawing on selected cases from sub-Saharan Africa the paper considers how groundwater has contributed to the ability of urban areas to navigate water shocks and water stress, and the implications of this for future developments.

The paper argues that shocks and crises form critical junctures that transform existing urban- groundwater relations. In the face of such transformations, socio-political systems for the management and governance of groundwater systems must also adapt. Failure to do so can lead to enhanced vulnerabilities that may imperil the ability of urban areas to meet the water requirements of their population and act as a source of vulnerability into the future.

For water resilient cities, we must move beyond the current paradigm of simply sourcing water from further or deeper and consider how water resilience is constructed and by whom. The paper concludes with insights for policy-makers at the local and national scales.

213

Groundwater Drought Indicators

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We will explore drought indicators and time series visualisation for groundwater to assess the messages conveyed on:

- how much lower than normal (consistent with usual definitions of drought);
- changes in what is normal (both due to climate change and to (anthropogenic) system changes;
- water shortage (relating to the perception of drought of the general public);
- risk for groundwater dependent ecosystems.

We will use e.g. the Standardized Groundwater Index (Bloomfield & Marchant, 2013), changes in vertical head differences or upward seepage pressure (where seepage provides the required water quality in the root zone), regime curves and transfer

function noise modelling of groundwater heads with precipitation and evaporation as explaining variables (Zaadnoordijk et al., 2019). We will formulate recommendations on indicators and visuatisation to inform groundwater management on drought related aspects.

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214

Multiple Drought Impact (2018-2019-2020) On The Groundwater System Of The Dutch

Sandy Area Perry De Louw, DELTARES
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In large parts of Europe, 2018 is known as an extremely dry year. In the Netherlands this 2018 drought caused over 1 billion euros of damage to different sectors like agriculture, shipping, and buildings and unrecoverable damage to nature. A large part of the damage was due to extreme low groundwater levels, large soil-moisture deficits and many streams stopped flowing due to an affected run-down groundwater system. While the groundwater system was recovering from this extreme drought, two consecutive extreme dry years (2019-2020) followed and enhanced the impact on the water system. This multiple drought showed clearly the vulnerability of the current groundwater system for droughts and change to a more climate robust water system to withstand future events is required.

A large research was conducted for the Dutch sandy area, which covers more than half of the Netherlands, to analyze the impact of this multiple drought on all aspects of the water system (soil moisture, groundwater levels, groundwater discharge and stream flow) and agriculture and groundwater dependent nature. The research was followed and guided by over 100 stakeholders of ministries, water boards, provinces, drinking water companies, nature conservation and agricultural organizations. For this research we used different types of available data and analysis methods like: satellite images (NDVI, NDWI), times series analysis of groundwater levels, stream discharges and soil moisture, detailed 1D vadose-saturated zone modeling (SWAP) and large-scale modeling of the entire sandy area using our integrated nationwide groundwater and surface water model (MODFLOW-METASWAP-MOZART). We combined the different data analyses and modeling results to understand the propagation of the drought through the water system, address spatial differences due to different area characteristics and to formulate operational ad-hoc measures and structural solutions to mitigate drought. A nice example is the detection of agricultural irrigated fields and quantification of extracted groundwater via the combination of satellite imaging and groundwater modelling.

We concluded that during a drought operational measures are limited to restricting surface and groundwater abstractions and a structural change of the entire water system is required to mitigate a drought. Already under normal meteorological conditions, the water system is far from robust and conflicting water interest between agriculture, drinking water abstractions and nature which act in the same spatial space is the major task to make the water system future proof.

The most striking results and guidelines for such a huge water transition will be presented.

215

Hydrogeologic Domains And Conceptual Model Of Graciosa Island (Azores - Portugal)

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Graciosa Island is a young volcanic island, located on the northern sector of the Central Group of Azores Archipelago. It is built essentially of volcanic rocks and deposits with some sedimentary pockets. The volcanic activity is related with the Terceira rift and the island building is organized in three volcanic complexes.

Historically, this small island had always problems with water supply and storage. The annual average precipitation is about 920 mm, the lowest among the nine islands of the Azores. Nowadays, occurs marine intrusion in the basal aquifers, particularly in the wells explored for human supply and agriculture.

According to the published data, mainly the geological and volcano-stratigraphic maps and charts and to the new studies and field data, the island hydrogeology express: (1) the occurrence of two distinct hydrogeological domains, each one with two subdomains; (2) the hydrogeological conceptual model evidences the occurrence of several small and discontinuous perched aquifers, however, the largest groundwaters bodies are the basal aquifers; (3) the aquifer's recharge is done by infiltration, occurring mainly in the greater relief areas; (4) the discharge occurs naturally through springs and through boreholes and dug-wells; (5) the perched aquifers express very distinguish discharge presenting small flow rates, very dependent on the recharge; (6) the active secondary volcanism contribute for the occurrence thermal springs and mixture groundwaters.

216

Geological And Hydrogeological Modelling Of Arcier Karstic Spring And Its Watershed (France) - Transkarst Project

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Karstic areas represent a significant part of the landscape of the Earth surface. Behind the originality and the variety of karstic reliefs, important societal, economic, and ecological issues can be encountered where karstic waters represent the only source of water supplies. The anthropogenic pressures, the problematics related to climate change and the extreme heterogeneity of karst make it highly vulnerable as it is the case of the Arcier karstic spring (Eastern France), which represents about 50% of the drinking water supply of Besançon city (117 000 inhabitants). TRANSKARST (TRANSdisciplinary research on KARST) is a consortium for the transdisciplinary research on karst, gathering scientists and water resource managers. Focused on the Arcier watershed, it aims, through a package of multidisciplinary studies, at better understanding the impact, the origin and the pathway of mineral, organic and microbiological contaminations affecting regional karstic aquifers. A part of the project focuses on geological and hydrodynamic modelling of the Arcier hydrosystem. It includes various types of data which have been collected and analysed since February 2020 including: structural, geophysical, hydrodynamic (rainfall, water level/flow rate), physico-chemical (electrical conductivity, temperature, turbidity, major and

traces ions, isotopes) data and artificial tracer tests. A 3D geological numerical model of the watershed has been established. New structural measurements carried out over the study area demonstrate that the structure and the fracture network of the Arcier catchment, which controls the water circulation, the watershed limits and the hydrosystem behavior during high and low water-level intervals This model will be completed with electrical geophysical investigations (ERT, gravimetry and passive seismics), which will help to define the depth of im/permeable lithologies. Then new results, like a hydrodynamic study based on rainfall/rate flow relations, will be used to build a global hydrogeological model predicting the contamination flows into the karstic waters of Arcier watershed.

217

Vulnerability Of Alluvial Hydrosystems To Global Change, Case Of The Allier River (France) And Its Alluvial Aquifer.

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Superficial waters, groundwaters and especially alluvial aquifers are used as a resource for drinking water production, irrigation and by industrial activities. In addition, it is a critical resource since it is put under more pressure with climate change, population growth and by all anthropogenic activities that generate pollution. This is the problematic of the AUVERWATCH project that aims to characterize some Auvergne water bodies and more peculiarly the alluvial hydrosystem of the Allier River, one of the main tributaries of the Loire River. Being subject to various pressures, the Allier River watershed is part of a territorial water management project ("PTGE" in French). A dialogue is then necessary between the different environmental and socio-economic players to build an action program. It shows that these issues are crucial and solutions will be found. But still, the Allier River is known for its severe and low water periods that increase with time. To avoid critical low waters which may have consequences on both environment and water supplies, Naussac dam has been built upstream. It maintains a minimum flow in the Allier River so the different socio-economic activities that need water can be provided during summer. However, as a result of climate change, the optimal filling of Naussac dam may not be assured which could have consequences on the Allier River flow. To better study the water budget of the Allier hydrosystem, an assessment of its quantitative and qualitative parameters is performed over the last 20 years. Various hydrodynamic data have been collected and analysed: daily temperature and rainfall (meteofrance.com), daily discharge of the Allier River (hydro.eaufrance.fr), groundwater levels (ades.eaufrance.fr, AUVERWATCH), pumping by use category (domestic, irrigation and industrial). The quantitative data allow determining the input flux of water in the Allier watershed (effective precipitation, groundwater recharge rate) and the output flux represented by the Allier River natural discharge at the considered outlet of the watershed plus the whole pumping volume for water supplies. This study is to inform water managers on the potential impacts of global change on the water resource and how water management could be modified to prevent future crisis. Analyses are performed at the Allier watershed scale but also at the Val d'Allier well-field scale that provides 60% of the Puy-De-Dôme population drinkable water needs.

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219

Application Of Environmental Isotopes 3H And 14C To Determine The Groundwater Age In Shallow And Deep Aquifers In The Eastern Desert Of Egypt

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In form of permanent flowing springs, deep and shallow wells, groundwater in the Eastern Desert of Egypt is the only available source for water supply and irrigation.

In the area extended between Wadi Araba and Hurghada at the Red Sea coast, samples from these discharge points in addition to rain and floodwater samples were collected to analyse the main ions, 18O, 2H and 3H.

Analytical results of 3H show that 3H concentrations in three springs in Wadi Araba range between 1.1-1.5 TU indicating a recent recharge in the last 15 years.

Contrastingly, all sampled located in Hurghada area are below the detection limit proving no recent recharge in the last 60 years. However, the stable isotopes signature in the shallow wells and springs correlates strongly with that of floodwater, implying a recharge process through modern precipitation.

The deviation of the deep groundwater from the LMWL and GMWL proves colder infiltration conditions compared to modern precipitation and show an evaporation effect.

As the deep water in Hurghada area and one permanent spring in Wadi Araba were free of 3H, six samples were collected to analyse 14C. The results prove a groundwater age between 5000-15000 years. The oldest age was determined for the permanent spring of St. Anthony Monastery in Wadi Araba with 3.5 PMC which seems to be discharged from the Nubian Sandstone aquifer that overlies the basement in this region. Moving southwards to Hurghada region younger groundwater ages in the Miocene aquifer were revealed. The deep wells located at the fault of Abou Shaar Plateau show higher concentrations of 14C. The determined age of 8000-12000 years shows an increasing age towards the north along the fault area where the wells are located. Comparing these ages with the age of Kebrit brine which was determined in previous studies proves that groundwater recharge took place before the formation of this brine.

220

Automatic Integration Of Geophysical And Borehole Data : A New Methodology Applied On The Upper Aare Valley, Switzerland

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In most urbanized and agricultural areas of central Europe, the shallow underground is constituted of highly heterogeneous Quaternary deposits. Geophysical methods can be a fast and reliable source of information to characterize this heterogeneity, but the integration of such data with geological logs in boreholes is time-consuming and does not account for uncertainty. Furthermore, linking geophysical data to permeability or lithology is always tricky. Therefore, there is a need for an automatic approach that would be able to integrate multiple data types at various scales and produce geological models with parametric fields for flow models, with a robust uncertainty quantification from the data to the model.

In this study, we propose a methodology to combine multiple data types such as boreholes, geophysical and hydrogeological data with uncertainty in an automatic framework.

This framework is based on stochastic methods such as Multiple Point Statistics algorithms and Gaussian Random Functions. We first estimate the lithology with its uncertainty from the geophysics by using the boreholes as control points, to then extend it in a continuous 3D model using a nondeterministic MPS Training Image to carry down the uncertainties. We applied this methodology to estimate various lithological, and hydrogeological parameters using a Time-domain Electromagnetic (TEM) geophysical dataset acquired in the Quaternary-filled upper Aare valley, Switzerland and covering more than 1500 hectares of land with a resolution in the order of 10m. The depth of investigation varies from 50m to 100m. Combined with thousands of boreholes and hydrogeological estimation as control points, we were capable to automatically generate realistic underground lithological and parametrical models at a valley scale, with a high spatial resolution, and with an uncertainty carried down the workflow.

221

Groundwater-Fed Ecosystems Under Pressure Of Nutrient-Enriched Groundwater

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In many peatland ecosystems in e.g. brook valleys, natural vegetation is adapted to wet and base- rich conditions, which are sustained by upward inflow of groundwater with high calcium concentrations. The hydrochemistry of this groundwater is controlled by many processes that modify groundwater quality along flow path from infiltration to exfiltration (seepage) in nature areas. Such processes include land use in the infiltration area, groundwater recharge, and hydrogeological and geochemical properties of the subsurface.

While seepage water quality is often considered static, changes in land-use and climate may lead to considerable modifications. Specifically, ecosystems reliant on groundwater that infiltrates in areas with intensive agriculture, are at risk due to elevated inputs of nitrate. Nevertheless, reactive subsoil compounds interact with dissolved nutrients and reduce, temporarily buffer, or increase pressure on vegetation of seepage-dependent peatland ecosystems. To date, however, there is no generic framework to identify conditions under which groundwater-fed peatlands are at risk due to elevated NO3 and SO4 concentrations. Here, we present a piston-flow-based time-dependent approach to identify whether nature areas are under potential risk of nutrient-enriched groundwater as a function of (1) hydrogeological setting (2) input groundwater quality (3) geochemical subsurface characteristics and (4) climate. Example of outputs are approximate durations of CaCO3 and FeS2 depletion, and timings of when NO3-enriched or acidified groundwater arrives at the root zone. The tool provides a quick evaluation of how environmental change may modify seepage water quality and put ecosystems at risk, and requires limited input.

222

Integrated Studies For Hydrogeological, Geophysical And Hydrochemical Characterization Of Dupi Tila Aquifer, Dhaka City, Bangladesh

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The over-exploitation of groundwater resulting in sharp groundwater level (GWL) decline has become critical and raised concerns globally, especially in urban areas. The Dupi Tila aquifer in Dhaka city, the capital of Bangladesh, has been subjected to sharp GWL decline since 1990. The present hydrochemical and geophysical study is an attempt to characterize this aquifer in view of mapping aquifer geometry, inferring water quality and revealing hydrogeochemical processes.

The aquifer investigation involved borehole logs, long-term GWL monitoring data, vertical electrical sounding (VES), electrical resistivity tomography (ERT), geophysical well logs, and water chemistry data. Three different aquifers, the Upper Dupi Tila aquifer (UDA), the Middle Dupi Tila aquifer (MDA) and the Lower Dupi Tila aquifer (LDA), have been delineated by analysing borehole logs and geophysical measurements. Water chemistry, water quality and hydrochemical processes have been deduced from bivariate plots, Piper plot, cluster analysis (CA), stable isotopes and geochemical modelling.

Analytical results of the water samples show that the order of cation abundance is Ca2+ > Na+ > Mg2+ > K+ and anion abundance HCO3- > Cl- > SO42- > NO3-. The total dissolved solids (TDS) of all the waters show an increasing trend with depth. All the major ion concentrations in groundwater are higher than the surface water except K+, PO43- and NO3-, the latter being indicative of anthropogenic pollutions. Water is mainly of Ca/Mg-HCO3 type in all aquifers, while surface water is of Ca-HCO3 type. Aluminosilicates weathering controls the concentration of the major ion chemistry in the aquifers. The CA and stable isotopes data reveal no influence of river water intrusion on the groundwater environment, even though there is significantly declined GWL both in UDA (> -85 m Public Works Department reference datum (PWD)) and MDA (> -65 m PWD). The overall groundwater quality in the aquifers is good. This study provides a clear picture of aquifer geometry, groundwater dynamics and water chemistry, which can be helpful in groundwater planning, protection and sustainable management of this aquifer in Dhaka city.

Keywords: GWL; VES; ERT; Geophysical logs; Groundwater chemistry; Groundwater quality.

223

Harmonisation Of Groundwater Quality Data And Groundwater Age Data For Transboundary Groundwater Management Of The Dutch, Flemish And German Area Of The Roer Valley Graben

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Harmonisation of (hydro)geological information and harmonized 3D characterization of aquitards and aquifers is a prerequisite for any transboundary groundwater management. The Roer Valley Graben, a Dutch, Flemish and German transboundary area, is a heavily used cross-border aquifer system where many subsurface activities compete for prioritization. The (hydro)geology of this area was modelled in 3D in cross-border so-called "H3O"-projects. In H3O-PLUS, which is part of the GeoERA RESOURCE-project, is built on the established (hydro)geological harmonization making the assessments more useful for groundwater policy and management and subsurface spatial planning.

A Groundwater Quality Viewer has been developed for groundwater quality, bringing cross-border existing groundwater quality together. The tool offers a 'static' view on groundwater quality, showing average concentrations. Data can be displayed in three different ways. Firstly, groundwater can be selected per depth trajectory and visualised in charts. Secondly, data can be analysed by geological formation. Finally, parameters can be viewed in a cross section (Figure 1). Tracer based groundwater age distributions were also aggregated and analysed using common interpretation methods. In the groundwater viewer, the groundwater ages (in years) are available as a separate parameter and are displayed in the same way as other (chemical) parameters.

With the Groundwater Quality Viewer, groundwater quality is analysed in a harmonised way, elucidating the stratification of groundwater composition with depth, such as the interface between salt and fresh groundwater or redox zonation. Using this viewer, we were able to compare the concentration-depth profiles of different redox-sensitive solutes for the Dutch and Flemish datasets in the GeoERA HOVER project for five shallow geological formations and translate them into total denitrification depth.

For example, in the Boxtel Formation, eolian sands and fluvio-periglacial deposits, the total denitrification depth is in most cases shallow and appears to be related to the thickness of the Boxtel Formation with shallower depth in area with great thickness of the Formation. Moreover, there is a relationship with the altitude of the surface elevation. Wells that reflect a deeper location of the NO3/Fe redox cline are situated mostly in areas with higher surface elevation.

Groundwater quality data in the Roer Valley Graben has been processed and made available in the GeoERA Groundwater Quality Viewer. Stakeholders can use this viewer to analyse groundwater quality across borders.

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224

Discrimination Of The Natural Geochemical Background Of Anthropogenic Geochemical Inputs: Conceptual Analysis Applied To The Characterization Of Groundwater Masses.

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The identification of groundwater bodies impacted by inputs of anthropogenic origin is essential in the context of the management (knowledge, protection, remediation) of water resources at the scale of territory. This identification is complex in the case of mining areas impacted by releases of metallic trace elements which are superimposed on natural concentrations. These can be elevated due to natural mineralization. The detection of enrichment relative to the geochemical background noise therefore requires a methodology adapted to this type of context.

The objective of this study proposes an approach integrating regional geological and geomorphological factors to improve the detection and quantification of metallic trace element enrichments in groundwater bodies compared to geochemical background noise, in a mining context.

From an assumption of normal distribution of the values of the natural geochemical background, a natural component, it is assumed, at an arbitrarily set confidence level, that the disturbances of anthropogenic origin are revealed by superposition. This superposition is revealed on the basis of three types of independent parameters, linked to the study area comprising areas of past or current mining activities: 1 - of geochemical type (median and variance of various subsets of these samples), 2 - geological type (natural predisposition of samples to be enriched by hydrogeochemical processes) and 3 - geomorphological type (hydraulic gradient, distance from sampling points to places known to be the site of anthropogenic activities). The geochemical parameter makes it possible to adjust the global distribution by superimposing two distribution functions: the apparent natural component and the apparent anthropogenic component, and to identify values as "atypical data". These components are qualified as apparent because they can contain "fuzzy data": data whose value, alone, does not allow to statistically determine the component of connection (data having undergone an anthropogenic influence, but insufficiently for the characterize as atypical data).

The integration of geological and geomorphological parameters makes it possible to filter these fuzzy data to improve the characterization of the natural component. An application to the detection of arsenic and antimony enrichments in the groundwater of the Gardons watershed in the South of France, having undergone intense mining in the 19th and 20th centuries, is presented. The method makes it possible to improve the detection of enrichment in metallic trace elements of anthropogenic origin, at variable spatial scales, less than 10 kilometers, with an integration of local geological, hydrogeological and topographic conditions.

225

Combining Geophysics With Numerical Modelling To Assess The Distribution Of Fresh And Saline Groundwater On Semi-Arid Delft Island, Sri Lanka

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This study assesses the spatial distribution of fresh and saline groundwater and the impact of abstraction on a small coral-limestone island – Delft Island, Sri Lanka, within a semi-arid setting. In the study area and similar to other coral-limestone islands, groundwater occurs as a lens of freshwater overlying seawater in a highly permeable aquifer. Increases in the permanent and transient population, coupled with shoreline retreat due to sea-level rise magnifies the stress to groundwater availability on the island. Correspondingly, the current study looks at solutions towards improved groundwater management via sustainable groundwater abstraction practices. Field assessments, involving well inventories, interviews with residents, and one-dimensional (1D) vertical electrical soundings (VES), are combined with steady-state analytical solutions and numerical modelling using MODFLOW & MT3DMS, to evaluate the spatial distribution of fresh and saline water, its sensitivity to recharge, and the impacts from abstraction. Results reveal a thin and irregularly shaped freshwater lens (FWL) overlying seawater with a relatively thin transition zone, small-scale heterogeneity in the aquifer and localised upconing below some pumping wells. 1D VES interpretations reflect FWL thicknesses ranging from 0.8 to 2.1m in the overlying sand deposits, and between 0.2 – 3.3m in the coral limestone. These thicknesses align with the shallow well depths (< 3.7m) measured during well inventories and interviews with residents. The very shallow occurrence of seawater is mostly a result of high aquifer transmissivity, low elevation and low hydraulic heads. Additionally, it is inferred that the lagoons presently at the centre of the island are in hydraulic connectivity with the ocean. Steady-state simulations highlight that the FWL and transition zone thickness are highly sensitive to recharge and mechanical dispersion. Additionally, simulations show the impacts of abstractions on the distribution of the FWL, namely the higher salinities in wells with greater abstractions. Therefore, solutions towards increasing groundwater availability for abstraction include managed recharge in the sandy aquifer during the rainy season and recovery through horizontal abstraction techniques. These techniques are currently being studied in more detail, which should ultimately result in a pilot employing these techniques on the island.

227

Hardrock And Sedimentary Aquifers Of Wako Kungo, Angola: Identification Of Groundwater Patterns Based On Remote Sensing

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Groundwater in Angola is used as supply water for several urban areas and is also a major source for rural water supply and agriculture. With the increasing demand of water, previous studies related to the use of remote sensing and GIS in groundwater mapping proved to be highly useful on the efficient and controlled development of groundwater resources and management.

In the study area, field observations and the geological data allowed to distinguish two main aquifer types in the area, one detritic and other fractured, on a region dominated by extensive agriculture and cattle production. In the present work optical and radar images were analysed and processed. Groundwater patterns have been identified based on satellite images, DEM and on field data, and all this was combined in a GIS. All data were integrated to prepare different thematic layers such as drainage, drainage density, lineament density, vegetation index and NDVI maps. The study shows that the resulting maps incorporating field observation and data are useful to predict groundwater recharge and discharge areas.

The results suggest that the high lineament intersection and density should be combined with other detailed structural elements to better reveal points of groundwater recharge and discharge.

Vegetation index, for example, is important for identification of groundwater discharge areas. Interpretation of Spot -5 image combined with high-resolution Sentinel-1 radar scenes and field work shows that NW-SE and NNW-SSE lineament directions present the best yields on groundwater prospecting. A lineament density map was correlated with the identified well and spring locations in Wako Kungo and shows that highly productive wells can be located along the intersection areas of faults, near active streams and springs. The fracture pattern and the position of springs in hard rocks are clearly linked to tectonic activities.

In these hardrocks, the zones of high lineament intersection density at higher altitudes are clearly areas of high potential for infiltration and the zones of high lineament intersection density at lower altitudes are feasible zones for groundwater prospecting, and hence, it is suggested that these zones can be combined with detailed geophysical mapping for quantitative evaluation of the groundwater potential of the study area. Groundwater in the sedimentary areas between hardrock outcrops originates by direct infiltration and discharge from the hardrock formations at higher altitudes, discharging in the valleys.

Hydrogeochemistry analysis shows that, for the physical-chemical parameters analysed, groundwater in the study area has a low level of mineralisation.

228

Determining Aquifer Hydrogeological Parameters In Coastal Aquifers From Tidal Attenuation Analysis. Case Study: The Malta Mean Sea Level Aquifer System

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The coastal and carbonate Mean Sea Level Aquifer (MSLA) of Malta is characterized by high anisotropy and heterogeneity which make a challenging task to evaluate the aquifer system parameters. In this paper we present an approach for the determination of hydrogeological parameters of this coastal aquifer based on tidal induced groundwater fluctuations that can be applied in other similar contexts. The analysis undertaken on those monitoring boreholes located in the Malta MSLA and exhibiting tidal induced groundwater fluctuations, allowed us to determine the values of three main hydrogeological parameters (hydraulic diffusivity, transmissivity and hydraulic conductivity) which will be subsequently used as an input for groundwater flow and reactive transport modelling purposes. In this study a methodology based on the Fast Fourier Transform (FFT) is proposed for improving the applicability of the Jacob-Ferris method to the observed groundwater level and sea level fluctuations. The FFT reproduced signals allowed to isolate the component induced by sea tides thus eliminating short- and long-term variations of the water table induced by other disturbing factors. Results showed high variability of hydrogeological parameters within a short distance reflecting the high anisotropy and heterogeneity of the aquifer system.

The estimated transmissivity values are complemented with results derived from the pumping tests with the aim of estimating the spatial distribution of the aquifer transmissivity for the study area.

The spatial variability of transmissivity values is analysed by means of geostatistics tools for estimating uncertainty, correlation and variation in space through the use of semi-variograms.

230

Groundwater-Stream Water Interaction As A Controlling Factor For Nitrate Concentrations In Stream Waters In Flanders (Belgium)

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Elevated nitrate levels in groundwater are a common environmental problem in most agricultural regions around the world. Surface and stream waters also suffer from this problem but often show a strong seasonal fluctuation. Analysis of 20 year long series of the stream monitoring network shows that the seasonal fluctuations do not always follow the same pattern. Sometimes maximal concentrations occur in winter time, in others areas in summer time. Or seasonality is rather small and nitrate levels are constantly high. This different behavior is related to the hydrogeological setting and characteristics of the underlying phreatic layer combined with seasonal variations in water balance contributions.

To study the relation between groundwater inflow into streams as the baseflow component and observed variations in stream water nitrate variations, 10 test sites consisting of small upstream catchments spread over Flanders were selected. They were chosen in different hydrogeological settings to obtain a large hydrolithological diversity.

Policy makers and regulators are strongly interested in response time scales which control the timeframe required to obtain measurable impacts of regulations on surface water quality. A pragmatic lumped parameter model was developed that allows the simulation of the observed nitrate series in catchments with a minimum of parameters and effort from the modeler. The model combines a detailed and advanced existing model of the root zone (EU-rotate_N) that is applied on a parcel scale, with a zonal approach for the underlying phreatic aquifer system, based on a fractioning of the water flow in the saturated zone for contributions from oxidized and reduced groundwater inflow and seasonal inflow from drains in winter time. Surface runoff can be entered as an additional water balance component, but needs to be estimated with a separate runoff model.

The effect of groundwater travel times as a delay on the nitrate inflow from groundwater to surface water is obtained by aggregating the results of the root zone model into an spatial average time function of nitrate concentration in the soil water leakage and applying a convolution of this series with a digital filter consisting of coefficients that are the values of the probability density function of the groundwater age distribution, sampled at yearly intervals. The model input is derived from a system analysis of the hydrodynamics and hydrochemistry of the test sites. The model reproduces the seasonal fluctuations and longer time trends quite well and can help to simulate future evolutions and alternative measures.

231

Multidisciplinary Approaches To Assess Nitrate Contamination In Arid And Semi-Arid Regions: Joys And Sorrows.

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Nitrate contamination of groundwater is a well-recognized, but still of considerable concern, issue at global scale. Literature interest on this topic accounts for approximately 30,000 papers published on international peer reviewed journals investigating surface water and groundwater systems in different climatic environments. However, for arid and semi-arid regions the existing knowledge on the origin of nitrate pollution remains poor.

Robust data and sound quality assessments are crucial in order to meet the Sustainable Development Goals (SDGs), given that nitrate pollution in groundwater is strongly interlinked with many of these targets and indicators. Among others, they include: SDG 6 (Clean Water and Sanitation), SDG target 2.4 (Sustainable food production systems and resilient agriculture), SDG target 8.4 (Decoupling economic growth from environmental degradation), SDG target 12.4 (Management of chemicals and wastes).

To tackle contamination distribution and source origin, multidisciplinary approaches are generally applied. Starting from conventional hydrogeochemical characterization (using major and trace elements), investigations often integrate land-use analyses, socio-hydrogeological assessments and isotope hydrogeochemistry. More recently, stable isotope mixing models (e.g. SIAR or MixSIAR) have been increasingly used for nitrate source apportionment, allowing for an estimate of the proportional source contribution to groundwater contamination. However, despite their robustness, mixing models are strongly dependent on the chosen mixing-end members, namely on the isotopic composition of the local nitrate pollution sources.

In arid ad semiarid regions, the long residence time of nitrate in the unsaturated zone may favour post-application processes (accumulation or volatilization), and trigger leaching years after the fertilization, therefore masking the isotopic signature of the original sources. These uncertainties can lead to biased source apportionment, with important repercussion on the management policies based on these scientific outcomes.

Using the case study of the Grombalia aquifer (NE Tunisia), the presentation will summarize the main strengths and constraints of multidisciplinary approaches targeting at nitrate source identification and apportionment in arid and semi-arid regions. The result confirms that, even in the case of well-established methodologies, like those of isotope hydrogeochemistry ($\delta^{15}NNO3$, $\delta^{18}ONO3$ and $\delta^{11}B$) and mixing modelling, it is fundamental to analyse regional and local sources of nitrates (especially in the case of nitrified synthetic fertilizers) to avoid misleading apportionment and to make proper use of these tools.

232

Sustainable Yield Of Hydrothermal Areas: Some Experimentation In Central And Southern Italy

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The thermal/mineral waters industry is of great importance in many countries. Worldwide, about 27,500 establishments related to thermal/mineral waters have been counted in 2015, including different types dedicated to recreational, medical or therapeutic uses or focused on wellness- enhancing experiences. Italy occupies the fifth position in 2015 top twenty thermal/mineral springs markets; in particular, the exploitation of thermal waters generated revenues of approximately 1.7 million euros for public administrations during 2015, which is equivalent to 0.1% of the sector's annual turnover (1.6 billion Euros in 2013).

This profitable market is based on the maintenance of quantity and quality of thermal waters, for which the current European and Italian national legislation is mainly focused on the definition of quality standards of waters for different uses. Differently, Italian regional rules concern research, exploitation and protection of these resources, but considering them separate from other groundwater resources. On the other hand, from the hydrogeological point of view, the thermal waters are simply groundwaters originated by specific circuits in the aquifers which determine their chemical-physical properties. Therefore, as well as other groundwater resources, the use of these resources should be developed without unacceptable environmental, economic or social consequences over time.

Estimates of the sustainable groundwater withdrawals from three hydrothermal areas in central and southern Italy have been carried out. The three areas differ in the quantity of thermal waters used by the spa facilities, as well as in the other uses of groundwater connected with the same hydrogeological system. On the basis of available and unpublished data, the natural recharge and discharge of the systems were compared with their variations induced by groundwater withdrawals. The sustainable yield was then determined considering the residual groundwater discharge and the maintenance of quality of thermal waters.

The cases examined highlight how complex is the task to define practical measures for groundwater management on the basis of the theoretical concepts of its sustainable use. A first crucial aspect is the difficulty in the definition of the recharge areas of thermal waters, since these circuits are part of a system that also feeds other circuits. Complications are also related to the interaction between groundwater resources used for different purposes or to the conflicts among different users of the same resource. An appropriate assessment of the residual discharge to spring and surface waters under development conditions seems to be the key to ensuring the maintenance of thermal water quality over time.

233

Investigation Of River-Aquifer Interactions In Belgian Lowland Floodplains Using A Combination Of Heat And Hydrochemical Tracers, Data-Driven And Process-Based Modelling

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Floodplains play an important role in the hydrological cycle. They serve as interfaces where water, solute and heat exchange take place between the shallow groundwater and surface water, and therefore often fulfill a unique ecohydrological role. The presented research focuses on estimating the river and shallow groundwater interactions in three Belgian lowland catchments (the Zwarte Beek, Mombeek and Dijle) across different temporal and spatial scales.

For the tracer-based approach, measuring in 1-D vertical streambed temperatures at multiple depths, is used for quantifying the exchange flux at point and segment scales. The calculated fluxes have an order of magnitude varying from 10-7 to 10-6 m/s from the point-in-time measurements. The flux direction, representing either a losing or gaining river, changes not only within the time of year but also along the longitudinal river profile. Furthermore, a number of hydrochemical tracers have been used, such as Cl, EC and radon (222Rn), for comparing the river and near-river shallow groundwater samples. The chemical link between river water and shallow groundwater is strong in the Zwarte Beek and relatively weak in the Mombeek and Dijle catchment. In general, there is a slightly higher radon activity in groundwater than in the river water, and in winter than other seasons.

For the data-driven approach, a combination of data imputation and impulse-response function modelling was used 1) to simulate the groundwater level in response to precipitation, 2) to estimate the baseflow in response to a representative groundwater level at the catchment scale, and 3) to investigate seasonality and trends, all over one 30-year climatic cycle (1990 – 2019). For the rainfall impulse to aquifer response (process 1), the hydrological system responses faster in the wet (October – March) than the dry (April - September) period, and response magnitude is higher during the wet than the dry seasons. For the aquifer impulse to baseflow response (process 2), the response is also fast and peaks at the first simulation day. The conclusions apply for all three catchments.

For the process-based modelling approach, MODFLOW-based numerical models were developed for each catchment, with refined child models in the floodplains. This enables simulation of the mid- to long-term hydrological dynamics of the floodplains and allows for the evaluation of changes in the surface water network, groundwater extraction, climate change, land cover change and urbanization. Relevant model outputs are extracted, and discussed in the framework of the tracer-based and data-driven approaches above.

234

Assessing The Economic Value Of Managed Aquifer Recharge. Case Study: Mar Scheme In The Pwales Groundwater Body – Malta

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The Pwales Groundwater Body, located in the northern region of Malta, sustains an intensive agricultural activity over its surface catchment area. Due to its proximity to the sea, abstraction activities and the limited thickness of the unsaturated zone, groundwater in this coastal aquifer system is highly impacted by sea-water intrusion as well as contamination parameters of agricultural origin. In fact, Malta's 2nd River Basin Management Plan considers this groundwater body as qualifying for less stringent objectives due to its highly impacted nature.

The potential of MAR to improve the quantitative and qualitative status of this groundwater body is being assessed under a project funded under the LIFE RBMP MALTA Integrated Project (LIFE 16 IPE MT 008). The recent commissioning of a water reclamation plant and the installation of a dedicated distribution network for the use of reclaimed water in agriculture, opens the possibility of undertaking MAR during periods of low uptake to remediate the status of the groundwater body.

The project therefore assesses the direct and indirect benefits which can potentially be generated by a MAR scheme.

A review of existing hydrogeological, quantitative and qualitative data was undertaken, and a new conceptual understanding of the groundwater body was developed. Furthermore, the economic activities sustained by the groundwater body were identified and their socio-economic value was assessed.

The project considers the conjunctive use of reclaimed water for irrigation purposes and MAR for the progressive achievement of good groundwater status. The rehabilitation of the groundwater body generates resource benefits which result in an improved security of supply to the agricultural sector, as well as environmental benefits to the adjoining wetland and the bathing waters in which the groundwater body discharges.

The capital and operational costs related to the MAR scheme are determined, whilst the potential beneficial impact of MAR on the economic activities sustained by the groundwater body is also assessed. The assessment is broadened to the valuation of the resource and environmental benefits generated by MAR, thereby enabling a comprehensive assessment of the economic benefits which the whole process generates. These considerations enable the evaluation of the potential financial and economic value of MAR in the context of this groundwater body.

The study thus proposes a methodology on how the economic value of MAR can be assessed within a comprehensive analytical framework aimed at sustaining the status of groundwater and the supply security of the agricultural sector.

237

Towards Joint Groundwater Management Of The Roer Valley Graben: Inventory And Analysis Of Hydraulic Conductivity Values Of The Aquifer System As Follow-Up On The H3O-Projects

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The Roer Valley Graben, an active rift basin in western Europe, is of great importance for drinking water supply in the Netherlands, Belgium and Germany. Although the occurrence and behaviour of groundwater are not restricted to national borders, groundwater managers were faced with inconsistencies between subsurface information from the different countries, which led to uncertainty in the understanding of the groundwater system in the border region.

Unambiguous (hydro)geological knowledge and information are essential for sustainable management and use of not only groundwater resources but of the entire subsurface.

A 3D hydrogeological model has been developed in a series of so called 'H3O' projects in the transboundary region in the Roer Valley Graben, comprising parts of Germany, the Netherlands and Belgium. The model contains 3D maps of the top, base and thickness of aquifers and aquitards. H3O- PLUS, a work package of the RESOURCE-project, aims to add attribute data to these maps to facilitate the use of the maps in decision making processes.

Groundwater flow models are commonly used in groundwater management. Various Dutch, Belgian and German models exist for (parts of) the Roer Valley Graben. These models require input data, of which the geometry and hydraulic properties of the aquifers and aquitards are important ones. The harmonization of the 3D geometry of the hydrogeological units in the H3O-projects constitutes a major step towards a common hydrogeological dataset of the Roer Valley Graben and thus the harmonization of these groundwater flow models. The next step is the characterization of these hydrogeological units with respect to their hydraulic properties, primarily their hydraulic conductivity.

Based on common criteria, an inventory and analyses of hydraulic properties of the Cenozoic aquifer system were made by Dutch, Belgian and German partners. Special attention was also given to the characterization of hydraulic properties of faults.

These results can be used in the parametrization of Dutch, Belgian and German groundwater flow models of the area, thus supporting management of transboundary groundwater water resources.

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238

Towards A Better Understanding Of Physical Clogging Processes Encountered At Mar Sites

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Managed aquifer recharge (MAR) techniques are of great interest in designing adaptation strategies to address freshwater scarcity. Surface infiltration systems are often preferred over other MAR techniques due to their simplicity and lower initial investments. However, when not meeting optimal water pre-treatment targets, i.e. in floodwater or stream water recharge, the site can be prone to physical clogging. Physical clogging is a primary concern in the MAR structure's functioning due to decreasing recharge rates by orders of magnitude. Periodical drying and cleaning schedules restore the infiltration rates temporally, through mechanical removal of the most superficial clogged layer.

However, fines such as silt and clays can intrude deeper into the sub-surface, leading to a thicker clogging layer over time up to several decimeters depth. The removal of the respective soil and the consequent deepening of the basin, can permanently compromise the site and shorten its life span. Predicting the risk of clogging can reduce the associated costs of operation and maintenance by evaluating various design and operation options. In this perspective, it is fundamental to assess the expected thickness of the clogging layer and the time to reach drastic reductions in infiltration rates. One main challenge in modelling clogging is anticipating the intrusion depth of fines in the soil matrix, responsible for reducing the pore volume and hydraulic conductivity at specific depths.

Concepts are presented to predict the vertical deposition of fines in the clastic matrix based on existing studies on sand column experiments. With this, the presented work aims to provide a first guidance in the assessment of the risk of physical clogging from soil and influent water characteristics, acquirable through site characterization. The differentiation between internal and superficial clogging and the estimation of depth-based information for fines accumulation will contribute to the computation of infiltration rates' reductions at the MAR site. Additionally, we investigated the possibility of retrieving information on the time-varying profile of deposited clay in sand column experiments through electrical resistivity measurements. This technique represents an undisturbed method to observe in soil column experiments how suspended clay intrudes and deposits in the porous media during water recharge. Challenges met are addressed and form the basis for further discussion in developing techniques to investigate potential physical clogging at MAR sites.

239

Water Quality Problems And Solutions With Aquifer Storage Recovery In Various Parts Of The World

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Aquifer Storage Recovery (ASR) is a great water management tool of the MAR family, to overcome water shortage by storing water in the underground during times of plenty, and pumping it back in periods of water shortage or high demand. ASR is being applied all over the world at different scales, using different infiltration waters and aquifers with diverging geochemical reactivity and ambient groundwater quality.

In this contribution, we address the most important drivers of water quality issues: the lowering of drinking water standards (e.g. As and Cr), bad quality of infiltration water (suspended solids, NO3, organic micropollutants, pathogens), well clogging, admixing of ambient groundwater (by dispersion, lateral bubble drift, buoyancy or upconing), and reactions with the aquifer matrix. The latter may lead to norm exceedance of e.g. Mn, Fe and Na (Netherlands), F (UK), Cr(VI) and As(V) (Abu Dhabi), As (Florida), and radionuclides (US, Australia). The responsible reactive solid phases and conditions under which they are mobilized will be discussed. The aquifer may thus release undesired elements, but normally it will only for a limited time due to leaching and mineral coating. Most likely various quality parameters will also improve by reduction (NO3, bromate), sorption and biodegradation (organic micropollutants, pathogens).

The solution of water quality issues consists of various preventive and curative measures. We discuss recent experiences with the pretreatment of infiltration water, risk estimators of well clogging, bubble drift and buoyancy, how to assess the maximum allowed admixing of ambient groundwater, and a simple approach to estimate the water quality changes during detention in the aquifer. All these insights and tools may help to select the best ASR site, raise the recovery efficiency and prevent the system to fail. In countries, where ASR is in the first try-out phase, such failure should be prevented by all means, because it would have detrimental effects on future development of these indispensable systems.

240

Understanding The Origin Of The Nitrate Contamination In A Sandy Aquifer (Case Of The Leefdaal-Puttebos Abstraction Site)

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Groundwater in the pumping wells of the Leefdal-Puttebos abstraction site in Flanders in Belgium are characterized by rising nitrate concentrations that are approaching the drinking water standard of 50 mg/l. In monitoring wells in the immediate vicinity, values of up to 140 mg/l are recorded, suggesting that a further increase cannot be ruled out. These high concentrations and uncertain future trend pose a severe risk to the quality and the security of supply of the extraction. It is therefore important to determine the origin of the nitrates, so that the appropriate measures can be taken to prevent a further increase.

A study, based on 22 groundwater samples and 2 surface water samples, combining classical hydrogeochemical tools, graphical analysis of the results of nitrate and boron isotopes and environmental tracers analyses has been carried out to build a geochemical conceptual model of the studied area, determine the origin of nitrate and the age of groundwater.

The study confirms that a nitrate pollution of the groundwater occurs in the catchment and allows to determine the spatial distribution of the pollution. Based on the isotopes and environmental tracers, it can be concluded that the high nitrate concentrations in the area are caused on one hand by an old pollution due to sewage dating from more than 60 years, and on the other hand to a more recent and spread pollution due to manure spreading on fields. There is no input due to surface water. The pollution due to sewage leaking is expected to be limited at present since the largest part of a new whole network was installed in the past decades, but a decrease in the agricultural use of nitrate in the area is needed in order to stop the nitrate concentrations increase in the groundwater.

241

Developing A Water And Environmental Studies Curriculum At University Of Yangon, Myanmar

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Before the pandemic and a military coup in Myanmar, work was being done to develop an undergraduate degree program (BSc) in water studies at the University of Yangon. This will be the first program like this in the country and will address the need for water professionals in the country. The Water and Environmental Studies Department was established in March 2019 to increase the capacity working in the water and environmental sectors. The vision of the department was to become a Center of Excellence in Water Studies and a leading scientific and educational resource on various aspects of water management. A curriculum development workshop was held on 9-13 March 2020. Four international experts from USA, Sweden and the Netherlands along with local stakeholders and faculty from geology, geography, chemistry, zoology, industrial chemistry, and physics worked to develop a meaningful curriculum to advance the whole water sector. The process involved understanding the stakeholders needs and developing courses that provided the necessary training for the students. Hydrogeology was integrated across the curriculum with plans for a hydrogeology field-training site on campus to be used for labs and was to be built over the coming years. The curriculum was unique in the country and brought together an interdisciplinary group to address an important issue in a country whose educational system lacked innovation.

242

A New Mcp Package For Reactive Transport Modelling In Mt3D-Usgs

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This research is part of an effort to develop an effective coupling tool for simulating reactive transport in the unsaturated and saturated zones. This tool (named MTHP for Modflow Transport Hydrus PhreeqC) builds upon the existing codes HYDRUS-1D (Šimůnek et al., 2013) / HP1 (Jacques et al., 2018), MODFLOW (Harbaugh, 2005), MT3D-USGS (Bedekar et al., 2016) and PhreeqC (Parkhurst and Appelo, 2013).

Simulating geochemical reactions in the aquifer required coupling MT3D-USGS to PhreeqC. This has been implemented by adding a new module MCP (MultiComponent Package) to the MT3D-USGS code using a similar versatile approach as in HPx. MCP has been successfully benchmarked against examples from the similar PHT3D code (Prommer and Post, 2010).

An application of the MCP package is presented for the simulation of redox plume development from an old landfill. In this case study, the contamination source is suitably conceptualized to be at the water table surface. Kinetic degradation of dissolved organic carbon (DOC) in the presence of several electron acceptors is simulated. Observations of NO3−, Fe2+ and Mn2+ concentrations at different points in space and time are used to manually calibrate the numerical simulations. In order to investigate what is the acceptable level of process and parameter simplification, simulations of the redox plume with the RCT package of MT3D-USGS are done in parallel using single Monod equations with inhibition terms which do not require the full geochemical system to be simulated.

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243

Climate Change And Groundwater Depth Influence On Recharge Parameterization In A Transient Modflow Model

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In lowland landscapes, groundwater depth is known to have an influence on groundwater recharge rates (Renger et al., 1986; Shah et al., 2007; Doble and Crosbie, 2017). With climate change, seasonal patterns of precipitation (P) and potential evapotranspiration (ET0) are expected to be significantly and durably altered. Because groundwater depth varies seasonally, the combined effects of climate change and groundwater depth dynamics can have important consequences for recharge parameterization and predictive modelling of groundwater fluxes in a transient groundwater flow model.

We illustrate, using a case study from North-Eastern Belgium – a small interfluve area (~20 km2) of the Kleine Nete catchment –, how spatially variable soil properties, land cover and groundwater depth information can be combined to parameterize recharge in a MODFLOW groundwater model. Our approach relies on HYDRUS-1D simulations with atmospheric upper boundary conditions (20- year times series of daily precipitation and potential evapotranspiration), which are run for different groundwater depths (as bottom boundary condition). Conveniently, the impact of climate change on recharge can then be assessed, by applying multiplication factors (obtained from regional climate models) to the input P and ET0 time series of the HYDRUS-1D simulations.

In our case study, soil texture from the Belgian soil map (Databank Ondergrond Vlaanderen) and a 2015 land use map (Agentschap Informatie Vlaanderen) are joined to obtain a total of 25 soil- vegetation combinations over the study area. For each of them, HYDRUS-1D results provide time series of monthly groundwater recharge (as a function of groundwater

depth), which are then used as input for the MODFLOW RCH package, in the following sequential approach:
(i) prepare the RCH package based on the recharge with a constant 1 m groundwater depth;
(ii) run a steady-state simulation of the groundwater model (MODFLOW);
(iii) use output groundwater depths from (ii) to look up new recharge values for the RCH package;
(iv) run a transient simulation of the groundwater model (MOFLOW);
(v) repeat once steps (iii) and (iv) (so that the transient recharge values in the RCH package are based on the more realistic output groundwater depth values from (iv) rather than from (ii).

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244

Managed Aquifer Recharge To Increase Freshwater Availability In A Salinized Flemish Polder Area

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Fresh water is scarce in the northwestern part of Belgium. The shallow coastal aquifer is salinized and the deeper aquifer is largely depleted after decades of overexploitation. Surface water is used for irrigation during summer months, but droughts lead to shortage of fresh surface water and an increase of saline seepage. Climate models predict drier summers and wetter winters which forces water managers to seek adaptation strategies for the increasing seasonal imbalance. In the European TOPSOIL project, countries around the North Sea investigate the possibilities of using the topsoil to solve current and future water challenges.

The Belgian part of the TOPSOIL project investigates the potential of local groundwater measures in polder area to tackle the effects of climate change. One of the measures with high potential is creek ridge infiltration. Creek ridges are former tidal gullies which became small sandy ridges when land was reclaimed. The higher topography of these ridges led to higher groundwater tables and the development of fresh water lenses. Infiltration of the surplus of surface water in these creek ridges during winter could contribute to a further increase of the thickness of the freshwater lenses and to the need to keep fresh water in the area instead of losing it to the sea.

The potential of creek ridge infiltration depends on local conditions like topography, soil conditions, geology, fresh-salt water distribution. By combining regional data, potential maps were made for this managed aquifer recharge system (Fig.1). The implementation of creek ridge infiltration was discussed at workshops and during field visits. Farmers were interviewed and asked about their water needs, water resources, water treatments and costs, water problems and their willingness to invest in a pilot installation. Finally, one location was selected for further investigation and implementation of a creek ridge infiltration system.

To determine the actual suitability of the location, additional field work was carried out to identify the local geology and fresh-salt water distribution. Based on this, a research and monitoring plan and a concept design have been drawn up for this potential pilot location. To determine whether such a measure would be economically feasible, a cost price analysis was carried out.

In the following phase, a 3D groundwater model was used for optimalisation of the design and to calculate the effects on the environment. The final design is now part of a licensing process in order to obtain authorization to build the installation.

246

Fate And Transport Of Microplastics In A Sandy Aquifer And Column Studies

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Micro- and nano-plastics (MNP) are ubiquitous in the environment. The term “microplastics” was first described over a decade ago to refer to plastic pellets, fibers, foams, and films with particles <5 mm with the lower bound of ~1 µm (nanoplastics). The explosion in plastic production and usage has resulted in an equally massive increase in plastic pollution affecting aquatic, terrestrial, and atmospheric environments. As the human population continues to increase, so does the production of disposable packaging materials and single-use items. MNP are rapidly accumulating within our natural environment, yet the identification of microplastics in food, organisms, and the environment remains a huge challenge. It has been suggested that the toxicity of these materials may arise from the polymer itself but also likely the result of leaching of embedded small molecules (plasticizers) and adsorbed toxins (bacteria, small molecules, heavy metals). Because these microplastic materials are exposed to solar radiation, mechanical stresses and microbial action in the environment, the particle sizes are degraded to very small nanoplastics and the parent polymeric structure can be substantially modified in collected samples. Ensuring clean, sustainable water supplies for the future is a human rights problem. MNP in water research has focused almost exclusively on marine and terrestrial surface water environments while groundwater is limited and mostly relates to detection. We investigate fate, and transport of MNP and how MNP change aquifer properties. We hypothesize that MNP can migrate through a sandy aquifer and that the size and type of plastic will influence the transport. The findings from these experiments will help set a critical foundation for how microplastics may be moving through and changing our modern drinking water systems.

248

Analysing Hydrographs Of Barada And Figeh Spring (Syria) And Ohers In Antilibabanon And Their Recession As Indicator For The Karst Development

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Several large karst springs exist in the Eastern Mediterranean region, some of them are used for drinking water supply like Barada and Figeh. More than further 80 karst springs in Damascus City and its countryside are documented. Their monthly average discharge which was registered for more than 30 years and range between 3-800 L/s. Analysing the discharge behaviour of these springs indicates very low retention values and a developed karst system. The majority of these springs fall dry during the summer periods without rainfall.

The hydrograph of Barada spring north west of Damascus (average 3 m3/s) shows a short phase with low retention and indicates a drain of nearby karst caverns which was also proven by tracer tests. The oscillation of the discharge in this phase indicates the connection to fractures. The second phase indicates a higher retention and changing volume which continues in the late dry period. Figeh spring, which is located around 18 km to the south east of Barada spring is the main sources for the water supply of the city and has a mean discharge of 8.5 m3/s. Its hydrograph shows faster recession indicating higher significant role of the developed karst in the aquifer feeding this spring which get more visible in years with much higher recharge than average and lower recharge where the less connected fractures produce the diffuse flow. A detailed hydrograph of Figeh spring with the daily measured rainfall of the average rainfall hydrologic year 1995-1996 shows that the increase of discharge retard of almost two months and reaches its peak flow after two more months. Due to the dry season before, the large catchment of the spring needed to be recharged before reacting. This shows evidence of siphonic systems discharging in cascades accumulating in a peak flow with a continued discharge.

249

Estimation Of Groundwater Contributions To Coastal Biscayne Bay, Florida, Usa

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The position of the freshwater interface determines the composition of freshwater and saltwater aquatic communities as well as the freshwater availability for water intakes. Estimating salinity concentrations in coastal waters allows characterizing the spatial location of freshwater/saltwater interface which would have implications for biological communities and also for urban settlements. A recent modeling study on the hydrodynamic regime and salinity spatial distribution in Biscayne Bay (Southeast Florida, USA) was able to replicate salinity concentration values and seasonal trends occurring within the bay. However, salinity concentration estimations for locations close to the coast were not simulated properly, especially during the wet season. A non-linear effect produced by freshwater inputs, which cannot be quantitatively described by means of mechanistic approaches, seems to be changing concentration values substantially. The influence of freshwater inputs from rivers and canals, and precipitation is evident because some of the lowest salinity values observed at the Biscayne Bay coast occur after storm events and high flows observed at the streams. However, there are low salinity values that are not related to precipitation and flow. Therefore, groundwater inputs are playing an important role on the salinity trends observed at coastal salinity stations, because the salinity trend is not proportional to either precipitation or freshwater flow trends. In this research, the estimation of groundwater flows is performed by combining estimations of salinity produced by an existing hydrodynamic/salinity transport model, and an artificial neural network that estimates salinity concentrations for coastal locations at Biscayne Bay. Since the hydrodynamic/salinity model replicates observed salinity data at offshore locations, it is assumed that the model estimations at the coast would be correct if no groundwater inflows would exist.

Therefore, the ANN model (that correctly captures the salinity concentrations at the coast) could be fed by surface water flows augmented by hypothesized groundwater inflows, until salinity concentrations (generated by the ANN) match those calculated by the hydrodynamic/salinity model. The additional flow introduced to the ANN model, required to match the salinity concentrations predicted by the hydrodynamic/salinity model, constitute the groundwater flow contribution.

251

Capacity Recovery Of Boreholes With Hydropuls Technology – Case Studies (France & Indonesia)

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The bottling industry relies mostly on boreholes for its groundwater supply. Some of these boreholes are operated since decades already. And experience shows a recurrent challenge that is capacity declining over time. Root cause analyses often point towards clogging. Developing substitution boreholes consumes time and costs money. More focus is given nowadays to innovative solutions likely to recover capacity from existing ones.

Danone Waters assessed a technology developed by the company 'TLM hydropuls gmbh' [TML]. This pulse generator works like the 'airgun' used for offshore seismic. Building on sudden release of compressed gas in a liquid, it generates a 'shock wave' propagating radially. Previous experiences suggested that the impact of this shock wave is not limited to the borehole screen but extends further through the gravel pack till the surrounding geological formation.

The potential risk of chemical contamination related to hydropuls was investigated at Evian (France). Some lubricating is needed to operate properly the pulse generator and there was a concern about the grease used (although food grade quality). The experiment was performed with nitrogen gas pulsing in a closed system [1m3 water tank] over 70 minutes, and water samples collected on regular basis. The chemical analyses will be presented. They allow to conclude that the contamination risks are negligible when dealing with an aquifer [open system].

The field test was performed in collaboration with TML. A production borehole located at Danone Aqua facility in Ciherang (West java, Indonesia) was selected because of historical data suggesting some clogging issue. The condition of the borehole was assessed before hydropuls through video inspection and pumping tests. Pulsing with nitrogen gas was performed in front of each screened section. The water extracted in parallel through airlifting came out first with a high load of sediments that were sampled for detailed analyses. Pulsing was stopped after 2 days when the water became clear and the borehole was tested again. The pumping test results will be shared. They show a significant increase of the specific capacity. The borehole could be brought back to production almost immediately.

The daily monitoring of this borehole will be illustrated. The data confirm that the benefit of the capacity recovery extended over months. As expected, they also highlight that clogging tends to rebuild over time. Based on this first experience, one hydropuls unit was acquired for supporting the yearly maintenance program of the boreholes across the Indonesian operations.

252

Controlling Factors For Improving Freshwater Recovery Of Asr Systems In Confined Coastal Aquifers Using Brackish Groundwater Interception Wells: A Generic Modeling Study

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Overexploitation and climate change have reduced fresh groundwater availability in coastal areas, with seawater intrusion ongoing in many coastal aquifers. With the use of aquifer storage and recovery (ASR), freshwater availability can be increased by storing temporal surpluses of e.g. precipitation or other freshwater sources in the subsurface for later use upon demand. However, recovering sufficient fresh water after storage is known to be challenging in coastal aquifers due to the lower density of fresh water compared to that of the more saline native groundwater. In this study, the use of brackish groundwater interception wells was considered to counteract the effects of buoyancy flow and to improve ASR performance in confined coastal aquifers in terms of freshwater recovery.

To test the potential of brackish groundwater interception for increasing ASR performance in confined coastal aquifers, and to determine its controlling factors for optimization, variable-density groundwater flow models were developed using SEAWAT. Hydrogeological parameters (e.g. hydraulic conductivity and salinity of native groundwater) and operational parameters (e.g. ASR storage volume, distance between the ASR system and the interception well, and brackish groundwater abstraction rate) were varied to assess their effect on freshwater recovery.

Additionally, the volume and quality of abstracted brackish groundwater were analyzed to determine the potential of brackish groundwater as feedwater for reverse osmosis (RO).

For given aquifer characteristics and a minimum salt load in brackish groundwater wells, results showed that the optimal application scheme of brackish groundwater abstraction was strongly determined by well placement, both in terms of screen length and distance from the stored freshwater volume. A sensitivity analysis using axisymmetric simulations showed that brackish groundwater interception with partially penetrating well screens at the aquifer bottom surrounding the stored freshwater volume resulted in an increased freshwater recovery by ASR for all scenarios tested.

Strongest recovery improvements (up to threefold compared to conventional ASR) were found in brackish aquifers where the partial screen length was reduced. Overall, the benefits of brackish groundwater abstraction for ASR performance through counteracting the effects of buoyancy flow seemed to outweigh the likely increases of dispersion losses as well as the fraction of fresh water lost through interception wells. Besides, fresh water lost through interception wells may make the application of RO on abstracted brackish groundwater more interesting.

Overall, the modelling results indicate the potential of brackish groundwater abstraction for improving ASR performance in coastal aquifers, if installed and operated correctly for given hydrogeological characteristics.

253

Preventing Pluvial Flooding While Providing Fresh Water During Droughts: A Field Pilot With Rainwater Harvesting And Aquifer Storage And Recovery In The City Of Rotterdam

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Climate change will result in an increased frequency and intensity of both rainfall events and droughts, increasing the challenge for urban areas to deal with risks of pluvial flooding, urban heat island effects and extreme water demands for both potable and non-potable use. Urban rainwater harvesting may mitigate flooding risks and provide a high-quality additional water source for use in times of high demand when combined with aquifer storage and recovery (ASR). This type of managed aquifer recharge (MAR) is particularly interesting for urban environments, due to its limited spatial footprint and large capacity, as well as the potential of disinfection through subsurface storage and aquifer passage.

For the coastal city of Rotterdam (The Netherlands), the combination of rainwater harvesting and urban MAR was developed and tested during nine months in a field pilot study that aimed to locally collect and retain on average approximately 16,000 m3 rainwater per year from 4.5 hectares of different urban areas. A retention basin was required for harvested rainwater to compensate for the relatively low infiltration rate of the ASR-well. A biofilter, integrated in the urban space as landscaping, was required to provide sufficient treatment to meet legal water quality limits for infiltration. Additionally, dissolved organic carbon, suspended solids, and dissolved iron required removal from harvested water prior to infiltration, as these posed an operational risk in terms of long-term well clogging and a reduced infiltration capacity. The stored rainwater was recovered and could be used as irrigation water for the field of a professional football club upon demand, and was partly required for maintenance of the vegetation in the biofilter in times of drought. Moreover, backflushes were performed during infiltration for preventive maintenance of the ASR-well.

The microbial quality of collected and stored rainwater requires attention and monitoring if used as irrigation water in urban areas. Compared to irrigation with tap water, a higher risk for pathogenic infections via aerosols is likely. Based on microbial risk assessment, however, a subsurface retention time of at least three days could increase disinfection in the pilot significantly for a recovered water quality suitable for irrigation. Additionally, by operating the system with two individual (partially penetrating) wells, aquifer passage and the disinfection potential can be further increased.

Overall, the results of the pilot are promising for the broader application of urban MAR to contribute to a more sustainable, robust and climate resilient water management in urban areas.

254

Comparison Of Methodological Approaches To Describe The Hydrodynamic Response Of A Coastal Karst Aquifer: The Case Of Salento Aquifer (Italy)

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Characterization of aquifer response to climatic factors is important for groundwater management, especially for water resources of the Mediterranean region that are subject to high climatic and exploitation stress. Reliable characterization becomes even more important where groundwater is the only source available to cover potable and irrigation demands, and is hosted in a highly vulnerable hydrogeological environment, as is the case for the Salento carbonate coastal aquifer (Southern Italy). This exercise has been carried out in the framework of the PRIMA funded MEDSAL project.

Because of the karst platform nature, groundwater discharge occurs only to the sea through diffused flow and focused brackish springs. The actual volume of abstraction, performed through numerous licensed and not licensed wells, is unknown.

In the last thirty years, characterization of karst aquifers considered time series analysis using both univariate and bivariate approaches. Thus, autocorrelation, cross-correlation and spectral analysis have been applied to understand the relationships between precipitation input signals and spring discharge, river flow or groundwater level output signals, assuming karst aquifers behave as low- pass filters.

The efficacy of time series analysis has been verified on four-, three- and two-years time series of rainfall, and groundwater levels consisting of daily registrations retrieved from pressure sensors installed in 11 wells of the Regional Monitoring Network of the Salento aquifer.

Interpretation of the results of time and frequency domain analysis is neither straightforward nor obvious. The response of Salento aquifer to precipitation input is spatially irregular and dissimilar from one well to another. The autocorrelation function confirms these results: it allows distinguishing areas where quick flow plays a fundamental role in the recharge process from areas where baseflow prevails, with a memory effect of a few hundred days. Results highlight the importance of some geomorphological, structural and hydrogeological aspects of the regional karst, where permeability is dominated by tectonics.

Time series analyses results were also confirmed by an alternative approach, which examines the relationship between the classic Standardized Precipitation Index and groundwater level fluctuation.

The results of this study reveal a nonlinear response of groundwater to precipitation events: the karst aquifer, acting as a filter to the input signal, leads to an asynchronous and attenuated response in terms of recharge timing. Moreover, these results are essential in understanding and evaluating the relation between short-term and long-term sustainable groundwater use with reference to the asymmetric impact of groundwater use on groundwater drought occurrence, duration, and magnitude.

255

Image-Based Priors For Probabilistic Inversion Of Nonstationary Hydrogeological Fields Through Conflict-Handling Direct Sampling

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An omnipresent research topic in hydrogeological modeling is the resolution of inverse problems in complex and heterogeneous geological settings. The heterogeneity of hydrogeological systems and the sparsity of data lead to uncertainty, which critically needs to be quantified. Due to the inherent limitations of multi-Gaussian priors in representing complex structures, the idea of using non- parametric geological image(s) as priors in stochastic inversion problems has emerged recently.

Multiple Point Statistics (MPS) algorithms are suitable for integrating these non-parametric priors under the form of training images (TIs). More precisely, a TI is a conceptual prior model that mimics the subsurface spatial structure and continuity.

In this study, we investigate the applicability of a workflow for inverse problems in nonstationary fields because of the simplicity and open-source availability of the constituents. To this end, we benefit from conflict-handling direct sampling (CHDS) as the prior sampler, the finite-volume algorithm MaFloT as the forward model, and a simple rejection sampler to explore the posterior. CHDS is a two-step multiple-point geostatistics simulation algorithm that is an extension of well- known direct sampling. In the first step of simulation by CHDS, the coarse and general structure of the proposal prior is generated with minimal conflicts by rejecting inconsistent spatial patterns and allowing the removal of previously simulated data. The detailed structure of the patterns which is considered as the fine grid is simulated in the second step by ignoring the conflicts. CHDS is able to represent the long-range connectivity and curvilinear patterns to model the complex heterogeneities that play a substantial role in subsurface flow and transport. Our application case is a synthetic nonstationary fluvial-aquifer characterized by the presence of curvilinear sand-filled channels within a background of mudstone. CHDS makes it possible to generate the prior models by directly sampling from the TI instead of drawing the samples from probability distributions functions. After the generation of an ensemble of proposal models, for each of the prior models, steady-state groundwater flow is simulated using MaFloT. Consequently, by a likelihood function, the conformity level of the simulated results with the measured data is evaluated. Finally, the posterior function is reproduced by a rejection sampling procedure for our 2D scenario due to its simple implementation and computational feasibility, contrarily to more sophisticated methods. The proposed method shows promising results in terms of connectivity preservation, pattern variability, and posterior reproduction.

256

New Method For Compound Specific Carbon Isotope Of Chlorinated Solvents In Porewater, Based On Solvent Extraction And Gc-Irms With Spme

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Although compound-specific isotope analysis (CSIA) for chlorinated solvents is widely used in studies of groundwater contamination, the same technique has hardly ever been applied to porewater. A CSIA of chlorinated solvents in porewater makes it possible to determine the initial isotopic composition of these compounds and the presence of discharges of different origins and degradation processes, among others. A new method for the extraction of chlorinated solvents from porewater with dimethylacetamide (DMA) used as a solvent and the determination of δ13C by gas chromatography/isotope ratio mass spectrometry (GC-IRMS) with solid-phase microextraction (SPME) is presented. The method has been used for the determination of δ13C of chloroethenes and chloromethanes. The extraction of the chlorinated solvents from the porewater with DMA has led to a minimal loss of mass. The accuracy of the method has been verified with the analysis of the pure injected compounds in elemental analyser – isotope ratio mass spectrometry (EA-IRMS).

The CSIA of chlorinated solvents in porewater has been effectively applied in two boreholes in a pollutant source zone of perchloroethylene (PCE) and trichloroethylene (TCE). Samples from the saturated zone have been analysed, specifically from the aquifer (composed of a more permeable unit and the transition zone to bottom aquitard) and the bottom aquitard (made of silts and fine sands). The quantification limit of the new method is 30 ug/L for PCE and TCE. The results have allowed us to characterise the initial isotopic composition of the PCE (δ13C0PCE) of -24.7 ± 0.5 ‰ and the areas where the PCE is being degraded, being a complementary technique to the determination of chloroethenes in the porewater at the centimetric level. Furthermore, these results are compared with CSIA for chlorinated solvents in groundwater of the multilevel wells installed in the studied boreholes.

This new method allows the CSIA determination of chlorinated solvents in porewater, which can be beneficial in sites where the identification of contamination sources and the behaviour of contaminants are not clear.

257

Results And Relevance Of Stakeholder Trainings On Reducing The Risks Associated With Managed Aquifer Recharge (Mar)

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Managed aquifer recharge (MAR) is a nature-based, worldwide successful process for sustainable water resource management and significantly helps increasing the security of water supply.

However, the lack of detailed and real-time data continues to hinder reliable monitoring as well as forecasting and avoidance of risks in aquifer recharge processes. This leads often to a hesitant implementation of MAR despite their far-reaching advantages.

To help overcoming these challenges, the SMART-Control project consortium (https://smart- control.inowas.com/) trains and engages MAR stakeholders using a three-step approach:

- Firstly, public stakeholder events are held to raise awareness and inform about the benefits of MAR and how to manage associated risks, bringing together a wide range of actor groups from academia, policy and practice,
- Secondly, managers and technical operators of MAR schemes are trained in the use of the SMART-Control innovative web-based real-time monitoring and control system (RMCS) at pilot sites in Cyprus and Brazil; and
- Thirdly, the concept is replicated at new potential MAR sites and discussed with interested stakeholders.

A needs assessment helped to best tailor the SMART-Control technical training to the needs of management and technical operators. A high interest was expressed for (a) real-time monitoring with online sensors including data visualisation and interpretation, (b) groundwater model-based predictions and running different scenarios, (c) microbial risk assessment and (d) cost-benefit analysis for MAR systems. The SMART-Control web-based modelling platform offers a variety of tools, including tools for the first three topics, the use of which was the primary topic of the technical training. Interactive discussion and feedback sessions organised at the end of each training session helped to further improve and adapt the SMART-Control platform to the needs of MAR stakeholders. A list of additional risks related to MAR that are not yet covered by the platform was compiled, as well as relevant future scenarios that are worth considering in MAR planning and monitoring.

The feedback from the training participants revealed a high interest in MAR solutions and monitoring and control tools to reduce MAR-associated risks, as well as a need for training and stakeholder engagement in solution development as an important pillar to reduce barriers towards MAR implementation.

258

Towards Improved Quantification Of The Influence Of Heterogeneities On Seawater Intrusion Through Coupled Hydrogeophysical Inversion

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Heterogeneity exerts a significant influence on the existence, magnitude, and characteristics of seawater intrusion in coastal aquifers. Direct borehole observation datasets are often too scarce to adequately capture the complex 3D patterns of salinity distribution. Electrical resistivity methods are widely used in seawater intrusion studies because of its high sensitivity to pore salinities. However, the interpretation of electrical tomograms from coastal aquifers is also prone to interpretative errors derived from the conceptualization and inversion steps. Depending on the options used in the geophysical inversion, distortions can be observed in the delineation of both geological heterogeneities and in the imaging of the freshwater-saltwater mixing zone (e.g. traditional smoothness constraints can lead to an impression of over-dispersion). As a result, and especially in heterogeneous aquifers where both salinity and lithology influence resistivity measurements, it is challenging if not impossible to establish a direct relationship between isovalues of electrical resistivities and salinity concentrations. In this work we evaluate the limits of traditional geophysical inversion for delineation and characterization of seawater intrusion in coastal heterogeneous aquifers. To overcome some of its limitations we have developed a coupled hydrogeophysical inversion workflow with integration of COMSOL and PEST that allows for estimation of primary hydraulic properties using multiphysical datasets such as hydraulic heads, salinity concentrations and electrical resistivities. We assessed the capabilities and limitations of the coupled inversion for improved characterization of seawater intrusion in heterogeneous aquifers. We examined the capabilities of different electrical resistivity acquisition arrays for the identification of seawater intrusion in different synthetic hydrogeological scenarios, including various types of heterogeneities. We further illustrate the approach through applying the coupled inversion to real coastal aquifer datasets from the UK. Since the groundwater model provides a physically-based constraint in the inversion, the coupled approach enables to discriminate between hydraulic parameters and salinity content. As such, some of the pitfalls in the use of electrical resistivity for the mapping of seawater intrusion in coastal aquifers can be avoided and more reliable results can be obtained for coastal aquifer monitoring studies. The methodology also offers a straightforward framework for wider integration of geophysical data in the calibration of groundwater models used for water resources management where sufficient computational resources are available.

259

Cfd (Computational Fluid Dynamics) Modeling Of Tracer Dispersion Through Karst Conduits: Influence Of Geometry And Comparison With On-Site Tracer Tests

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Tracer tests are widely used for characterizing hydrodynamics, from stream scale to basin-wide scale. In karstic environments, the positioning of field fluorometers (or sampling) is mostly determined by on-site configuration and setup difficulties. Most users are probably aware of the importance of this positioning for the relevance of data, and single-point tests are considered reliable. However, this importance is subjective to the user and the impact of positioning is not well quantified. Therefore, this study aims at quantifying the spatial heterogeneity of tracer concentration through time in karstic environment, and its impact on tracer test results and derived information on local hydrodynamics. Two approaches are considered: on-site tracing experiments in various karstic rivers with different geometries, and CFD modelling of tracer dispersion through a discretized karst river channel. Comparison between on-site tracer breakthrough curves and CFD results are allowed by a thorough assessment of the river geometry using various techniques, comprising the use of a sonar-based remote-controlled boat.

The assessed geometry is then implemented in the CFD model by discretization steps, allowing for the simulation of tracer dispersion through existing karst rivers, that are subjected to on-site multi-point tracer tests. Early results of on-site tracer tests show significant heterogeneities of breakthrough curve shape from fluorometers placed along a cross-section. CFD modelling of tracer test through the associated discretized site geometry show similar heterogeneity and are consistent with the positioning of on- site fluorometers, thus subjecting that geometry is a major contributor of spatial heterogeneity of tracer concentration through time in karstic rivers.

260

Multi-Point Dye Tracing In Karstic Rivers: Early Results From Transversal Configuration

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Tracer tests are widely used for characterizing hydrodynamics, from stream scale to basin-wide scale. In karstic environments, the positioning of field fluorometers (or sampling) is mostly determined by on-site configuration and setup difficulties. Most users are probably aware of the importance of this positioning for the relevance of data, and single-point tests are considered reliable. However, this importance is subjective to the user and the impact of positioning is not well quantified. Therefore, this study aims at quantifying the spatial heterogeneity of tracer concentration through time in karstic environment, and its impact on tracer test results and derived information on local hydrodynamics. The use of multi-point dye tracing (using multiple field fluorometers or sampling) is appropriate in the scope of this study. Three major fluorometers configurations can be considered: transversal multi-point, along-stream multi-point and capacitive zone multi-point. Early results from transversal configuration in Wallonia (Belgium) indicate significant heterogeneity of tracer concentration across a stream section through time. These heterogeneities seem to be well correlated with anomalies in the conduit geometry, thus indicating that local karst geometry influences spatial distribution of tracer through time, and induces heterogeneity of concentration along a cross-section. Characterization and quantification of this influence is investigated. Further investigations on various sites with different karst geometry are considered in the future.

261

Assessing The Potential Impact Of Managed Aquifer Recharge On A Coastal Aquifer In Guanacaste Province, Costa Rica

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IIn the province of Guanacaste, a tropical coastal area in the northwest of Costa Rica, groundwater pumped from alluvial aquifers plays an important role because it is the most reliable source of freshwater. Nonetheless, concerns over the sustainability of water resources are increasing considerably in recent years, due to rapid population growth and accelerated development of the tourism industry, demanding access to water. Moreover, the effects of climate variability and climate change are expected to affect the levels of regional aquifers. Managed Aquifer Recharge (MAR) appears in the scene as a potential tool to improve the sustainability of groundwater and mitigate negative impacts on water availability.

In this work, a transient numerical model was implemented to represent the hydrogeological system of the Huacas-Tamarindo basin (85.6 km2) in the North Pacific Region of Costa Rica.

Based on the available information, different scenarios were implemented using MODFLOW2005 simulating the baseline of groundwater flow, and the potential future effects in the aquifer due to demographic growth (up to 52% by 2050), touristic expansion (4% per year), and climate change represented by a decrease in aquifer recharge from precipitation (according to the IPCC projections scenario RCP8.5).

Managed Aquifer Recharge techniques were simulated to assess the impact of such strategies on the sustainability of groundwater. Based on the results of drawdown, varying from 10 to 20 meters depth, four critical areas were selected and injection wells were simulated in the vicinity with injection rates of 1000, 2000, and 3000 m3/day. With the simulation running for 31 years, starting in 2015, it was possible to recognize that MAR does play an advantageous role in progressively reducing the drawdown in two of these critical areas of the aquifer system, meaning the possibility to completely recover the groundwater level to the initial head condition with respect to the worst- case scenario modeled. Nonetheless, the results also expose the fact that, regionally, MAR is not a substitute for other groundwater management strategies based on decreasing abstraction and adapting withdrawal to the resource's availability together with water heads monitoring.

It is recommended to continue developing further studies in the region aimed at the refinement of the hydrogeological conceptual model and the improvement of the numerical model before the implementation of infrastructural measures, as well as the design of an integrated water resources management plan where communities alongside government and universities contribute to the monitoring, control and sustainable management of the aquifer.

262

Groundwater Recharge Estimation In Data-Sparse Sub-Humid Aquifer Of The Upper Beles Basin, Ethiopia

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Quantification of groundwater recharge is imperative to the sustainable management of groundwater resources. There are several direct and indirect methods for estimating groundwater recharge with inherently different assumptions and datasets used. Hence different groundwater recharge estimation methods give a wide range of results. Data limitations are a major challenge to an estimation of groundwater recharge mainly in developing countries, including the Upper Beles Basin of Ethiopia. The main objectives of this study are: a) to estimate groundwater recharge in the Upper Beles Basin using multiple techniques (Water Table Fluctuation (WTF), Chloride Mass Balance (CMB) and WetSpass water balance model); b) to demonstrate the use of global hydro- meteorological data: TerraClimate (potential evapotranspiration, wind speed, and temperature) and CHIRPS (precipitation) for groundwater recharge estimations (using WetSpass model) in the Upper Beles Basin where distributed gauge meteorological data are very scarce; c) to evaluate the spatial variability of groundwater recharge within the basin using remote sensing data; and d) to compare groundwater recharge estimates from different methods. Results showed an average recharge of 420 mm, 308 mm and 365 mm annually using WTF, CMB, and WetSpass methods respectively.

Based on the WTF method, the annual recharge rates range from 180 mm to 802 mm. The groundwater recharge map (from WetSpass) shows that the distribution is highly controlled by soil type on the highlands and by land use on the lowlands. Recharge estimation using global climatic data (in the WetSpass model) shows a comparable result with estimates using primary data (WTF and CMB). This study demonstrates that high-resolution global climatic remote sensing data can be a good option in estimating spatially distributed groundwater recharge in data-sparse regions.

Keywords: shallow groundwater recharge, remote sensing climatic data, Beles Basin

263

Flow And Heat Transport Modelling For Long-Term Sustainability Assessment Of A Mine Water Geothermal Scheme: Application To The Fondón-Candín Mines In Spain

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After closure and water rebound, some underground coal mines require pumping to prevent overflow causing surface flooding of cities and infrastructures. Warm pumped water is being used in some mines for geothermal energy. An example is the new geothermal district-heating scheme under development in the Fondón and Candín mines in Langreo (Asturias, Spain). To assess the geothermal resource, we have developed a groundwater flow and heat transfer numerical model using the finite element software COMSOL Multiphysics. The mining and geological information has been utilized in conjunction with a regional groundwater model to propose and develop alternative conceptual models of the two connected mines at the local scale. For the numerical implementation we have adapted specific equations for flexible simulation of water flow in the mine galleries defined as discrete 1D geometrical features in the 3D model. We have used pre- and post- closure hydrogeological information to assess the recharge estimations and the extension of the catchment area and to identify the preferential flow paths both in the aquifer and the mine. The groundwater model was coupled with a heat transport model for the simulation of spatial and temporal distribution of temperatures in the aquifer and the mine voids and galleries. We evaluated the outcomes of the model, in terms of temporal changes of water pumped and temperature variations in the mine shafts, for alternative plausible conceptualizations under different scenarios of recharge and distribution of hydraulic properties. The results are useful to assess the geothermal potential of the mines and for the future management of the infrastructure.

264

Bayesian Evidential Learning Combined With Experimental Design: The Case Of Wellhead Protection Area Prediction

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Decisions related to groundwater management such as sustainable extraction of drinking water or protection against contamination can have great socio-economic impacts. Ideally, a complete uncertainty analysis should be performed to foresee all possible outcomes and assess any risk.

Uncertainties arise from our limited understanding of the involved physical processes and the scarcity of measurement data, whether directly or indirectly related to the physical parameters of interest. In this contribution, we predict the wellhead protection area (WHPA, target), the shape and extent of which is influenced by the distribution of hydraulic conductivity (K), from a small number of tracing experiments (predictor). Our first objective is to make stochastic predictions of the WHPA within the Bayesian Evidential Learning (BEL) framework, which aims to find a direct relationship between predictor and target using machine learning. This relationship is learned from a small set of training models (200) sampled from the prior distribution of K, which are forward-simulated to obtain the associated 200 pairs of simulated predictors and targets. Newly collected field data can then be directly used to predict the posterior distribution of an unknown WHPA, avoiding the classical step of data inversion. The uncertainty range of any prediction is affected by the number and position of data sources (injection wells). Our second objective is to extend BEL to identify the optimal design of data sources that minimizes the prediction uncertainty of the WHPA. This can be done explicitly, without averaging or approximating because once trained, the BEL model allows the computation of the uncertainty corresponding to any new input data, using herein the Modified Hausdorff Distance (MHD) and the Structural Similarity (SSIM) index metrics.

We demonstrate that increasing the number of injection wells effectively reduces the uncertainty on the WHPA prediction, because (i) the breakthrough curves store information on a large area of the K field surrounding the pumping well, and (ii) some injection wells are more informative than others, as validated through a k-fold cross-validation procedure. Overall, the application of experimental design combined with BEL makes it possible to identify the data sources maximizing the information content of any measurement data within limited budget constraints, and at low computational costs.

265

Innovative Real-Time Sensing Of Flow Dynamics In Groundwater And Sediments

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Groundwater dynamics play a crucial role in the spreading of a soil and groundwater contamination. However, there is still a big gap in the understanding of the groundwater flow dynamics.

Heterogeneities and dynamics are often underestimated and therefore not taken into account. They are of crucial input for successful management and remediation measures.

This study contains the use of novel real-time iFLUX sensors to map the groundwater flow dynamics over time. The sensors provide real-time data on groundwater flow rate and flow direction. The sensor probes consist of multiple bidirectional flow sensors that are superimposed. The probes can be installed directly in the subsoil, riverbed or monitoring well. The measurement setup is unique as it can perform measurements every second, ideal to map rapid changing flow conditions. The measurement range is between 0,5 and 500 cm per day.

We will present the measurement principles and technical aspects of the sensor, together with two case studies.

The first case study was performed on behalf of the remediation of a canal riverbed. Due to industrial production of tar and carbon black in the past, the soil and groundwater next to the small canal 'De Lieve' in Ghent, Belgium, got contaminated with aliphatic and (poly)aromatic hydrocarbons. The groundwater contaminants migrate to the canal, impact the surface water quality and cause an ecological risk. The seepage flow and mass fluxes of contaminants into the surface water were measured with the novel iFLUX streambed sensors, installed directly in the river sediment. Based on these data, a remediation concept was designed: a hydraulic conductive reactive mat on the riverbed that makes use of the natural draining function of the waterbody, the adsorption capacity of a natural or secondary adsorbent and a future habitat for micro-organisms that biodegrade contaminants. The reactive mats were successfully installed and based on the mass flux calculations a lifespan of at least 10 years is expected for the adsorption material.

The second case study lies in the field of ecosystem restoration. The City Walls of Damme are a nature reserve of 140 hectares, located near walls of Damme. Specific measures were taken to achieve the rewetting of grasslands and swamp forests. A unique real-time hydrological measurement network supports the measures. The network consists of several iFLUX flow sensors to map infiltration, drainage & horizontal flow, combined with a network of groundwater and surface water level, salinity and meteo data.

266

Testing The Validity Of Different Synthetic Scenarios For Flow And Transport Simulation In Karst Systems Using A Real Case Study Application.

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Climate change and pollution are posing additional unprecedented threats to existing water resources, especially to water supply from karst aquifers in Mediterranean and semi-arid regions. A numerical model considering the most important key hydraulic parameters can forecast the impact of any given input on model quality and quantity output. In this work, we propose to model flow and transport using Comsol multiphysics in a synthetic model and to apply it to a simplified real case study (Jeita spring in Lebanon supplying water to 1.5 million inhabitants). The model geometry consists of a 5300 m long variably saturated horizontal conduit portrayed as 1) 2-D continuum and/or 2) a channel draining a porous equivalent matrix (400 m thick). Flow is simulated using the Richards Equation in both saturated and unsaturated media. Recharge is applied vertically as both diffuse and point source in a shaft linked to the conduit. Percentages of fast infiltration rates are obtained from the analysis of event time series recorded at the spring (electrical conductivity and discharge). Flow rates at the outlet are used for transient model calibration. Mean velocities, dispersivities, and phreatic conduit diameters obtained from tracer experiments under various flow periods are used for transport validation in the channel. The aim is to test the validity of a functional simplified flow model on a complex real case and to identify based on a sensitivity analysis the key parameters that allow an optimal calibration of such a model.

267

Towards {Rmodflow} 1.0.0: Bridging The Ubiquitous Open Source Groundwater Modelling Suite With The Lingua Franca Of Statistics And Its Modern (Spatial) Data Science Stack

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While the {RMODFLOW} R package started, about a decade ago, as a handful of R functions, tailored towards a very specific groundwater flow modelling exercise involving MODFLOW, it has grown tremendously over the years, enabling pre- and postprocessing of MODFLOW files, targeting full compatibility with the MODFLOW-2005 based codes.

About seven years ago, however, the {tidyverse} packages started revolutionizing the use of R for data science, and two years later, the modernization of the R spatial data science stack initiated as well, resulting in packages like {sf} and {stars}. Both these events where highly relevant for the R community at large, but certainly for anyone doing hydrogeology in R. It was decided to work towards compatibility with these modern data science and spatial data science stacks, to make

{RMODFLOW} a lot more powerful and user-friendly at the same time.

Today, working towards a release of {RMODFLOW} 1.0.0, we believe we cover most of the functionality within the MODFLOW-2005 based codes, and the package API, objects and workflows nicely integrate within the modern R ecosystem. We believe the latter is the main advantage of

{RMODFLOW} over similar projects in other programming languages, as the R solutions for reproducibility, literate computing, (interactive) 2D and 3D data visualization, calibration, talking to web APIs for querying public data, etc. are among the best in class, and all available from the same environment.

Furthermore, we also believe this to be highly relevant in a professional context, not just in academics or scientific research, for exactly the same reasons. Moreover, the automation possibilities that come with the use of code also enable e.g. automatic generation of reports of standardized lab/field tests, potentially resulting in huge efficiency gains, only requiring a one-time investment to adopt this type of workflow.

For illustrating all this, we will create a single text file, in which we download public data, import it into R, construct a MODFLOW model, calibrate it, visualize the results, and put all of that in our poster for this conference. By doing so, we want to highlight the power of {RMODFLOW}, R, and more in general, the use of code, for doing hydrogeology and numerical modelling in a transparent and reproducible way.

268

Three Decades Of Characteristic Groundwater Levels In Three Floodplains Of Belgian Lowland Catchments: A Modelling Approach

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In the framework of assessing the ecohydrological status of the floodplains of the Zwarte Beek, Mombeek and Dijle, Belgium, a series of groundwater flow models is developed, starting with 1D unsaturated zone models for all relevant land cover and soil type combinations, and a range of potential groundwater table depths. The 3D saturated zone models cover the (sub)catchment scale, which also allows propagation of the catchment-wide land use and groundwater extraction to the hydrological status of the floodplain. To enable realistic river-aquifer interactions in these valleys, the surface water network was included in these models in a dynamic way. For providing more detail in the floodplains, one-way coupling with refined child models is implemented as well.

The model results will be used to assess vegetation potential in the floodplains. Characteristic groundwater levels, seepage fluxes and groundwater ponding are important factors that drive vegetation occurrence. Therefore, we use time steps of two weeks in order to extract characteristic groundwater levels, typically summarizing yearly groundwater dynamics for a longer period.

Seepage fluxes can be calculated with the same time interval. To assess the impact of groundwater ponding, a specific numerical model layer is added on top of the land surface to simulate surface runoff in a realistic yet simplified way.

First we discuss data sources, model setup, calibration and validation. Then we present the model results for a period of three decades, and discuss the corresponding patterns in space and time and their ecohydrological relevance.

This research is conducted in the framework of the FWO-SBO Future Floodplains project (www.futurefloodplains.be).

269

Quantitative Microbial Risk Analysis For The Subsurface As A Pathogen Treatment Barrier

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Microbially safe water is essential for water utilities to prevent waterborne diseases and outbreaks. Although groundwater is the main source of drinking water in many areas of the world, there are relatively few studies on fate and transport of pathogens in the subsurface and its consequences for human health. In most cases, the random sampling of drinking water has been proven successful for more than a hundred years, especially for controlling the most important water-associated diseases. However, advances in microbiological analytics and epidemiology have shown that not all pathogens are reliably detected, especially viruses and permanent parasite forms. In this study, a quantitative microbial risk analysis (QMRA) is presented for a managed aquifer recharge (MAR) site following WHO guidelines and focusing on the subsurface as the hygienic barrier. The QMRA modelling applied a stochastic Monte Carlo simulation process performed using R software QMRA package.

The QMRA is conducted with site-specific temporal removal rates (Escherichia Coli) and literature values (Rotavirus and Cryptosporidium parvum). Various Log Reduction Values (LRV) for the subsurface passage are related to Hydraulic Residence Times (HRT) using the example of the Berlin- Spandau (Germany) MAR site.

This study shows that human health disease burden measured in Disability-Adjusted Life Years (DALY) (pppy - per person per year) and infection probability (pppy) is reduced proportionally to the temporal removal rates of the respective pathogen group. The calculation of the health burden of pathogens shows that 50 days of HRT is sufficient to meet the health-based targets in all pathogen groups, corresponding to mean LRV >10 log10 units in the subsurface. It is shown that LRV achieved by the subsurface are only comparable to high- performance technical treatment systems, e.g. reverse osmosis. Calculations represent worst-case values and alternative assumptions are to be examined and rapidly updated if new data become available.

270

Thermomineral Waters Of Spa "Gata" And Their Protection Based On Vulnerability

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Spa "Gata" is situated in the northwest part of Bosnia and Herzegovina in the Dinaric mountain range. Thermomineral waters that occur on this site are artesian and they come from a hydrogeological carbonate complex which consists of permeable and impermeable rocks – stratified limestones and dolomites.

The carbonate complex, from Upper Triassic over the Jurassic all to the Lower Cretaceous (more than 2500 m) was formed in unique sedimentation cycle with no hiatus so there were no conditions for paleokarstification in the interzones, which means that the porosity of the fissure-karst aquifer is limited to the current degree of karstification and its development only in the shallowest horizons, up to 100 m while with depth increase there is a significant change in the structure of the aquifer and the transition from fissure-karst to the dominant fissure aquifer.

Thermomineral waters are defined as SO4-HCO3-Cl-Ca-Na-Mg type of water, proven curative with constant temperatures of 36-39 oC and mineralization of 1,1-1,5 g/l. Presence of SO4 and Cl ions indicates the fact that water migrates from great depths. Based on the chemical analyses it was determined that with the increase of the water temperature, radioactivity as well as mineralization and concentration of SO4 is also increased. Radiological analyses of tritium point to the conclusion that there is a mixture of prenuclear and postnuclear waters, i.e. deep and shallow waters.

During the assessment of the vulnerability of thermomineral waters, all in order to protect them, an index method was formed. The main analyzed parameters were the results of geothermal research (determination of the discharge zones with the highest water temperature) and the hydrogeological conditions of the site with the slopes of the terrain. Hydrogeological structure of the terrain is characterized as the most sensitive factor of vulnerability of the "Gata" spa thermomineral waters. The position of the isotherms have confined the discharge zone and the mixing zone of thermomineral waters with cold groundwater so the vulnerability is limited to the discharge zone. Morphology of the terrain – the slope is marked as the largest limiting factor that affects the retention of pollutant particles in sensitive zones. Based on the all analyzed parameters and conducted multi-criteria analysis a vulnerability map was generated and protection conditions of thermomineral waters were determined.

Keywords: thermomineral waters; groundwater protection and vulnerability

271

Groundwater Accumulation In Northwest India And Pakistan In The 20Th Century Donald

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Northwest India and central Pakistan are vital for food production in South Asia and as a result have become global hotspots of groundwater exploitation. The region has a long history of major surface and, more recently, groundwater development for irrigation and is the largest contiguous tract of irrigated land in the world. The Gravity Recovery and Climate Experiment (GRACE) satellites, launched in 2002, provided early evidence of the scale of groundwater depletion in the region.

More recently, a number of studies have shown that groundwater depletion is more nuanced and regionally heterogenous, and is influenced by a combination of human and climatic factors, including changes in monsoon precipitation and recharge from the regions vast canal network. The areas of most concern for the long-term sustainability of the transboundary aquifer are within the states of Punjab and Haryana in India and Punjab Province in Pakistan. Here groundwater levels can be 20 – 50 m below ground level and are falling at rates of 0.5 – 1 m per year.

Recent groundwater depletion is set within a much longer history of groundwater level variation spanning the last 150 years. Using a unique long-term dataset, we investigated groundwater level change throughout the 20th century and the first decade of the 21st. The dataset contains time- series from 3827 observation wells and includes 110 years of groundwater level data from 1900 to 2010. Our aim was to: 1) examine changes in post-monsoon groundwater levels during the 20th century and; 2) unravel the influence of canal construction, tubewell development and precipitation on long-term groundwater storage in northwest India and central Pakistan.

We found that for the majority of the 20th century groundwater levels were rising and estimated net groundwater accumulation of c.350 km3 (estimated range: 150-450 km3). Large scale irrigation development via canal construction played a defining role in groundwater accumulation during the early twentieth century. The groundwater depletion that occurred in the first decade of the 21st century, and which we estimate at c.75 km3(estimated range: 25-100 km3), was driven by the superimposed effects of low rainfall and large-scale tubewell development. However, between 1970–2000, when large increases in tubewell irrigation began, groundwater levels stabilised as a result of higher than average rainfall. Our study clearly demonstrates that human activity in the early 20th century increased the total volume of groundwater available prior to the large-scale exploitation that began in the late 20th century.

272

Comparison Of Aquimod And Transfer Function-Noise Models With Impulse Response Functions For Groundwater Level Modeling In Latvia

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Groundwater forms an integral and stable part of water supply, that is a buffer against varying meteorological influences. Although affected by climate change, the actual extent of the impact is still unclear, and studies trying to quantify this impact are becoming increasingly more widespread. Time series of groundwater levels that are sufficiently long and accurately describe the dynamics of fluctuations are an indispensable resource for such objectives. In practice, however, the observation periods and frequencies strongly vary, and they can contain even years long gaps and various types of errors, either caused by technical defects or data processing, among other factors. To meet the criteria of certain studies, such as gapless 30 year long daily series for calculating the Standardized Groundwater index, it is necessary to model the series on a daily time step. To achieve the aim, multiple methods can be used, including lumped parameter models such as AquiMod and transfer function - noise (TFN) models using impulse response functions. TFN models rely on precipitation and evaporation data that is fit to groundwater level time series. AquiMod, in addition, uses algorithms of soil drainage, unsaturated zone flow and groundwater flow, therefore requiring a comparatively high number of parameters and extensive knowledge of the site characteristics. While this knowledge is not necessary when using TFN models, the fit can be impacted by missing significant characteristics that are not included in the model. Additionally, for both models the fit is site-specific. In this study, both models were fitted to the Latvian groundwater level time series and the outcomes from both models were compared.

The obtained results provide an insight of model fit differences, and the possible causes are discussed.

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273

Mathematical Model Of The Balkhash Lake Coastal Zone

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A mathematical model of the hydrogeological conditions of the coastal zone of the Balkhash lake was created to predict the area of groundwater pollution as a result of the tailing dump operation of the Balkhash concentration plant.

To predict the spread of pollution from the tailing dump and storage pond, the hydrodynamic and geomigration model was build. To solve the hydrodynamic issues was used the MODFLOW module and to solve the geomigration problem was used the MT3DMS module which are part of the GMS mathematical modeling system.

Based on the results of building the model it was determined that during the forecast period (10 years), the pollutants from the tailing dump will reach the Balkhash Lake if preventive measures are not taken to change the hydrogeological conditions. Drilling drainage wells down to bedrock between the existing drainage channel and the tailing dump (14 wells) can significantly slow the spread of pollution during the forecast period. The created mathematical model reflects the process of transport of pollutants by the flow of groundwater.

274

Mobilization Of Sedimentary Arsenic During Reclaimed Water Infiltration Into Aquifer

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Reclaimed water infiltration into aquifer has been suspected to trigger arsenic release from sediments into groundwater, which has been a new concern for managed aquifer recharge schemes. However, few studies have investigated the impact of reclaimed water on arsenic mobilization.

Anaerobic incubations were conducted to simulate reclaimed water infiltration through Beiyun River riverbed sediment (depth: 0-0.5m) containing 5.3 mg/kg bulk As, as well as Baoding Plain aquifer sediments (depth: 1.0-1.8 m and 13.6-16.1 m) containing 29.5 mg/kg and 6.8 mg/kg bulk As, respectively. Raw reclaimed water from Beiyun River was tested without and with carbon amendment (20 mg-C/L or 200 mg-C/L of equally-mixed yeast extraction and humic acid). Within 60 days, high concentration of As (33.5 μg/L) was released from the Beiyun River riverbed sediment with no carbon amendment, coinciding with increased Fe (2.4 mg/L) and Mn (0.8 mg/L) concentration. In contrast, Baoding Plain aquifer sediments showed much lower As release (<6.5 μg/L) with no or low carbon amendment. Only high carbon-amended reclaimed water triggered the release of 25-270 μg/L As (>90% as As (III)), with <0.1 mg/L Fe and 0.5-1.4 mg/L Mn. Meanwhile, HCl- leachable Fe(II)/Fe(II+III) of aquifer sediments increased from 13%-25% to 40%-60%. These results indicate that sustained reclaimed water infiltration during unmanaged aquifer recharge can trigger high As mobilization into groundwater by reductive dissolution of Mn(hydr)oxides, which appears to be the main As carrier phase in Baoding Plain aquifer sediment.

275

Recharge Estimation In The Semi-Arid Greater Banjul (Gambia) Superficial Continental Terminal Aquifer Using Different Methods

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The Greater Banjul Area (GBA) shallow groundwater is the most important water resource for its entire population and for socio-economic development (domestic, agriculture, and industrial). This coastal aquifer which is prone to salinization and anthropogenic pollution receives direct recharge from rainfall which in the context of semi arid climate is highly fluctuated. It constitutes therefore an important issue to investigate in order to ensure quantitatively and qualitatively water demand in the future. This situation has prompted the need to quantify the available groundwater resource for sustainable utilization. This present study aims to (1) compare groundwater recharge estimates from three water balance methods (Thornthwaite, Penman and Turc) and groundwater modelling (MODFLOW developed by USGS), and (2) identify the potential groundwater recharge zone by Multicriteria Decision Analysis. Water balance methods was used to calculate infiltration rate based on ETP estimation from 2 stations (Yundum and Banjul) between 1984-2016 period, a runoff coefficient of 20% and a soil water capacity estimated at 125mm. Computed values from the three different water budget methods reveal annual average recharge values of 86mm (10% of annual rainfall) in Banjul and 131 (14% of annual rainfall) in Yundum with Penman method and higher values (by 2 to 3 times) of 191 and 256 mm by Thornthwaite method, and 265 and 344mm by Turc method. Calibrated recharge values using groundwater flow model (with 54 water points, Root Mean Square error of 0,9m and R2 of 0.99) gives a recharge value of 122.5mm/year, representing a total recharge of the GBA aquifer system of 2,9.105 m3/year. In comparison, the groundwater modeling and the Thornthwaite water balance are expected to give a better approximation of recharge for the study area. Through this study, the groundwater potential infiltration zone mapping carried out using a combination of the 7 factors (geology, land-use/cover, slope, drainage density, soil texture, groundwater fluctuation and aquifer transmissivity) indicates that about 10.5 % of the total study area falls under 'poor' and 'moderate' zone and cover the estuarian portion of GBA, 40% of the total area falls under 'very good' zone which is a fair indication for potential drilling of boreholes and future artificial recharge planning.

276

Natural Background Levels In The Groundwater Bodies Of Brussels Capital Region

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Natural background levels are important for setting regulatory limits. The Water Framework Directive (WFD 2000/60/EC) and its daughter directive (2006/118/EC) aims at achieving good status of groundwater in the EU (initially by 2015). To achieve good chemical status, Member States must set threshold values for pollutants and indicators of pollution. Some substances may occur both naturally and/or as a result of human activities. For this reason, it is necessary to determine natural background levels (NBL).

In the Brussels-Capital Region, 5 groundwater bodies are defined. They have different lithology (sand, sand-clay, chalk and Paleozoic basement), some are unconfined and others are confined. Defining the NBL of these groundwater bodies is a challenge because the surface area of the Brussels-Capital Region is highly urbanized, and it is also quite small, so there are few monitoring sites.

The NBLs were defined following the European methodologies (Bridge project, Baseline project and guidance note). Hydrochemical data used correspond to the sampling sites reported in the monitoring programmes, linked to the Water Framework Directive, and supplementary monitoring sites of Brussels Environment for the period 2006-2017. Additional data from neighbouring groundwater bodies in the Walloon and Flemish Regions have been added to complete the dataset and to place the studied groundwater bodies in a larger regional hydrogeological and hydrochemical context. Data quality was examined through the calculation of the ionic balance, the analysis of limits of quantification and the analysis of the presence of pollutants to exclude some monitoring stations from the data set. To understand the processes influencing the geochemical composition of groundwater in each groundwater body, different tools were used (Piper diagram, spatial and temporal changes in concentrations, Na/Cl ratio and saturation indices of calcite, halite and gypsum to understand the origin of salinity, study of atypical values, correlation matrix, multivariate analysis). On the basis of all these analyses, several sampling stations were selected for the calculation of the NBLs of each groundwater body as the Percentile 90 of the selected samples. The NBLs could then be used by water authorities to set/adapt threshold values.

277

Effect Of Model Structural Error On Estimation Of Parameters And Uncertainty From Aquifer Tests Using Open Source Software

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Aquifer tests are commonly analyzed using a somewhat simplistic representation of the aquifer: often a well in a single confined or semi-confined aquifer. Overlying or underlying aquifers are often neglected. Boundary conditions such as nearby surface water or rock outcrops are rarely included. Although such a simple setting is often reasonable, there are just as many cases where this over- simplification is a form of model structural error that effects the estimated parameters and underestimates the uncertainty of the estimated parameters. In this presentation, the open-source software package TTim is used for aquifer test analysis (Bakker, 2013). TTim is a Python package for transient analytic element modeling of multi-aquifer flow (Bakker, 2021). A number of synthethic and real aquifer tests are analyzed to demonstrate the error in the estimated parameters when the model contains structural error. Analysis of the uncertainty of the estimated parameters shows that the confidence intervals are generally estimated as too narrow when the model contains structural error.

As a first example, consider the (synthetic) data from a 10-day pumping test in a two-aquifer system. The head is measured in an observation well located 10 m from the pumping well. The dots in the figure below were generated by a two-aquifer model and a small error was added. The true values of the parameters of the aquifers and leaky layer are known. The data was first analyzed with a simple Theis well to estimate the hydraulic conductivity and specific storage of the aquifer. Next, the data was analyzed with a Hantush well to estimate the hydraulic conductivity and specific storage of the aquifer, and the resistance of the leaky layer. This gives a better fit. The true parameters and estimated parameters are listed in the table below. The Hantush model performs better, because a Hantush well is a better approximation of a well in a two-aquifer system than a Theis well.

The estimated aquifer parameters for the Hantush model are quite reasonable, but the estimated resistance of the leaky layer is still a factor of almost 2 off, because the model contains structural error.

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278

Protecting Drinking Water Resources From N-Nitrosomorpholine Dual Migration Through The Fécamp – Lillebonne Chalk Aquifer System In Normandy

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Chalk aquifer systems in Normandy show characteristics which include darcian, fractured and karst subsurface environment whenever groundwater flow or contaminant transport are being addressed. This triple porosity leads to complex flowfields, which may in turn bring about peculiar contaminants transport.

These complex flowfields are not easely detected through classical hydrogeological approaches such as 2D piezometric maps based on available unevenly distributed wells, with variable open sections located at different depths and groundwater models focusing on darcian flow. On the contrary, these can sometimes lead to biased groundwater flow interpretation, and subsequently, when protecting drinking water wells against pollution plumes is at stake, to partially ineffient solutions.

The Bolbec area laying in this complex chalk setting suffered in 2012 from a severe groundwater and surface water pollution event. Indeed, an emerging pollutant - N-nitrosomopholine – stemming from a single pollution source in the upper Bolbec valley was found migrating in two opposite directions. Indeed, this pollutant was both found (1) south of the pollution source, downstream according to available groundwater level maps, in the Commerce valley in wellfields used for drinking water purposes and industrial processes, but also (2) way up north, across a « groundwater divide », in a karst channel system at Yport, pumped to provide drinking water for the « Le Havre » urban area, in what was previously believed to be a completely different watershed. This led to a several weeks long rupture or partial rupture the drinking water services, until costly emergency solutions were set in place.

To restore all the polluted water resources, a multi-criteria approach based on innovative combinations of targeted field investigations was implemented in the framework of large scale study, carried out along a major fault system passing through the Bolbec area and extending from the Seine river to the English chanel. This paper intends to present and discuss the general innovative methodology used to (1) understand and set up the geological and structural framework and characteristics of the aquifer system, (2) assess the evolving interactions between surface water, 3D groundwater matrix flow and karst flow, (3) determine precise 3D pollutant pathways axes and

(4) establish strategic nodal points on which to act upon to design an optimal technico-economical solution aiming at rehabilitating the water resources in the Commerce Valley and in the Yport karst system, in order to secure clean groundwater production for drinking water purpose in the area.

280

Stable Isotope Techniques For The Evaluation Of Water Sources For Domestic Supply In Stellenbosch, South Africa

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During 2017-2018, the City of Cape Town, South Africa faced an unprecedented drought crisis with the six main water storages supplying Cape Town falling to a combined capacity of just under 20%. With the threat of severe water shortages looming, various additional water sources were examined to supplement the municipal water supply network. These were focussed on groundwater, desalination and treated effluent. However, private citizens and businesses also made plans to avoid shortages, resulting in numerous uncontrolled water sources competing with the municipal supply network.

Throughout the crisis, groundwater was considered the most important alternative urban water supply source but also the most vulnerable to contamination through accidental and uncontrolled return flows from the municipal network, private residences and agricultural industries. This project aims to constrain the water supply network in the Stellenbosch municipality and monitor the augmentation of groundwater into the network using stable isotopes. Long term monitoring points have been established at 35 tap water sites, 20 private wells as well as at the supply reservoirs that feed the municipal network. Preliminary data show's distinct isotopic signals associated with each supply reservoir as well as in the local groundwater. The data also shows significant return flow into the alluvial aquifer system during warmer months when private stakeholder's water consumption is at its highest. Groundwater is expected to supplement this urban supply network in the latter part of 2021 and will likely disrupt the current distribution of stable isotopes in the network, providing further insight into the potential return flow into the local groundwater system.

281

Machine Learning Algorithms And Sintacs Method For Groundwater Pollution Risk Assessment, Case Of Saiss Basin, Morocco.

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Groundwater pollution is one of the most dramatic natural disasters worldwide, with its socio- economic and environmental consequences. The aim of this study is to evaluate the groundwater vulnerability in the Saiss basin, located in the central part of Morocco based on the combination of SINTACS method and two Machine learning algorithms, namely, Random Forest (RF), and Support Vector Machine (SVM). To do so, a number of 61 samples of nitrates concentrations were used to assess the groundwater contamination risk in this aquifer, after we randomly divided our data into 70% into a training dataset and 30% as validation dataset. The result of SINTACS vulnerability method showed that 0.64 % of the aquifer had very low vulnerability, 21.98 % had low vulnerability potential and 64.96 % had a medium vulnerability, 12.41% had a high vulnerability potential, and only 0.01% had very high vulnerability in the aquifer. whereas groundwater contamination risk results according to RF and SVM models showed that 9.82%, 26.2% of the area had very low nitrate pollution, 14.73%,18.8% had low pollution potential, 17.3%, 13.63% had medium classes of Nitrates pollution, 19.57%, 13.36% had high pollution while 38.58%,28% had very high nitrates pollution, respectively. The Receiver Operating Characteristic (ROC) curves were used to evaluate the performance and efficacity of the modeling, the AUC value for original SINTACS Method was 0.52. However, in comparison to SINTACS method, both RF and SVM had better performance with AUC value respectively 0.76 and 0.65 which indicate that the use of ML algorithms improves result performance. Therefore, the outcomes of this research can be useful as a guide for decision-makers in groundwater pollution to mitigate strategies in this study area.

Keywords: Saiss basin, SINTACS method, risk assessment, groundwater pollution, Machine Learning algorithms.

282

Investigation Of Subsurface Heterogeneity And Its Relevance For Successful Managed Aquifer Recharge (Mar) Operation

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Managed aquifer recharge (MAR) represents a potential water resource management approach to mitigate the negative consequences of overuse and climate change on groundwater quantity and quality.

It is the purposeful enhancement of groundwater recharge under controlled conditions to maintain a balance between the limited water availability and increasing demand. In general, MAR applications comprise of large-scale infrastructure such as infiltration trenches, recharge basins, well or borehole recharge. Optimal performance of MAR facilities requires high infiltration rates.

Numerical simulations have been performed to predict the MAR performance where the conceptualization of the model is often simplified by considering homogeneous subsurface conditions which leads to uncertainties in the model output. Reliable prediction of infiltration rate for MAR sites is in fact complicated by the subsurface heterogeneity which may result in under- performance of MAR schemes. Therefore, heterogeneity in hydrogeological properties should be identified prior to the construction of a full-scale MAR system.

The primary goal of the study is to exemplarily investigate the spatial variation in hydraulic properties of the subsurface and its influence on the infiltration rates at a MAR site situated near Schiavon, Italy.

The detailed subsurface investigation will contribute to assess the spatial variation in expected infiltration rates over the MAR site for improving the cost-benefit relation by better planning and design.

283

Estimating Daily Groundwater Level Time-Series At Unmonitored Sites Based On Comparative Regional Analysis

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Regular and high-resolution groundwater level time-series are fundamental for effective management of groundwater resources. However, groundwater level observations are generally scarce in space in time across heterogenous hydrogeological settings. A new method is presented to efficiently estimate daily groundwater level time series at unmonitored sites by linking groundwater dynamics to local hydrogeological system controls.

The presented approach is based on the concept of comparative regional analysis, an approach widely used in surface water hydrology (compare Predictions in ungauged basins, PUB). Cumulative frequency distributions (CDF) of groundwater levels are estimated at unmonitored locations based on sites with daily time series available, using physiographic and climatic site characteristics, such as aquifer thickness or average annual precipitation.

The CDF is then used to construct a groundwater hydrograph using time series from distance-weighted neighboring (gauged) locations. Evaluation is carried out through leave-one out cross-validation and hold-out data. The methods were applied to groundwater level time series at 320 sites in Southern Germany, mainly located in alluvial aquifers. Ten-year daily measurements were selected from confined and unconfined aquifers situated in diverse landscapes ranging from mountain valleys to more extensive lowlands aquifers. Three estimation methods were compared: regional averaging of neighboring wells (NB), multiple linear regression (MLR), and the decision tree learner extreme gradient boosting (XGB).

While all three methods show similar results for median performance (median coefficient of determination R2=0.7-0.73), XGB clearly outperforms NB and MLR regarding matching the groundwater dynamics at unmonitored sites (seen by significantly higher Nash Sutcliffe Efficiency and lower root mean squared error). This method makes possible both imputing patchy groundwater level time series as well as estimating time series at unmonitored sites on the regional scale.

284

Groundwater Recharge Zone Mapping Using Gis-Based Multi-Criteria Evaluation And Analytical Hierarchy Process: A Case Study Of Trarza Aquifer (Mauritania)

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Artificial recharge plays a very important role in the sustainable management of groundwater resources. The present study uses GIS, remote sensing and the multi-criteria evaluation (MCE) technique to explore potential areas for artificial groundwater recharge in the Trarza aquifer located in southwest Mauritania. Geology, groundwater depth, land use and cover, slopes, aquifer transmissivity, drainage density and soil texture influence groundwater recharge directly or indirectly. These thematic layers are extracted from geological maps, Landsat ETM+ images and other conventional data sources. The Analytical Hierarchy Process (AHP) is used as a multi-criteria evaluation (MCE) technique to normalise the weights of the different criteria. Each class of the different thematic layers was given an appropriate score and normalised. Furthermore, the normalised weighted layers are mathematically overlaid for the preparation of the groundwater recharge potential map, using weighted linear combination (WLC) in a GIS environment. The poor, moderate, good, very good and excellent potentialities represent 2.58%, 37.20%, 44.05%, 14.05% and 2.10% respectively. The low and flat plains in the south, west and northwest of the study area are favourable for groundwater recharge, while the central and northeastern areas are less suitable for recharge. The result was validated with tritium (3H) data, showing that the approach is appropriate for this region.

291

A New Methodological Approach For The Protection Of Peri-Urban Groundwater Catchments

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In the Walloon region of Belgium, as in many other countries, approximately 80% of drinking water supply is provided by groundwater catchments. Many of these catchments are located in rural areas and often threatened or impacted by pollutants of agricultural origin (nitrate, pesticides). However, a significant proportion of groundwater catchments are located in peri-urban environments surrounded by residential, industrial, economical areas where many different types of sources of point and diffuse pollution coexist: accidental spills, continuous, hidden leaks in drainage networks, old dumps, treated and untreated wastewater or watercourses.

In this context, the CASPER project funded by SPGE has focused on the development of an integrated methodology for the protection and management of groundwater quality in such peri- urban catchments. The aim is to distinguish between various possible sources of contamination from possible mixtures between different types of water and pollution sources.

The methodology is based on few basis concepts. First, data and expertise are collected to be applied specifically to the groundwater catchment area, corresponding to the land surface perimeter in which abstracted groundwater is recharged, either by direct or indirect infiltration of surface water. Secondly, a groundwater monitoring network is established, and groundwater sampling organized by focusing on a combination of physicochemical parameters, traditional hydrochemicals and a set of more advanced hydrochemical indicators of different types of pollution sources. In particular, stable isotopes of NO3- and boron are used to distinguish between sources linked to urban effluents and agricultural fertilisers. The occurrence of specific molecules such as pharmaceutical and lifestyle products is used as effective tracer of anthropogenic contamination. Microbiological analyses are also included to identify microbial populations associated with specific sources or certain biochemical reactions occurring in soil and groundwater. This detailed dataset is finally interpreted by multivariate analyses and clustering. The third step of the approach consists in evaluating the contribution of the different pollution sources identified in the catchment area based on in situ measurement and modelling of pollutant mass fluxes and discharge. This evaluation allows to prioritize remediation measures on the most intense sources of pollution.

This newly developed approach has been tested using the groundwater catchment site of Boussu (province of Hainaut, western Belgium) as a first pilot case study. It is a peri-urban area impacted by various sources of pollutants coming from old dumps and slag heaps surrounding the site, railway wastes, discharges from small and medium-sized enterprises, hospitals, housing and possibly agriculture.

292

New Geological, Hydrogeological And Geothermal Insights Into The Potential Of The Cambrian Basement For Geothermal Energy In Brussels, Belgium

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In Belgium, the shallow geothermal energy (SGE) use for heating, cooling and seasonal storage has the potential to become a key instrument participating into the national effort for reducing significantly the primary energy consumption and lowering emissions by enhancing the decarbonisation of the building sector. In Brussels, the closed-loop systems were commonly adopted the last ten years, and more recently the open-systems seems to encounter a larger interest.

In the Brussels Region and the surrounding areas, soft sedimentary rocks deposited during the Tertiary overlie hard and massive rocks belonging to the Cambrian (Paleozoic) series of the Brabant Massif. The Cambrian bedrock is: i) highly heterogeneous (i.e. interstratified quartzite, sandstone, and shale layers), ii) is strongly folded and faulted, and iii) the intense weathering and deformation episodes have affected the upper part of the basement with extremely high fracturation zones and weathering modifications of the rocks. Most of the existing shallow geothermal systems were stopped at the contact between Tertiary/Mesozoic soft rocks and the Cambrian hard rocks due to the lack of geological and hydrogeological knowledge on the bedrock. Nevertheless, some recent explorations have shown the probable high potential of the Cambrian layers (high thermal conductivity, large groundwater flow) suggesting an interesting groundwater reservoir.

An important scientific exploration phase started in 2016 in the scope of the Brugeo project (EFRO) and is continued since 2020 within the GeoCamb project (funded by the Belgian Science Policy) to acquire new data decreasing thereby the hydrogeological and geological uncertainty of the bedrock.

Several in-situ parameters are measured by e.g. new piezometers implementation and monitoring, pumping tests, cores sampling, geophysical logging, and enhanced thermal response tests (eTRT). In parallel, GeoCamb also addresses the economic and environmental impacts of geothermal installations by evaluating open system interferences e.g., at the Tour & Taxis site in Brussels with 3 nearby open-loop systems in operation, monitoring existing installations, evaluating environmental risks, and analyzing efficiency and exploitation costs of existing Cambrian and non-Cambrian geothermal installations.

In this contribution, we are going to present how application-oriented hydrogeological and geothermal research programs can promote a sustainable use of the geothermal energy resources and enhance the development and implementation of shallow geothermal energy, as the research results have created a clear leverage effect for private companies (6 new projects in 2020 were under investigation in the Cambrian aquifer in Brussels).

295

Multi-Disciplinary Approaches In Scarce Data Area: The Best Way To Produce A Robust Preliminary Conceptual Model

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While basaltic volcanic aquifers are well described in the literature (Hawaii, La Réunion, Galapagos...), andesitic groundwater systems are less studied, even if they are often much more complex. Nevertheless, these aquifers are widespread in subduction areas, and supply large population worldwide. In Indonesia, the growing needs for water induce an increase of the pressure on such aquifers that must be better known to favour their sustainable management. With that objective, building-up a hydrogeological conceptual model is a prerequisite to any action. We thus present in this research how to build a Preliminary Conceptual Model (PCM) of such a complex aquifer system with simple and quick to acquire data. We rely on the case of the Arjuno- Welirang (Java Island), and compare it with a well-known neighbour hydrogeological system, the Bromo-Tengger. While the Arjuno-Welirang volcanic complex is well studied for its geothermal potential, and its possible links with the Lusi mud volcano, its local aquifers are not known even though, groundwater uses are developing in order to satisfy industrial, agricultural and domestic water needs. The building-up of this PCM was grounded on (i) on few geological and geomorphological data (DEM, existing geological maps, "Google Earth and Google Maps Pictures field geology"), (ii) the location and measurement of the discharge of the main springs of the area, as well as identification of the type of existing wells (dug wells, boreholes, self-flowing artesian wells), (iii) data mining in the data bases from the local authorities that issue groundwater exploitation licenses, and (iv) water hydrochemistry data available on site. All these data, and notably springs' location and discharges and type of wells were compared with the neighbour well know Bromo-Tengger system.

The results of this research:

(i) Highlight the diversity of andesitic aquifers structure and functioning, resulting of this kind of volcanism. The two neighbour volcanic complexes exhibit very different types of hydrogeological structures;

(ii) Enable to set-up a PCM of the Arjuno Welirang, with (a) high elevation small perched aquifers, (b) medium elevation complex superimposed medium size unconfined and confined aquifers, with medium discharge springs (< 100 L/s), and the absence of a generalized self-flowing volcano-sedimentary aquifer at the base of the volcano. Such PCM is needed to define further appropriate detailed hydrogeological investigations, required to set-up sustainable aquifer exploitation, management and preservation rules.

(iii) Show that rather simple investigations can help building a robust preliminary conceptual model of complex volcanic settings.

296

The Impact Of Topography, Geology And Local Hydrogeology On The Efficiency Of Managed Aquifer Recharge – A Case Study From The Danube-Tisza Interfluve, Hungary

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The Danube-Tisza Interfluve is one of the largest areas covered by wind-blown sand in Hungary characterized by sand plains, dunes and deflationary depressions. Two major morphologic region types are the flat-bottomed valleys of the Danube and Tisza rivers and a central elevated ridge region. The ridge area is poor in surface waters. Previously many lakes were present here, but most of them dried out due to climate change, water abstraction, forestation and canalization related water level reduction. In the past, several replenishment plans have been made, involving large, cross-regional technical investments, but have not been implemented due to the lack of adequate financial resources and environmental concerns. The main aim of this research was to compare the possibilities of different Managed Aquifer Recharge methods, in the context of the local topographical, geological and hydrogeological conditions of the Danube-Tisza Interfluve, studying a characteristic area, to increase the resilience of water reserves of this ecologically important area.

Firstly, a MAR surface infiltration suitability map was constructed, that shows areas with favourable hydraulic conductivity in the upper 10 m and characterized by deeper water levels, which means that there is a reservoir in the unsaturated zone to store infiltrated water. Based on suitability mapping, a local research area was selected which showed promising potential. Geophysical measurements (ERT – Electrical Resistivity Tomography, RMT – Radio-magnetotellurics) were performed, existing shallow wells were surveyed and additional boreholes were drilled to characterize shallow hydrogeological conditions. Finally, a saturated-unsaturated flow model and different scenario models were built up in 2D, in order to analyse different Managed Aquifer Recharge possibilities (infiltration basin, shallow and deeper wells) and their effectivity considering the topographical conditions and geological-hydrogeological built-up.

The results of the different model scenarios can provide a good basis for planning further water replenishment plans and selecting appropriate MAR methods for the area. This research is part of a project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 810980.

297

Use Of Multivariate Geostatistics To Investigate Time-Dependent Saltwater Intrusion And Perform Groundwater Quality Zonation In A Nile Delta Area (Northern Egypt)

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Freshwater salinization is a global problem that impacts water resources as well as ecosystems worldwide and is increasingly worsening in recent years. Possible causes multiple, whereas one of the most important is the saltwater intrusion, which is fostered by overexploitation of groundwater resources, in urbanized and cultivated coastal areas. This is the case of deltaic regions of large river systems, where porous multi-layer aquifers are present.

Regular shapes and considerable amounts of water resources make them areas suitable for human activities. This leads to an increasing water demand, which provokes groundwater overexploitation and consequently freshwater salinization. Since deltaic aquifers are generally characterized by clear surface water/groundwater relationships, anthropogenic modification of surface water bodies (e.g., canals, and lakes) for irrigation and fish livestock purposes can contribute to salinization, by moving the freshwater/saltwater interface and altering the aquifer recharge.

The eastern portion of the Nile Delta hosts a multi-layer aquifer, whose recharge inflow is represented by the Damietta branch and Ismailia canal. At NE, this area is bounded by Manzala Lake and Suez Canal, both saline water bodies. In the last decades, this area has experienced increasing groundwater exploitation for irrigation and drinking purposes, canal and lake modifications, and progressive groundwater salinization.

This work aims at assessing the groundwater quality by partitioning the aquifer into different zones. Data refer to three surveys of chemical analyses on water samples, collected in the 1996-2018 period. The methodology is based on multivariate geostatistics using Multi-Collocated Co-Kriging (MCCK) and Multi-Collocated Factorial Kriging (MCFK) and considering distances from the different surface water bodies as exhaustive auxiliary covariates. The approach consists of four steps: 1) Gaussian Anamorphosis to transform raw variables into Gaussian transformed variables; 2) fitting a Linear Model of Co-regionalization on both experimental direct and cross-variograms; 3) estimation of the spatial distribution of the studied variables with MCCK; 4) extraction and interpolation of the sets of scale-dependent regionalized factors with MCFK.

Maps of the individual variables showed a clear decreasing trend in the N-W direction, due to a manifest process of saltwater intrusion. The saline front advanced southwards, over the years. Three zones were defined: the northern zone was characterized by the highest salinity values, the middle zone by the lowest values, and the southern zone by intermediate values as well as more pronounced variability. This partitioning does not follow a linear trend and is indicative of the complexity of processes and interactions occurring in groundwater.

298

The Origin Of Anomalous Electrical Conductivity Horizons And Brackish Bedrock Groundwater

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Two clear anomalous electrical conductivity horizons were identified in several exploration boreholes while investigating the groundwater water balances for a Lithium mine project in Finland. These anomalies could not be explained thoroughly with geological variations, and further studies on the hydrogeochemical characteristics and isotopic composition were conducted. The hypothesis was, that the abrupt rise in electrical conductivity shows a limit of waters of different ages, the lower being old brackish groundwater which has a very slow hydrological cycle compared to the upper groundwater zone. Brackish (total dissolved solids, TDS 1–10 g/l) to saline (TDS 10–100 g/l) groundwater can be found almost everywhere in Fennoscandian Shield, but usually deeper in bedrock. The study site rose from the Baltic Sea about 5000 to 7000 years ago and is located around the highest Litorina shoreline where most of the saline wells have been observed.

Stable isotopes (δ^2H and $\delta^{18}O$), dissolved trace element geochemistry and physico-chemical characters of water were used to constrain the origin of anomalous electrical conductivity horizons, and potential hydraulic connections through bedrock fracture in selected boreholes. As expected, according to the first geochemical results, salinity originates most likely from the Litorina stage of Baltic Sea. Although clearly brackish, the deep groundwater at the site is less saline and the H and O isotopic composition differs from the ancient brines found elsewhere in Fennoscandian shield.

Therefore, the evolution of the groundwater is more likely linked to climatic and shoreline changes during and after the last glaciation than old brine, and further isotope studies (Sr, Li, tritium/He3) will be carried out in 2021 to assess the origin and possibly the age of the groundwater at the site.

299

The Useful Role Of Airborne Electromagnetics Data Reprocessing For Hydrogeological Purposes: A Case Study In Cobar Region, New South Wales, Australia

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Large legacy Airborne Electromagnetics (AEM) datasets are currently available and they can represent a valid tool for hydrogeologists, by providing a valid tool to achieve a detailed hydrogeological model (through resistivity values) over wide areas. But to achieve this task, it is mandatory to run an advanced reprocessing, as they were mainly used for mining projects.

We present an example drawn from the Cobar region (New South Wales, Australia), where serious water issues occur, so that water is currently piped from ~200km away and so even brackish water that could be desalinated would potentially be of interest. The main aquifers are formed by the Alluvial (Upper and Lower Lachlan) and the Lachlan Fold Belt (fractured rocks). The former can be represented by thick cover material deposited in palaeochannel systems, reaching a thickness up to 80 m, which could hold fresh water, but with a poor yield. Larger amounts could be captured into the fractured rock (mainly sandstones) systems, although the water would be saline. Cenozoic sedimentary units cover most of the area, so that bedrock outcrops are very limited (Figure 1). This circumstance is very common in most regions, especially in Australia or Africa, where thick regolith can mask just the subsurface features that can be relevant for hydrogeological purposes.

The AEM data were collected by NRG (Xcite system). Our advanced processing/modelling allowed to reconstruct the resistivity distribution down to of 300 m, and more. To assess the reliability of our modelling, we compared the results with the stratigraphic logs drawn from the MinView dataset (https://minview.geoscience.nsw.gov.au), specifically the groundwater boreholes.

Figure 2 shows the modelling obtained for a segment of L10170. The stratigraphic logs of the groundwater borehole were simplified, so that to enhance the occurrence of the Bedrock aquifers (dark blue). All the other lithologies indicate aquitards or aquicludes. It must be noticed the good resolution of the Sandstone aquifer in the Western side of the profile: this aquifer captured by the wells has a local lower resistivity (40-60 ohm-m), likely due to the fracturing that contributes to increase the permeability.

Our advanced processing led to the better resolution of the cover thickness, a crucial point to capture alluvial aquifers: an example is shown by a segment of L10220 (Figure 3), where the Quaternary deposit are characterised by lower resistivity (< 20 ohm-m) than the bedrock (> 100 ohm-m).

300

Determining Heat Losses From Buildings To Better Predict And Quantify Formation Of Groundwater Urban Heat Islands

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Groundwater urban heat islands which refer to elevated groundwater temperatures in densely populated areas in comparison to the rural surroundings have been investigated over decades. Therefore, groundwater temperature data are collected to quantify heat island effects. Initially, the impact of elevated temperatures upon groundwater quality was critically investigated. In recent years, the potential of groundwater urban heat islands as heat source, e.g. to be used as geothermal source, became subject of scientific interest. However, only little information is available about the formation of heat islands over time.

To overcome this lack of knowledge, this study analyses the heat losses from buildings and their contribution to the formation of groundwater urban heat islands over time for a refurbished quarter with a building stock of 150 houses and intensive use of shallow geothermal energy in Cologne, Germany. To simulate heat losses from buildings, different scenario analyses with houses of varying insulation standard were performed using a building physics software. Obtained results were then coupled with a groundwater flow model to evaluate the impact on groundwater temperatures over time. This approach does not only allow quantification of the additional thermal potential when using shallow geothermal energy on quarter scale. It rather contributes to untangle the different impacts on groundwater temperature in urban areas and allows a more accurate determination of the actual impacts of the intensive use of shallow geothermal energy in newly built quarters.

301

Assessment Of Climate Change Impact On A Partially-Confined Sand Aquifer Through A Specific Modelling Routine Development

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A regular drop in the water table has been observed for about 30 years in the partially-confined part of the Cenomanian sand aquifer within the Parisian Basin. To develop management rules aimed at regaining sustainable exploitation of the aquifer, a large multi-layered model, over a 30 000 km2 area, was first developed and calibrated over the period 1994-2008 using Feflow.

This model enabled the promulgation of enforcing management rules which succeeded in stabilizing groundwater levels, in the 2010s, for most sensitive areas.

The water authorities then decided to update and improve the model with the addition of more recent data (2009-2018) with the aim of possibly adjusting the management rules and taking into account the impact of climate change on groundwater resources.

The possible impact of climate change in the region will be a decrease in meteoric recharge. The main impacts on the Cenomanian sands will then be as follows: (1) reduced recharge in outcrop areas, (2) decrease in the water table of the overlying Seno-Turonian aquifer due to the combined effect of reduced recharge and increased irrigation pumping.

To assess the influence of the Seno-Turonian water table change on the Cenomanian sands, it was decided to represent the Seno-Turonian aquifer by a prescribed head boundary condition. The impact of the reduction in recharge on the Seno-Turonian water table was then evaluated by correlation between the recharge and the piezometric observations and by extrapolating this relationship to the modeled domain using the recharge values impacted by climate change.

The decrease in the Seno-Turonian water table due to the evolution of pumping was evaluated by Theis equation.

The integration of these boundary condition changes in a transient model was performed through the development of a specific routine using the Python interface for Feflow. The simulations made it possible to show the areas most sensitive to climate change.

302

Well Clogging Detection Using Real-Time Ah-Dts Groundwater Flow Monitoring

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For water utility companies, well clogging is an ongoing issue in the extraction of groundwater from unconsolidated aquifers. To address this issue, these companies invest in innovative well designs (e.g. depth, screen and backfill of the wells) and regular maintenance options. The ability to monitor groundwater flow is key to the successful application of these designs.

In this study, we developed a continuous groundwater flow monitoring system using Active – Heating - Distributed Temperature Sensing (AH-DTS). DTS enables temperature monitoring using fibre optic cables with high temporal and spatial resolution. In AH-DTS, the cooling effect of the groundwater flow on a heated fibre-optic cable is used to estimate the groundwater flow velocity. The relation between groundwater flow and the measured thermal response was determined by laboratory measurements and modelling, which also informed the design of an optimum AH-DTS cable for this purpose. This abstract presents the results of a field experiment where this configuration was applied to a groundwater extraction site in the Northern Netherlands.

At the extraction site, multiple wells extract groundwater from a depth of 40 to 80m below surface level to produce drinking water. Clogging of the well screens by mechanical clogging, whereby small particles block the flow through the backfill, is an issue here. To obtain insight into this process, two sets of AH-DTS fibre-optic cables were attached directly in the backfill of two groundwater wells to help determine the groundwater flow around the well screen. At a distance of 5 meters, a third AH-DTS cable was installed to gain understanding of the groundwater flow further away from the wells.

Groundwater flow was estimated using the AH-DTS method when the well was turned off and when the well was extracting at a rate of 100 m3/hour. First analyses of the data show that distinct sections of the well screen can be identified where significantly higher groundwater flow rates occur. This indicates differences in well design and in the hydraulic conductivity of the aquifer possibly in combination with changes in backfill (figure 1). When these measurements are continued in time, changes in the observed groundwater flow rate patterns are expected to indicate where well clogging occurs. This can be used to optimize well designs and maintenance.

303

Impact Of Covid-19 Lockdown On Groundwater Quantity And Quality In Southern Italy (Campania)

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In this research, we observed the impact of COVID-19 lockdown on groundwater levels and ion concentrations in the groundwater quality and quantity monitoring network of the Environmental Protection Agency of the Campania region in Italy (ARPAC). The period observed was the winter- spring 2020, in consideration of the fact that in Italy the total lockdown began on 9 March and finished on 18 May. For some wells with continuous groundwater levels monitoring in alluvial aquifers, we noted a slight but clear increase in the usual 'shape' of the annual groundwater table fluctuation. To avoid the coupled effect of meteorological variability we also studied the distribution of precipitation and temperature in the same period. The statistical comparison between hydrogeological and meteorological time series data for 2019 allows the establishment of the residence time and the recharge law. This law was used to evaluate the significant shifts in 2020.

The chemical monitoring network of ARPAC consists of 320 sampling points, sampled and analyzed each semester or, where needed, each trimester, for dissolved components (Mg, Ca, K, Na, Cl, HCO3, SO4, NO3, NH4, F, Li, Br, metals) and physical parameters (EC, T), in order to perform the annual chemical status classification. The available groundwater chemical analyses were considered before, during and after the lockdown period.

Previous studies especially focused on a large coastal plains of Campania region, demonstrate that before the lockdown some values exceeded the WHO limits for drinking uses. Peculiarly, groundwater is reach of: NO3, due to anthropogenic causes, and, for natural causes, As and F, deriving mainly from water–rock interaction, and Fe and Mn, related to reducing conditions of the aquifers.

The observed variations in ion contents within lockdown period highlighted the correlation with land use. Moreover, it should be pointed out the cumulative effect of the decreased land-use, e.g., the decreasing use of fertilizers, and the effect of dilution due to the above mentioned upraise of the water table.

304

Spatio-Temporal Variation Of Groundwater Recharge And Comparison Of The Different Estimation Techniques On A Tropical Basin Comprising Volcanic Aquifers, Northwestern Ethiopia

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A physically distributed water balance model called WetSpass is applied to estimate the recharge for a semi-humid Lake Tana basin in northwest Ethiopia. Lake Tana basin, one of the major sub-basins of Upper Blue Nile River basin, covers 15,077 km2 of which 3,156 km2 is the lake water body. The basin is regarded as one of the growth corridors of the country, and where huge waterworks infrastructure is developing. The basin has complex volcanic aquifer systems due to multi-stage volcanism of the Cenozoic and Quaternary eras together with many dikes, extended volcanic necks and centers. Hence, estimating hydrological terms such as groundwater recharge considering the high basin physical heterogeneities is difficult but highly important. In this study, the WetSpass model is developed, and recharge surface, surface runoff, and evapotranspiration at 90 m grid resolution have been developed. The spatial recharge map is cross-validated with water table fluctuation (WTF) and chloride mass balance (CMB) methods. The mean annual recharge, surface runoff, and evapotranspiration over the whole basin using the WetSpass are estimated at 315 mm, 416 mm, and 770 mm, respectively. The mean annual recharge ranges from 0 mm to 1085 mm: 0 mm at water bodies and highest on highly fractured Quaternary basalt. Similarly, a higher range of recharge is also noted using WTF and CMB methods showing the strong heterogeneity nature of the hydro(meteoro) logical characteristics of the area. Generally, the recharge is found higher in southern and eastern catchments and lower in the northern catchments, primarily due to higher rainfall amounts and highly permeable geological formations in the former parts. A fair general correlation between the recharge by WTF and WetSpass is found. However, the WetSpass is effective in the highland areas where the recharge is controlled by rainfall while the WTF is effective in the storage controlled flat floodplain area. The land use change from 1986-2014 brought relatively smaller hydrological change although the land use has changed significantly.

Keywords: Lake Tana basin; recharge; WetSpass; WTF; CMB; storage controlled; rainfall controlled

305

Hydrogeochemical And Isotopic Characteristics Of Thermal Sulphur Springs Along The Slovenian Coast

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Underwater springs are common along the karstified carbonate coast of the Adriatic Sea. These are submerged karst springs, which are characterized by freshwater or brackish water. Underwater springs near the town of Izola differ from typical carbonate ones in origin and characteristics as their water smells of H2S and has elevated temperature up to 29.6°C. The springs occur on sandy-silt seabed, inside the funnel-shaped depressions at a depth of between 19 and more than 30 meters below the surface of sea bottom by Jože Žumer and other divers. Springs occur along the submerged Cretaceous and Paleogene carbonates, which outcrop only around Izola town and are submerged also below the sea, providing the possibility for the underground water to flow out of the carbonate aquifer. Eleven underwater springs were detected by sonar scanning, grouped into three spatial groups (Izola, Bele skale and Ronek) and are subject of this research.

The salinity of the spring water showed the dilution of the spring water with seawater by mixing and advection, and the presence of sulphide indicated the reduction conditions in the aquifer. After more than a decade, the springs are the subject of new research with emphasize on the more detail, seasonal geochemical and isotopic characterisation.

Physico-chemical parameters have already confirmed previous measurements of underwater springs, where a slightly elevated temperature and the smell of H2S were detected. The EC (electrical conductivity) of underwater springs is closer to sea water (54300 µS/cm), which is the result of mixing with seawater during sampling. Based on the EC of the sulphur spring on mainland we can assume that the source of sulphur water is deeper, but during the sampling it mixes with other types of water. Isotopes (δ18O, δ2H) also indicate that seawater was most probably included in most submarine springs at the time of sampling. All seawater samples indicate the effect of evaporation, which is reflected in the deviation from the Global Meteoric Water Line. The results of δ13CDIC, 87Sr/86Sr and alkalinity show that most of the dissolved inorganic carbon in submarine springs originates from carbonate dissolution and 3H indicates older groundwater (<40 years).

Due to mixing of submarine spring water with seawater, the sampling methodology would need to be improved in the future. Further, a systematic assessment, evaluation and mapping of these resources at regional and national scales, would provide a useful basis for the management of thermal water from deep carbonate-rock aquifers.

306

Modelling Groundwater Recharge Scenarios In Recife, (Brazil) Using The Web-Based Simulation Tools Of The Inowas Platform

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Despite the abundance of natural water resources, urban areas of Latin America and the Caribbean (LAC) countries are facing shortcomings in the delivery of basic services such as safe water supply, while also being affected by floods during the raining season. The cause is manifold and includes the spatial and temporal heterogeneity of water resources, the negative water balance caused by overexploitation, and the insufficient human capacities and governance. In this context, managed aquifer recharge (MAR) is proposed for enhancing traditional water infrastructure with nature- inspired solutions that allow for a more equitable water provisioning. DIGIRES ("Digitally-enabled green infrastructure for sustainable water resources management in Latin America and the Caribbean (DIGIRES)" is an international collaboration project funded through the ERANet-LAC 3rd Multi-Thematic Joint Call 2017/2018 by funding agencies from Germany, Belgium, Brazil, Guatemala and Cuba. The project aims at the development and utilisation of information and communication technology (ICT) tools for planning of MAR schemes as potential solution for sustainable water resources management in LAC region. The work includes the development of numerical groundwater flow models that are expected to support the understanding and prediction of the processes occurring at MAR sites.

The models have mainly demonstrative character and aim primarily at showing the benefits of MAR at locations in the participating countries, as well as the usability of advanced ICT systems for the evaluation of MAR projects at different implementation stages. For the groundwater simulations, the project team uses the free groundwater modelling platform developed by the INOWAS research group at TU Dresden (www.inowas.com). The INOWAS platform contains a collection of web-based simulation tools of different complexities for the simulation of groundwater processes related to MAR. This presentation introduces the development of a MODFLOW-based numerical model and its application for the simulation of different recharge and management scenarios at a potential MAR site in Recife, Brazil.

307

Biotic Control Of Well Incrustations In Groundwater Heat Pump Systems In Melhus, Norway

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Groundwater heat pump systems (GWHP) utilize aquifers as heat sources or heat sinks for heat pumps. Nine GWHP systems currently operate in the town center of Melhus, Norway, primarily for heating but also for cooling purposes.

The Melhus town center locates above a glaciofluvial ice-marginal deposit of sand and gravel. When the glacier retreated, the sea inundated the valley floor, followed by an isostatic uplift of ~175 meters. This has left the area with a thick marine clay layer on top of a semi-confined aquifer. The marine clay layer influences the groundwater quality which is brackish with varying salt content and anoxic with high iron and manganese concentrations.

All nine GWHP systems in Melhus have experienced incrustations problems. Camera inspections of wells and laboratory incrustation analysis (XRD, ICP-MS) have revealed that the incrustations primarily consist of iron oxides, iron sulfides and sediments. Flow-through cell measurements in situ (pH, O2, electrical conductivity, alkalinity and redox potential) and water sample analyses (ICP-MS) have revealed that the systems clogged by iron oxides are distinguished from those clogged by iron sulfides by: higher redox potentials and lower electric conductivity (salinity). Still, iron and oxygen concentrations, pH and alkalinity values are comparable. Biological activity reaction tests (BART) show that the iron related (IRB) and slime forming (SLYM) bacteria are much more aggressive in an iron oxide incrusted system than a comparable iron sulfide incrusted system. In the observed pH interval (7.2-8.2) the Leptothrix genera is a suspected iron oxidizing bacteria. Loss on ignition analysis (LOI at 400 °C) of incrustation material have revealed higher organic matter to iron concentrations in the GWHP system operating at 7.2 < pH < 7.3, which is close to the optimum pH for Leptothrix (7.3-7.5) according to literature. Furthermore, previous studies have also revealed that Leptothrix prefer waters of lower salinity, which could further explain why these bacteria are absent from and iron sulfides incrust GWHPs of higher salinity in Melhus.

The existence of both iron oxides and sulfides incrustations in the GWHPs implies rehabilitation methods should be customized for each system. This study shows that water quality assessment can be used to predict incrustation problems in current and planned GWHP systems.

308

Characterization Of High Transmissivity Aquifer By 2D, 3D Electrical Resistivity Tomography And Proton Magnetic Resonance In Hard Rock Context

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In hard-rock context, the weathering processes develop stratiform horizons: the unconsolidated one (saprolite) of several tens of meters above a fractured one (stratiform fractured layer) at least generally twice as thick as the unconsolidated one. These horizons constitute two distinct groundwater reservoirs. The stratiform fractured layer is the most transmissive horizon.

Subvertical weathered structures may exist locally and be transmissive but are irregularly distributed: the implantation of water boreholes in such structures is a challenge and often random because of the limited extension of permeable fractures.

This research project aims to image the main geophysical signature of the highly transmissive weathered aquifer and potential structures of tectonic origin in the axial area of the Montage Noire (granite-migmatitic dome), with the objective to implant an exploitation borehole for Natural Mineral Water. Several types of investigations were carried out: (i) 2D electrical resistivity tomography (ERT-2D), (ii) 3D electrical resistivity tomography (ERT-3D) and (iii) Proton Magnetic Resonance (PMR) soudings carried out within a first stage. These investigations contributed to the location of an 100 m deep exploration borehole, drilled afterwards.

By combining the 2D and 3D profiles, a spatial interpretation of the electrical profiles is made possible and leads to a high-resolution conceptual diagram of the stratiform fractured layer and the sub vertical aquifer fault structure.

The results from ERT show a steeply inclined conductive corridor interpreted as a fractured and water-bearing zone. This structure seems to allow water to flow upwards from the deep electrically conductive compartment attributed to aquifer zones to the spring. Several major sub-vertical discontinuities interpreted as potential aquifer fractured rocks are also defined. PMR soundings image the hydraulic properties of the weathered aquifer but fail to fully characterize the potential deep aquifers because of thelack of resolution at depth.

The geological and hydrogeological information provided by the exploration borehole allow to improve this conceptual model. It appears that only the combination of different imaging methods combined with borehole information's leads to a realistic "picture" of the aquifer characteristics.

309

Assessment Of Spatiotemporal Variations Of Groundwater Recharge In The Upper Lerma River Basin Using A Process-Based Hydrological Model

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Water resources are under high stress worldwide due to multiple factors. There is a general need to develop better and more efficient management practices. The understanding of groundwater and surface water as one source is crucial for this determination. A clear comprehension of groundwater and surface water interactions as an integrated system requires a good knowledge of topography, geology, and climate.

This research analyzes the spatiotemporal variation and availability of surface water resources and groundwater recharge in a highland basin using a comprehensive hydrological model. The hydrological model is based on the Soil and Water Assessment Tool (SWAT), which allows spatially distributed assessment using sub-basin and hydrological response units.

The case study is the Upper Lerma River basin located in the central part of Mexico. Its location and topography (highland) have made its aquifer the second most source to satisfy the water demand of Mexico City since 1940. As a result, groundwater levels have declined and springs in the surrounding mountainous regions have progressively disappeared over time. Although few studies attempted to estimate recharge and variability, a lot is unknown to fully analyze the declining water resources in the basin.

This research contributes to the understanding of the basin water resources using the modeling approach, which integrates topography, land use, soil, and climate data to calculate different water cycle components in space and time. The statistics of model calibration show a good correlation between the computed and measured discharges in the period of 1986-2005 with a Nash-Sutcliffe Efficiency (NSE) value of 0.62, an R2 value of 0.72, and a PBIAS of -1.4%.

The preliminary results show that the foothills and alluvial fans are the biggest recharge areas, which agree with the piezometric data. Detailed analysis on recharge and surface runoff is ongoing.

310

Co-Developing A Demonstration Project, Aiming At Reducing Water Stress Within A Climate Change Context, With Stakeholders In The Pout Area, Senegal

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Senegal faces multiple environmental challenges related to the impacts of climate change. In the future, water availability could decrease due to the combined pressures of climate change impacts, higher temperatures and lower rainfall with higher variability, and a growing water demand.

The wellfields of Pout in the Horst Diass aquifer system, located 50 km east of Dakar, Senegal, provide up to 23% of the drinking water supply of Dakar. Groundwater is also used for large and small-scale agriculture, mining and water supply for rural areas.

Intensive groundwater abstraction has result in the depletion of the aquifer system, with groundwater levels dropping more than 30 m during the last 40 years. The consequences of the overexploitation of the aquifer system have economic and social impacts, particularly in terms of growing inequalities. For instance, small farmers, who cannot afford to invest in deep wells, have to face insufficient access to the resource during the dry season. Other users such as agro-business and mining companies have the resources to invest in deeper wells and ensure their water security.

In this context, the French Development Agency, within its initiative Adapt'Action, supports the development of a demonstration project to address the issues of water security and climate change adaptation in the Pout area. Different kind of technical solutions are considered, including artificial aquifer recharge to bridge the gap of water scarcity in between wet seasons for small-scale farmers, implementation of agriculture techniques to reduce water demand, improve the governance and management of artificial reservoirs.

Several criteria are consider in the selection of the demonstration project. It must be sustainable at medium and long term, effective, in terms of reducing water stress, and replicable in other regions under similar conditions.

The approach of the project includes, initially, the development of a shared vision of vulnerability to current and future water stress of all users. Possible adapted technical solutions are then discussed with the stakeholders through participative workshops. Finally, a concerted decision-making process has been developed to ensure that, on one side, the project corresponds to stakeholders' choice and implies shared responsibility, and, on the other side, that it is technically feasible. These two components are strong factors to reach a certain sustainability of the demonstration project.

The overall approach could be summed up as:

- Sharing knowledge with stakeholders,
- Expression of all actors to bring about solutions,
- Build on user communities to share responsibilities

311

Positive Impact Of Watershed Protection On Chloride Concentration In Shallow Groundwater (Plateau De Gavot, Haute-Savoie, France)

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On the plateau de Gavot, water resources are protected to guarantee the quality of drinking water and natural mineral water.

To protect these water resources, an association called "APIEME" was created in 1992. The APIEME has put in place protection policies to meet three main objectives which are (i) to maintain agriculture that respects the environment, (ii) to preserve natural environments and wetlands and (iii) to support a reasoned territorial development. Several protection measures are implemented in collaboration with local stakeholders, among others a strong reducing of road salting (staff training, equipment modernization, new practices). To evaluate the effect of these protection policies, a network was set up in 1990 to monitor shallows aquifers and rivers (chemical analysis of major ions at monthly intervals).

In this study, a temporal analysis of the chloride concentration in the shallow groundwater of the aquifer complex has been carried out to evaluate the effect of salting practices evolution.

For most of the springs monitored, the evolution of chloride concentration show an increase between 1995 and 2011, then a significant drop since around 2012, to reach concentration equal to or lower than those measured during the beginning of 2000s.

Comparison with snow removal practices shows that (i) road salt is the main responsible factor for shallow groundwater chloride concentration fluctuations and that (ii) the protective actions implemented since 2011 to adapt the practices related to salting have significantly decreased the amount of winter salt, about 43% for an equivalent winter severity index.

The collaborative work carried out with the department and municipalities in charge of salting and their commitment is decisive for the achievement of such a result.

312

Nitrate And Pesticide Fate During Managed Aquifer Recharge Of Tile Drainage Water

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Agricultural Managed Aquifer Recharge (MAR) is a promising method to reduce water scarcity under climate change in saline deltas of the Netherlands and elsewhere. It collects tile drainage water for storage in brackish aquifers and retrieves the water during dry periods for crop irrigation. Infiltrated water consists of nitrate and pesticides which form a risk for groundwater contamination.

However, aquifers often function as so-called 'natural reactors' and improved water quality is often observed during MAR. The objective of this study is to obtain insights in the conditions and processes related to nitrate and pesticide fate during MAR. The study was performed on an agricultural MAR system near the Wadden sea, in Breezand, the Netherlands. Before MAR operation, push-pull tests were performed to assess aerobic respiration, denitrification and pesticide degradation at 6 different depths. O2 concentrations were reduced to <0.1 mg/L at most depths after 1 day.

A lag-phase was observed for NO3 reduction: concentrations were constant during the first 5-6 days, after which significant NO3 reduction was observed. No significant pesticide degradation was observed during the push-pull tests. During MAR operation, denitrification and pesticide degradation were investigated three times during so-called "storage periods", in which degradation was studied over ~6 weeks.

Relatively stable denitrification rates were observed within the aquifer at 6 depths and over time. Generally, pesticide degradation rates were low. Rates also did not increase with subsequent storage periods, suggesting that microbial adaptation either has not occurred yet, or is ineffective in stimulating nitrate and pesticide transformation in this study. Obtained knowledge will be utilized by collaborating governmental parties to assess risks for groundwater pollution of these agricultural MAR systems.

313

Climate Change And Vulnerability Of Western Normandy'S Coastal Aquifers With Respect To Salt Water Intrusions

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GIECC Models today show that climate change in Normandy will probably induce greater precipitation events in winter time, dryer summer, to which must be added the relentless sea water level rise. At the same time, pressure on coastal water ressources is increasing as the demographic center of gravity tends to move toward the coast lines.

The coast of west Normandy extends over more than 450 km and shows a variety of geologic settings, thereby hosting numerous coastal aquifers, This area is also affected by the presence of low lands several of which may extend over great distances in land.

In 2015, the West normand authorities decided to launch a regional study to assess vulnerability of coastal aquifers to salt water intrusion, so as to set in place an appropriate coastal water resources management plan at the regional scale. Salt water intrusion which generally extends from the bottom of the aquifer up to the fresh/salt water interface, depends on the nature and geometry of the reservoir and can greatly be enhanced through sea waler level rise under climate change and pumping for human needs, irrigation or more generally, economic purposes. This process tends to modify the content of disolved elements, and more generally water chemistry and often leads in turn to disastrous consequences for drinking water production and economic activity.

The study notably revealed that the west normand coast is highly vulnerable to future salt water intrusion, particularily in urban areas and in estuaries under low tide conditions, and that the deep extension of the salt wedge inland will in some cases become dramatic for drinking water production, but also for the general economic activity of western Normandy. This already prompted the establishment of a large scale regional water resources plan for the « Manche département », one of the 3 regions constituting western Normandy.

This paper intends to present and discuss some aspects of the general methodology used, notably to

(1)caracterize the fresh/salt water interface and the reservoir geometry, (2) identify the components of the context which may exert a significant influence on the intensity of the phenomena, (3) determine aquifer vulnerability and (4) to simulate salt water intrusion using BRGM's MARTHE model. It will also present the main results of the study.

314

Inspiring Groundwater: Innovative Groundwater Control And Geotechnical Design For The Protection Of Groundwater Resources During Construction Projects

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Historic over-abstraction from aquifers has led to the depletion of groundwater as a resource throughout the world. This depletion is expediated by climate change and a growing, particularly urban, population. As a consequence, the need to protect groundwater as a resource, together with the challenge to increase its resilience to future climate change, is inspiring engineers to develop innovative design solutions across various sectors. One such area of innovation is in the design of groundwater control solutions during construction projects. Groundwater control required for construction projects typically involves the process of construction dewatering, that is, the temporary lowering of the water table to a target level. This process requires the temporary abstraction of groundwater from beneath the water table and, on some of the largest construction projects, can result in the loss of over three billion litres of potable groundwater from an aquifer over a period of one year. To address these losses of precious potable groundwater, in England and Wales, the process of construction dewatering is regulated by the Environment Agency to ensure that potential negative impacts on water resources are mitigated. These potential negative impacts are most likely to be experienced in urban areas where groundwater resources are already strained and over-exploited. With this in mind, the authors have been inspired to develop temporary groundwater control solutions on several projects which utilise an alternative approach to the conventional methods of groundwater control, and which reduce or remove the need to directly abstract groundwater. Such innovative solutions generally involve a degree of geotechnics and finite element modelling, and are often developed on projects where the protection and conservation of water resources is a key stakeholder concern and design constraint. Examples of 'non-conventional' groundwater control solutions developed by the authors include (i) the design of low permeability Tube-a-Manchette (TAM) grout barriers, and (ii) the design of vertical wick drain systems. Through the implementation of such solutions, both construction risks from groundwater, and groundwater resource risks, can be mitigated in harmony.

This paper presents examples of innovative methodologies which can be utilised to reduce or remove the need for groundwater abstraction on some construction projects, where excavation below the water table is required. Several recent case studies are presented.

315

Sorption Assessment Of 9 Pesticides In An Anoxic Sandy Aquifer During A Continuous Field Injection Experiment

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Sorption characteristics of 9 common agricultural pesticides were studied during a continuous field injection experiment in an anoxic sandy aquifer (organic carbon content 0.057-0.91%d.w.). Natural tile drainage water (TDW) was injected using a well, and the arrival of the water and pesticides was monitored at 6 wells at 2.5m distance. Observed pesticide concentrations were fit using a non-linear least squares routine to an advection-dispersion equation to obtain retardation factors (R). Pesticide degradation was not observed during this experiment. The most mobile pesticides were bentazon and cycloxydim, for which R<1.1 were observed at all depths. Desphenyl chloridazon, methyl desphenyl chloridazon, and imidacloprid were generally less mobile: a maximum R of 1.5 was observed. Boscalid, chloridazon, fluopyram, and flutolanil were the least mobile pesticides. At the shallowest depth, R>2.0 were observed. The obtained R and Koc values varied largely, and generally less sorption was observed with depth in the aquifer. Observed pesticide mobility was significantly lower as expected in comparison to sorption data reported in the PPDB database. The higher pesticide mobility observed is likely resulting from colloidal transport and low sedimentary organic matter reactivity in this aquifer. These mobility differences between observed and literature data show the necessity of field studies for the assessment of pesticide sorption in aquifers.

316

Using Convolutional Neural Networks To Evaluate Long-Term Groundwater Trends In Germany

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Even water-rich regions like Germany are more and more subject to climate stress. Severe droughts, followed by reduced groundwater recharge and decreasing groundwater levels resulted in recent years in local shortages in drinking water supply. We use a machine learning groundwater forecasting framework based on convolutional neural networks to investigate the direct impact of climate change on Germany's groundwater resources until 2100. Groundwater levels at 118 monitoring sites - showing strong reactions to meteorological signals in the past and are spread across Germany - were predicted. The input data is taken from the RCP8.5 scenario with six climate models pre-selected and pre-processed by the German meteorological service, covering a large part of the range of expected changes over the next 80 years. Our models are using solely precipitation and temperature as input, are carefully evaluated using past observations and all achieve high predictive skill scores. Only effects of natural climate change are considered, as reliable future input data on highly uncertain human factors such as increased groundwater extraction or irrigation effects are basically unavailable. For most of the wells considered in this study, we can show a significant ($p<0.05$) drop in the annual mean groundwater level, including longer periods of low groundwater levels during the annual cyclealong with an increased number of extremely low groundwater events. Spatially, results indicate stronger decreasing groundwater levels especially in northern and eastern Germany, aggravating the already existing decreasing trend in these regions.

318

How Robust Are Inverse Methods When Prior Changes? A Categorical Multiple-Point Statistical Case With Pumping Test

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Groundwater flow depends on subsurface heterogeneity, often represented by categorical fields describing different geological facies. Adequate subsurface models help make better decisions about managing groundwater resources. Unfortunately, our knowledge about subsurface is very limited, and often the only observations come from state variables, such as hydraulic heads or contaminant concentrations. Therefore, solving an inverse problem is often an important step in subsurface modeling. A compelling framework for the inverse problem is given by Bayesian formulation, which allows to properly account for uncertainty and to include the prior geological knowledge. Recent developments in Monte Carlo techniques or Data Assimilation frameworks propose relatively efficient ways to solve the inverse problem when the prior geological knowledge is explicitly modeled by multiple-point statistics (MPS). MPS allows simulating categorical and continuous variables and generating geologically realistic fields. MPS is not the only method that can be used to model geologically realistic priors. Generative adversarial networks (GAN) offer an interesting alternative due to their ability to reduce the dimensionality of the problem but require a lot of training samples. In this work, we compare how the solution of the inverse problem depends on the choice of prior and its parameters: MPS or GAN, and compare the quality, computational efficiency, and robustness of the following approaches: Posterior Population Expansion, Multiresolution Approach to Condition MPS with Iterative ensemble smoother, and Markov Chain Monte Carlo with GAN. To assess the quality of results we propose a framework based on continuous ranked probability score (CRPS), which compares single true values with predictive distributions. Such a framework is generic, as it requires only a set of observations and predictions. The methodology is illustrated on a synthetic example of a pumping test in a fluvial channelized aquifer, with 10 piezometers and transient hydraulic heads simulated using flopy (MODFLOW) groundwater solver.

319

Detailed Characterization And Simulation Of Groundwater Dynamics In A Complex Lowland Interfluve In Belgium

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Long-term safety of radioactive waste disposals needs to be carefully assessed using multiple models, including groundwater flow and solute transport models. A vigorous model qualification, justification and validation on the current groundwater flow conditions is a necessary step in developing a modelling framework providing robust estimates related to the environmental impact. In this work, we describe an extensive data collection at the site of the future radioactive waste disposal leading to a substantially improved site-specific groundwater flow model compared to the previous iteration entailing more accurately simulated groundwater dynamics.

The data collection included detailed piezometry with a subsequent time-series analysis including impulse-response function modelling filling up gaps in piezometric time series data. This enabled to construct daily piezometric maps and derive representative hydraulic gradients for the site.

Groundwater flux measurements were performed using a point-dilution method in several (including specifically for this purpose built) piezometers. New multiple-layer pumping tests delivered in situ values of hydraulic conductivity completing existing estimates.

The new site model is developed in MODFLOW-LGR, featuring a more coarsely discretized (50×50m) parent model coupled to a finely discretized (10×10m) child model (~ 3.5 km²) delineated around the disposal site. The coupled modelling scheme is necessary to include all relevant boundary conditions into the model without jeopardizing its numerical efficiency. The transient model with a monthly time-step was calibrated during a two-year period using the hydraulic heads and measured groundwater fluxes. The Bayesian inversion with Markov Chain Monte Carlo (MCMC) using the DreamZS code required a transformation of the observed hydraulic heads to achieve an optimal result. The model was validated for another time period including the piezometric maps and derived hydraulic gradients. During the validation period, hydraulic gradients were locally influenced by human activities (pumping & reinjection). This issue could be addressed by adding these local sources/sinks in the model conceptualization, delivering a model accurately describing the current conditions at the disposal site.

320

Hydrogeological Modelling Of The Tsanfleuron Glacierized Karst Aquifer To Assess Future Water Availability

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Glaciers play an important role in water availability, providing meltwater during summer when other resources are limited. Due to climate warming, a rapid retreat of alpine glaciers has been observed since the industrial era. Water availability in these regions is thus expected to be heavily impacted. Glacier retreat has been widely studied, but glacier-karst interactions and water availability assessment in this context are more scarce. The study focuses on the Tsanfleuron-Sanetsch area, located in the Swiss Alps, and consisting of a glacier overlying a karst aquifer. The aquifer is drained for a major part by the Glarey spring used for drinking water supply. The Tsanfleuron glacier is rapidly retreating: its length has been reduced by nearly half – a retreat of almost 2 km – since 1880, and given the current trends it is expected to disappear before 2050.

To assess future water availability at the Glarey spring under climate change scenarios, a mass balance model of the glacier and a structural geological model of the aquifer are developed and used in the hydrogeological study of the aquifer recharge by the glacier and discharge at the Glarey spring. The mass balance model is a temperature-index melt and accumulation model, based on temperature and precipitation data from past meteorological measurements and future predictions according to climatic scenarios for Switzerland (CH2018). It is calibrated with in situ mass balance observations (GLAMOS). High resolution maps of the bedrock topography under the glacier are simulated using GPR (Ground-Penetrating Radar) measurements and geostatistical methods (kriging, SGS, MPS), allowing a good understanding of the glacier geometry. The total volume has been estimated to be between 144 and 160 Mm3 in 2019 with these methods. A 3D structural model of the aquifer mostly drained by the Glarey spring is established with the GeoModeller 3D program.

This constitutes the base to simulate plausible stochastic karst network geometries with the python code pyKasso. Preliminary results and field observations suggest that the karst system is highly influenced by the fracture network but because of the low dipping structure of the Diablerets nappe, its exact position remains uncertain. The use of stochastic simulation methods such as pyKasso allows representing this uncertainty in the model. The combination of the mass balance model, the meltwater production and recharge estimation, with a set of simulated geometries, allows to forecast the future discharge at the Glarey spring under climatic scenarios.

321

The Urb'Eau Project: Evaluate The Sustainability Of Groundwater Resource In A Peri-Urban Area. Conciliate Drinking Water Supply And Land Use Of The Metropolis Of Lille.

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The Lille metropolitan area supplies almost 60 Mm3 of drinking water annually, 40% of which comes from the chalk aquifer in the catchment fields located in the south of Lille. This strategic water resource remains acutely vulnerable due to shallow depth of the water table, a lack of geological protection and the growing influence of urbanization.

Significant changes of land use occurred in this catchment area, which is now very attractive for agriculture, industry and logistics, as well as for urban development. Quality (several concomitant pollutants such as selenium, nitrates, nickel, pesticides, ammonium, iron, volatile organic halogen compounds and perchlorate ions) and quantity (low water table observed in recent years) issues have emerged. In addition, the Intergovernmental Group of Experts on Climate Change globally forecasts a decrease of aquifer recharge by 2070 in the Hauts-de-France administrative region with periods of accentuated droughts mostly in summer. These climate and land use changes may impair the access to a local drinking water supply in the near future.

From an operational point of view, the 'Lille metropolis' (metropolitan governance) aims to adapt the peri-urban development of this strategic catchment area to ensure policy coherence and a focus on sustainable development. In fact, the preservation of groundwater resources requires limiting the urban sprawl on the municipalities within the catchment supply area. A new development model must be proposed for these municipalities, aiming at guaranteeing the sustainability of the catchment fields while ensuring the wellbeing of their inhabitants through housing development, depollution of brownfields, changes in agricultural practices and development of natural spaces.

The URB'EAU scientific project, started in 2021, aims at addressing these questions.

The planned tasks include:

- Review the most impactful urbanization and land use change processes.
- Adapt a previously developed hydrogeological model [1,2] to take into account these processes and their historical evolution in the last 40 years.

- Co-construct scenarios for the future evolution of land use and practices compatible with the protection of the catchment area.
- Use the enhanced hydrogeological model to evaluate the quantitative and qualitative evolution of groundwater resource in the defined scenarios.
- Assess the proposed scenarios, in terms of implementation costs, technical efficiency (with regard to the protection of the resource), benefits, and preferences of the population of the Lille Metropolitan area.

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322

Groundwater Recharge And Flow In Periglacial Environments: Understanding The Mechanisms Based On The Ledo-Paniselian Aquifer In Belgium

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The Ledo-Paniselian aquifer in Belgium is proposed to offer unique opportunities to study groundwater recharge and flow in periglacial conditions during the Last Glacial Maximum (LGM), due to its location in the permanent permafrost area, south of the ice sheet at that time. A palaeoclimatic record had been set up for this aquifer, consisting of major ion chemistry, stable isotopes, radiocarbon and noble gases. Methane data have been used to further refine the paleoclimatic model, along with revisiting in detail the set of chemical data, focusing on the area of occurrence of groundwater that was found to have been recharged around the LGM. The high methane concentrations corroborate the hypothesis of groundwater recharge taking place during permafrost melting, from methane-bubbling lakes that had developed to the south of an eolian sand ridge. A relict flow path, existing in the aquifer during some period as permafrost was thawing, has been established, starting from these temporary recharge areas, based on various chemical parameters, radiocarbon model ages and noble gas recharge temperatures.

323

Mapping Drought Severity Over Flanders For Policy Purposes

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Flanders experienced a succession of extremely dry summers during the past years. These droughts resulted in unprecedented socio-economic and ecological impacts, and evidenced the urgent need for a tailored drought policy. In order to strengthen its policymaking on droughts, the Flemish Environmental Agency investigated the following questions: How exceptionally dry were these recent summers? How do these recent dry summers compare to historical dry spells? What will be the impact of climate change on drought patterns and impacts across Flanders?

To answer these questions, a new model instrument was developed using a combination of a parsimonious hydrological model and a SWAP soil moisture model. The instrument allows to simulate low flows and soil moisture content. Hydrological PDM models are used to simulate low flows, and are included to emulate a correct mass distribution between (fast) runoff and infiltration.

These hydrological models are calibrated on (gauged) catchment scale to avoid overparameterization, and hereafter spatially disaggregated and transferred to ungauged catchments. Soil moisture is simulated with SWAP models at a pixel scale, which receive a mass flux from the hydrological models. Both PDM and SWAP employ medium-resolution datasets of soil type, land use and terrain characteristics, resulting in a final pixel resolution of 100x100m. Full 50-year meteorological time series for the current and future climate with time horizons 2050 and 2100 were simulated to analyze spatial drought patterns and impacts.

During the development of the model instrument, a number of challenges were overcome. A first challenge involved the setup of a model instrument that simulates both low flows and soil moisture accurately, makes use of high-resolution inputs for Flanders, but simultaneously is sparse and fast. A second challenge involved the selection and definition of drought indicators in order to investigate droughts over time (e.g. the drought duration and intensity) and in space (e.g. for different land use and/or and soil types). A third challenge involved the set-up of the computational infrastructure to produce results for the vast amount of pixels.

The outputs of this new model instrument are drought severity maps with 100x100m resolution for different return periods, both for low flows and for soil moisture content. The drought severity is expressed as the annual number of drought days and the annual volume deficit. Additional outputs show the ranking of historic years, expected yearly low flows and the increase of drought days and volume deficit with climate scenario's.

324

Is Managed Aquifer Recharge (Mar) The Solution For The Barind Region In Bangladesh?

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In recent decades, the Barind region in northwestern Bangladesh has developed from an area with low agricultural productivity in the early 1980s to an important agricultural region vital to Bangladesh food supply. The success behind this transformation in this drought-prone area is dry season irrigation to grow Boro rice using groundwater from deep tube wells. However, recharge of groundwater during the wet season in this area is limited due to the low infiltration capacity of the thick clay layer at the surface. As a result, groundwater levels in the region are declining rapidly and groundwater resources in some areas are already inadequate to meet the present water demand.

Managed Aquifer Recharge (MAR) has been mentioned as a solution for the decline in water tables for many years. However, its actual potential for the area has not been established yet. Pilots of MAR techniques carried out face challenges with clogging and groundwater mounding inhibiting the recharge rates. In this research, we investigate technical MAR designs suitable for the Barind region and look at their upscaling potential and economic feasibility. With this information, we will address the question of whether MAR is the solution to overcoming the water crisis in the Barind region in Bangladesh, or whether MAR is only a partial solution and should always be combined with other adaptations on the water supply and demand side.

325

Gender And Groundwater: Where Are We?

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The concept of gender gives rise to distinct roles of women and men in society, determines the interactions between them, and brings about significant implications in terms of rights, responsibilities, behaviours and identities.

These roles are variable in space and time and, therefore, can differ significantly in function of geographic location, culture, and era. In relation to (ground)water and gender, however, delineated trends manifest themselves worldwide that may result in significant inequalities that can hamper the equitable access to groundwater related services, jobs and rights.

As concerns the professional domain, there is an evident lack of women leaders in the water sector. Similarly, in institutions and associations, female hydrogeologists are heavily underrepresented in higher positions, management, and boards. In geoscience, most full professors are men, and at groundwater related events, mainly male experts are invited as keynote speakers. This does not reflect the fact that there are no female experts in this field. Rather, professional networks, especially at a senior level, are male-dominated. But still, it is a common opinion that these imbalances and the lack of female representation in top positions are due to meritocratic reasons rather than gender discrimination only.

These beliefs may be partly the result of a lack of sex-disaggregated data, which can highlight areas that require action, at the academic, professional and associative level, to promote and ensure effective gender equality, and favour a more inclusive working environment.

In 2020, the Socio-Hydrogeology network of the International Association of Hydrogeologists (IAH- SHG) launched a global online survey to shed light on gendered issues in the groundwater sector. Overall, the goal was to generate data on the evident imbalances in power relations, leadership roles and recognitions in water management-related activities. This session will present the results of the online survey together with some key actions targeted to gender, diversity and inclusion.

326

Analysis Of The Sensitivity Of A Coastal Aquifer To Climate Changes: The Roussillon Aquifer Case Study

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In a context of global climate changes, coastal water resources are subject to many stresses that can lead to water use restrictions, saline intrusions and can permanently modify or damage the regional resources. Moreover, in a coastal region, groundwater is often the only freshwater resource available. Therefore, a good understanding of the aquifer is essential for decision makers.

To address these problems, it is necessary to estimate how the water level will react to climate changes. For this purpose, calibrated groundwater flow models are used. The study focuses on the Roussillon aquifer located in the Southern part of France.

Firstly, different models (homogenous and heterogenous) were built using MODFLOW 6 and the hydraulic conductivity parameters were calibrated with PEST (Figure 1) using the pilot points method. The calibration process reduces the Mean Absolute Error of the models at approximately 2

m. Also, the estimated hydraulic conductivity reveals W-E oriented, highly permeable structures, which can be assimilated to "paleochannels". This interpretation is consistent with the sedimentology setting of the aquifer.

The calibrated models are then used as input to test different climate scenarios (by 2080) and to study the potential impact of climate change on the water resource. Due to the continual lowering of the aquifer's water table level, there is a high risk of seawater intrusion. Using simple assumptions, the projections highlight a strong climatic and anthropogenic impact on the water table, leading to a drawdown which can reach locally several meters, even in the offshore domain. In some places, the seawater interface is advancing several hundred metres inland and rises by about ten metres, especially near the coast where pumping is rather intense. It is therefore possible that these intrusions may reach exploited water wells and endanger their sustainability.

Lastly, this study also showed that the more heterogeneous models are more impacted than the homogeneous ones.

These results show the critical importance of properly characterising the geology and its heterogeneity. Poor predictions can lead to inappropriate decisions that put critical resources at risk, especially in a coastal context.

327

Surface-Ground Water Interaction: Understanding The Influence Of Catchment Characteristics On Spatiotemporal Variability Of Perennial Streamflow In A Tropical Landscape – A Tracer Based Approach

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Source areas, flow pathways, and travel time of baseflow to interact with stream water are critical in hydrological and geochemical investigations. This study aimed to understand surface and groundwater interactions of the mesoscale Kabini drainage using physio-chemical and isotopic parameters in a tropical monsoon climate. Kabini is a tributary of river Cauvery in south-western India, unique for hydrology because of its exceptional climatic gradient with the mean annual rainfall from west to east characterizing the unique humid, transition, and semi-arid zones in the basin(Nara et al., 2019; Sekhar et al., 2016). Throughout each field campaign between dec'2017-dec'2019, river water and groundwater samples were collected on a monthly scale. Rainwater samples were collected during the monsoon on an event basis. The unsupervised machine learning algorithm Principal component analysis (PCA) was used to identify the possible end members of river flow during monsoon and non-monsoon periods. Two-component and three-component end-member mixing model enabled to quantify source contribution to the river. This analysis demonstrated that the stream was reaching minimum discharge during March. However, the chemistry concentrations are minimum during May, after the initial shower of rainfall. It describes that all the initial precipitation infiltrates the ground and pushes out old groundwater to the stream. During the monsoon, the baseflow contribution is 55% of the river flow, and the annual baseflow contribution to the river is 62.5%. An attempt has been made to compare the EMMA results with the Bayesian statistical mixing approach(He et al., 2020; Woodward and Stenger, 2020) to quantify the end- member contribution to the river flow.

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328

Advanced Automated Integration Of Aem And Drilling Data

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Airborne electromagnetic (AEM) surveys are widely used for hydrogeological applications. In areas that present large quantity of good ancillary information (e.g., lithology, resisticity logs), integrating the latter with the AEM data is a common goal. Whether done a-priori or a-posteriori, quantitative integration is often hindered by locally conflicting information. That is, the airborne data and the drilling data may not be reconciled everywhere. For example a number of drillings may have been logged imperfectly. Conversely, the AEM data may have a bias that make it inaccurate. Either case can leave the end user at loss, with the question of which part of the model can be trusted.

In this study we propose to use a generalization of the minimum support norm, namely the asymmetric generalized minimum support (AGMS) norm, for defining the data misfit in the objective function of an iterative reweighted least squared (IRLS) gauss-newton inversion. The AGMS norm in the data misfit puts a cap on the weight of non-fitting data points, allowing for the inversion to focus on the data points that can be fitted. Outliers (either boreholes or AEM data) can be identified after the AGMS inversion, excluded and a classic L2 misfit can be applied to the final inversion model.

The synthetic example in Figure 1 illustrates the applicability of this innovative approach to AEM data (using the Xcite helicopter time domain system's specs) and drilling information in the form of lithological logs translated to resistivity. The AGMS uses the "good" drilling information to locally improve the sensitivity of the AEM to some model parameters, whilst ignoring the "bad" drilling data. It also automatically flags the bad borehole, for review. The standard L2 norm, on the other hand, yields results clearly affected by the incongruous drilling information. At the conference we will present a real case study from The Netherlands. We argue this innovative approach may be especially suitable in scenarios like the Dutch one, which sees large amount of dense, quality drilling data and a desire to continue using AEM as a key methodology to map hydrogeology.

329

Conflicts Of Use: Groundwater Must Always Be Preferred For Drinking Water

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Until the end of the 20th century, mineral resource development, as well as urban or rural planning, only exceptionally took into account their interactions with groundwater. Regulations tended to favor the statu quo and authorizations were given in a form of administrative routine. The increasing pressure on water resources, and in particular on groundwater, prompted the European Union to set up strict regulations for their protection, sustainable management and restoration of their quality.

Thus, in theory, water should have become the common good indispensable to mankind, becoming the priority resource against all kinds of development projects, whether industrial, urban, tourist or agricultural. However, old habits are still well established and there is no shortage of examples in Europe to illustrate the difficulties that oppose citizens to decision makers and their administrations in order to recognize the absolute necessity of respecting the rights in terms of protection of drinking water resources.

As the IAH congress is being held in Brussels, we have chosen a Belgian example of a conflict of use that is typical of these difficulties in having the primacy of the use of a groundwater resource, however modest, recognized as drinking water. The Tridaine spring discharges from a karstic aquifer in the Upper Devonian reef limestone, covering about 3 km², providing an average flow of about 90 m3/h, intended for the drinking water of an abbey and its Trappist beer brewery, and for the inhabitants of the town of Rochefort.

For many years, this groundwater resource has been disturbed by a quarry exploiting the rock for a cement factory, without any possibility to assess the impacts due to a lack of knowledge of the initial state. In light of the knowledge on the functioning of karst aquifers, assumptions can be put forward on the effects of the extension of the quarry since its origin. The planned extension of the quarry, either at depth or on the surface, obviously constitutes a threat to the sustainability of this water resource, to the point that users are trying to oppose it. In this conflict of use, the local authorities as well as the courts have difficulty in deciding on the most appropriate solution, between the maintenance of an economic activity that provides jobs, exploiting a non-renewable resource, and a water resource that is essential to local life for which there is no local substitute resource.

330

Groundwater Vulnerability And Nitrate Concentrations Survey In Karst Aquifers Of Wallonia

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Groundwater Vulnerability and Nitrate Concentrations Survey in Karst Aquifers of Wallonia.

Drinking water in Wallonia largely depends on groundwater from carbonate aquifers which supply most Walloon and Brussels consumers. About 80% of drinking water supply is provided by groundwater catchments. The significant storage capacity of these aquifers is explained by a network of interconnected cracks, favouring infiltration from the surface; a connection that induces a vulnerability of the resource.

In this framework, EPUKARST is a project funded by SPGE as part of the protection of groundwater resources. This research is led by the CWEPSS (Walloon Commission for the Study and Protection of Underground Sites) in partnership with the ISSeP (Scientific Institute of Public Service), Sanifox (company specialized in applied hydrogeology). Associations of speleologists and naturalists, the Haute Meuse, Ourthe and Lesse river contracts and finally the municipalities whose territories is located in the karst basins studied are also associated.

The data collected in this study consist of one-off and continuous measurements of nitrate concentrations and physicochemical parameters at the various sampling points, flow monitoring, tracer tests, isotopic studies and description of water basins feeding of the different systems studied.

EPUKARST aims to better understand changes in nitrate concentrations over a period of 3 years and to highlight seasonal phenomena. In addition to common analyses at the entry and exit of given karst systems, samples directly underground target three types of water with different transfer times: unsaturated zones, underground rivers and manholes on the aquifer. Full knowledge of investigated underground situations is necessary for these further analyses are required. The involving of qualified and aware speleologists as partners is considered as absolutely essential

The sampling scheme should make it possible to compare the quality of the water encountered. The multivariate analysis applied to the results will make it possible to highlight the determining variables in the evolution of water quality from upstream to downstream.

331

Dynamic Controls On Hydro-Physico-Chemical Signal Transmission In Karst Systems

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Groundwater flow and transport processes in karst systems are mainly controlled by physical system characteristics. Process-related parameters of fractured rock matrix and solutionally-enlarged conduits, as well as conduit network configuration, challenging to determine and/or conceptualize, control the dynamic responses observed as hydro-chemo-thermo-graphs at springs and boreholes. The dynamic changes suggest that the sensitivity, i.e., the importance, of the corresponding characteristics may not be constant in time. An influential parameter during high-flows (e.g. conduit diameter) may become insensitive during low-flows, and vice versa. These changes are of high relevance for applied karst modeling and system understanding, although they have not been systematically investigated so far.

Discrete-continuum models (DCMs) are suitable process-based modeling tools for representation of measured system-state variables, boundary conditions, and parameters of real-world karst systems. Therefore, utilization of global sensitivity analysis (GSA) to such models allows for exploring the temporal variation of model parameter sensitivities.

In this contribution, we adopted a previously calibrated model of Freiheit Karst System (Minnesota, US), in response to a multi-tracer and hydraulic experiment, as the base model for the Sobol' variance-based GSA. Because of the spatially and temporally small-scale of the experiment, we could effectively investigate the dynamic of system behavior in the course of groundwater flow, heat, and mass transport signal transmission. Overall, 68,000 forward model runs were conducted for an accurate calculation of the Sobol' indices.

Results demonstrated a strong temporal variability of parameter sensitivities, from the pre- experiment to rises, peaks, and recessions of hydro-physico-chemical signals. Specifically, conduit diameter, tortuosity, roughness, associated drainable storage, and the water exchanges between conduits and matrix mainly affect the observed spring hydro-chemo-thermo-graphs and conduit hydraulic head at the middle of passage, acting dynamically in concert. For example, while the conduit diameter of a section is the most influential parameter for the chemograph peak value, its relevance decreases prior or after peak time, while for tortuosity it was the opposite. Although, the system behavior (i.e., sensitivity of parameters) was dynamically changing throughout the signal transmission, the changes had a trend, approaching the pre-experiment condition, implying a pseudo-steady state. Moreover, results showed that the matrix hydraulic head over the conduit passage, was statically controlled by the conduit roughness, diameter, and exchanges; such that there was no dynamic behavioral change in those parameters. This outcome can be justified by the fact that the experiment results are largely controlled by the characteristics of preferential flow paths.

333

Selecting A Decision Support System Framework To Assess The Sustainability Of Human-Water Systems In Urbanized Environments: The Case Of The Human-Water System Of Louvain-La-Neuve, Belgium.

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The majority of the world's population currently lives in urban environments and this proportion will only increase shortly. Human activities and urbanization interact with the water system in many ways and potentially jeopardizes the availability of the water resource in such urban settings. Yet, there are still many questions about how urbanistic and water management decisions will affect water resources and water services in these environments, and whether current management is sustainable after all. To assess the sustainability of current practices within such complex human- water systems, robust Sustainability Assessment Frameworks (SAF) are needed. SAFs are conceptual multi-dimensional models, encompassing criteria, indicators, reference values, norms and other metrics, allowing the assessment of the sustainability of a system in a

robust, effective, efficient, transparent, and replicable way. In this study, we aim to identify the most appropriate SAF for the complex human-water system of the city of Louvain-la-Neuve in Belgium. We identified 2 widely used SAFs. The first one is a Multi-Criteria Decision Analysis (MCDA) framework based on sustainability standards with Principles, Criteria, and Indicators (PC&I). The second one is a Decision Support System (DSS) based on the European Environment Agency DPSIR causal framework used for describing the interactions between society and the environment. Using the town of Louvain-la- Neuve as a case study, a panel of actors having decision power on water and urban management was interviewed to identify which of the two frameworks is perceived as the most functional one for the evaluation of the sustainability of the water system of this city. We used an Analytical Hierarchy Process (APH) to set the priorities and select the most appropriate SAF in an optimal objective way. The identified most optimal SAF will be implemented in the next steps of this research.

337

Climgrasshydro: Ecohydrology Of Mountain Grassland Under Multiple Global Change

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Grasslands cover almost one-third of the land surface in mountain landscapes, thus greatly affecting the region's water cycle. Climatic conditions have been shown to affect the water cycle of mountain grasslands, however little is known of how multiple climatic changes affect the ecohydrology of these grasslands. The project ClimGrassHydro, therefore, aims to understand the effects of multiple levels of warming, elevated CO2 and droughts on the soil water components of mountain grasslands.

For this purpose, field experiments are conducted at the ClimGrass experimental site established by the AREC Raumberg-Gumpenstein, situated in the Enns Valley of the Austrian Alps. ClimGrass is a long-term facility for testing the effects of warming, elevated CO2 and drought events on grassland productivity and biogeochemical cycles. The experiment follows an innovative experimental design that permits multiple levels of climate warming, elevated CO2 and severe drought on a total of 54 grassland plots using a response surface approach. To study the effects of these changes on the soil water budget components, the facility is equipped with six high-precision weighable monolithically lysimeters and four (smaller) smart field lysimeters (METER Group) allocated to the main treatments, which involve individual and combined effects of strong warming (+3°C above ambient), elevated CO2 (+300 ppm) and drought.

First results reveal that CO2 enrichment results in a decrease of evapotranspiration and an increase in seepage. By contrast, heating enhances evapotranspiration and thus reduces seepage. The combined effect appears to depend on hydrological conditions: while heating is found to be the dominating factor during most times, CO2 enrichment appears to compensate the heating effect under dry conditions. Inverse modelling of unsaturated flow and transport will provide further information about the impact of climatic factors on root water uptake, effective soil hydraulic parameters and the soil water budget components. The results will help understand the mechanisms and effects of multiple global change on the ecohydrology of mountain grassland. Altogether, we aim to identify the influence of climate change on the regional water cycle and groundwater recharge.

340

Aquifer Characterization Of The Volcanic Province And Alluvio-Lacustrine Deposit In The Lake Tana Basin (In The Upper Blue Nile), Ethiopia

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The Lake Tana basin is located in the basaltic plateau of the northwestern highlands of Ethiopia. It is situated in a very complex volcanic province. The groundwater reservoir of the basin was classified into two hydrogeological systems: volcanic aquifer and alluvio-lacustrine (aquitard) system. The volcanic aquifer system itself was further classified into Tertiary and Quaternary basaltic aquifers.

The main purpose of this work is to estimate the transmissivity of these aquifers for the forthcoming groundwater modeling and water management of the aquifer system. The transmissivity of the volcanic aquifer system was estimated by using analytical solutions based on 68 constant rate pumping and recovery tests collected from governmental offices and governmental enterprises.

Before doing pumping test analysis, we used diagnostic plots to identify whether the flow to the well is radial or non-radial. In the diagnostic log-log, semi-log and log-derivative of drawdown versus time graphs, the early time was used to identify wellbore storage. The intermediate time graph was used to identify the flows to the well and late time data were used to identify the boundary conditions.

Mainly Theis and Cooper-Jacob methods were used to estimate the transmissivity of confined aquifers. The Theis residual drawdown solution was also used to estimate the transmissivity of all aquifer systems. The Neuman method was used to estimate the transmissivity of the unconfined aquifer system. Finally, the Hantush/Jacob (1955/1964) method was used to interpret data from a leaky aquifer. The results show that the transmissivity of Tertiary basalt varies from 0.23 m2/d to 860 m2/d, whereas transmissivity of the Quaternary aquifer system ranges from 2.33 m2/d and 18*104 m2/d. This shows that transmissivity increases with decreasing age of the volcanic flows. Specific capacity (SC) (Q/s) was estimated for 74 wells using steady-state drawdown data and the values were found ranging from 0.62 to 5860 m2/d. This wide variation of transmissivity and specific capacity in the volcanic aquifer system shows strong aquifer heterogeneity. A statistical relationship between transmissivity and specific capacity was developed using data from well pairs. With log-log relation, a better correlation coefficient (0.71) was found compared to the arithmetic relationship (0.16). This empirical evaluation of aquifer transmissivity, which is relatively new to the area, will help to develop a model for optimal use of the groundwater resources.

341

What Is Needed For Better Representation Of Groundwater In Multi-Sector Integrated Water Resources Planning To Improve Water Supply Resilience In England?

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Despite an international reputation for it always raining a lot, some areas of England could face water supply shortages in the future due to projected climate change impacts and population growth if no action is taken. Groundwater is an important source of water supply in England, accounting for approximately 30% of total water supply, but in the most water-stressed South and South-East of England this can reach approximately 70%. Several regions of England are already classed as 'water-stressed areas', and current proposals will add the majority of England to this list.

Recent changes to the water resources planning process in England have included the development of a national water resources framework and regional planning groups, developed by the environmental regulator, the Environment Agency. This shifts the focus of water resources management planning from private water company areas to a more collaborative national to regional approach. The regional planning groups include key stakeholders from multiple sectors including agriculture, energy and businesses to work alongside water companies. The tiered approach, from the national framework, to regional planning, to water company areas, allows inter- regional water transfers to be considered to improve water supply resilience across the country.

The planning process itself is becoming a more integrated systems-based approach with stakeholders engaged in decision-making and assessing the risks and trade-offs for different management scenarios.

It is vital that groundwater is understood by stakeholders and properly represented within this new approach to water resources management planning. Current barriers to this include a lack of understanding about groundwater processes amongst many stakeholders outside the discipline, and the need for improvements in groundwater monitoring data to better represent groundwater in integrated models. Without overcoming these barriers, the risks and trade-offs related to groundwater resources will not be properly understood. Here, we discuss what is needed to address these barriers and enable groundwater resources in England to be managed more sustainably. This includes: raising awareness of the importance of groundwater for England's water supply; improving drought risk communication regarding groundwater resources; ensuring groundwater datasets are robust; and ensuring groundwater resources are fully represented in risk-based assessments for water resources management planning.

342

Hydrogeochemistry And Environnemental Isotope Tools For The Assessment Of The Quaternary- Mio-Pliocene Aquifer System Of Douala/Cameroon

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The Douala Coastal Sedimentary Basin (DCSB) is chracterized by an important economic activities in the Gulf of Guinea, densely populated with an annual average precipitation around 4000 mm. A hydrogeochemical study relative to chemical and environmental isotopes was thus carry out, with the aim of evaluating groundwater quality for water supply. 160 samples were collected and analyzed from 4 streams, 40 dug-wells and 31 boreholes through Douala city and surroundings. The Quaternary alluviums (unconfined aquifer system) with a depth ranging from 0 to 20 m exhibit slightly hard groundwater while the Mio-Pliocene sands (semi-confined aquifer system) with a depth between 20 to 70 m indicates fresh groundwater, slighty acid and weakly mineralized relative to the Quaternary system. Major ions of both aquifers do not exceed WHO guidances except for nitrate in the Quaternary alluviums. Groundwater types vary from mixed types (Ca/Na-HCO3/Cl), Na-Cl, NaHCO3 to Mg-Cl for surface water, to mostly Na-Cl, mixed-Cl (Na/Ca-Cl), CaHCO3 to mixed-HCO3 for springs and dug-wells. In contrast the semi-confined system shows groundater types ranging from Na-Cl, Ca-Cl to Na-HCO3 and in a lesser extend mixed-HCO3, Na-mixed and Ca-HCO3.

Multistatistical Analysis (HCA and R-mode FA) decipher cation exchanges and carbonate minerals dissolution. Geochemical equilibriums reveal saturation indexes between equilibrium to oversaturation and are prone to deposit which increase SiO2 in solution coming from hydrolysis of silicate minerals. Stable isotopes reveal depleted values of surface water from upstrem to downstream through the flowpath, caused by evaporation. Furthermore, the unconfined system is under a combination of loca fractionation processes such as surface mixing, direct infiltration and fractionation on the ground surface and within the unsaturated zone. In contrast, the semi-confined aquifer indicate more depleted signature probably due to less evaporation and mixing groundwater from the unconfined aquifer. Both systems are under recent and modern recharge and are post-nuclear groundwater. A natural permanent dilution process occurs and affects significantly the hydrogeochemistry and geochemica processes of groundwater in the study area.

Keywords: major ions, isotopes, hydrogeochemistry, fractionation processes, DCSB

344

Using Distributed Temperature Sensing And Borehole Logging To Track The Movement Of Infiltration Water In Asr Systems

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The drinking water company of Noord Holland in the Netherlands (PWN) is investigating if subsurface water storage (Aquifer Storage & Recovery, ASR) can be used to meet water demands during dry periods or calamities. The goal of the research is to predict the efficiency and water quality changes during production.

The pilot project started in 2020 with a deep well installation that both can infiltrate and abstract water. The results of the first test will be presented.

The test site is located in Noord-Holland. The natural water quality in the targeted aquifer is brackish. The well is screened from 50 to 80 and from 90 to 100 meters depth (figure 1). There are two deep monitoring wells at 8 meter and 13 meter distance, with screens at 6 depths. The monitoring wells are equipped with sensors that can measure Temperature, Pressure and Electrical conductivity. The deepest filter is used for induction logging which gives the conductivity of the formations around the well (Robertson Dual induction natural gamma). The formation conductivity depends on water quality and temperature. To measure temperature Fiber optic cables for Distributed Temperature Sensing (DTS) are installed in the pumping well and both monitoring wells. The fibers are connected to a DTS machine with a mini-PC for remote monitoring.

During the test cold and fresh drinking water is infiltrated in both screens, followed by water extraction during 21 days over the shallow screen and 4 days over the deep screen. The DTS profiles (figure 2) show clearly the preferential flow through different layers. In the upper screen most of the water infiltration water is collected, but part of the water that is infiltrated in the lower screen is still in place. The changing water quality around the 3 wells can be seen in the conductivity profiles that show a similar pattern. Only two of the permanent EC-loggers in the monitoring wells were able to catch the breakthrough of the infiltration water. The preliminary results show that DTS measurements are very suitable to track the infiltration water if there is enough contrast between the temperature of the native water and the infiltration water. But a combination with Borehole loggings is needed to differentiate between temperature and chloride content. At the conference we will present a thorough comparison of the different measurements, and conclude with recommendations for monitoring ASR systems, improving groundwater models for pump or infiltration systems in general.

345

Characterization Of The Main Karst Aquifers Of The Middle Valseriana (Northern Italy) Based On Isotopic And Hydrogeochemical Data: Nossana And Ponte Del Costone Springs

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Valseriana (Northern Italy) is a valley within the Orobian Pre-Alps of Bergamo Province, and it is characterized by high water availability due to the combination of its carbonate environment and an elevated average precipitation rate (about 2000 mm/year). In this context, the catchments of the main karst springs (Nossana and Ponte del Costone) become of strategic importance for the water exploitation and the related domestic service of the city of Bergamo and the municipalities in the area.

This study elaborated the results of chemical and isotopic analyses of waters sampled during the campaign conducted between May 2018 and July 2019, thanks to the collaboration between the Università degli Studi di Milano and the company of the integrated water service (UniAcque S.p.a.). A total of 37 points was sampled from natural karst spring, river waters, wells, karst caves, and water of the Val del Riso mine. The chemical composition of the waters was described by applying the hierarchical cluster analysis technique to group them into uniform hydrochemical groups based on the values of major cations and anions, alkalinity (CaCO3), temperature, and CO2 partial pressure.

The results of the stable isotope analysis indicate a dependence of the recharge on meteoric waters (the calculated study area regression water line is $\delta^2H=7.3\delta^{18}O+7.2$) and a secondary evaporation effect in the recharge area due to the morphology of the territory, markedly mountainous. The two karst systems can be simplified by a hierarchical flow system model, dynamically controlled by karst network development and infiltration water.

Besides, the water reservoirs of the main springs were dated using the 3H/3He technique obtaining values of approximately 10 years for the Nossana spring and 30 years for the Ponte del Costone water system. The comparisons with a previous 2015 campaign indicate that the water reserve is not undergoing renewal. This leads to the need to continue to investigate whether this is a temporary phase or a warning sign.

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346

Groundwater Monitoring Of Outflows From The Faro-Olhão Wastewater Treatment Plant In Southern Portugal

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Environmental Impact Studies recommend the monitoring of groundwater resources to assess potential contamination from wastewater treatment plants (WWTP). The Faro-Olhão WWTP has recently upgraded its treatment operations in 2019. This WWTP is located on the southern limit of the Campina de Faro groundwater body (PTM12) in the Algarve region of southern Portugal. The M12 aquifer is an important groundwater unit, mostly used for irrigation in the drought-prone region, and is connected to the environmentally and biologically important Ria Formosa coastal lagoon, recognized by the Ramsar Convention of wetlands of international importance. The M12 hydrogeological setting is within a meso-cenozoic basin, composed of calcareous sandstones and limestones, and belongs to the Ribeiras do Algarve Hydrographic Region (RH8) administered by the Portuguese Environment Agency (APA). The quantification of impacts associated with the operation of the WWTP on surrounding groundwater resources is the main objective of a multi-year monitoring program. A biannual monitoring plan (sampling in March and September) was designed to monitor water resources upstream and downstream of the WWTP which include water quality, quantity (piezometric level), and hydrochemical parameters. Monitoring data obtained are compared with the Portuguese legal instruments and environmental quality standards (EQS).

Analysis of the results is based on the non-conformities detected with the EQS, and additional hydrogeological chemical analysis tools have been implemented to assess the evolution of the groundwater chemical status to find possible relations with the WWTP. Preliminary results show lead and sulfate parameters in the effluent of the WWTP and considerable increases in the magnesium and manganese were detected at downstream monitoring points. Although other parameters were detected with high values in non-conformity with the legal criteria, these may originate from a source other than that of the WWTP and may relate more to the location of the sampling points affected by seawater. Further assessment of the environmental impacts of the WWTP on groundwater quality is warranted in order to provide a consistently reliable source of uncompromised groundwater in the Algarve region.

347

Using Water System Services To Prioritize Between Water Protection Measures

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Reliable access to water resources of good quality is of great importance to enable a safe and sustainable drinking water supply. In addition to drinking water, water resources constitute a necessary part in the supply of other goods and services, such as food production, energy provision, and recreational services. However, human activities, increased water demand and climate change create significant risks for water resources. To safeguard those valuable resources, protective measures such as water protection areas are implemented.

Although water protection is a widely supported goal in society, the implementation of water protection areas is often complicated by competing economic interests, recreational activities, and even other environmental protection goals. Since there is a trade-off between the extent of water protection areas and the control of overlaying land use activities, decision makers need a solid and transparent approach to base their decisions on. This also requires to be able to communicate and negotiate the extent of water protection measures with affected stakeholders and the public.

Moreover, the benefits of protection efforts are often underestimated since the focus is on the provision of drinking water but simultaneously overlooks the further services provided by the drinking water source. A holistic approach is needed where all services provided by a water resource are considered.

We developed a list of water system services (WSS) which allows to assess all biotic and abiotic services that are provided by a drinking water source. The water system services are based on the Common International Classification of Ecosystem Services (CICES) and are specifically tailored for a Scandinavian context.

The aim of this study is to present an approach for evaluating source water protection based on the services provided by a water source and the risks it is exposed to. Specific objectives are to: (i) introduce the concept of water system services (WSS), (ii) present the development of the water system service list and (iii) illustrate a practical application of the WSS-assessment in a case study where different source water protection options are evaluated and compared

348

Use Of Satellite Imagery To Characterise Changes Of Irrigated Land Use And Its Effect On Groundwater Abstraction In Campina De Faro Aquifer, South Portugal

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Campina de Faro aquifer, located in the Meso-Cenozoic basin, South Portugal is a coastal multi- layered system comprising several sequences of calcareous sandstones and limestones aquifer formations.

This aquifer is the main source of water for agriculture and touristic activities in the area, in which the golf exerts a significant use.

In recent years, lower rainfall and changes of groundwater abstraction patterns lead to a considerable decline of groundwater levels, raising awareness amongst the water users and authorities to problems related with water scarcity and seawater intrusion. Groundwater abstraction in this system is driven not only by meteorological conditions (rainfall and evapotranspiration), but also by the changes of irrigated land use within aquifer limits.

The irrigated areas over the surface of this aquifer has changed considerably within the past 20 years, with a decline in the agriculture area in early 2000's followed by an increase after the 2010's. Nonetheless, the evolution of abstraction values in the area is poorly known.

In the current work, the authors propose to assess how groundwater abstraction has changed in this aquifer within the last 20 years, based on irrigated land use estimated from satellite imagery. This is done under EU PRIMA funded project eGROUNDWATER, aiming at citizen science and ICT-based enhanced information systems for groundwater assessment, modelling and sustainable participatory management, since it has been identified as a major concern of the water users and regulators in the aquifer.

The first section of the work consists in the analysis of satellite imagery to identify, characterise and quantify irrigated areas in the aquifer. Changes in irrigated areas are classified and quantified through satellite images from Landsat 5, Sensor TM and Landsat 8 Sensor OLI-TIRS.

Two different methods of classification have been tested. One is an automatic classification without human intervention, known as unsupervised classification (based on the Mahalanobis distance). The other consists of a supervised classification (based on Maximum likelihood approach), which is fed with "real data" information by the user to perform the land use classification. The classification of both methods is calibrated based on previous land use assessment performed on aerial photographs from June 2007, and later validated on the field.

The estimated irrigated area is then used to indirectly quantify the evolution of groundwater abstraction in the aquifer according to the land use type and crop water demand. The outcome of such quantification provides an updated status on the groundwater availability.

349

How Can New Technologies Improve Water Quality Monitoring To Help Reduce Waterborne Disease And Make Progress Towards Sdg 6?

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Groundwater is a critical source of drinking water worldwide. For communities in Low and Middle Income Countries (LMICs) with no access to mains water supply, hand-pumped boreholes and shallow wells provide a lifeline. Groundwater is even more crucial in the dry season, when rivers can run dry. Groundwater quality is often better than surface water quality, due to natural filtration in the aquifer, but without water treatment facilities communities are still vulnerable to waterborne disease. Contamination of drinking water with bacterial pathogens is a risk to public health.

Sustainable Development Goal 6 includes a specific target for drinking water to be 'free from contamination', however, at least 2 billion people still drink water contaminated with faeces.

There is currently limited data available for bacterial water quality in LMICs due to the complexities of collecting data. Bacterial contamination is commonly detected using proxy indicators such as culturing thermotolerant coliforms and E. coli. However, culturing methods are characteristically labour intensive and time-consuming, requiring suitable laboratory facilities, consumables and sample storage facilities. Typically, results cannot be obtained for at least 24 hours due to the required incubation period, which makes rapid reporting to users problematic, and allows time for disease to spread if a contamination outbreak occurs. In LMICs, where the public health issues are greatest, access to consumables, laboratories and storage facilities can be particularly problematic. New technologies are now emerging that could overcome some of these long-standing issues.

Research into the application of two new technologies was completed in rural Malawi. Water supplies in the study area consist primarily of untreated groundwater sources from hand-pumped boreholes and hand-dug-wells. The technologies tested were tryptophan-like fluorescence (TLF) and high throughput sequencing (HTS) of bacterial DNA. The two technologies have very different approaches to assessing water quality and offer different benefits. TLF can provide rapid results, but it is only suitable for high-level screening of sources. HTS can provide more detailed results about bacterial communities and although currently slow, has the potential to provide for more rapid results and further improved specificity in the future. It is important that water quality assessment methods are selected based on their suitability for monitoring requirements within a given context. Both these methods can provide valuable insights for drinking water quality assessments, detecting contamination outbreaks that could affect public health, and evaluation of progress towards SDG 6.

350

Surface And Groundwater Dependence In Natural And Restored Salt Marsh Lagoons: The Case Of La Pletera Salt Marshes

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Coastal wetlands are some of the most productive and dynamic ecosystems in the world, and their hydrology is conditioned by irregular meteorological disturbances, which in turn conditions ecological functioning and nutrient dynamics within aquatic communities. Also, coastal lagoons are classified depending on their connection to the sea. Confined lagoons have a short period of connection and become highly dependent on freshwater discharges, either from surface run-off or groundwater. The La Pletera salt marshes (NE Spain) is a confined Mediterranean coastal ecosystem under the Life+ project, aimed at restoring this protected area and to recover the ecological value of the area that was altered by construction works. With the presence of two existing lagoons, one lagoon was constructed in 2002, followed by three new lagoons in 2016, with the intention of conserving the ecological functioning of the coastal ecosystem and to increase population numbers of the endangered endemic fish species Aphanius iberus. In conjunction with the one dimensional General Lake Model (GLM) and isotopic and hydrochemical data, we analyzed water level fluctuations, salinity variability and lagoon circulation, as this is known to alter nutrient dynamics and community structure in confined coastal lagoons. We then compared the hydrogeological dynamics of the newly established lagoons with existing ones to analyze the effects of restoration and how lagoon morphology and their connectivity to the aquifer contribute to water salinity. Results indicate that lagoon morphology influenced the evaporation effect. However, salinity levels were influenced by the connectivity to the aquifer and inflow water salinity levels during and after confinement indicated the level of connectivity. This indicates that careful consideration of the hydrogeology of the area during restoration had an effect on circulation and evaporation patterns of the new lagoons, which ultimately influences their hydrology to patterns similar to the existing lagoons. This also has had an effect on new colonies of Aphanius iberus, as salinity levels are a limiting factor. These results highlight not only the importance of groundwater in maintaining these ecosystems and their ecological functioning, but also careful planning and knowledge of these hydrological dynamics will help in developing sustainable management guidelines for these specific type of ecosystems.

351

Managed Aquifer Recharge As An Option For Sustainable Management Of Karstic Aquifer Of The Island Of Vis, Croatia

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Implementation of managed aquifer recharge (MAR) systems in karst environments is generally considered challenging due to the high heterogeneity of karst aquifers and only a handful of global examples demonstrated optimal methods for research and sustainable operation of such systems. Throughout the project DEEPWATER-CE, an integrated approach to the investigation of the feasibility of MAR systems in various geological and hydrogeological environments in Central Europe was fostered. In particular, our research was focused on conducting a MAR feasibility study on the island of Vis, a small karstic island in the Croatian part of the Adriatic Sea, where favourable geological and hydrogeological conditions enabled the formation of high-quality karst aquifers, making the island autonomous in terms of water supply. The island's main aquifer is protected from the seawater intrusions by various barriers, however, climate change and high seasonal pressures related to tourisms pose the greatest threat to the island's freshwater supply.

In order to increase the resilience of the island's community and to support its further development, MAR options were considered in the past during the 1970s, however, extensive investigations were not carried out. To provide an answer to whether a MAR system is feasible, sustainable, and economically justifiable, interdisciplinary investigations have begun in 2019 on the island of Vis. Up to date, detailed field and laboratory investigations were carried out. Field investigations included in-situ measurements of physicochemical parameters (pH, O2, temperature, electrolytic conductivity, and HCO3 content) on water samples from springs and boreholes, continuous and detailed groundwater monitoring by loggers (conductivity, temperature and water levels), geophysical methods (ERT, magnetotellurics, and seismic refraction) and structural-geological measurements. Laboratory analyses included measurements of water isotopes (δ2H, δ18O, δ34S, and 3H activity), and principal cations and anions. Based on the acquired data, a 3D model will be developed and various effects of climate change and MAR will be simulated. Furthermore, the investigation follows a detailed methodology for the assessment of the suitability of certain MAR types, and besides classical geological and hydrogeological investigation, special attention is given to socio-economic aspects, such as cost-benefit analyses, sensitivity analyses, and environmental impact assessment. The expected results of this study are: (i) to assess the suitability of infiltration pond or ASR (aquifer storage and recovery) methods on the island of Vis, and (ii) to determine the efficiency of the proposed methodology of MAR investigation in various porous, fractured, or karst aquifers.

352

Expanded Diameter Gravel Well (Edgw): Development And Field Demonstration Of A Novel Way To Efficiently Realize Large Diameter Wells At Depth

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Larger well diameters allow increased groundwater production capacities and may decrease clogging risks. However, rather than having to drill with a large diameter across the entire depth range, it is more efficient to be able to only enlarge the borehole across the intended well screen depth in the target aquifer.

Over the past century, several different types of expandable drilling bits have been developed for drilling in consolidated formations, mainly for oil, gas and geothermal industry.

However, for unconsolidated formation, only a few designated techniques are commercially available. Thus far, these carry limitations such as borehole expansion ratios that do not go beyond a factor 2 and in addition their performance has been poorly evaluated.

To overcome the identified limitations, we developed a novel technique to enlarge the borehole diameter in a controlled manner by jetting with a high pressure nozzle that can be expanded close to the borehole wall. The technique was thoroughly evaluated in a field trial at a drinking water production site in the Netherlands, where groundwater is abstracted from a finely grained sand aquifer and wells are sensitive for particle clogging. During drilling, the borehole diameter was expanded 2.83 fold from 0.6 m to 1.7 m at a depth of 53.5 to 67 below ground surface.

Subsequently, a well screen was placed and the remaining borehole was gravel packed to create an expanded diameter gravel well (EDGW). During the subsequent 4 year routine production period, the performance was in keeping with the larger diameter and borehole surface: volume flux per m screen length was factor 2 higher and borehole clogging equally fast compared to similar nearby wells. Also different methods for regeneration of the well were tested. Overall, the EDGW technique seems a promising new approach to efficiently increase well diameter for increased capacity and reduce well clogging rates, particularly in deep formations. Although the borehole expansion ratio may not be limited to what was tested in this study, remaining challenges for the EDGW technique are its stability during jetting and the regeneration of the borehole once it is clogged after a period of operation.

353

Exploitation Potential Of Brackish Groundwater Resources In Jordan

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As a water scarce country, Jordan increasingly relies on non-conventional resources. Amongst others, the exploitation and desalination of brackish water is one option.

The Ministry of Water and Irrigation (MWI), supported by the German Corporation for International Cooperation (GIZ), has assessed the exploitable quantities of brackish water across Jordan, broadly defined by total dissolved solids (TDS) concentrations between 1 and 10 grams per litre. The assessment incorporates four basic steps:

1. Desk-based review and synthesis of available literature, data, maps and historical reports produced from water and oil/gas exploration.
2. Screening of specific sites using criteria such as the sources of water, means of developing and transmitting water to demand centres, and options for brine disposal.
3. Field surveys.
4. Pre-feasibility planning for priority sites.
5. Developing recommendations for exploration activity, including important data and knowledge gaps.

Outcomes will guide MWI's investments in future wellfields, water treatment (including desalination) plants, and water transmission systems. Brackish water resources are almost exclusively represented by groundwater. The current project provides an updated picture of the exploitation potential in relevant aquifers and in different hydrogeological settings, ranging from shallow (<200 m deep) Quaternary alluvial sediments in the Jordan Valley and Wadi Araba to deep (>800 m) Proterozoic sandstone formations in the interior of the country and along the Jordan Valley.

The Jordan Valley, including the Dead Sea, is a natural and regionally significant discharge area for brackish groundwater. Accordingly, expanded exploitation along the Jordan Valley is the preferred option for large-scale brackish water development and desalination (>10 Million cubic metres per year per site). Alluvial aquifers in Adassiyah to the north, and deep sandstones immediately to the east of Azraq, are additional sites proposed for further exploration and potential development.

Based on conceptual hydrogeological models, the project has examined possible structural influences on groundwater flow and potential hydraulic interactions between aquifer formations. These may constrain development. There are, for example, indications that over-abstraction of shallow freshwater aquifer units in Azraq induces head gradients and salinization from deeper (sandstone) formations.

Growing water demands and climate change are expected to add pressures to groundwater usage and availability. Expanded exploitation of brackish groundwater will nonetheless be an important contribution to enhanced water supply in the short to medium terms. Additional exploration and monitoring activity will be required to address hydrogeological questions that have arisen during the study, and to safeguard new investments in related infrastructure and operations.

354

Causes And Prevention Of Clogging During Sub-Irrigation Of An Agricultural Field: A Detailed Field Pilot Using Treated Effluent

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Globally, society is increasingly confronted with drought damage in agriculture and nature. In addition, there is an increasing pressure on the availability of groundwater for high-grade applications, such as the production of drinking water. To mitigate drought risks and secure sustainable long-term supplies of fresh groundwater, both efficient and selective use of different fresh water sources need to be considered. These include technologies that promote local re-use of water, such as sub-irrigation.

Since sub-irrigation involves actively infiltrating water underneath the root zone of plants through drains, it can be more efficient than classical surface irrigation methods. Only water that is used for plant transpiration leaves the soil system, thus minimizing evaporation losses, and unused water recharges the groundwater system. A major challenge to allow large scale application is the development of cost-effective infrastructure, requiring a minimum of pre-treatment of the infiltration water. However, from experience it is known that sub-irrigation systems can be vulnerable to clogging. In addition to poor infiltration water quality, other factors such as infiltration dynamics, drainage depth to water table and infiltrate-soil interaction may be of impact.

Therefore, in this study, we performed in-depth monitoring of a sub-irrigation system on a local agricultural field with effluent of an industrial wastewater treatment plant. Our aim was to gain more insight into what physical, hydrochemical and biological processes occur in the sub-irrigation system, how these can contribute to clogging and how to prevent clogging while optimizing water supply for agricultural crop production. The infiltration water and water in the soil receiving infiltrated water were monitored during a 5 years period for a range of parameters including heads, fluxes, water quality and microbial populations. We also experimented with various management measures. A column experiment was conducted on large (0.5 m3) in-situ soil samples to simulate field conditions.

The results of this study indicate that one important interaction between the infiltration water and native soil that is typically not considered in clogging risks is secondary gas production. For this risk, we found that periodic back-flushing was in itself not enough to prevent clogging. However, back- flushing in combination with dryfall was successful to prevent clogging, despite the high clogging potential associated with the relative poor quality of the infiltration water. Overall, these findings contribute to refine existing water quality guidelines and management strategies to prevent clogging of sub-irrigation systems and make them more robust in mitigating droughts and recharging aquifers.

355

Groundwater Availability Forecasting For Irrigation Management

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Irrigated agriculture forms one of the main sources of socio-economic stability and growth in the Mediterranean south. According to recent surveys, 73.4% of irrigation water in Greece, is covered fully or partially by groundwater. Hence, reliable knowledge and accurate forecasting of available groundwater reserves and their zonal distribution on a basin scale during the irrigation period, is critical in ensuring food security. This is the scope of one of the numerous agricultural oriented services developed in the framework of the H2020 ATLAS project and in particular at Pinios Hydrologic Observatory, which is an ILTER site, located in central Greece.

A groundwater flow model is compiled utilizing detailed field data on its geometry and hydrodynamic evolution. Recharge to the modelling domain is applied via a grid of spatially distributed values of deep percolation calculated from soil water budget using a semi-empirical, fully-distributed water balance model. Land use and management is accounted for based on the official national inventory data whereas water use, groundwater level evolution and soil moisture status are accounted for using big data originating from the high frequency dedicated monitoring network established in the region.

The service envisages to assess groundwater availability based on the aquifer system's potential, the capacity of the production wells and the near real time evolution of the resources, accounting for abstractions, sort- and mid-term weather and water demands' forecasts.

Hence, water availability will be offered employing a multi-criteria approach, in an attempt to reach realistic conditions as close as possible. Operationalisation of the service is envisaged to include continuous automated feed-in, execution and processed output of the models involved via data streams channeled through carefully developed APIs, on the ATLAS standard data exchange protocols, interconnected on a uniform digital cloud platform. Groundwater availability service is part of the irrigation programming services that are developed in parallel, aiming at irrigation optimisation and overall minimization of the use of natural resources.

Coupled with the groundwater resources availability service, it is aimed to improve on operational level water use efficiency in irrigated agriculture and enable on the spot assessment and in time design of alleviation and adaptation measures against prolonged droughts that may threat the production and disrupt the environment. disrupt the environment.

357

Transport And Fate Of Plant Pathogenic Bacteria During Managed Aquifer Recharge: Microcosm And Column Studies

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Freshwater availability can restrict agricultural production in coastal areas as groundwater can be brackish and surface water not suitable for irrigation. A natural solution to provide safe irrigation water is managed aquifer recharge (MAR) for agriculture where tile drainage water (TDW) is stored in the subsurface. This results in a fresh water 'bubble' giving farmers access to sufficient irrigation water even in times of drought. As the injected TDW may be contaminated with plant pathogens their removal during MAR is investigated. We focused on three plant pathogenic bacteria, namely Ralstonia solanacearum, Dickeya solani, and Pectobacterium carotovorum.

MAR is designed as an aquifer storage transfer and recovery system where bacterial pathogens are removed during subsurface passage by die-off in the liquid phase, die-off on the solid surface of a soil grain, (ir)reversible attachment or straining. To predict changes in water quality during MAR, the bacterial inactivation in water microcosms and their transport in anoxic saturated sediment columns was analysed.

Results of aerobic microcosms with natural TDW at 10 ℃ show that all bacteria were not detected anymore in 0.1 mL samples within 19 days using viable cell counting, corresponding to 3-log10 reduction by die-off. The bacterial densities declined slower in anaerobic natural aquifer water at 10

℃ where all bacteria were detected for up to 45 days. Furthermore, we evaluated the bacterial removal by soil filtration in column experiments filled with clean quartz sand or natural sand from a MAR site. Bacterial breakthrough curves were fitted with a two-site kinetic transport model using HYDRUS 1D. High removal was observed in columns filled with fine or coarse natural MAR sand while little removal was achieved in clean sand that offers less attachment sites for the bacteria. Finally, the bacterial removal rates obtained from microcosm and column experiments will be implemented in quantitative microbial risk assessment to assess the pathogen risk in the recovered water and demonstrate the feasibility of MAR in agriculture.

358

Developing An Oop Python Library To Query, Visualise, Analyse Flanders' Groundwater Data And Report On Status And Trends

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The groundwater management unit of the Flanders Environment Agency (VMM) is responsible for measuring, monitoring, analysing and reporting groundwater quality and quantity. During the recent decades Flanders' dense monitoring network developed large datasets to comply with Flemish and European environmental legislation.

Flexible toolsets help to fulfill the requirement to frequently produce real-time status and trend overviews. Managing datasets to deliver results through user-friendly interfaces has been key to meet efficiency needs with regard to growing datasets and increasing workloads.

Open-Source programming allowed to automatise routines and add tasks. The use of Python coding permits synergies with "pydov", a python package to query and download data from the "Database of the Subsoil of Flanders" (DOV).

The groundwater management unit developed its own GitHub managed python library to query, visualise, analyse Flanders' groundwater data and report on status and trends. It is currently used within the context of the River Basin Management Plans (RBMP), cartographical reporting and laboratory data validation. Its algorithms run through scripts on Python IDE's or through Jupyter Notebooks, supporting user efforts to step into the code.

The RBMP project requires the production of tables and histograms to evaluate groundwater quality with regard to numerous substances (e.g. pesticides, heavy metals, nutrients, ...) Therefore, automation has been introduced to create tables on aggregated data per substance (per well/groundwater body/year). Histogram outputs show well distribution among groundwater quality classes per substance and per groundwater body (or system). Outputs include classification of chemical status of groundwater bodies. Maps are created for each substance and groundwater body illustrating groundwater quality status geographically.

Laboratory analyses get validated through a semi-automated process incorporating existing tests based on current and historical data. Detected deviations are reviewed manually, and sent back to the laboratory for control. In a second step, adapted laboratory values get reprocessed by a post- validation code for final revision.

359

Evaluating Large-Scale Mar In Botswana Based On Water Supply Security, Cost-Effectiveness, And Sustainability

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Botswana has a water stressed situation due to the climate and a continuously increasing water demand. Managed Aquifer Recharge (MAR) is considered, among other measures, to improve the situation. To evaluate the potential of MAR for improving the water supply security a probabilistic and dynamic water supply security model (WSSM) was developed. Statistically generated time series of source water availability are used in combination with the dynamic storages in dams and aquifers.

The WSSM also includes the infrastructure components of the systems, e.g. pipes, pumps and water treatment facilities and the dynamic reliability of these components. The WSSM compares possible supply from the system with the demand to simulate the magnitude and probability of water supply shortages. The model simulates the system and the effects on water supply security from possible mitigation measures (scenarios) for a chosen time-period using one-month time steps. In previous studies, application of the WSSM showed that MAR can substantially increase the water-supply security in the regional so-called North-South Carrier water supply system in eastern Botswana.

This led to more detailed investigations being carried out in the Palla Road aquifer, located approximately 150 km northeast of the capital Gaborone, where three different scenarios for full- scale MAR have been identified. The WSSM was updated with respect to the three defined scenarios, taking into account needed modifications in infrastructure for a full-scale MAR operation at Palla Road as well as new information on aquifer properties from site investigations and hydraulic modelling.

The expected effects on water supply security is compared to the costs for installing and operating MAR over the chosen time-period to evaluate the cost-efficiency, i.e. the cost per unit of water supply security improvement, for each of the three MAR-scenarios. Each scenario is also evaluated with respect to expected social and environmental effects using a multi-criteria analysis approach, addressing the long-term sustainability of the scenarios. This ongoing work will provide decision-support for the design and construction of what will potentially be the first large-scale MAR facility in Botswana.

360

Characterization Of Sbeïtla Aquifer System Using An Integrated Gravity And Seismic Approach (Central Tunisia, North Africa)

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Groundwater is an important natural resource that sustain life on Earth. In the last century, the gigantic expansion of industrial and agricultural activities has led to an increased environmental pressure on shallow and deep aquifer systems. In central Tunisia (North Africa), aquifers are used as the principal source of water for these purposes. Sbeïtla Aquifer system is associated with the sandy Miocene levels and Upper Cretaceous carbonates of the Sbeïtla syncline which is about 250 km from Tunis city and occupies a central position in the Tunisian territory.

A piezometric drop and a deteriorated quality-water due to an increased-exploitation characterize Sbeïtla aquifers during the period 1975 to actual. Advanced gravity and seismic refection analysis were used to improve the characterization of deepest Miocene and Upper Cretaceous levels.

Firstly, detailed gravity data in conjunction with available geological data are analyzed and interpreted to better understand the structuring of the study area. Different structures and discontinuities as well as the "Sbeïtla fault" and "Kasserine fault" were identified. Spectral analysis of the Bouguer gravity field makes it possible to estimate the major density contrast interfaces and their depths. Specific residual gravity map and Horizontal Gravity Gradient map were also generated to map specific anomalies and lineaments. Finally, a detailed structural map of the Sbeïtla-Bled el Gonna syncline was produced after the extraction of the different lineaments using the source edge detect filter and the estimation of Euler deconvolution Solutions.

In a second step, two regional seismic profiles were studied along Sbeitla Basin in order to examine the aquifer's geometry and different groundwater levels. The NE-SW and NW-SE seismic profiles, crossing the Sbeïtla basin and Bled El Gonna, were calibrated and interpreted referring to previous studies done on the zone, field geology and available hydraulic/petroleum wells. The obtained results focus on the position of the water table target such as the Miocene aquifer levels named G3, G2 and G1 and the Abiod Formation (Campanian-Maastrichtian).

KEYWORDS : Sbeïtla aquifer, Groundwater, Hydrogeophysics, Seismic, Gravity.

361

Groundwater Flow Assessment In Jimma Area, Ethiopia

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Groundwater is the major source of water for domestic, agricultural and industrial purposes in many countries including Ethiopia. This study presents a map of groundwater flow of Jimma area, Ethiopia from 210 numbers of boreholes. The database includes exhaustive information on key parameters such as borehole location, depth, yield and static groundwater level. This study is new for the region, because in Jimma area there has been no previous studies indicating groundwater flow. Also, such large borehole number has rarely been used in Ethiopia to assess groundwater flow. Based on these data, the direction of groundwater flow is to the center of the study area mainly to Jimma city. And also there is flow to the Northern and Western part of the study area. The results indicate that the topography controls groundwater flow in the watershed. This implies that, these outcomes show that groundwater flow direction of Jimma area is highly variable, and that local and regional-scale information will be very useful for groundwater management purposes.

362

Iodine In Drinking Water From East African Groundwater Sources: A Contribution To Sustainable Development Goal 3

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For decades it has been widely known that optimal iodine consumption is vital for physical and mental development and is critical during pregnancy, yet iodine deficiency remains widespread in many regions and there is no defined guideline for iodine in drinking water. Iodine Deficiency Disorders (IDD's) are prevalent in regions of East Africa, and governments have had some success in reducing the number of incidences through salt iodisation programmes. Groundwater and rainwater harvesting are increasingly being used in rural Africa in the pursuit of sustainable and resilient drinking water sources, yet the iodine content of these sources is rarely considered in water quality assessments. Iodine is a vital micronutrient that should be considered as contributing to Sustainable Development Goal 3, Good Health and Well-Being.

This is the first widespread study in East Africa to consider the iodine content of rainfall and provides the largest database of iodine in groundwater in the region. We present the distribution of iodine in groundwater collected by the British Geological Survey from 486 drinking water sources across regions of Ethiopia, Kenya, Uganda, Tanzania and Malawi. Monitoring across 4 regions of Ethiopia shows that iodine regularly varies by up to one order of magnitude on a sub-seasonal basis in rainfall but is consistent throughout the year in groundwater.

Our findings suggest that depending on dietary iodine intake, communities reliant on rainwater harvesting are more at risk from IDD's than those regularly drinking from hand-dug wells and boreholes. We show that there is a general lack of data on the iodine content of drinking water. Further collaboration is needed to ensure adequate intake from food/ water and iodised salt, and to monitor dietary iodine sources. We encourage public health and environmental geochemistry researchers to routinely include iodine in future drinking water quality surveys in order to establish the baseline level of iodine within a communities' local environment.

We conclude that the contribution of iodine to the diet from drinking water is often low, but in some places can contribute significantly to the recommended daily intake of 150 µg/day (6 – 103 µg/day). We suggest that a minimum guideline is still not required, but that iodine concentration be included in water quality assessments, to assess the risk of a community to IDD's, and to support the prioritisation of salt distribution. We also provide a guide on iodine sample collection and analysis for public and private organisations.

364

Strengthening Fundamental And Innovative Karst Approaches For Upgrading Groundwater Vulnerability Assessment

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The Swiss Water Protection Ordinance requires vulnerability assessment as the appropriate approach for delineating groundwater protection zones in karst terrains. For this objective, the first vulnerability method specifically dedicated to karst groundwater has been developed in Switzerland 20 years ago, based on the mapping of four parameters, i.e. epikarst, protective cover, infiltration conditions, and karst network. This methodology has been updated taking into consideration practical experience in groundwater protection zoning and integrating recent karst research findings. It is now adjusted to a more comprehensive origin-pathway-target approach, with the protective effect of the above parameters assessed and summarized in a quantitative manner.

In particular, transient water storage in soil, subsoil and epikarst – known to play an essential role in relation to the vulnerability of many karst systems – provides prolonged residence times for potential attenuation of non-persistent contaminants, mainly with regard to fecal microorganisms. Such attenuation can be expressed as reduced recovery of the potential pollutant while passing through the successive sub-systems, and be defined in terms of a number of protection units. A protection unit then corresponds to the smallest class that can be attributed to a mapping parameter. The sum of protection units, finally, describes the overall protective effect between the catchment surface and the karst spring.

The presented approach is to provide a better quantitative basis for the classification of the vulnerability assessment criteria, with classes yielding a similar degree of protection. Mapping results thus become more comprehensible and comparable. The relevance of the approach is illustrated by both comparative tracer testing results and observation of selected water quality indicators in various settings and contrasting hydrogeological conditions. It is believed – in conjunction with some adaptation in the Swiss legislation for reducing land-use conflicts – making protection zoning in karst catchments more meaningful and easier to implement.

365

Quantifying And Comparing Spatial And Temporal Contributions Of Recharge, River Stage And Groundwater Extraction In A Groundwater Monitoring Network.

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In the Overbetuwe region in the Netherlands, Vitens extracts groundwater for the production of drinking water. This region lies between two large rivers, the Nederrijn and the Waal, and there are four locations at which drinking water is extracted from the subsurface. In recent dry summer periods groundwater levels dropped to lower levels than in prior wetter years. The goal of this research was to quantify the spatial and temporal contribution of different hydrological processes to these dry periods and to study the feasibility of reducing groundwater extraction rates to reduce drawdown in those dry periods.

Timeseries analysis with Pastas (Collenteur et al., 2019) was used to quantify the effects of recharge, groundwater extraction and river stage on observed heads in 243 piezometers. An iterative modeling approach was used to determine which hydrological processes were relevant and cross- validation was applied to select the best models. Each timeseries model represents an independent estimate of the contribution of different hydrological processes on observed heads that is derived exclusively from observed data. The characteristics of the estimated contributions of each hydrological process showed clear spatial patterns. On average, river stage has a larger effect on heads over a larger distance (measured as the shortest distance to a river) in deeper aquifers than in shallow aquifers and the time it takes for heads to respond to a change in river stage is shorter in deeper aquifers. For groundwater extraction the estimated contribution to the drawdown was largest in the pumped aquifer, and smaller in shallower aquifers. Timeseries analysis on a groundwater monitoring network allows the results of individual independent models to be interpreted by comparing their estimated hydrological behavior to other models. In addition to the statistical criteria for testing timeseries models, comparisons of estimated hydrological behavior serve as an extra criteria on which models can be tested.

The accepted models were used to determine the feasibility of using the groundwater extraction rate to control groundwater levels, i.e. preventing low groundwater levels by reducing extraction rates in dry periods. Control is potentially feasible when the influence of the extraction on the head is sufficiently large while the time-lag for a change in extraction rate to cause an effect at that point is sufficiently short. For one extraction location it was shown that this strategy was feasible in all nearby locations in a deeper aquifer, but only at some locations in the most shallow aquifer.

368

Joint Use Of 3H/3He Apparent Age And On-Site Helium Analysis To Identify Groundwater Flow Dynamics And Transport Of Pce In An Urban Area

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3H/3He apparent water ages have been shown to provide essential insights on groundwater-related processes. However, their analysis is expensive as well as labor- and time-intensive. Recent developments of a portable field-operated gas equilibrium membrane inlet mass spectrometer (GE- MIMS) system (Brennwald et al.,2016) provide a unique opportunity to measure dissolved gas concentrations, such as helium-4 (4He), in groundwater systems with a high resolution at relatively low costs.

By establishing an inter-relationship between 3H/3He apparent groundwater ages (analysed in the laboratory) and helium-4 concentrations (analysed in-situ with the GE-MIMS system; Popp et al., 2019) we demonstrate that the 4He concentrations derived from the GE-MIMS system serve as a suitable proxy for the sophisticated laboratory based analyses. The combined use of 3H/3He lab- based ages and predicted ages from the 3H/3He – 4He age relationship opens new opportunities for more detailed site characterization due to the high-resolution measurements facilitated by the GE- MIMS.

For an urban study site, we combined groundwater ages with hydrochemical data, water isotopes (δ18O and δ2H), and perchloroethylene (PCE) concentrations (1) to identify spatial inter-aquifer mixing between artificially infiltrated groundwater and water originating from regional flow paths and (2) to explain the spatial differences in PCE contamination within the investigated groundwater system. The results obtained from the age distribution analysis are strongly supported by the information gained from the isotopic and hydrochemical data (Moeck et al., 2021). Moreover, for some wells, we identify fault-induced aquifer connectivity as a preferential flow path for the transport of older groundwater, leading to elevated PCE concentrations.

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369

Distributed Hydrological Modelling With Spatially Resolved Hydrostratigy To Investigate Managed Aquifer Recharge Potetnial In The Baoding Plain

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North China Plain (NCP, 14 0000 km2) is a global hot spot of groundwater overexploitation. Bounded by the Taihang Mountain to the west, Baoding Plain (10516 km2, or 7% of NCP), is located in northwestern NCP. Here, an integrated surface water and groundwater hydrological model of Baoding Plain incorporating a hydrostratigraphic model constructed by the transition probability geostatistical software (TPROGS) is developed for assessment of regional managed aquifer recharge (MAR) potential. The spatially resolved hydrostratigraphic model is binary (clay and sand) using 684 boreholes (depth: 0.15 m to 600 m) records. The simulated period includes warm up (1990-1999), validation (2000-2009) and calibration (2010-2016). The model is calibrated based on the multi- objective algorithm Pareto Archived Dynamically Dimensioned Search (PADDS) to simultaneously optimize fits to groundwater head, trend and amplitude. By the end of 2016, water balance shows that a groundwater storage deficit of 23.9 km3 remains. However, the storage reverses to a small net gain for 2012-2106, with year 2012, 2013, 2015 and 2016 gaining 0.229, 0.619, 0.124, and 0.857 km3, respectively, though 2014 still sees a loss of 1.122 km3. Analysis of water balance terms indicates that changes in precipitation and pumping are responsible for the reversal. Precipitation is 11.5%, 12.4%, 12.0% and 13.2% higher in 2012, 2013, 2015 and 2016, respectively, but is lower by 13% in 2014 compared to average precipitation of 14.4 km3 over 2000-2016. Corresponding to the wet/dry year, the pumping is reduced by 9.7%, 22.5%, 0.5% and 35.2% in the wetter years, but is increased by 10.8% in 2014 compared to average pumping rates of 3.4 km3 over 2000-2016. Results demonstrates the buffering role of groundwater in Baoding Plain, suggesting the need to enhance recharge through MAR.

370

Long-Term Groundwater Dynamics At Schietveld Houthalen-Helchteren

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'Schietveld Houthalen-Helchteren', a military shooting range and protected Nature 2000 site, is a large groundwater recharge area on the dividing line between the Scheldt- and Meuse basin. It consists of an alternation of wet heathlands and fens in between dunes and dry heathlands.

Downhill this area many local streams find their origin. Besides anthropogenic activity, groundwater levels at recharge areas strongly depend on and are key indicator of alternating meteorological conditions.

Long time measurements of EVP show a steady increase of 20% from 1980 till now. The start of the trend coincides with 2 decades of excess precipitation. From 2000 on there is an imbalance between the decreasing excess of precipitation and increasing EVP, resulting in a potential recharge deficit. Despite the strong groundwater dynamic, wet heathlands have always been able to persist till now.

A long-term series of groundwater levels (since 1986) is available for a monitoring well at the recharge area. In the period 2005 and 2020 the long-term groundwater level dropped for about 1 m. Moreover, a strong interannual dynamic in groundwater level of almost 1,5 meter between wet and dry periods was observed until 2005. Since 2005, high groundwater levels during winter period no longer occur.

A Menyanthes time series model confirmed the strong correlation between the measured groundwater levels and the groundwater recharge. A long-term simulation from 1900 till 2020 shows this long steady drop of the groundwater levels is characteristic for the past 15 to 20 years. Prior to 2000, low level periods were limited in time.

Groundwater recharge is simulated with a spatially distributed model for historical (1960-1980), current (2006-2016) and future climatic conditions (2060-2080). Resulting groundwater dynamics are simulated with a groundwater model. The changing climatic conditions result in a decrease of the groundwater levels at the recharge area. The area with suitable groundwater depths for groundwater dependent terrestrial ecosystems decreases significantly and become limited to the river valleys. This puts a pressure on the nature conservation ambitions, earlier defined for this area.

371

Hydrogeological Investigation Of The Radionuclide Content In Groundwater In The Vicinities Of Two Crystalline Outcrops In Hungary

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Geogenic contamination arising from rock-water interactions can limit the use of groundwater resources in drinking water supply. Among others, radionuclide content can pose a health risk due to water consumption. The natural radionuclide content of groundwater is primarily determined by the geologic background but their re-distribution by groundwater flow systems also has to be taken into account. Two study areas (Velence and Sopron Region) are in the scope of the present study, where quality monitoring measurements found gross alpha activity exceeding the 0.1 Bq L−1 limit in drinking water wells. Both areas are characterized by outcropping crystalline basement (granite in the Velence- and gneiss in the Sopron Region) overlaid by thick Pannonian-Quaternary siliciclastic fluvial sequences. Furthermore, shallow lakes characterized by recent organic-rich sedimentation are found in each area. Previously, both areas were targeted by uranium ore exploration and preliminary studies found radon activity up to 221 and 279 Bq L−1 in spring waters and indoor radon activity up to 900 kBq m−3. Though, until recently no observations or measurements were made regarding the occurrence of radioactive isotopes in the groundwater. In this study, hydrogeological investigations were made to understand the natural radioactivity phenomena in these areas. Pressure-elevation profiles and tomographic potential maps were compiled to evaluate the groundwater flow system.

Those areas were delineated where the geochemical environment modified by the groundwater is favorable for elevated radionuclide content. Then, water samples were collected from both ground- and surface waters. Beside the general hydrochemical analysis, nuclide-specific measurements were applied and 234U+238U, 226Ra and 222Rn activities were determined by alpha spectrometry and liquid scintillation. The novel combination of hydrogeological investigation and nuclide-specific measurements and the comparison of the two areas can help to derive general conclusions regarding the mobility and transport of radioactive isotopes in groundwater. Uranium were measured in the highest concentration (up to 753 mBq L−1) in correspondence with recharge areas characterized by oxidizing conditions and downward flow.

This study was supported by the ÚNKP-17-4-III-ELTE-73 New National Excellence Program of the Ministry of Human Capacities and by project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 810980. The results here presented have been developed in the frame of the MIUR Project "Dipartimenti di Eccellenza 2017—Le Geoscienze per la società: risorse e loro evoluzione".

372

Social-Ecological Regulation Of Groundwater: Linking Inter-And Transdisciplinary Perspectives

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Groundwater has thus far been a neglected resource in social-hydrological and hydrosocial research. However, given the multiple hydrogeological and social dynamics in the Anthropocene epoc, understanding their interlinkages is particularly important. We see this for instance in the design and implementation of groundwater governance in the European Union with the Water Framework Directive. Knowledge gaps exist on interactions between land and water use, climate change impacts and the ecological and hydrological functioning of groundwater bodies. Further unknowns pertain to the social dynamics involved in the formal and informal regulation of the 'invisible resource'.

Groundwater has been described as a global resource to be governed locally, given the regionally distinct features of social-ecological groundwater regulation (for instance Foster et al., 2013).

The objective of the junior research group 'regulate – regulation of groundwater in telecoupled social-ecological systems' is to conceptualise the social-ecological regulation of groundwater in a way that hydrogeological, ecological and social dynamics as well as the cross-scale and long-distance interactions entailed can be addressed holistically in research and governance.

In an inter- and transdisciplinary research mode groundwater in Europe is studied from the disciplinary perspectives of aquatic ecology, hydrogeology, social hydrology, political ecology and anthropology. In three case studies in Spain, Germany and Croatia, interactions of local groundwater use in agriculture and water supply, associated institutions and conflicts and hydrogeological and ecological conditions are assessed. The research design and interim findings are continuously discussed with key stakeholders at EU level. The research seeks to contribute to social-ecological research on groundwater by (one) conceptualising social-ecological regulation from a deeply interdisciplinary perspective linking basic natural sciences research with social sciences and the humanities and (two) developing an adaptive governance approach to groundwater in the EU based on a transdisciplinary understanding. We will present our research design and first insights from the inter- and transdisciplinary research process.

373

Review Of Groundwater Age Of A Transboundary Aquifer System Using 14C And 36Cl, Case Of The Continental Intercalaire Aquifer In Algerian Sahara And Southern Tunisia

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The Continental Intercalaire aquifer (CI) (North Africa) is one of the largest transboundary aquifer system in the world. It contains around 20 000 × 109 m3 of groundwater. The recharge comes mainly from the occidental part of the aquifer (southern foothills of the Saharan Atlas, Algeria) going east to the outlet area in South Tunisia. Several studies have showed, using 14C, that the principal recharge has taken place in Late Pleistocene (› 25000 B.P.) and Holocene (≈ 5000 B.P.). However, doubts exist about the results of some of these studies as it was demonstrated that samples containing less than 10 pmc could have been contaminated by modern air during the sampling procedure. Previously, the DIC is precipitated in situ using a hyperalkaline solution which privileges atmospheric CO2 uptake.

Based on a new field survey and the combination of new 14C and 36Cl data, the data of the previous studies are reviewed and new insights on the groundwater age are given.

Close to recharge area, 14C age showed that there is a significant amount of modern recharge (less than 2 Ky B.P.) than any sample was found to have an age between 2 to 11 Ky P.B. This means that during this period, Northern Sahara was dominated by a hyperarid climate. From 11 to 30 Ky, it is observed that there is cyclicity of approximately 4 Ky between given ages. This indicates that this period is dominated by an arid climate. Those 14C ages are calculated using Fontes & Garnier model. Beyond 30 Ky P.B., the use 14C is critical because of its limited half-time. 36Cl is more relevant in that case (half-time equal to 301 Ky). Samples close to recharge area, where 14C activities are sufficiently high and halite dissolution is not significant, are explored in order to define the initial values of 36Cl. In this area, the initial 36Cl/Cl ratio is around 145 × 10-15 at/at and the initial chlorine concentration is around 175 mg/L. Based on these values, the age of Cl groundwater in the Great Oriental Erg basin and South Tunisia has to be 300 to 700 Ky old instead of 40 to 50 Ky calculated by 14C. This is supported by the ages calculated by 81Kr performed in the South Tunisia. However, the applicability limit of each technic has to be investigated.

374

Behavioural Classification Of Private Well Users In The Republic Of Ireland: A Quantitative Pathway Analysis Approach

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Private domestic groundwater wells are unregulated in most European countries, placing supply maintenance responsibility with well users. Approximately 16% of the Irish population is served by private wells, with appropriate treatment, periodic testing and structural inspections thus vital to safeguard rural Irish homeowners from supply contamination and consequent adverse health impacts. Recent national research has reported low levels of supply "stewardship" and harmful socio- hydrogeological patterns through which well users emerge as both sources and receptors of supply contamination. Accordingly, the need for improved education of and engagement with private well owners is clear. The necessity for effective interventions is further elevated by the increasing occurrence of extreme weather events (EWEs) such as pluvial flooding, which has been shown to accelerate microbial contamination of private groundwater supplies. Increasingly frequent and severe weather events will require routine, seasonal private well maintenance and, in turn, greater awareness of supply integrity.

A national survey of 560 Irish private well owners was conducted in 2019, with structural equation modelling for the first time employed to identify predictor and mediating variables that determine well user behaviours. Pathway analysis was used to establish demographic, cognitive and supply- specific predictors of three binary outcomes: well user testing behaviour (Y/N), information seeking behaviour (Y/N) and post-EWE action (Y/N). Chi-square Automatic Interaction Detector (CHAID) decision trees and stepwise regression were used to identify and constrict potentially significant variables, with three models developed and evaluated via comparative fit indices and measures of parsimony.

All three final models demonstrated good model fit (CFI > 0.95) and appropriate model parameterisation. Perceived self-efficacy (i.e. confidence) in maintaining supply was identified as a predictor for all three behavioural outcomes; respondent age and presence of a vulnerable householder (i.e. aged 0-5 or >65 years) represented the sole demographic variables for predicting both information seeking behaviour and post-EWE action, while duration of residency represented the sole demographic variable in the case of supply testing behaviour. A supply-specific variable ("tenure", i.e. construction relative to residential presence) emerged as an indirect predictor of post- EWE actions. Findings suggest that impacts of temporal demographic variables on well maintenance actions are mediated by cognitive factors, with perceived-self efficacy in maintaining supply lying at the heart of well user decision-making. Study findings will inform future educational interventions for private well users and represent a frame of reference for other European countries characterised by high private-groundwater reliance and similar behavioural gaps among groundwater end-users.

375

Using Stable Isotope Analysis (Δ2H And Δ18O) And Multivariate Statistical Techniques To Characterize The Regional Hydrogeological Characteristics Of The Hodna Basin, Algeria

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The Hodna basin located in the south-east of Algeria in the arid climatic stage has experienced an exponential decline in its piezometric level in recent years, related to the overexploitation of the Mio-Plio-Quaternary aquifer and the impact of climate change.

Geochemistry, environmental isotopes and multivariate statistical techniques were three methods utilized for delineating the hydrogeological conceptual model of the Mio-Plio-Quaternary alluvial aquifer of the study area, in addition for defining the main factors that affect the hydrochemistry at the scale of a plain and for reconstructing the origin of groundwater and its mechanisms of recharge of groundwater.

The results of chemical analysis of 18 groundwater samples were explored by means of two multivariate statistical analysis methods: ascending hierarchical classification (AHC) and factor analysis (FA). These methodologies allowed the identification of three groups of water samples, which could represent different stages of groundwater evolution in this region. The Ca-HCO3 groundwater of type corresponds to water coming from the carbonate massifs in recharge zone in the northern part. Conversely, SO4-Cl-Na groundwater type corresponds to more evolved waters, because of their proximity to a salt lake (Chott El Hodna), which naturally represents the natural outcropping of the alluvial aquifer water table.

Multivariate statistical techniques have been applied to analyze obtained on the quality of groundwater reveal the presence of three groups. Moving from upstream to downstream (North- South) we pass gradually from unsalted water to strongly salted water near the Chott. The infiltration water of group 1 mixes with all the reserves of the aquifer progressively along the underground flow up to result in a more loaded water of group 3 in the discharge zone. Nitrate concentrations could be related to agricultural activities at the lowland level. The isotopic analyzes showed a very quick recharge of the aquifer, and that the groundwater has undergone a strong evaporation in the salt lake.

The results of this study clearly demonstrate the utility of multivariate statistical analysis and isotopic analysis in hydrogeochemical studies.

377

Hydrogeochemical And Isotopic Assessment Of Groundwater In The Lake Chad Basin: Case Study Of Kanem, Barh El Gazel, Hadjer Lamis And Lake Regions.

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The study area is located in the central part of the Lake Chad Basin and is characterized by a Sahelo- Saharan to Saharan climate where aquifer recharge is generally scarce and groundwater constitute the main resource available for drinking water, livestock and agriculture. The objective of this study is to perform a hydrogeochemical and isotopic characterization in order to identify the main hydrogeochemical processes responsible for mineralization and groundwater recharge mechanisms and to estimate the groundwater residence time. Groundwater sampling campaigns were conducted in July 2013 (wet season) in the Hadjer Lamis region, October 2013 (dry season) in the Kanem region, February 2014 (dry season) in the Lake region and April 2015 (dry season) in the Bahr El Gazel region. Results of this study show that groundwater is acidic to basic with pH values ranging from 5.61 to 8.35 and is very low to high mineralized with electrical conductivity values ranging from 49 µS/cm to 6525 µS/cm. The plot of chemical data in Piper diagrams shows several types of water with a predominance of the calcic bicarbonate facies (Ca-HCO3).

The hydrogeochemical study reveals that the chemical composition of groundwater is primarily controlled by water-rock interaction through the processes of silicate hydrolysis, salt and carbonate dissolution and basic cation exchange. Isotopic results show that groundwater has various origins and is affected by the evaporation process. The weighted average isotopic composition of the rainfall is -2.4‰ V-SMOW and -11.12‰ V-SMOW for δ18O and δ2H, respectively, indicating that rainfall contributed to groundwater recharge until now. Isotopic study also indicates the occurrence of pre-nuclear, post-nuclear and mixed waters. Most of groundwater samples contained tritium-free water, which indicates the predominance of old water in the aquifer.

378

Producing Aquifer Water Table Maps Using A Remote Sensing Method Based On The Observation Of Pastoral Wells – Application To Iullemeden Basin Aquifers (Niger)

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Pastoral wells are ubiquitous in Sahelian countries. They help local communities make better use of the pastureland that constitutes their main resource.

For centuries, such wells were hand dug by artisans in soft sandstone layers. These age-old wells are cleaned year after year. In the north of Niger, pastoral wells in the immense Iullemeden basin are very deep (up to 150m). This great depth has significant economic and technical consequences as the wells are expensive to dig and extracting water requires a lot of energy.

Rational management of a such large aquifers therefore requires good piezometric maps. Unfortunately, producing piezometric maps with conventional field surveys in this landlocked and unsafe region is a difficult operation by now. To address this difficulty, we have developed a method for constructing piezometric maps based on remote sensing.

Remote sensing has already been used to study the piezometry of shallow aquifers in wetlands based on vegetation density. The twin GRACE satellites have also been used to assess variations in subsurface water storage. However, neither of these methods can directly measure the depth of the piezometric surface.

To map aquifers in the Iullemmeden basin, we developed an original measurement method based on the observation of trails made by animals used to draw water from wells equipped with pulleys. They leave tracks on the ground that become deeper over time to the point that they can be observed and measured on satellite images. We demonstrate that these tracks provide a very accurate measure of the water table depth (to within 2 meters).

After developing, testing and calibrating the method, we were able to construct a piezometric map of the Iullemeden aquifer based on the observation of more than 2,000 wells. This map is both detailed and updated. It completes the old, often obsolete maps of these aquifers. This remote sensing mapping method has several advantages: (a) the very large number of measurement points allows for tightly meshed kriging that improves the accuracy of the map; (b) the length of the tracks is a weighted average of the water level at the beginning and at the end of the day, in the dry season and in the wet season; and (c) this method overcomes the accessibility and insecurity problems that have made surveys in Niger very difficult.

Using freely available satellite data, this approach offers the possibility to continue monitoring groundwater resources in Sahel, whatsoever access difficulties.

379

Building An Integrated Methodology For Water Resource Assessment And Management In Urban Coastal Areas Of Southern Philippines: Preliminary Hydrogeological Findings

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Water resources in the coastal municipalities of the Philippines are threatened by population increase, rapid urbanization, land use/cover change, excessive groundwater withdrawals for industrial use and salt water intrusion.

Those issues are studied at the Medina and Opol municipalities which are located in the northern part of the Mindanao Island. Communities in these municipalities rely only on groundwater resources for domestic and industrial use. In Medina, aquifers are predominantly composed of volcanic deposits with massive pyroclastic materials and lava flows of andesitic and basaltic composition. In Opol, aquifers are predominantly composed of limestone, corral rubbles and agglomerate, calcareous and tuffaceous sandstone.

This study presents the preliminary findings of the hydrogeological investigation undertaken since 2018 in Medina municipality, with a local water service cooperative, which includes pumping tests results, groundwater fluctuation monitoring, hydrochemistry and water balance analysis. Fast groundwater transfers in the volcanic deposits with discharge at the sea and at the interface with alluvial deposits were observed. Some of these springs are primary sources of drinking water in the communities. Estimated permeability and transmissivity from the pumping tests was in the range of 9.5 × 10-5 – 3.2 × 10-4 m s-1 and 9.1 × 10-4 – 6.9 × 10-3 m2 s-1, respectively. These aquifers receive substantial recharge during the months of December-February and June-August from upstream catchment areas and its losing streams.

Tide influence and freshwater-seawater interaction were also observed in the monitored wells and springs near the coast. One of the wells with screen located between 19.24 to 20.24 m below mean sea level has sodium and chloride concentrations of 511 mg/L and 883.7 mg/L, respectively.

Electrical conductivity in these coastal wells also increased by 27% between September 2019 to January 2021. Electrical Resistivity Tomography campaigns and density-dependent groundwater flow and transport are being developed, to better characterize the freshwater saltwater interfaces and manage the resources.

Lessons from field experience working with the local communities will also be presented. The research and development project is actually undertaken through partnerships between three Belgian universities and two Philippine universities and collaborated with two local water service cooperatives.

380

Physico-Chemical Characteristics Of Thermal Waters Of Gushing Aquifers In The Coastal Sedimentary Basin Of Benin (West Africa).

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The thematic of this study aims to characterize from a physico-chemical point of view the thermal waters of the gushing aquifers of the coastal sedimentary basin of Benin.

The projection of the coordinates of the thermal water points on the geomorphological map of the coastal sedimentary basin of Benin showed that they are distributed in the valleys of the main rivers of the coastal sedimentary basin with a temperature between 38 °C and 69 °C. The hydrogeological correlations carried out in the coastal sedimentary basin following the North-South direction in the valleys of the main rivers (Couffo and Ouémé) have shown that the thermal water boreholes have captured the sands and the marls and limestone whose depth varies between 66 meters and 420 meters which are in unconformity middle finger on the crystalline base.

Chemical analyzes have shown that the springing thermal waters are mineralized in the South with a neutral to basic pH and have a high concentration of bicarbonate, calcium and magnesuim ions. on the other hand, the thermal waters are acidic with a low mineralization in the North of the valleys of the main rivers of the coastal sedimentary basin.

Keywords: Gushing aquifers, thermal water, physico-chemical, coastal sedimentary basin, Benin

381

Assessing Effects Of Climate-Smart Agriculture On Groundwater Recharge

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Growing populations and the challenges brought about by climate change such as recurrent droughts, increasing water scarcity and ever-rising food insecurities have resulted in many governments in sub-Saharan Africa struggling to work towards attaining the sustainable development goals (SDGs) on universal access to water, zero poverty and zero hunger.

To counter these negative effects, governments in the Southern African Development Community (SADC) region are promoting policies that enhance agricultural production, for example increasing the acreage of food crops under groundwater irrigation and introducing climate-smart agricultural techniques such as conservation agriculture (CA). CA is a farming system that is composed of three main crop management practices of minimum soil disturbance or no tillage, crop or surface residue retention, and crop diversification or rotation. Previous studies comparing CA to conventional tillage (CT) have indicated that CA had benefits of higher yield, increased soil moisture and improved soil fertility leading to it gaining support over CT with policy makers particularly in water scarce climates.

There is however a general lack of scientific data on the impacts of CA on groundwater recharge even though many studies have implied that CA leads to greater infiltration than CT and therefore greater potential recharge.

To fill this gap, we undertook an inter-disciplinary investigation into the impact of CA versus CT on groundwater recharge at three sites in Malawi, Zambia, and Zimbabwe. The methods implemented include the use of a combination of monitoring soil moisture through the rooting zone to 1m depth, electrical resistivity tomography (ERT) and groundwater levels in monitoring boreholes on previously established experimental sites in Malawi, Zambia and Zimbabwe. The monitoring was conducted over a 3-year period.

This presentation describes early results from the intensive field monitoring programme and initial insights gained on the differences between groundwater recharge responses in the CA and CT treatment plots both within and between countries.

384

Modelling Exchanges Between Surface Water Reservoirs And Groundwater In Basement Areas: Case Of Kierma (Burkina Faso)

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Small-scale surface water reservoirs are essential for water storage in arid and semi-arid areas worldwide and particularly in sub-Saharan Africa (Cecchi et al., 2020; Saruchera and Lautze, 2019). These infrastructures provide water for a wide range of activities, in particular irrigation (Forkuor et al., 2019). Besides their essential functions, surface water reservoirs can induce local groundwater recharge (Bambara et al., 2020; Mushtaha et al., 2019). In a context of increasing and pressing water needs of populations and the implementation of a sustainable and integrated water resources management policy, a more complete understanding of the hydrological processes in the watersheds with surface water reservoirs is essential (Ala-aho et al., 2015). It is mainly important to characterize the interactions between surface and groundwater (Boubacar et al., 2020) which remain very complex in general and particularly difficult in semi-arid watersheds where few accurate data are available. The objective of this study is to characterize and assess the interactions between surface water reservoirs and groundwater for water supply to the population. The study was carried out in the Kierma basin in Burkina Faso, which contains surface water reservoirs for irrigation.

The physically-based hydrological model, HydroGeoSphere, integrating surface and subsurface flow processes was used for the study. A fully integrated hydrologic model of the Kierma watershed hydrologic was built and calibrated with a three-stage temporal resolution approach. This ranges from steady-state average conditions to dynamic equilibrium with repeating monthly normal forcing data and, fully transient conditions. Simulations results show that the model reproduces seasonal surface water flows and the dynamic of the groundwater levels fairly well.

The model allowed to qualitatively and quantitatively evaluate the interactions between surface water and groundwater. The water reservoirs constitute privileged zones of focused recharge estimated on average at 504 mm/year. Direct groundwater recharge also occurs during the rainy season and is estimated on average at 144 mm/year. Groundwater in the Kierma watershed can therefore be exploited for water supply to the population and complementary irrigation.

385

The Best Of Two Sides: Combining Ert And Groundwater Modelling To Optimize The Management Of A Drinking Water Abstraction In A Fractured Aquifer (Borgloon, Belgium)

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Fractures provide preferential pathways for fluid flow in low permeable rocks. These structural weaknesses can strongly increase the maximum achievable well capacity at water extraction sites. It is however difficult to identify the pattern of these fractures on a large scale and implement them into groundwater models. Geophysical methods can help to identify secondary porosity in an aquifer, but the introduction of identified fractured zones to increase the reliability of a groundwater model remains nonetheless a challenge. We investigated the Borgloon extraction site of De Watergroep, located in the northeast of Belgium, that is used for the production of potable water.

Groundwater is extracted from the Formation of Maastricht, a relatively dense chalk aquifer intersected by highly permeable fractures. To investigate the heterogeneity of the aquifer and to better understand the role of fractures, an electrical resistivity tomography (ERT) survey was conducted. Several ERT profiles were set out in different directions crossing both valleys and hillsides since a relation with topography was expected. Interestingly, the survey revealed that the fractured

zones occur both in the valleys and hillsides and run subparallel to each other in a north-north-western to south-south-eastern direction.

A groundwater model was constructed and calibrated, initially using homogenous layers. Subsequently, the identified fractured zones were implemented in several scenarios and these were compared with the homogenous model. It was concluded that a model with fractured zones was better able to simultaneously simulate the observed hydraulic heads and drawdowns. The best scenario was selected and further used to simulate an increase of the pumping rate. As implementing the fractured zones improved the calibration, the model was also able to identify with a higher confidence the zones where an important drawdown or possible subsidence related to peat layers might occur. Finally, the model was used to optimize the location of new pumping wells. A new pumping well was simulated either located within or outside a fractured zone identified by the ERT. It was concluded that a new pumping well simulated within a fractured zone is better able to spread the drawdown over a larger surface area and thus reduce the maximum drawdown.

Overall ERT has proven useful in identifying and imaging fractured zones, while the integration into a groundwater model improves the calibration. A degree of uncertainty however remains mainly due to the concentration of information in the centre of the model.

388

Modeling An Extended Groundwater Pfas Contamination In Northeastern Italy

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Per- and polyfluoroalkyl compounds (PFAS) have in recent years received increasing public and scientific attention due to their ubiquitous presence in the environment, long-range transport, and bioaccumulation properties.

PFAS have been used since the 1950s in manufacturing processes and products, including surfactants and surface protectors, photographic films, lubricants and pesticides, fighting foams, due to their unique properties, such as heat and acid resistance, water and oil repellence.

An important groundwater PFAS contamination has been discovered, between 2011 and 2013, in the province of Vicenza, North-East Italy. This environmental pollution has peculiars characteristics compared with other similar situations all over the world: the effects on surface and groundwater involve a territory of about 170 km2, the concentrations reach levels over 10000 ng/l for some compounds and a population of about 350000 people has been exposed to these substances.

This study is focused on reconstructing the evolution of annual average concentrations of two main contaminants: perfluoro octane sulfonic acid (PFOS) and perfluoro octanoic acid (PFOA). To do that a numerical model of groundwater flow and solute transport was implemented using MODFLOW-2005 and MT3D-USGS codes. The results were compared with available experimental data to validate the simulations.

The simulated groundwater flow follows the course of the valleys in the upper part of the model domain and then it splits in two directions: North-West and South. The transport simulations reproduce the average annual concentrations of PFOA and PFOS, showing how such compounds traveled consistently with the direction of groundwater flow and confirming the anomaly of very high PFOA concentrations in an intermediate part of the study area, far from the source. Finally, the results of forecast simulations emphasize that the only natural attenuation cannot significantly reduce concentrations for the next 50 years. This fact supports the need to expand monitoring activities and design an effective remediation campaign to anticipate the reduction of concentrations over time.

390

Use Of Geophysical Data To Highlight The Role Of Pre-Existing Faults In Spring Appearance/ Disappearance: Case Study Of The El Gouna Springs, Souss River, Morocco

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Groundwater, in the Souss-Massa Basin (South western Morocco), occurred under unconfined conditions in the Pliocene and Quaternary formations of the plain, often overlying one or several confined sub-aquifers, such as Neogene and Turonian deep aquifer. The ensemble constituted the multi-layer aquifer system of Souss-Massa Basin. The El Gouna springs emergence, flowing from the Turonian deep aquifer, was one of the natural outlets of the system, with a low flow rate in the downstream part. This study focused on the El Gouna springs area and aimed to understand its hydrogeological functioning based on geological structures and their role in the appearance/disappearance of springs in this area, then studied the relationship between deep and shallow aquifers. For this reason, vertical electrical soundings (VES) using the Schlumberger array and seismic sections using were carried out in the study area. All geophysical data were calibrated by mechanical well logging and geological outcrops, and used to build geoelectrical and seismic cross- sections and structural map.

The geoelectrical results showed the alternance of conductive and resistive zones related to the Plio- Quaternary deposits. This alternance followed by a conductor layer (< 30 Ωm) related to the Senonian marl and marly limestones. The deep resistant layer corresponded to the Cenomano- Turonian limestone aquifer (170 Ωm) with a thickness of about 95 m.

Seismic sections showed that the fault pattern in the studied area was mainly concentrated along corridors with a major direction of ENE-WSW and secondary direction of NNE–SSW. The first one constituted an extension of regional faults such as the El Klea and Agadir faults.

The highlighted structures bringing the two aquifers into contact, allowing the emergence of some springs in the area. These resurgences came from the Turonian limestone and dolomite deep aquifer. Despite deepening of the impermeable covering deposits (Senonian marls), the water was forced to flow along higher permeability paths of the fault zone.

This upward flow was controlled by structural discontinuities in the impermeable Senonian marls. This hypothesis could explain the spatial variation of salinity in the El Gouna area.

Keywords: Hydrogeological functioning; Geophysics; El Gouna spring; Aquifer connection; hydro- structural discontinuities; Souss River Basin; Morocco.

391

Integrated Surface And Groundwater Resources Management In A Coastal Aquifer (Cap Bon Peninsula-Ne Of Tunisia)

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Coastal aquifers are usually the main source of water supply for irrigation, drinking, and industrial purposes in coastal regions. They are often subject to overexploitation and consequent quantitative and qualitative degradation. The groundwater flow system of the Chiba watershed in the CapBon peninsula (NE of Tunisia) is a typical case of an overexploited aquifer, where a piezometric depression exceeding -10 m (a.m.s.l) appeared has developed over the two last decades. Among the numerous remediation tentatives, the SMART-WATER project aimed to propose a remediation plan based on a smart monitoring and water-energy nexus solution through the installation of smart energy and water meters (SEWM). This technology aims to optimize groundwater pumping at a set of selected representative farming systems in the watershed. In this context, a first coupled surface water-groundwater flow model has been developed and applied, coupled with energy nexus for the irrigated Chiba plain. The model is implemented using a dynamic coupling between MODFLOW WEAP and LEAP in order to assess the SEWM system efficiency in reducing aquifer exploitation and electrical energy consumption at the farm level. Multi-objective calibration of the model using river discharge and GW level data has yielded accurate simulation of historical conditions and resulted in better-constrained parameters compared to using either data source alone. Model simulations show that crop water demand cannot be met during droughts due to limited GW pumping capacity and that increased GW pumping has a relatively strong impact on GW levels due to the small specific yield of the aquifer. Groundwater and energy models have also revealed that, under different management and climatic scenarios, electric energy consumption and groundwater table decline are intricately connected. Despite the short monitoring period and the intermittence of the received data, SEWMs have shown a promising role in monitoring groundwater pumping and engaging farmers in energy-saving and aquifer sustainability.

392

What Is Impacting Transboundary Aquifers? Climate Or Global Changes?

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In Eastern Belgium, one of the main groundwater reservoirs is located in Cretaceous chalk geological formations. The recharge zone of this aquifer corresponds to the Hesbaye chalk aquifer of the Geer basin, in the Walloon region of Belgium (Groundwater body BERWM040). In Flanders, the chalk layer deepens to the North-West where it becomes confined under Tertiary sediments (Groundwater body BLKS_1100_GWL_1M).

Groundwater from this chalk aquifer has been exploited for decades by different water companies, through pumping wells and galleries. These last decades, groundwater level time series have started to exhibit decreases, particularly in the recharge zone, when comparing the 1960-1990 and 1990- 2020 periods. These decreases have been mostly attributed to first signals of climate change, with observed temperature increase and precipitation decrease, inducing a decrease of recharge.

However, hydrogeological budgets calculated over different time periods for the Walloon part of the catchment have indicated increased water losses, attributed to a probable increase of groundwater abstraction in the Flemish part of the aquifer.

All these results are reanalysed here in terms of water budget, evolution of groundwater levels and changes in indicators reflecting the pressure of groundwater abstraction on the evolution of groundwater reserves. Conclusions show that climate change is indeed a driver but increased anthropogenic pressure is also likely to be a key controlling factor.

Based on this analysis, conclusions are drawn in terms of the need for efficient integrated transboundary management of such very important groundwater resources in a context of global change.

394

Transient Spatially Varied Groundwater Recharge Modeling In An Arid Climate Aquifer

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Estimating the groundwater recharge plays an essential role in managing the water resources in the arid region environments. Groundwater recharge is affected by human activities and climate change. Groundwater recharge is highly variable in terms of time and space. Also, it is difficult to be measured the field. Hence, different methods are used to estimate the groundwater recharge such as direct and indirect methods. One of these methods is numerical modeling.

This study aims to estimate the groundwater recharge under limited data availability in an arid climate aquifer located in the Sinai Peninsula, Egypt. Since groundwater recharge is characterized by temporal and spatial variability and is affected by natural and anthropogenic factors, estimating the recharge is considered a complex process. Hence, a methodology was developed to estimate the groundwater recharge via a distributed numerical modeling approach using two models: WetSPASS, Hydrus-1D. Gridded land use, soil, and climate data were acquired and processed. Look-up tables were utilized due to the lack of soil hydraulic parameters measurements. The two models were run from the year 1986 to the year 2015. The results show a close agreement between WetSPASS results and Hydrus-1D results, as the mean annual recharge rate are respectively 4.16 and 4.7 mm/year for WetSPASS and Hydrus-1D, whereas the ratio between the recharge to the precipitation is respectively 31% and 35% for WetSPASS and Hydrus-1D.

397

Groundwater Contamination Monitoring By Isotopes (2H, 18O And Tritium) Application: An Italian Case History

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Leachate coming from municipal solid waste landfills is a serious environmental issue for groundwater contamination.

The application of isotopic methods for the investigation of leachate contamination has given good results, mainly for monitoring the interaction between landfill activity processes and groundwater environment. Stable isotopes, like deuterium (2H) and oxygen (18O), have found application to environmental engineering during recent years. In fact, deuterium (2H) and oxygen (18O) isotopes have successfully used to assess the groundwater contamination phenomena in case of interactions with the municipal solid waste landfills leachate, having a significant organic amount.

The methanogenesis phenomena, typical of the degradation processes of the organic portion in landfills, lead to an enrichment in deuterium (the “heaver” isotope), as the bacteria use preferentially the “lighter” isotope (1H). On the contrary, tritium (3H) is a radioactive isotope of hydrogen and can be present in low quantities in natural waters. Due to its sensitivity as a tracer of leachate leaks from landfills, tritium measurements are useful to assess the groundwater path. Numerous in field studies have shown as the tritium content of the leachate is superior to that present in the natural waters. Its content in landfill leachate can be very high in some municipal solid waste, not due to bacterial activity as for deuterium, but for the presence of objects with high levels of tritium (for example luminescent paint, luminous signs, watches, key chains ...).

A case study of a municipal solid waste landfill area in Central Italy is shown. 2H, 18O and 3H isotopic data of groundwater sampling in April 2020 are considered. 2H and 18O isotopes allow to assess the contamination phenomena of groundwater in some sampling points positioned near leachate wells. The elaboration and interpretation of 3H measurements, not only confirms what is shown by the isotopic data 2H and 18O, but provides further information about contamination phenomena by leachate in other sampling points. This study aims to show how isotope tracers are effective tools for the assessment of leachate contamination of groundwater.

The aim is to show the effectiveness of the use of 3H isotope as an environmental tracer, combined with 2H and 18O isotopic data. In fact, small variations of the 3H isotopic content, but greater than the values present in natural waters, are able to identify minimal leaks, not easily identifiable, of landfill leachate.

400

Enhancing The Implementation Of Mar Technology Through Geospatial Analysis And Web-Based Decision Support Tools To Cope With Water Scarcity In Semi-Arid Regions Of Ne Tunisia

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Suitability mapping for managed aquifer recharge (MAR) is recently gaining more attention because of its potential in producing comprehensive maps easily interpreted and used by policy makers. In front of the divers existing methodologies, an adapted approach for the arid and semi-arid conditions of Tunisia was developed to generate MAR suitability and feasibility maps within a participatory approach with stakeholders. A GIS-based multi-criteria decision analysis (MCDA) was applied to establish the suitability and feasibility of MAR in Enfidha plain, NE of Tunisia. Selected criterions were spatialized under GIS thematic layers and they were standardized based on literature and experts' opinions regarding their importance in MAR implementation. Weights of each criterion were determined using analytic hierarchy process (AHP). Intrinsic suitability map was obtained using weighted linear combination (WLC) by the mean of ArcGIS software and via the INOWAS (Innovative web-based decision support system for water sustainability under a changing climate) platform. It shows that more than 80% of the total plain area is intrinsically suitable and highly suitable for MAR. MAR feasibility map was established by overlaying intrinsic suitability, recharge water availability and water demand maps of the region. It reveals that almost a fifth of the plain has high MAR feasibility potential. The INOWAS DSS web-portal is an effective tool to create, store, and share MAR suitability maps.

401

Saltwater Intrusion And Flow Reversal At The Submarine Spring Of A Mediterranean Karst Aquifer : Explanation And Modelling

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The Vise spring is the main outlet of a Jurassic karst aquifer located close to Montpellier city, South of France. The Vise spring is submarine, occurring at the bottom of the Thau lagoon at a depht of 30

m. The lagoon , made up of brachish water is connected to the Mediterranean sea. The fresh water from the karst aquifer as a whole, and especially from the spring, contributes to the qualitative state of the Thau lagoon which is well known for shellfish farming activities.

During the last fifty years (from 1967 to 2014), six occasional saltwater intrusions (called "inversac" in French) occurred, inversing the water flow at the submarine spring during a period varying from a few weeks to a few months. This backflooding process at the spring induces a very large saltwater intrusion into the karst aquifer. Given that this aquifer provides several highly important ecosystem services (drinking water supply for the coastal villages, fresh water to the Lagoon, thermal water to Balaruc spa and health resort), a large program of groundwater monitoring has been recently launched particularly at the submarine spring (discharge, temperature, quality) and several neighbouring borewells.

In november 2021, a seventh backflooding event started and is observed with the new monitoring system. From an initial flow rate of about 60 l/s from the aquifer to the lagoon through the spring, the flow inverted to about 350 l/s from the lagoon to the aquifer in a few minutes on the 28th November 2020 at 9:40 AM. This sudden backflooding created a sudden water level rise of about 2.5 meters into the karst confined aquifer. A few months later, the saltwater intrusion into the aquifer is still high, equal to 150 l/s.

A physical mechanism is proposed to explain the sudden inversion of flow and its long duration after that the event has started. The propagation of a piezometric wave through the aquifer is simulated using simple analytical solutions. A preliminary meshed model of the aquifer and its interactions with the lagoon has been developed for identifying the main processes. First attempts for proposing alert indicators are also discussed.

402

A Novel Finite Analytic Method For Analyzing One-Dimensional Unsaturated Flow In The Heterogeneous Soil

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Richards equation is the commonly used equation to describe the water movement in the unsaturated zone. However, it is difficult to solve Richards equation due to its highly nonlinear. Although Kirchhoff transform can linearize the second-order spatial term in Richards equation, there is a typical discontinuity problem in the variable Kirchhoff transform (K transform) at the interface between two types of soil. Therefore, K transform has been severely restricted to apply in simulating soil water movement for heterogeneous soils. In this study, we derived a formula of finite analytic method (FAM) in order to overcome the discountinuity at the interface node. The new formula is based on the conversations of mass and energy at the interface node. The results show that the developed algorithm can effectively handle the discontinuity across the interface between different soils in contrast with analytical solutions. In addition, FAM can obtain a more accurate and stable numerical solution even under the condition of relatively coarse grid size compared to the modified Picard finite different method (MPFD). Another advantage of the FAM is that it can reduce mass balance errors. This study has significance for solving the Richards equation and describing the unsaturated flow in the heterogeneous soil.

404

Reviewing Earth And Atmospheric Tides Models To Derive T And S And Comparing Results To Pumping Tests

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The passive technics using earth and atmospheric tides to assess aquifers properties regained popularity during the last decade, but there is however a lack of robust studies comparing the results from these methods with the traditional pumping tests. In this study, transmissivity and storativity values were obtained in shallow aquifers in Cambodia using earth and atmospheric tide induced groundwater fluctuation models. A new method was developed, which use barometric response functions as slug test in order to assess transmissivity. Earth tide models were reviewed in order to fit tide frequency dependent data.

The results are compared with transmissivity and storativity obtained from pumping tests carried out at three distinct aquifers. While transmissivity data from atmospheric tides are in good agreement with the pumping test values, storativities derived from earth tides show large discrepancies from one to several orders of magnitude between tide models and pumping test results when the negative borehole skin effects are neglected. Such effects, when neglected, can lead to misunderstandings in model choice, if the latter is only based on phase shift sign between the original earth tide and the groundwater levels.

None of the earth tide models of the literature with realistic transmissivities were able to reproduce the tide frequency behaviour observed in the three studied sites: a strong decay in well sensitivities with frequency and close to zero phase shifts. This work emphases the need of validation when evaluating hydraulic parameters using earth and atmospheric tides only, as well as the necessity to better characterize the frequency dependence of hydraulic and poroelastic parameters.

406

Carboniferous Limestone Transboundary Aquifer Case (Belgium/France)

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The carboniferous aquifer of the international hydrographic district of the Scheldt river extends across three regions: France, Wallonia (South Belgium), Flanders (North Belgium) covering 1420 km² (Figure 1). More than 75 million cubic meters of water are pumped every year in this aquifer for drinking water distribution, agriculture, industry, and quarry dewatering. Stresses on groundwater resources in the aquifer are therefore important and pumping operations need to be managed adequately. Groundwater levels have been decreasing significantly due to the overexploitation of the aquifer caused by the industrial and demographic development of the region during the 20th century. In some area the piezometric level has dropped by 90 meters between 1910 and 2010.

The aquifer is mainly composed of fractured carboniferous limestone. The aquifer is considered as unconfined in the east and confine below marls and chalk in the northwest area. Recharge is thus mainly observed within the unconfined area, with important groundwater transfers to the confined area.

Groundwater flow in the aquifer has been modelled in 3D using the finite volume calculation code MARTHE, in collaboration between the different involved entities, and using data officially exchanged between administrations. The model has been calibrated for the 1900-2017 period considering abstracted groundwater volumes, recharge calculated from precipitation and evapotranspiration data, observed piezometric levels and river flow rates, collected or reconstructed since 1900.

The model is used for predictive purpose. Simulations are performed on the 2020-2050 period following several scenarios including the possible evolution of groundwater abstraction as function of the demographic and economic development of the region, climate evolution and related groundwater recharge change in the evolution of dewatering operations in stone quarries.

Sensitivity analysis of groundwater levels were also performed according to the location of pumping wells and others according to different climate scenarios. All these simulations constitute a scientific support for the decision-makers of each party involved which will ensure coordinated actions for a future "good state" and sustainable management of the aquifer, considering anthropic pressures and climate change.

407

Recent Advances In The Use Of Process-Based Groundwater Vulnerability For Risk Mapping

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Groundwater vulnerability and hazard maps are often combined to produce GIS-based cartographic representations of the risk of groundwater pollution in studied aquifers. Results remain however often quite subjective for two main reasons. First, identification, in the investigated catchment, of anthropogenic activities often requires a combination of heterogeneous sources of information.

Their classification in terms of the potential hazard they induce for groundwater quality remains subjective. Second, most of the time, groundwater vulnerability maps that are used for this combination are often based on relatively empirical approaches, with the combination of different factors using rating and weighting methods. These factors are also often implicitly interdependent which is not so consistent for evaluation methods based on multi-factor indicators.

Here, we take advantage of the process-based groundwater vulnerability Apsû method (Popescu et al. 2019) to develop a more rigorous methodological framework for the integration of groundwater vulnerability and hazard maps into sound risk assessment maps. We show with examples that the different process-based criteria that are the basis of the Apsû method for intrinsic vulnerability mapping (travel time to groundwater) and specific vulnerability mapping (relative quantity of pollutant reaching the saturated zone or water table) can be used to elaborate efficient decision support maps for land use planning and groundwater protection. We also propose a new concept of “aquifer scale protection zone” and a screening approach that allows restricting the use of targeted hazardous substances in specific areas of the groundwater catchment zone where they show elevated risks of groundwater pollution. The proposed concepts and methodology are illustrated using a mixed urban – agricultural catchment in the Walloon region of Belgium.

Ref : Popescu, C., Brouyère, S. and A. Dassargues, 2019. The APSÛ method for process-based groundwater vulnerability assessment. Hydrogeology Journal 27(7): 2563-2579.

409

Transfer Of Trace Organic Compounds In The Soil Aquifer Treatment System Of Agon-Coutainville (France)

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In order to avoid threatening seashore economical activities from direct discharge of secondary- treated wastewater (STWW) into the sea, Soil Aquifer Treatment (SAT) is used in the wastewater treatment plant of Agon-Coutainville (Normandy, France) as an additional treatment step since 2005. STWW is infiltrated into a sandy aquifer through three reed beds. Only one of the three ponds is flooded by STWW rotating every four months. Recent monitoring including Traces Organics Compounds (TrOCs) highlight a very significant reduction of TrOCs concentrations in the groundwater (Picot-Colbeaux et al., 2020). However, the nature and the magnitude of the mechanisms, either geochemical processes and/or dilution, are not clearly understood.

An experiment is set up to highlight the nature and the magnitude of the processes involved in TrOCs mitigation as well as the efficiency of the SAT by determining residence time. The experiment started at the beginning of the infiltration pond

flooded with STWW at an average flow rate of 780m3/d. A pumping ensured hydraulic gradient to one piezometer located at 35 meters of the main discharge point where the sampling of groundwater is carried out.

STWW and groundwater are monitored (water level, pH, Eh, salinity and analyses of major ions and trace elements including TrOCs) during 34 days of experiment. Specific targeted TrOcs are carbamazepine and oxazepam.

The mean initial chloride concentration in groundwater was 182 mg/l whereas the STWW concentration was 555mg/l. During experiment, chloride concentrations in groundwater showed a fast increase between 8 and 13 days reaching a plateau at the initial STWW concentration.

Oxazepam and carbamazepine concentrations were initially low in groundwater (120 ng/l and 170 ng/l, respectively) in regards to STWW (2000 ng/l and 800 ng/l respectively). A slow increase of TrOCs concentration in groundwater is observed after more than 13 days of infiltration reaching a maximum concentration depending on TrOCs. For all these contaminant, concentrations ratios (Cgroundwater/CSTWW) remained below 1 until the end of the experiment. For oxazepam and carbamazepine, the maximum concentrations (715 ng/l and 425 ng/l, respectively) were reached in the groundwater at the end of the experiment.

The results indicate 1) slight or no dilution of infiltrated waters with regional groundwater and 2) an estimated mean residence time between 8 and 13 days from the infiltration point to the observation well and 3) degradation and/or sorption processes driving TrOCs mitigation.

410

On Pressure, Temperature And Tidal Effects In Deep Piezometers

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At the NIRAS/ONDRAF Kallo and Doel investigation sites, near the Scheldt river in the Antwerp region (Belgium), several deep piezometers were placed more than 10 years ago to characterize the aquifers and aquitards above and below the Ypresian clays. Well tests were performed and a piezometric monitoring campaign was initiated.

The present study aims at characterizing the deep aquifers using more unconventional techniques: direct pressure, temperature and tidal measurements.

Considering the varying water density in the different hydrogeological units, due to differences in salt content and temperature, direct pressure measurements instead of hydraulic head measurements were performed to derive the pressures below and above the aquitards and consequently the hydraulic gradients over these aquitards. With the direct pressure measurements and the depth measurements, the groundwater densities and fresh water heads in the aquifers were calculated. At high groundwater densities and in deep aquifers, this leads to differences between hydraulic head and fresh water head of more than 4 meter.

In addition, temperature-depth profiles were measured in the same piezometers. In all these piezometers, the slope distinctly differs for sand and clay layers. This becomes even clearer when the thermal gradient is plotted in function of depth. Sandy layers are characterized by a thermal gradient of about 0.03 °C/m, where clayey layers are characterized by a gradient higher than 0.04°C/m. This contrast is due to the different thermal conductivity of both sediments, where sands are characterized by a higher thermal conductivity than clays. This proves that a temperature log can also be useful for lithostratigraphic interpretation and hydrostratigraphic delineations of aquifers and aquitards. In addition, there is also a strong similarity with a performed electrical conductivity log in one of the piezometers, except that the electrical conductivity also includes the effect of the salinity of the water.

Finally, tidal measurements were performed in the several piezometers to find out whether the correlation between the tides measured in the piezometers and the tides measured in the Scheldt could lead to a large-scale estimate of the hydraulic parameters of the different aquifers. Although the tidal amplitude is clearly damped with increasing distance from the Scheldt, the expected phase lag, however, does not occur. The usefulness of tidal measurements for determining the hydraulic properties of the aquifers is therefore questionable in this particular case. It appears that the instantaneous mechanical response dominates over de hydraulic response.

411

The Positive Water Balance Feedback In Hydric Nemoral Forests

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Feedbacks, both negative and positive, are omnipresent in natural systems. Negative feedback renders the system resilient to external disturbances, while positive feedback would amplify the impact of external disturbance. A mechanism is proposed that forests in hydric growing conditions are one such example where a period of low precipitation can shift the ecosystem from a wet to a dray state. An occasional wet spell later can kick the system back to a wet state. In fact, it can be argued that the very persistence of forests in some locations prone to developing waterlogged soil conditions due to combination of climatic, geomorphological, and geological factors are possible due to positive feedback between moderate droughts an enhance root water uptake and transpiration. A working hypothesis is that the poor soil aeration during prolonged water logging reduce tree root ability to abstract the water leading to reduced leaf area index and reduced transpiration. In turn when drought event leads to well aerated soil, root growth is reactivated, leading to increased root water uptake, enhanced leaf growth and overall higher evapotranspiration further decreasing groundwater table and stimulating root growth. If this is the case, such wet and dry spells should be evident in groundwater table and dendrochronological records. The research is supported by project No. 1.1.1.2/VIAA/3/19/524.

412

Identification Of Cerium (Ce) Anomalies In The Groundwater System Of Coastal Rhodope (Ne Greece)

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The coastal aquifer of Rhodope region (NE Greece) is a complex groundwater system which is impacted by various processes and sources such as seawater intrusion; water rock interaction; geothermal fluid circulation; and agricultural practices. In the context of MEDSAL Project (www.medsal.net) a thorough study of its hydrogeochemical characteristics was performed by collecting and analyzing 47 groundwater samples for a wide set of parameters, including cerium (Ce).

Results revealed anomalous Ce concentrations, reaching up to 142 μg/L. Nearly half of the samples (53%) appeared to have concentrations over 1 μg/L which is an indicative threshold for most natural waters. The anomalous Ce values were not widespread in the area, but oriented along the dominant tectonic structures, indicating their possible connection. Based on geological and hydrogeological evidence, the basement which is consisted of Mesozoic chlorite and sericite schists of the Circum- Rhodope complex and hosts within its deepest sections (>400m) a geothermal reservoir, underlies the aquifer system (hosted in the Neogene formation and the Quaternary deposits) with which is hydraulically connected through preferential flow paths.

This could be further supported by the results of data processing, which resulted in similar hot spots for the relatively elevated groundwater temperature (up to 27oC) and Ce concentrations.

The outcome of the R-mode factor analysis of the entire dataset, outlined a co-variation between Ce-U which indicates their common source, probably due to granites (occurring in the eastern neighboring section of the study area), as well as a factor including Ce, Al and Mn (with antithetic loading) denoting the impact redox conditions due to Al-Mn oxides. The elevated salinity content of the aquifer system seems to negatively affect Ce mobility, as reported in similar cases, by resulting in flocculation and immobilization of most particulate Ce. On the contrary, the afore described redox conditions and the increased permeability through preferential flows, seems to be the dominant factors for its fate and transport.

Overall, the hydrogeochemical fingerprint of Ce can be used as a tool in delineating hydrogeochemical processes and solute transport tracing, as well as for revealing groundwater chemical evolution in complex groundwater systems, which are probably affected by deep groundwater circulation and/or impacted by the elevated heat flow regime.

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413

Coupling Hydrogeochemical Data And Structural Modelling To Enhance Understanding Of Groundwater Circulation Controlled By Faults In Northern Sardinia (Italy)

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The complex flow pattern in groundwater originating from the geological structure often leads to difficult predictions of the main flow paths and potential mixing of groundwater. We describe a methodological approach based on structural mapping and modelling, fault sealing behaviour and hydrogeochemical tools to enhance understanding of groundwater circulation and to overcome the scarcity of data.

The Logudoro basin was considered as a test site. It is a Burdigalian half-graben that includes mainly subhorizontal continental to marine deposits such as conglomerates, sandstones, limestones and mudstones. The infill unconformably lies over an Oligo-Miocene volcanic succession. Pleistocene basaltic flows unconformably overlie both volcanic and sedimentary Miocene rocks.

The geological model was improved through detailed mapping (1:10.000). Outcrop geology and boreholes were used to constrain cross-sections. The subsequently created 3D-model validated the geological map and allowed to analyse recharge areas, aquifers interconnection and sealing conditions of the faults. Two fault sealing conditions were studied: 1) juxtaposition of different lithotypes with varying permeability along the fault section, 2) shale smear into a fault-core membrane using the Shale Smear Factor (SSF). Faults show a barrier-conduit behaviour, changing horizontal hydrogeological transmittivity.

Comprehensive field surveys, including hydrogeochemical sampling and hydrogeological measures were carried out. Water samples were collected from 13 springs, 28 wells and 3 surface waters.

Piezometric data were measured from 101 monitoring point.

The major ion composition of water samples indicates a wide range of geochemical compositions of groundwater depending on aquifers heterogeneity and their partial interconnection.

Hydrogeochemical features linked to hydraulic heads and the stratigraphic model allowed to classify water groups. Hence aquifer vertical interconnection and specific lithotype signature were determined. Furthermore, the lateral extension of an aquiclude, separating two different aquifers was identified. Adding fault seal properties allowed to understand lateral aquifers interconnections and/or disconnections. The fault sealing model confirmed the groundwater flow trend determined by the piezometric contour lines.

414

Hydrochemical, Isotopic And Noble Gas Analyses To Validate The Conceptual Flow Model Of Sedimentary Aquifers In The Cuvelai-Etosha Basin, Northern Kalahari

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The Cuvelai-Etosha Basin (CEB) hosts several aquifers, including a major deep-seated fresh water aquifer (KOH2). Located in the semi-arid region of northern Namibia, where about 40% of the country's population is concentrated, groundwater of good quality is of high socio-economic importance.

A conceptual model of the KOH2 was set up by means of geophysical surveys, core drilling and 2D numerical groundwater modelling in previous studies. First estimates on recharge areas and rates, groundwater travel time and flow direction were made.

The northern aquifers are developed in a set of intracontinental megafans formed by the paleo- courses of the Kunene and Cubango rivers. Groundwater of KOH2, recharged in the Angolan Highlands, flows southwards. The southern aquifers (DO and KEL), developed in the Otavi Moutainland (dolomite) and secondary limestone deposits are assumed to flow in a northeasterly direction (Fig. 1). The systems presumably converge east of the Etosha Pan, where the Oshivelo Aquifer (KOV) is located. The discharge area of the aquifers, their interconnections and flow directions are still subject to uncertainty. We investigated a comprehensive set of hydrochemical, stable and radio- isotope data to characterise the chemical evolution of groundwater along presumed flow paths, to identify mixing and delineate aquifer boundaries in order to ultimately validate the presumed flow model.

Data obtained from previous sampling campaigns and historical reports (1970 - 2019, > 1,000 hydrochemical analyses) was checked for accuracy and analysed statistically. Additionally, first reliable groundwater ages for the KOH2 based on 81Kr combined with the determination of noble gas (i.e. recharge) temperatures underpinned the analysis.

Low content of d18O (9.7 to 9.3 ‰ VSMOW) and d2H (67 to 63 ‰ VSMOW) in samples of KOH2 indicate colder than present-day recharge temperatures, affirming the "semi-fossil" nature of the aquifer. Noble gas temperatures of around 18°C and krypton ages of between 40 and 160 ka confirm this finding. Stable isotopes and chemical parameters (especially Ca/Mg, pH and SiO2) of samples east of the Etosha Pan show a clear distinction between the KOH2 and KOV. Since neither mixing, nor a hydrochemical evolution between KOH2 and KOV are observed, groundwater of KOH2, contrary to original assumptions, is thought to be diverted to the Southeast, instead of flowing to the Etosha Pan. The chemistry of DO and KEL is carbonate-dominated (Ca-Mg-HCO3 type), whereas the KOH2 is evolving from a CaHCO3-type to a NaHCO3-type with cation exchange and freshening as the dominant processes.

415

Classification Of Private Well Users In Ontario For Quantitative Risk Assessment And Socio-Epidemiological Modelling: A Cross-Sectional Population Study

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Background: Unlike consumers receiving water from regulated public systems in Ontario, private well users are responsible for undertaking source protection measures, including source maintenance, treatment and laboratory testing. However, previous studies have reported low participation rates with respect to these actions, thus constituting a public health concern. To improve protective behaviours, it is critical to understand and characterise unregulated well users in terms of their awareness, risk perceptions and practices.

The current study sought to examine the effects of socio-demographics, experience(s), and cognitive factors on behaviours, and classify and characterise private well users in Ontario based on cognitive factors.

Methods: A province-wide online survey was distributed from May to August 2018. The survey was designed to quantify Ontario well owners' awareness, perceptions and behaviours in relation to their personal groundwater supply and local sources of contamination. To both quantify and compare results, a scoring protocol for four cognitive factors or "risk domains" (i.e., awareness, attitudes, risk perceptions and beliefs) was developed. Two-step cluster analysis was used to classify the survey cohort based on individual risk domain scores. Binary logistic regression was employed to identify key variables associated with cluster membership.

Results: In total, 1140 survey respondents were included for analyses. Overall, increased awareness (p = 0.018) and positive attitudes (p = 0.006) towards personal well water supplies were associated with an increased probability of well water testing. Respondents reporting an annual household income >$125,000 were 51% more likely to use a water treatment system (OR = 1.51 95% CI 1.145 – 1.991). Cluster analysis identified three distinct sub-groups based on two risk domains; groundwater awareness and source risk perception (high, moderate and low scores). Cluster analysis and binary logistic regression models indicate that female respondents and those characterised by lower educational attainment were approximately twice as likely to be characterised within the "low awareness and moderate risk perception" cluster. Drilled well users and those with higher educational attainments were significantly more likely to be characterised within the "high awareness and risk perception" cluster.

Conclusion: Findings illustrate that specific risk domains and socio-demographic factors are significantly associated with well user behaviours. Cognitive clusters may be used to develop targeted interventions and communication strategies by effectively characterising well users. Characterisation of private well users will ultimately contribute to increasingly evidence-based modeling approaches (e.g., quantitative risk assessments, socio-epidemiological modelling) and reduce the health burden of water-related illness in Canada and further afield.

416

Modelling Fluoride Contamination Of Groundwater In Ghana To Estimate The Exposed Population With A Focus On Children

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About 25% of Ghana's population lacks access to essential drinking water services, and 73% have no access to secure services that provide reliable and clean water (Safe Water Network 2017). The population, especially in rural areas, is dependent on groundwater for drinking. However, groundwater fluoride contamination leading to dental fluorosis is well documented across the north of the country, where most of the population lives in rural areas (Alfredo, Lawler, and Katz 2014; Atipoka 2009). Children, especially in the first two years of life, are particularly susceptible to non- cancerous adverse effects such as dental fluorosis caused by elevated fluoride levels in drinking water. Young children can retain 80-90% of a given fluoride dose compared to 60% in adults (WHO 2001, 2004, 2008). The World Health Organization (WHO) has set the guideline for fluoride in drinking water at 1.5 mg/L. It has also recommended identifying locally relevant standards based on their characteristics (WHO 2017). For countries with a hot climate where people drink more water, such as Ghana, an even lower threshold of 1.0 mg/L has been suggested.

Despite numerous local studies on fluoride contamination in Ghana, there is no spatially continuous picture of the fluoride occurrence across the country, nor is there an estimate of children and adults potentially exposed to unsafe levels.

Therefore, we created a geospatial machine-learning model of the probability of fluoride concentration above and below 1.0 mg/L in groundwater across Ghana to identify areas at risk. We used data from 3,150 groundwater wells, including 1,214 of our own measurements, and a set of geospatial predictor variables from topography, geology, soil, hydrology, climate and ecology with random forests to model and map fluoride contamination. The resulting risk map achieved a correct classification of 76% [81, 72] and an average performance of 70% (sensitivity, specificity, precision and balanced accuracy). The distribution of fluoride varies across the country. However, fluoride was consistently high in the northeast of the county with a mean probability of 75%.

Overall about 15% of the country has an elevated risk of groundwater fluoride exceeding 1.0 mg/L. Based on recent census data, some 250,000 children aged 0-9 years live in areas at risk. In districts such as Karaga, Gushiegu and Mion, 4 out of 10 children are potentially exposed to fluoride poisoning. This information has a great potential to raise awareness and understanding, and advise local-level actions to avoid or mitigate fluoride water contamination-related risks.

417

Water Balance Modelling For Monitoring Groundwater Storage And Valuing Groundwater Recharge, A Case-Study For Flanders

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The groundwater system offers a natural buffer that can store large quantities of water for a long period of time. In case deep phreatic aquifers are present the volume of water stored in the phreatic groundwater system could be large. Nevertheless, especially in areas with shallow groundwater tables where groundwater dependent terrestrial ecosystems systems occur, the amount of water that can be extracted from the groundwater without damaging natural ecosystems is generally limited. Driven by the recent dry spring and summer periods in Flanders the societal and political awareness to carefully manage our groundwater storage has grown. Along with the growing awareness of the value of groundwater there is a strong demand for methods and indicators giving insight in the availability of groundwater. Current indicators are primarily based on scattered groundwater head observations and provide only limited insight in the regional availability of groundwater. To provide additional information on the groundwater storage dynamics we propose a straightforward water balance approach based on catchment scale groundwater recharge simulations (WetSpass-M model), river discharge measurements and groundwater abstraction data. This approach has the additional benefit that the value of different ecosystem types for groundwater recharge can be considered. This feasibility study shows that the proposed groundwater balance simulations could provide important insights in both the dynamics of the groundwater system and the contribution of different ecosystems. The results also indicate that more information is required on local parameters linked to specific ecosystems that impact the groundwater recharge to allow substantiated groundwater system management based on the water balance simulations.

418

Groundwater Level Predictions Using Machine Learning Algorithms In The Agricultural Region Of Campo De Dalías (Almería, Spain)

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The semi-arid regions of the Mediterranean coast, such as Campo de Dalías and Sierra de Gador aquifer (SE Spain), are characterized by frequent and long time periods of low rainfall, high temperatures and a strong dependence of groundwater.

In the 80's, Campo de Dalías became one of the most intensive and productive agricultural areas in the world. Otherwhise, the greenhouse's irrigation activity has been increased totalizing nowadays more than 20.000 has of greenhouses. Groundwater pumping has caused a decrease in piezometric levels and water availability in the Campo de Dalías aquifer systems. The intense exploitation of groundwater (> 100 hm3/yr) also affects water quantity and quality, with episodes of marine intrusion at some specific sectors. Currently, there are some ways to provide water to agriculture for the greenhouse's irrigation in addition to groundwater extraction, being desalinated and reclaimed water potential alternative water sources in the region.

In this study funded by European PRIMA call (GOTHAM on-going project), have been assessed the impact of water availability on groundwater quantitative status at Campo de Dalías and Sierra de Gador Groundwater Body (060.013) by Machine Learning techniques. First of all, a clustering has carried out to identify the representative points of water table time series in each aquifer sector, to preprocess the data and complete the missing values using "Mice Forest" algorithm, among others.

The input data used for the groundwater availability forecasting have been piezometric time series as the target variable (univariate approach). Moreover, to improve the goodness of fit of the predicted results, different Machine Learning algorithms (Linear Regression, XGboost, Random Forest...) have been tested and the target variable (groundwater table) has been iterated with other explanatory variables (natural recharge in Sierra de Gador aquifer and meteorological datasets such as rainfall and temperature). We have also fitted the best combination of variables to obtain a high precision (≈70% in the coming 3 and 6 months) while maintaining a good bias-variance ratio. The use of Machine Learning models can be a very helpful tool for an efficient management of water resources in scenarios such as the one studied, where socio-economic activities are highly dependent on groundwater availability.

419

Machine Learning As A Tool To Improve Subsurface Heterogeneity Characterization

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Modeling groundwater flow requires heterogeneous values of hydraulic conductivity, which commonly are only sparsely available, if at all. State variables such as hydraulic head are generally more extensively sampled and can be assimilated to improve the characterization of parameters such as hydraulic conductivity. In the last decades, many works have focused on the assimilation of piezometric heads to characterize hydraulic conductivity heterogeneity by using variants of the ensemble Kalman filter (EnKF).

In the EnKF, the assimilation is performed based on a linear interpolation that can only capture the linear component of the non-linear relationship between conductivities and piezometric heads. Alternatively, machine learning (ML) algorithms are able to capture more than the linear component and can enhance the results of the parameter characterization using inverse modeling. Algorithms of machine learning are permeating all ambits of science and technology nowadays. In hydrogeology, ML has been used mainly as a replacement for more costly modeling approaches involving the solution of complex state equations and rarely as a tool to improve the characterization of the subsurface.

The aim of this work is to propose a new inverse modeling approach by coupling machine learning and the EnKF to improve hydraulic conductivity heterogeneity characterization. Our results show that the proposed method not only is able to improve the characterization of the heterogeneity but also that it is more computationally efficient than the EnKF for the studied cases.

420

Global Assessment Of Geogenic Fluoride In Groundwater

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The geogenic occurrence of high concentrations of fluoride in groundwater is a global problem potentially affecting 100's of millions of people, predominantly in the Global South. The health effects resulting from long-term exposure include dental and skeletal fluorosis. As groundwater quality is often not tested in many areas, it is often unknown if the water in a given well or spring contains harmful levels of fluoride. In order to help determine where high concentrations of fluoride are likely to be found naturally in aquifers, geospatial prediction maps can be created that take advantage of known fluoride concentrations and the natural conditions related to fluoride accumulation in groundwater.

We have produced a global prediction model of the occurrence of fluoride in groundwater exceeding the WHO guideline of 1.5 mg/L using the random forest machine learning algorithm. A dataset of over 400,000 fluoride measurements from around the world along with a dozen high-resolution global predictor datasets of environmental parameters have allowed us to produce a very detailed and comprehensive assessment of groundwater fluoride. In addition, to better understand the factors related to fluoride accumulation in groundwater, we conducted correlation analyses between high fluoride concentrations and the predictor variables as well as other chemical parameters measured in groundwater.

The modeling results indicate that most of the fluoride-affected areas and population are found in Africa and Asia, with somewhere between 60-330 million people globally potentially consuming groundwater with fluoride concentrations exceeding 1.5 mg/L. The strongest links between environmental parameters at the surface and high fluoride concentrations in groundwater are related to an arid climate. This is confirmed in the analysis of the physicochemical parameters, where some other interesting and unexpected relationships were also detected.

The hazard and risk maps created offer a first step toward addressing widespread health consequences from the regular consumption of high-fluoride groundwater by helping raise awareness and prompting more testing of groundwater sources in high-risk areas. As contaminated sources get identified, possible mitigation solutions include switching/blending water sources or the removal of fluoride through filtering.

421

Groundwater Modelling As A Decision Support Tool For The Sustainable Management Of Strategic Drinking Water Reserves In The Chalk Aquifer (Flanders, Belgium)

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Groundwater is an important and well protected source of drinking water in Belgium. In some regions, locally produced groundwater is the source of 100% of the drinking water supply. One of the most important aquifers in the eastern part of Belgium is the Chalk Aquifer. This aquifer is phreatic in the northern part of Wallonia, but dips down towards the north, in Flanders, where it quickly reaches large depths. This largely confined aquifer is of strategic societal importance because it is well protected against negative influences on the water quality from the surface (nitrates, pesticides). However, (hydro) geological information is scarce leading to important uncertainties regarding sustainable yields. Due to the large depth of the aquifer in its confined part, relatively little borehole information is available. Furthermore, the Chalk Aquifer is characterized by a double porosity system which results in a strong heterogeneity and spatial variability of the hydrogeological properties.

In this study, the geology and hydrogeological parameters of the Chalk aquifer are characterized in detail.

Exploitation results are linked to (hydro)geological data providing insights why some exploitations have higher yields than others. A negative correlation between hydraulic conductivity and depth of the aquifer is found, explaining higher yields in the southern shallower parts and lower yields in the deeper northern parts of the aquifer. A regional transient groundwater flow model (MODFLOW) is set-up to model the current and historical situation. The challenges encountered and lessons learnt during the modelling of this complex aquifer are discussed. Next, the groundwater model is used to simulate different management strategies for the future and their influence on the groundwater system. An extensive uncertainty analysis on the model and scenarios is performed by implementing the Integrated Bayesian Multi-model Uncertainty Estimation Framework (IBMUEF).

This is done by coupling the MODFLOW model with the DiffeRential Evolution Adaptive Metropolis (DREAM) algorithm. Results show a larger impact of extraction in the north compared to the southern part of the aquifer. The potential for extraction is mapped by combining spatially distributed maps of influencing factors as transmissivity, aquifer depth, head above the top of the aquifer and simulated drawdown for a synthetic well. Based on these results, well-founded decisions regarding the sustainable exploitation of this aquifer can be made, which is of strategic importance for long-term drinking water supply in Flanders.

422

Nitrate Monitoring Of Groundwater In Flanders To Evaluate The Efficiency Of Manure Policy For The Protection Of Water Quality

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Since 2004 a Flemish phreatic groundwater monitoring network with around 2100 multilevel-wells exists to fulfil the obligations of European and Flemish environmental legislation, e.g. the Water Framework Directive and the Nitrates Directive. Originally, this network was installed exclusively in the agricultural area of Flanders to evaluate the efficiency of manure action plans (MAP) for the protection of water quality against agricultural pollution. For that purpose, a conceptual model has been developed, dividing Flanders in zones with comparable vulnerability of phreatic aquifers for nitrate pollution, the so-called hydrogeologically homogeneous zones (HHZ's). Inside these HHZ's nitrate transport and nitrate removal take place in a comparable way. Depth and spread of the observation wells are related to the nitrate vulnerability of the HHZ's.

As policy instrument for the evaluation of the groundwater quality goals serves the upper screen level of the multilevel-wells, because here most recent changes of nitrate input are expected. The observed status and trend give a good indicator for the efficiency of taken measures.

From 2004 till 2014 a clear global decrease of nitrate concentrations was observed for the upper screen level. Taken measures seemed to work, even if the nitrate quality standard was not reached everywhere. However, since 2015 a trend reversal took place with slightly increasing and finally stagnating average nitrate concentrations in Flanders. Stronger measures had to be taken to reach groundwater quality goals. Therefore a combined approach for the evaluation of surface- and groundwater and the introduction of measures on catchment-level has been developed in 2019. The larger the gap between water quality goals and measured status and trend is, the more stringent are the measures. For this purpose a four class area-type system has been introduced, going from type 0

– no additional measures – to type 3 – maximal reinforced measures. Reinforced measures are for example lower fertiliser application standards and obliged cultivation of catch crops. Despite this new adapted MAP 6, no further improvement of surface- and groundwater quality could be observed yet (23% of phreatic groundwater below arable land won't reach the goals end 2022). For groundwater, a delay of response time should be considered, but this isn't the case for surface water, neither for the nitrate residue values in the subsoil below arable land in autumn, which remain too high.

423

Recognition Of Drilling Companies: An Improvement In Quality Of Drilling And Reporting?

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Flanders is a region in Belgium where al lot of drilling takes place. At the time of writing (spring 2021), about 125 drilling companies are operating within Flanders. This means approximately one drilling company per 100 square kilometres. Boreholes are drilled for all kind of purposes : dewatering, groundwater abstraction, shallow and deep geothermal systems, stability.

Boreholes were often not reported to the relevant administrations and required permits were not always applied beforehand nor afterwards. Besides that, not all boreholes were installed in a correct manner and it was difficult to impose sanctions on drilling companies.

In order to have better control on execution and reporting by drilling companies and to keep administration and necessary permits to a minimum for the customer, in 2017 Flanders introduced a mandatory recognition for almost all drilling activities that are carried out within its boundaries.

Drilling companies are, a.o. obliged to verify the necessary permits before starting the project and to upload drilling reports within 2 months after the project. These drilling reports are collected via a digital portal of the database of the subsoil of Flanders (DOV) and are publicly available.

4 years after implementation of the recognition we have seen significant improvements, but also other opportunities.

On site enforcement of the drilling activities is not yet optimal, because not all projects need to be announced beforehand. If a drilling company knows an inspection is possible, it is more likely to work as required. Surprise inspections have a higher number of nonconformities. Therefore, a change in legislation is on its way to require prior notifications for all projects. This way, every project has a more equal chance of being inspected and it acts as an incentive to work according to regulations.

A strong increase in permit applications for dewatering was observed. The number of reported drilling sites also boomed from less than 3.000 in 2017 to over 8.000 in 2020. On the other hand, still not all projects are reported. Therefore a mandatory GPS-tracking for drilling equipment will be introduced no later than 2025. The goal being to largely reduce the possibility for illegal drilling. Due to the increasing number of reports, an automatic validation is in development. This will not only facilitate the quantity of reports, but also their quality.

424

Geogenic And Anthropogenic Assessment Of Groundwater In The Basement Aquifer Of The Communes Of Dassa And Kyon In The Sanguié Province (Center-West Region) Of Burkina

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Steady population growth in several developing countries has generated a strong demand for water, and groundwater in particular, especially in basement regions like Burkina Faso.

One of the challenges of the National Drinking Water Supply Program (PN-AEP) in Burkina Faso is knowledge of the water resource for achieving universal access to drinking water by 2030.

The objectives of this study are to assess and know the physico-chemical and bacteriological quality of 93 samples of drilling water distributed over two rural communes (Dassa and Kyon in the Sanguié province of Burkina Faso) but also to understand the geogenic and anthropogenic factors that control the chemism of these waters.

The groundwater of the communes of Dassa and Kyon is generally soft to moderately soft.

On the physicochemical level, they are of good quality overall, however, with 33 boreholes (including 11 in Kyon and 22 in Dassa) showing turbidities above WHO standards. It is also noted that Kyon borehole 28 has the highest nitrate concentration of 85.36 mg / l above the WHO standard.

High values of fet and Mn greater than 0.3 and 0.12 mg / l respectively are reported mainly in Dassa, especially in its north-eastern part and to a lesser extent in Kyon in its southern part for iron.

Bacteriological analysis showed that 46.23% of the sample boreholes (respectively 35 and 54.71% at Kyon and Dassa) are unfit for human consumption because they contain microorganisms (total coliforms, and / or coliforms and faecal streptococci) due to faecal pollution.

The application of both statistical, geostatistical and geochemical approaches helped to highlight the processes that could control the quality of groundwater in Dassa and Kyon. Indeed, the chemism of the groundwater in our study area is mainly reflected by the water-rock interaction process due to the hydrolysis of carbonate and silicate minerals. Two other processes are associated with this dominant process of the mineralization of the underground waters of Dassa and Kyon, namely: pollution due to anthropogenic activities and that linked to the activities of microorganisms. Pollution linked to humans are mainly due to the use of fertilizers such as potassium chloride and fertilizers of phosphate and nitrogen origin but also to the use of laundry products rich in sodium sulphates and that linked to microorganisms is reflected by the phenomenon of redox.

Keywords: Basement, water-rock interaction, pollution, redox, PCA, geochemical modeling, geostatistical modeling, quality

425

Isotopic And Geochemical Evolution Of Rainwater Percolating Through The Rocky Outcrops.

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Groundwater recharge of mountain aquifer requires a detailed knowledge of the hydrologic system and adequate monitoring and modeling methods to determine water amount and water quality evolution. Mountain aquifers are well known of their highly complex lithologic structure and surface morphology. These become more significant in dry climate regions (<300 mm rainfall/year) which are characterized by erratic rain pattern and extreme deep thickness of the unsaturated zone.

In this study we monitor the isotopic and geo-chemical evolution affecting the composition of the unsaturated porewater during deep infiltration, from surface to depth that is not affected from evaporation. The geo-chemical processes were characterized related to land surface morphology and climate conditions.

The research setup includes instrumentation of first order stream which is characterized by two main typical geomorphologic setting: rocky terrain and deep soil along the stream channel. Each plot was instrumented with monitoring setup that include meteorological station and Vadose Zone Monitoring System (VMS) that enables continuous water content measurement and collection of unsaturated porewater from the vadose zone.

Fast increases in water content and arrival of depleted δ18O (VSMOW) reveal quick and deep infiltration of rainwater during storm events, while enriched δ18O arrival indicates slower infiltration of water that are exposed to evaporation. In addition, the geo-chemical processes exhibited depletion in δ13C (PDB) of rainwater during the infiltration (-19 to -11 ‰) which indicate on dominant of biogenic activities and relatively low rock-water interactions.

Major elements correlation network expresses the contribution of dust and rain to the rock evolution across the water flow path.

The study results clearly exhibited different infiltration rates in each site. Fast infiltration at the rocky terrain due to rock outcrops on the surface create funnels for collecting the local runoff and delivering it into high permeability fractured zones where the water penetrates directly to the deep sections. In contrast, the bare soil areas such as hilltops or man-made terraces in streams with highly developed soil cross section, reveal limited infiltration. Also, the annual rainfall pattern impact on the geochemical process and finally impact the groundwater quantity and quality.

426

In Situ Nano-Enhanced Nitrate Removal In Groundwater Using Fe0 Nanoparticles: The Life Nirvana Project

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Nitrogen fertilizers are applied in agriculture to increase crop production but its extensive use has resulted in nitrate contamination, leading to the degradation of groundwater quality and contamination of drinking water supplies, which can pose immediate risks to human health. This is specially the case in areas with intensive agriculture of the Mediterranean area, that additionally suffer from cyclical and severe water scarcity; the degradation of water bodies by nitrates in these contexts worsens water stress and limits economic growth. Although the European Union (EU) has been developing environmental policies to protect water resources for 30 years now, nitrate is still the major responsible for the bad chemical status of European groundwater bodies (54% according to the last Report on European Waters Status and Pressures).
The objective of this contribution is to introduce to the scientific community the EU-funded LIFE NIRVANA project as well as its preliminary results. The main goal of this project is to validate under real conditions a novel methodology aiming at decreasing the concentration of dissolved nitrate in groundwater by the injection of nano-zero valent iron (nZVI). These nanoparticles (diameter around 50 nm) are characterized by large reactive areas (20-25 m2/g) and high reducing capacity, and are stabilised with an organic substrate which could stimulate microbiological activity in the aquifer. The project's pilot site is composed of two injection wells, seven monitoring piezometers and one pumping well, and has been built in a multi-layered porous aquifer located in Murcia (Southern Spain). The operation of the pilot site started in April 2021 with a doble tracer test using halite (NaCl), which let us know the flow velocity and verify the hydraulic connection between the different permeable layers. Then, we proceeded to inject the Fe nanoparticles in the aquifer and monitor the effects on the receiving groundwater.

427

The Effect Of Dental Fluorosis In Communities In Borno State, Northeastern, Nigeria

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Dental Fluorosis is a disease most commonly attributed to water consumption with excessive fluoride concentration. The primary source of drinking water in Borno State is groundwater, tapped from the three major (upper, middle and lower) aquifers of the Chad Basin, occurring in the State at different depth intervals. A more significant percentage of the local residents in the State depend on groundwater tapped from these aquifers. This study aims to investigate the root causes of dental fluorosis affecting the citizenry in parts of Borno State and to determine the concentration of fluoride in the three distinct aquifers. This aims to proffer sustainable solution(s) that will address the effect of dental fluorosis affecting the local populace. Both qualitative and quantitative data were utilised in the study. A total of 150 water samples were collected and analysed for their fluoride concentration using Spectrophotometer. The survey results show that about 15%, 30% and 55% of the individuals sampled were affected by mild, moderate and severe dental fluorosis, respectively.

Also, interview results show that only a handful (21%) of the interviewees have mild mottled teeth, while about 25% and 54% have moderate to severe dental fluorosis, respectively.

Furthermore, about 76% of the focus group participants were affected by severe dental fluorosis. The remaining percentage of the focus group participants had mild fluorosis. Lastly, the majority (over 90%) of the people affected by dental fluorosis are unaware that the problem was due to high fluoride concentration in their drinking (ground)water. Likewise, groundwater quality analysis shows that fluoride concentration is low (1.72 mg/l) in the upper aquifer. In the Middle and Lower aquifers, fluoride concentrations are in the range of 4.3 and 8.7 mg/l, respectively. The low fluoride concentrations in the Upper aquifer could probably be attributed to the shallow phreatic nature of the aquifer while the high fluoride concentrations in Middle and Lower aquifers of the study area can be as a result of fluoride dissolution from fluoride bearing minerals probably within the confining clay horizons of the area. The outcome of this study will be vital to the local policymakers in providing the solution to the effects of dental fluorosis affecting the citizenry in the study area.

428

Karst Morphology And Hydrology : An Environmental Overview Of The Bojonglopang Limestone Formation In Buniayu Karst Area, Indonesia

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The heterogenous characteristics of the environmental feature in Buniayu karst area, West Java, Indonesia was represented by the morphological complexity of karst hydrology. The knowledge of the effects and most important key to understand environmental feature controllers can be done by conducting effects measurement of hydrology and geomorphology. This study was aimed to investigate the importance of hydrology and geomorphology to environmental management in the Buniayu karst areas.

The Buniayu Karst area investigation has been conducted. The location of the Buniayu Karst area is in Sukabumi Regency, West Java, Indonesia. Based on the morphological analysis, the Buniayu karst area is dominated by the limestone of the Bojonglopang Formation and showing a mountainous region with the characteristics of karstic morphology which extends along the northern Sukabumi Regency. The Buniayu Karst area shows a distinctive morphology in the karst area in the form of caves, rows of hills and the presence of underground rivers. The Buniayu karst area generally have a system of fractures and dissolving cavities which cause limestone in the Buniayu Karst area affect to the environment in the Buniayu karst area. The characteristics of karstic hydrology in the Buniayu karst area generally have a distribution of porosity in the Bojonglopang limestone formation and also a porosity of the endokarst zone. The Buniayu Karst area has an allogeneic recharges system originating from rivers on the surface that have infiltration zones and an autogenic recharges system originating from the karstic ponor. Most of the recharge systems found in the Buniayu karst area come from the ponor which is a natural channel in the karst area where surface water enters into underground passages and has an impact on the environment of the Buniayu karst area, especially during the rainy season. Based on the hydrological analysis the surface water of the Buniayu karst area contains a high number of suspended loads. In the Buniayu karst area, the water movement is seen dominantly by the fissure and diffuse flows system.

This importance or these contributions of morphology and the complexity of the karst hydrology factors to the annual karstic environment provides a good reference for selecting key factors when developing karst area. This study yields a more prominent understanding of the impacts of morphology and the karst hydrology on environmental studies and is helpful for better management in karst regions.

Keywords: Karst, Geomorphology, Hydrology, Karst Management.

429

Investigating Properties Of Geotechnical Fills From Recycled Materials By Means Of Passive Sampling

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Industry and civil engineering are the largest consumers of non-renewable mineral resources. On the other hand, industry produces large quantities of residues (waste materials and by-products), which are potentially suitable for beneficial use, especially in the building sector. Some of these residues are widely used as recycled materials in geotechnical applications as a substitute for natural raw materials. Compared to natural aggregates and earth, geotechnical composites based on recycled materials can contain a higher total content of potentially toxic elements (heavy metals, chloride, sulphate, fluoride, organic pollutants etc.). The prerequisite for beneficial use of such composites is that the potentially toxic elements are immobilized in the composites, meaning that they are chemically inert.

The objective of the presented study was to investigate the storage and transport of contaminants which can be released from three selected composites (TERSAN, TERSAN P and DIGETERM) that are used as geotechnical fills. For this purpose, the field laboratory, based on a system of pan lysimeters, was constructed. Selected composites made using recycled materials were installed. Leachates were collected by means of lysimeters in order to study potential emissions of released contaminants.

Passive samplers have been proved to be a suitable tool in monitoring of groundwater quality. To improve analytical methods and appropriate sampling technology to support monitoring programs, we investigated the dynamics of pollutants with the Chemcatcher® passive samplers which is configurated for metals. Samplers such as Chemcatcher® are composed of a receiving phase and covered by a thin diffusion limiting membrane. Chemcatchers® are a highly versatile and cost- effective passive sampling device for monitoring a wide variety of pollutants in different waters. The results of Chemcatchers® measurements will be compared with chemical analyses of leaks. Thus, we will evaluate the applicability of the method for conducting environmental monitoring. So far, this method has shown good results, being an alternative for more expensive spot sampling techniques.

430

Detecting Persistent Organic Pollutants In Groundwater By Use Of Passive Sampling

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The presence of persistent organic pollutants in the environment is causing an increase in demand for sensitive and reliable monitoring tools, used for determining the presence of these contaminants in groundwater. They have been recognized as an important factor in environmental pollution.

Developments in a range of analytical techniques are expanding the number of persistent organic pollutants that can be detected in groundwater. Monitoring programmes for groundwater are largely based on the collection of grab (spot) samples. One of the methods to determine the presence of organic compounds in groundwater v can also be passive sampling. Contrary to grab sampling, passive sampling is less sensitive to accidental extreme variations of the organic compounds concentrations in groundwater and it also allows determination of a large range of contaminants at once. A passive sampler can cover a long sampling period, integrating the pollutant concentration over time. This paper presents the application of the passive sampling technique for monitoring organic pollutants within the four major alluvial aquifers in Slovenia used for water supply. The aim of the study was to assess the presence of persistent organic pollutants in these important water bodies, which are burdened by strong anthropogenic pressures.

The results are the basis for the implementation of measures to reduce the impact of the pollution. Passive samples were analyzed by gas chromatography mass spectrometry (GC-MS). For the interpretation of chromatograms, the AMDIS deconvolution was used. The deconvolution was covered by the GC-MS library with retention times for 921 organic contaminants from Agilent USA, as well as by the NIST 2008 library of mass spectra. Most frequently detected persistent organic pollutants were classified in different pollutant groups with respect to their origin (urban source, agriculture or industry).

Based on the results, a comparison of the presence of persistent organic pollutants in the present aquifers was made. Passive sampling with active carbon fibres was proved to be an appropriate method for monitoring micro-organic pollutants in groundwater.

431

A Multi-Disciplinary Approach Towards The Characterization Of Hydrogeological Properties And The Mitigation Of Hydrogeological Hazards In N'Djamena, Chad

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With about 30% of the Earth's fresh water hidden underground, groundwater plays an important role as a source of drinking water, especially in arid and semi-arid regions. Characterizing aquifer systems is important for the sustainable use of groundwater resources and for the mitigation of hydrogeological hazards. A main consequence of groundwater depletion in overexploited aquifers is land subsidence, which can generate further issues such as increasing flooding risks, infrastructural damages, and reduction of storage capacities of the aquifers.

This work is conducted within the framework of the second phase of the ResEau project which was launched in 2012 as a partnership between the Chadian Government and the Swiss Agency for Development and Cooperation to address the issue of water scarcity in Chad. The overarching objective of ResEau is to develop the knowledge on water resources and help establish an integrated water management system to improve Chad's resilience to climatic changes.

The present work focuses on N'Djamena, the rapidly expanding capital city in Chad where an annual growth rate of 7% creates an increasing demand for water resources and a greater reliance on groundwater. As a result, there is an increasing pressure on urban sanitation infrastructures, most of which are failing. Additionally, in recent years this area has experienced frequent flooding which is linked to the overflow of the Chari and Logone rivers and increased extreme precipitation events, which might also be exacerbated by land subsidence induced by groundwater overexploitation.

The methodology developed to characterize the groundwater resources in N'Djamena is based on a multidisciplinary approach that integrates field hydrogeological measurements and

monitoring, three-dimensional sub-soil modelling, and advanced satellite-based Earth Observation techniques. Investigation of the spatiotemporal correlation between the ground surface deformation derived by Sentinel-1 Synthetic Aperture Radar datasets acquired from 2016 to 2021, along with past and present hydrological and hydrogeological records provides insights into the hydraulic properties of the phreatic and semi-confined aquifers which are the main source of water for a population of around one million inhabitants.

The approach used in this work takes advantage of an innovative method allowing an enhanced understanding of the behaviour of the aquifer system in a region where hydrogeological monitoring is still largely absent. Further developments will lead to the implementation of tools for an integrated sustainable water resource management scheme for the city of N'Djamena.

433

From Quantitative Seismic Geomorphology To Hydraulic Conductivity: Deltaic To Fluvial Deposits In The Pannonian Basin, Eastern Hungary

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Hydraulic conductivity is the ability of a rock to transmit water under a hydraulic gradient. This value

(K) which is an essential parameter in flow simulations depends mainly on the connectivity of the pores. Here a novel work flow is demonstrated in order to build up a semi-3D lithological model for the uppermost 1500 m of the late Miocene to Pliocene basin-fill succession and to transform it into hydraulic conductivity values that can be used in numerical flow models on various scales. This study aims to focus on the methods to transform palaeogeomorphology and stratigraphy of geobodies into physical parameters which can be widely applicable to any other matured basins, where plenty of data is available.

Analyses were conducted on five 3D seismic volumes in the Pannonian Basin covering an area of 1356 km2. We started by mapping seven stratigraphic horizons and generating their associated RMS amplitude maps revealing seismic geomorphological features, such as sandy lobes, channels, channel belts and muddy floodplains in deltaic to fluvial environments. As the third step, volume of shale (VSh) was generated from the gamma-ray of 46 well logs, allowing the determination of the sand thickness in zones of interest. The corresponding sand percentages (S%) in 30 m thick intervals around the center horizons of the RMS maps, confirmed and calibrated the lithological interpretation of geomorphological features. This method efficiently demonstrated the spatial variability of sand content depending on the scale and orientation of investigation. For the vertical evaluation, the same method was applied, i.e. calculation of VSh, sand thickness and sand percentage in successive 30m thick intervals. Results reveal connection of various seismic facies and S%. High amplitude, high continuity deltaic lobes at the bottom (86.3 S%) are followed by a variety of fluvial deposits. High amplitude, moderate continuity seismic events reflect big meandering channel belts (71.3 S%). Higher up in the succession, short, high amplitude reflectors mark a significant change in fluvial style, the anastomosing rivers become widespread (54.5 S%). Even higher up, the meandering system is back to the succession (72.3S%).

Based on the lithological distribution the conductivity is interpreted in different directions, as NE-SW is the main strike of the paleo-channels. Therefore, the highest hydraulic conductivity is in this direction, whereas in the perpendicular direction SW-NE, the channel belts are crossed, we have the lowest hydraulic conductivity.

434

Characterization Of The Hydraulic Properties Of An Aquifer System Using Electrical And Electromagnetic Geophysical Measurements

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During the last decades, the water's scarcity and incremental need, climate change and its related effect such as desertification, groundwater overexploitation and contaminations, and other hazards, has led to a rapidly growing awareness in the field of groundwater management at local, regional, and global levels.

The quantitative characterization of an aquifer system has become crucial to address several hydrological and hydrogeological problems. Fluid transmissivity, transverse resistance, longitudinal conductance, hydraulic conductivity, and aquifer depth are fundamental properties describing subsurface hydrology. Many, in situ, characterization techniques are commonly used for the estimation of the spatial distribution of the above-mentioned hydraulic parameters. One of the most effective methods to estimate the hydraulic conductivity of an aquifer is the pumping tests.

We know that such field measurements are not always available due to the cost, the availability of the proper knowledge or equipment to deploy such measurements. Moreover, pumping tests are local and can only provide a sparse/limited spatial distribution of the estimated hydraulic parameters.

Geophysicists have realized that the integration of aquifer parameters acquired from existing boreholes and geophysical (electrical and electromagnetic) measurements can be highly effective since a correlation between hydraulic and electrical aquifer properties can be possible, as both properties are related to the pore space structure and heterogeneity. We should of course keep in mind that the resulting resistivity values are not absolute but relative, and therefore only relative conclusions about the area's hydraulic parameters could be made.

The main purpose of this study is to demonstrate the use of surface geophysical (electrical and electromagnetic) methods for the characterization of the hydraulic properties of the shallow aquifer at Keritis Basin in Greece.

435

A Python Framework For Reproducible Groundwater Flow Models

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There are many processes involved in creating a groundwater flow model such as: Data collection, data processing, using existing tools, creating new tools, storing raw data, storing model data, running models and processing model results. Ideally all these processes are reproducible so that others can understand, repeat and modify them. In practice these processes are hardly reproducible at all, especially when it comes to data-intensive, large models.

With a new Python framework we aim to make fully reproducible groundwater flow models starting with raw data and ending up with visualized model results. We use only open source tools and prefer to use only open data. Within our framework every model is basically a Python script. The script contains the code to convert raw data into model data, run the model and processes the model results. Thereby using a combination of existing open source tools such as FloPy and GeoPandas and new tools developed specifically for the model. Below you find a schematic overview.

The model scripts and tools are put under version control with GIT and put in separate repositories on Github. For now we store raw- and model data on a server using JupyterHub. This makes it possible for anyone to run the model without the need to install software locally. We used this framework for a number of groundwater flow models in the province of Noord-Holland in the Netherlands. The models were developed together with the Dutch Waterboard "Hoogheemraadschap Hollands Noorderkwartier" and the drinking water company "Puur Water en Natuur".

437

Impacts Of Secondary Porosity And Permeability On The Hydraulic Properties Of Brine-Saturated Salars

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Many salar systems (e.g. salt flats, salt pans, playas, etc.) are currently being targeted for lithium resources via brine extraction. Salars are complex hydrological environments where evapoconcentration increases the salinity of inflowing fresher groundwaters that contribute to brine formation. The internal hydrogeological architecture of salars dictates pathways and rates of subsurface recharge. Using a large compilation of data from numerous salars, we show that the secondary dissolution and precipitation of salts are an important factor controlling the distribution of porosity and permeability in the subsurface salar environment.

In evaporite-dominated salars (e.g. halite, gypsum), we observe that there is an ambiguous correlation of hydraulic conductivity to primary lithologic units and that the permeability appears to be controlled by secondary processes. Primary halite and gypsum have very low permeability and porosity compared to porous media. Therefore, the dominant permeability of halite and gypsum is related to depositional and secondary (dissolution and fracturing) mechansism. Many salars illustrate a strong depth dependence (reduction of >200% of original value at depths less than 30 meters) of permeability which is also due to secondary processes (i.e. compaction and loss of dissolution permeability). Comparatively, non-evaporitic units tend to maintain porosity/permeability with depth. Thus the presence of volcanic units, lithologic contrasts (mechanical stratigraphy), clastic, and biogenic units, and faulting and fracturing also impose strong control on hydraulic properties. The pattern of dissolution and precipitation is not evenly spatially distributed in salars, but it tends to correlate with inflow conditions. Our observations and interpretations suggest that (1) there is a strong scale-dependence of hydraulic properties, (2) extraordinarily high degree of heterogeneity occurs in these systems in both the horizontal and vertical directions, (3) poor correlation between observed lithology in cores and larger scale hydraulic tests indicate that core-based measurements are not representative of larger-scale hydraulic properties, and (4) brines are stored in both matrix and fractures/fissures. The role of dual-porosity varies among lithologic units and depths, therefore, transport models, resource/reserve estimates, and environmental assessments must take into account these processes.

438

The United Nations Framework Classification For Resources: New Draft Supplemental Specifications For Groundwater

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The United Nations Framework Classification System for Resources (UNFC) is used to rate, classify, and compare natural resource-development projects. The UNFC assigns ratings in terms of economic, social, and environmental viability, technical feasibility, and confidence in resource estimates at the project scale. These three ratings are termed the E, F, and G axes of the UNFC, respectively. The general standards of the UNFC are applicable to any resource-development project to help decision making in the areas of policy, regulation, capital allocation, and corporate decision-making in alignment with the UN Sustainable Development Goals. Supplemental UNFC Specifications for Groundwater released in April 2021 give hydrogeological context for using the UNFC in groundwater projects.

For the E-axis, we recognize that groundwater resource-developments have the potential to mutually interfere in time and space. For this reason, we incorporate explicit ties to groundwater- resource inventories as a pre-requisite for a project to receive a preferred E-rating. The Specifications acknowledge that shallow, renewable groundwater projects will have more E-axis constraints than deep, non-renewable developments. We added a place in UNFC for socially necessary groundwater projects, i.e., those which are small, numerous, generally unregulated, and necessary for household and small farm sustainment.

For the F-axis, we recognize that many groundwater projects are done without prescribed advancement through a technical feasibility ladder, where technology would be chosen through staged pilots and demonstration projects, and where additional performance or economic data can be gathered before sanctioning a full development. We see this gap as an opportunity for the UNFC Specifications for Groundwater F-axis to drive better technical design in groundwater developments.

For the G-axis, we are developing a robust and repeatable approach to express confidence or certainty in groundwater quantities per the UNFC standards. For groundwater projects, we recognize that while estimation of in-place quantities is an important factor in communicating project confidence, there are other factors that must be considered like: confidence in chemical quality, deliverability in the face of seasonality and climate change, project robustness and reliability, changing social values, and surface-water connectivity. The UNFC Groundwater Working Group continues to work through this challenging area and will evolve its solution in a subsequent version.

439

Conceptual Frameworks To Describe Water Age Partitioning Between Freshwaters And Brines In Lithium-Bearing Aquifer Systems

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Demand for lithium is growing rapidly as the world pushes to decarbonize the transportation system. The endorheic basins of the dry Andes (Argentina, Bolivia, and Chile) hold ~75% of the planet's reserves in the form of brines within massive evaporite-dominated aquifers. The mining of these brines and associated freshwater use has raised concerns over the sustainability of lithium extraction but much is still unknown about how the different components of the hydrological cycle interact in space and time. This incomplete understanding has led to the perpetuation of misconceptions about what constitutes sustainable or renewable water use in this region, and therefore how to allocate it responsibly. We present a new integrated hydrological framework that defines multiple distinct water stores based on their unique residence times, physical characteristics, and connectivity to other parts of the hydrological/hydroclimatic system. This framework is critical to deciphering groundwater and surface responses to natural and anthropogenic perturbations in these basins.

We utilize a combination of environmental tracers (3H, 18O/2H), hydrogeochemistry, and hydrophysical, remotely sensed, and terrestrial hydroclimate data to identify and characterize discrete natural water systems. The brines in these basins are primarily composed of fossil water that has accumulated slowly over geological time scales, juxtaposed against brackish and freshwater systems supplied with water of varying ages, the interactions between these two systems are key to understanding their environmental sensitivity. Results indicate that characterizing these systems with only a water balance approach does not allow a sufficient understanding of these systems. Due to deep vadose zones, long flow paths, and poorly mixed waters, assessment of transit and residence time is required along with budgeting modern inflows and outflows. Impacts from water extraction in each water body differ greatly, thus any sustainability assessment must be done in the context of each of these individual systems.

The resulting framework shows that water consumption is not equal for all waters and lumping different sources into one water footprint can result in unreliable estimates of sustainable extraction rates and prediction of impacts.

440

Hydrochemical And Stable Isotopes Assessment Of Groundwater In The Semi-Arid Zones Of Bauchi, North-Eastern Nigeria

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One of the issues militating against food and water security in the arid and semi-arid regions of sub- Saharan Africa is the unfavorable meteoric conditions and climate change. Sustainable management of groundwater resources, however, remains the panacea and lifeline for such zones. There is, therefore, a great need to investigate the chemistry and recharge characteristics of groundwater reserves, to ascertain their quality and stable isotope fingerprints in the face of the slow-burning climate change. This study focused on the characterisation of groundwater in a typical semi-arid in Bauchi, Northeastern Nigeria.

Groundwater samples (45) were purposively collected and in-situ determination pH, conductivity, Total Dissolved Solids (TDS) were performed using a digital meter. Hydrochemical and stable isotope analyses were accomplished using atomic absorption spectrometry (cations), ion chromatography (anions), and mass spectrometry (isotopes) correspondingly.

The TDS and pH values of 95-1,154 mg/L and 6.8 -7.7 and 49 -1,105 mg/L and 5.0-6.5, characterised the basement terrain and the sedimentary areas respectively, suggesting a moderately acidic to alkaline low mineralised groundwater. Calcium (2.6-128 mg/L) is the dominant cation in the basement areas, suggesting silicate weathering/ dissolution, while Na+ (1.9-106 mg/L) dominated the sedimentary zones, attributable to base exchange reactions. The water quality index revealed that the basement setting is predominated by poor to unsuitable groundwater, while the sedimentary terrain is characterised by potable groundwater. The dominant hydrochemical facies in the basement areas were Ca2+-(Mg2+)-HCO3,-characteristic of recharge meteoric water. The Na+- (K+)-HCO3- facie (14.1%) characterised the sedimentary zones, indicative of cation exchange reactions. Stable isotopes revealed meteoric source characterised by kinetic evaporation with values of $\delta^{18}O$=−3.4‰ and $\delta^{2}H$=−19.6‰ for the basement area. However, values of $\delta^{18}O$=−4.1‰, $\delta^{2}H$=−25.7‰ for the sedimentary terrain are indicative of depleted groundwater due to latitude effect and longer residence time.

The recharge system of the basement groundwaters is influenced more by precipitation as compared to the sandstone aquifers.

Keywords: hydrochemistry, water quality index, groundwater, stable isotope, kinetic evaporation

441

Estimation Of Groundwater Potential For Manual Drilling Using A Machine Learning Approach And A Groundwater Database In South Western Democratic Republic Of Congo (Drc)

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The interpretation of groundwater data is important for a correct groundwater management. But most of the countries they do not have an updated, completed and easily accessible groundwater database.

The aim of this research is to evaluate the contribution of automatic analysis of groundwater data with a specifically designed tool based on a machine learning approach to estimate the groundwater potential in low- income areas of Africa with limited direct hydrogeological information.

The study area is located in the South-western provinces of Democratic Republic of Congo (DRC). The region is covered by Quaternary alluvial deposits, with tertiary sandstone and small areas of Precambrian crystalline rocks. Morphology is almost flat or slightly undulated. The access to safe drinking water is low (less than 50% in most of the study area). Groundwater is exploited mainly with moderate shallow boreholes, generally manually drilled in the unconsolidated aquifer.

In order to estimate the potential for groundwater exploitation using manual drilling techniques at national level, a study focused to the identification of suitable zones has been carried out in 2018. In the meantime, a preliminary example of national groundwater database has been set up, using the methodology already applied in Guinea Bissau by UNICEF and the University of Milano Bicocca.

In this research the correlation between hydrogeological conditions, geological context and morphometric indicators have been analysed using different statistical procedures.

Furthermore, the tool Mlmapper, developed by the University Complutense of Madrid, has been applied to process the data using a machine learning approach and estimate two indicators related to the groundwater potential of the unconsolidated aquifer: the expected yield of boreholes and the percentage of coarse texture in the saturated exploitable zone.

A series of GIS layers related to the geology, geomorphology and hydrography of the area have been generated. The Mlmapper plugin uses different algorithms to estimate the probability of drilling positive boreholes across the region, (according to threshold values for the two indicators defined taking into consideration water points for small-medium communities). This procedure is carried out automatically splitting the data set in a trial subset (used in the learning process of the algorithm) and a control subset (used to estimate the accuracy of the results).

The study demonstrates that setting up national groundwater database and processing the information with simple automatic tools could provide a strong support for the decision-making process in the implementation of sustainable groundwater development in Africa

443

Groundwater Origin Determination And Groundwater Flow Modeling Coupled With Isotope Analysis In Endemic Ecosystems Over The Coastal Desert Of Perú

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The Lomas is a particular endemic ecosystem in the coastal desert of Peru where vegetation is sustained by air moisture rather than precipitation and recharge is considered marginal low with an estimated value of 0.15 mm/year. Even with those conditions, groundwater flow regime over the lomas in the Pachacamac Valley allows the presence of a single spring that was utilized for centuries and is still considered sacred.

The urban and industrial development has reached the limits of the Pachacamac lomas and an increased interest has been developed to understand the origin of the spring and the overall aquifer system together with the interaction with a nearby valley. To reach an acceptable understanding of the groundwater flow regime without disturbing the ecosystem, an comprehensive field work coupled with numerical modeling and isotope analysis have been conducted on the lomas area and a nearby river valley.

Recharge was estimated with an unsaturated zone flow modeling done with MODFLOW UZF on a daily basis for over a year. This recharge was an input for a numerical model on a regional scale developed in MODFLOW and calibrated with 3 springs over the lomas and the valley and 23 observation points. From the simulated groundwater flow regime, the lomas spring capture zone was determined with MODPATH. Results from the simulations were compared with stable isotope analysis (Deuterium and O18) over the dry and wet season. The study concluded that the lomas spring has its origin on the regional recharge and other valley springs originated from the interaction from the river and the granular aquifer.

444

Mapping Seasonality In Seawater Intrusion: Geophysical Investigation And Numerical Modeling

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Groundwater is an essential resource worldwide for human beings and the sustainability of ecosystems. The majority of the coastal populations globally are directly dependent on groundwater as their primary source of water. The study of coastal aquifers forms a unique discipline in groundwater hydrology because they are typically characterized by salt, which demands the special treatment of flow, chemistry, and overall management.

Geophysical methods are widely used techniques for saltwater intrusion; however, time-series monitoring using advanced geophysical techniques is relatively new. In this study, we use the electrical resistivity imaging technique to monitor the saltwater - freshwater interface and its inland and seaward migration as a function of seasonal changes in hydrological control. The hydrological regimes are terrestrial head gradient, salinity/density differences, recharge, and hydraulic conductivity. We develop a coupled MODFLOW- SEAWAT numerical model to cross-validate the geophysical measurement, taking the southern coast of Rhode Island in the Northeastern United States as a test site.

445

Constraining Modern And Historic Groundwater Flow Dynamics And Recharge Rates In Large Sedimentary Basins Using 14C Ages And A Coupled Flow-Reactive Transport Modeling Approach

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Proper evaluation and forecasting of regional groundwater resources and sustainability in response to climate change and human-induced stresses demands a thorough understanding of the ensemble of hydrological dynamics characterizing multi-aquifer systems. Towards this goal, groundwater residence times have frequently been implemented in complement with traditional hydraulic observations to provide insight into groundwater flow dynamics, recharge rates, paleo-hydrologic conditions, and subsurface heterogeneity. The utility of groundwater ages has made them particularly important for calibrating groundwater flow models. In this study, we take advantage of the extensive archive of geochemical and hydraulic data available for the Aquitaine sedimentary, multi-aquifer basin located in Southwest France to inform a 3D regional numerical flow model.

Reactive transport capabilities were integrated into the flow model to simulate radiogenic carbon (14C) transport behavior both spatially (spanning a distance of ~80 km) and temporally (over the past 40 ky). An inverse modeling approach using measured 14C activities was then implemented to infer groundwater age distributions and constrain modern and historic (~20 ky) recharges sources along with aquifer response times. Spatial variations in 14C activities and apparent groundwater ages suggest recharge in the aquifers characterizing the Aquitaine Basin is largely driven by vertical infiltration and passage through low permeability aquitards.

446

Monitoring The Development Of A Fresh Ground Water Lens In Artificial Dunes

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Due to climate change, countermeasures are necessary to protect coastal zones from the effects of sea level rise. One measure is the construction of high artificial dunes. This solution is more natural and flexible compared to conventional dikes. A mixture of sand and salt water is put on the beach by a hopper dredger through a floating pipeline or using the 'rainbowing' technique. In both cases a vast amount of sea water is deposited as well. After construction a fresh water lens will develop. In our case, this could have an negative effect on the inland nature area, that depends on the brackish water quality conditions that existed before construction of the dune. To determine the extent and timing of the changes a comprehensive monitoring network is used. We will show the results 7 years after construction. The borehole geophysics (multiple measurements per year in transects perpendicular to the coast) proved to be indispensable to understand the fate of the fresh water. The measurements were used as a basis for conceptual modeling. Further research will focus on improving the model and specifying the effect on the nature area as well as proposing effective mitigating strategies.

447

The Unicef Programme To Support Groundwater Development In Democratic Republic Of Congo

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Democratic Republic of Congo (DRC) has only 43% of the population with access to safely managed or basic service for drinking water (source: JMP data 2017). There are political, financial and technological factors that make difficult to put in place an effective strategy to improve the situation at country level.

To tackle this situation, UNICEF since 2010 promoted manual drilling, low cost drilling techniques that can be an adequate solution for a large part of the country. Manual drilling techniques allow the installation of high quality boreholes with one third of the cost of mechanized boreholes and the use of light equipment that can be transported in those regions with difficult access. UNICEF program to support low cost drilling techniques in includes: a) training in hydrogeology, administration and construction of drilling tools; b) Creation of provincial associations and national federation of manual drillers; c) Market strategy to facilitate availability of spare parts; d) Strengthening external supervision and data collection.

In 2018 a study to identify those areas with suitable hydrogeological conditions for manual drilling has been carried out, indicating that 40% of the territory has suitable conditions, with another 24% moderately suitable.

With this program it has been possible to complete 1806 manual drilled boreholes between 2010 and 2018, providing safe water to an estimated population of 650'000. Although these activities were mainly oriented for manual drillers, in the last years they have been extended to the whole drilling sector: Several companies had expanded their activity to mechanized drilling, targeting those areas where it is necessary to drill into fractured aquifers.

In the mean time a groundwater database, not existing in DRC before has been installed, using the approach previously used in Guinea Bissau for the definition of the data structure and making a pilot test of application of tools for automatic data analysis in the South Western region of the country.

At the moment the groundwater database contains the information of almost 1000 boreholes. Technical details of the boreholes are easily accessible online and can be used for the planning of drilling programs, Given the strong interest received for this database, UNICEF is ready to launch a larger activity to increase the number of boreholes included and define improved procedures for data collection, organization, retrieval and interpretation.

The collaboration between UNICEF and the government is producing positive results and contributing to improve the dramatic water situation of DRC.

448

Self-Organizing Maps For Groundwater Quality Assessment Of A Belgian Chalk Aquifer In The Presence Of 1,1,1-Trichloroethane Abiotic Degradation

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In a Belgian chalky aquifer, groundwater quality has been locally affected by a mixture of Chlorinated Aliphatic Hydrocarbons (CAHs) dominated by 1,1,1-trichloroethene (1,1,1-TCA). The first results showed that the latter undergoes abiotic degradation by hydrolysis and dehydrohalogenation in the saturated zone. The released acids (hydrochloric and acetic acid) from these reactions influence calcite buffer action in the aquifer and change locally the water hydrochemistry.

In addition, the leaching of soluble inorganic compounds from a backfill layer has also influenced the groundwater composition in the same area. Calcium sulfate has migrated to the saturated zone with recharge water.

To confirm the first findings and elucidate the effect of each pollution source on the groundwater quality, 3 datasets from 3 annual sampling campaigns were used for Kohonen's Self-Organizing Map (SOM) analysis. The groundwater chemistry dataset used comprised: pH, electrical conductivity, Ca2+, Cl-, SO42-, HCO3-, (Ca2+-HCO3-), TCE, 1,1,1-TCA, 1,1-DCE and the molar ratio 1,1-DCE/(1,1,1- TCA + 1,1-DCE).

For each dataset, 3 clusters were identified within the groundwater plume. The first cluster is characterized by a chemical composition that reflects the presence of 1,1,1-TCA degradation reaction products, an increased calcite dissolution, and migration of Ca2+ and SO42- from backfill soil to the groundwater. The second cluster is characterized mainly by the effect of Ca2+ and SO42- migration to groundwater. The third cluster reflects the less contaminated groundwater with a composition approaching the groundwater background composition (before pollution) in the studied aquifer. The clusters spatial distribution and their chemical specifications were quite similar between the 3 datasets.

In this study, the application of SOM's is a useful tool to improve the understanding of groundwater quality changes in a contaminated site. Based on this multivariate statistical method, detection of zones influenced by two different groundwater pollution sources was possible within the studied plume.

The combination of SOM's results with the results from: backfill soil characterization, sulfate isotopic signature in groundwater, compared to the one in backfill eluates, has led to a better understanding of the ongoing mechanisms influencing hydrochemistry in this study site.

449

The Use Of Phytoscreening To Assess The Occurrence Of Vinyl Chloride In The Shallow Critical Zone At Illegal Dumping Sites With Potential Exposure For Residents

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Chlorinated ethene (CE) contamination is widespread in groundwater and the occurrence of vinyl chloride (VC) among others is a well-known issue due to its mobility, persistence, and carcinogenicity. Human exposure to VC generally occurs through inhalation from soil vapor intrusion into buildings at sites with shallow groundwater contamination. Soil vapor intrusion risk is traditionally assessed through soil gas surveys or by measuring gas emissions at the surface with flux-chambers. Phytoscreening (sampling and analysis of tree trunk cores) was proven as an alternative cost-effective technique to indirectly detect contamination by higher chlorinated ethenes occurring in the shallow critical zone, i.e. from the shallow groundwater up to the ground surface.

However, the technique has appeared barely capable to screen for contamination by the lower chlorinated VC, likely due to its fugacity, with only one literature record showing successful detection in trees.

We applied phytoscreening at two sites with severe CE contamination nearby residential buildings caused by illegal dumping of chlorinated pitches from petrochemical productions. The two sites show variable amounts of VC in the shallow groundwater (in the order of 1e1 up to 1e4 µg/L) posing sanitary risk issues. However, preliminary soil gas and flux-chamber measurements were not able to detect VC.

At both sites, we collected trunk micro-cores from a few poplar trees close to contaminated piezometers and analyzed CE concentrations (µg/kg) with Purge&Trap or Direct Thermal Desorption followed by Gas Chromatography/Mass Spectrometry.

Besides core analysis, the occurrence of CEs in the tree trunk was assessed in the field using colorimetric gas detector tubes inserted in the core sampling holes. Three to four sampling surveys were performed between 2019 and 2021 at each site in different seasons.

CEs were detected in all trunk cores with total concentrations ranging between 150 and 5300 µg/kg. VC was detected in many instances between 2 and 33 µg/kg. Positive results were also obtained from gas analysis through detector tubes. Trunk core and shallow groundwater concentrations of CEs were compared showing consistent trends over time. The effect of hydrogeological and meteorological factors on CEs detectability in trees was assessed to identify optimal sampling conditions for VC recovery.

The literature states that reductive dechlorination of CEs into trees is expected to be minimal, thus the detection of VC in tree trunks would indicate the occurrence of the compound in the shallow critical zone, suggesting higher screening effectiveness of phytoscreening compared to more traditional soil gas or flux-chambers.

450

How Do We Ensure That Hydro(Geo)Logical Models Serve The Society Better?

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Reliable predictions of groundwater systems are highly important to ensure informed decision- making to support sustainable water resources management for human use and the functioning of healthy ecosystems. Groundwater models offer a potential to understand and forecast groundwater flow systems under anthropogenic and climatic influences to provide information for decision- making and hazard risk analysis. However, the reliability of groundwater model predictions is strongly influenced by various sources of uncertainties. In this paper, we present six basic principles to improve the reliability and accuracy of groundwater model predictions considering explicitly stakeholders' needs and, thereby, serving the human society. Six principles are: (i) clearly defining the objectives and the purpose of the model, sustaining them during the entire modelling process;

(ii) incorporating local expert knowledge through stakeholders' feedback; (iii) implementing a multi- model approach in which a range of conceptualisations are explored ; (iv) considering the uncertainty arising from model inputs, parameters, conceptual model structure and measurement/information error; (v) translating the results to concrete and understandable strategies that policymakers can use for their informed decision-making; and (vi) long term capacity building and monitoring data collection to reduce knowledge gaps, test and improve predictions.

We approach the objectives by looking into various groundwater cases from different regions.

451

Assessment Of Illegal Drilling By Combination Of Drought Indices And Ndvi: Case Of The Nadhour-Saouaf Aquifer (Northeast Tunisia)

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In Tunisia, the phenomenon of illicit drilling has existed since the 1980s in both southern and central Tunisia. However, since 2011, with the weakening of the administration, several farmers and landowners have been drilling in a frantic manner in the various aquifers throughout the country.

According to DGRE , aquifers are in advanced overexploitation, more accentuated in case of drought. It would therefore be relevant to monitor, detect and forecast this phenomenon by combining drought (SPEI and SGI) and remote sensing (NDVI) indices.

The objective of this work is the monitoring, detection and prediction of illicit drilling by the cross- checking and exploitation of hydroclimatic and vegetation indices, derived from remote sensing for Nadhour-Saouaf aquifer. SPEI makes it possible to take into account precipitation and evapotranspiration on different time scales which facilitates the analysis of drought impact on water resource demands. The same is true for SGI, which makes it possible to analyze the water table level. As for NDVI calculated on time series, it allows monitoring the state of crops and their development over time.

These different indices have been used in different contexts to detect anomalies that would be interpreted as illicit drilling, since the detection of significant plant cover in drought conditions could indicate the existence of such drilling. We first computed SPEI and SGI from time series of rainfall (series of more than 30 years derived from DGRE Zaghouan database), temperatures and piezometric levels. The prior analysis of the data allowed (1) describe and illustrating, condensing, summarizing, and evaluating the data and (2) Fill gaps where they existed. Then we extracted NDVI time series derived from LANDSAT data. Finally the multidimensional exploratory analysis of the three indices combined (SPEI, SGI, NDVI) revealed relationships between them.

A robust indicator is currently being constructed to detect the probable existence of illicit drilling. The variation of this indicator will make it possible to detect the over-exploitation of aquifers caused by these drillings, based on DGRE data. This analysis, moreover, took into account the social typology of farmers in the study area and was supported by interviews with farmers. This index makes it possible to analyse the socio-spatial and temporal evolution of the study area.

452

Water Utility Behaviour And Wms Integrated With Climate Perspectives

Ariel Toh, marcharh

Contemporary challenges to meet water saving systems oriented around efficiency-saving and promoting sustainable water as a human resource plays a crucial role during weather-related scenarios. The role of climate solutions is an expanding target to meet water demand by means of tackling "efficiency" and tackling water directives compliances. In this paper, a review of water saving models and pricing policies examples are included. The content analysis provides a legitimate resource to help shape water policies into other objectives - in particular meeting climate change targets, and to safeguarding quality water for both production and consumption.

453

Social Perception Of Groundwater In Chile: A Transdisciplinary Approach For Increasing Awareness Of Water Resources

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The increasing anthropogenic and climatic pressures critically impact the availability of groundwater resources. In this context, Chile has been experiencing an uninterrupted sequence of dry years since 2010. The rise of withdrawals together with the drought caused an alarming decline in groundwater levels. This scenario demands the integration of collective practices, projects and frameworks to better improve public awareness of water use.

Taking this context into account, this paper describes some results of the project "Water: an (in) finite journey". This project aims to create an interactive children´s book to increase public awareness and critical thinking about groundwater. Based on a transdisciplinary approach, it crosses academic knowledge (communication, hydrogeology, sociology, and pedagogy), art, and empirical knowledge.

Building on and contributing to the literature that examines the social perception of groundwater, the overarching goal of this paper is to describe one of the phases of the project "Water: an (in) finite journey, particularly related to social perception of the resource. The methodology selected was to conduct workshops, using drawing as a method of data collection and participatory observation. Workshops were transformed into online format due to the Covid pandemic. In 2021, a series of online workshops took place in Santiago and Putaendo. During the process 25 children from eight to 12 years participated. Each participant created two drawing, one about how the water cycle is and another one about how groundwater moves under our feet. In total 50 drawing were analyzed. The data was codified by themes identified in the drawings in order to illustrate the scientific information they have, and also the information gaps. In the workshops, participants described their drawing and participatory observation took place.

Among the results we found that early engagement with children helps producing a more relatable science communication product. Besides, the results point out that children manage scientific information about the water cycle, however, it is not seen as a cyclical and simultaneous, being the evaporation the starting point of the process. In regard to groundwater, participants acknowledge the relevance of the resource, however, they represented groundwater as rivers and lakes. They do not include rocks or sediments. They described the underground as a homogeneous block.

This applied project offers an opportunity to describe challenges of including children into a codesigned process, highlighting the importance of understanding social perception to build better dissemination strategies, especially among young population, residents of water scarcity areas.

455

Feasibility Study Of A Hungarian Mar Pilot Site

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The demand for irrigation water in Hungary is not always met by existing surface water supplies. Based on climate water balance calculations, this study shows that the climate exposure pattern is changing, with some scenarios leading to higher exposure indicators.

A Transnational Decision Support Toolbox was developed in the framework of the DEEPWATER-CE project designed to facilitate a sustainable water management in Central Europe.

This Toolbox serves for the delineation of potentially suitable locations for different MAR systems. It includes three major components:

1. Climatological exposure mapping to find areas where MAR can be beneficial in the near future, based on trends shown by climate model simulations;
2. General mapping (national or regional screening) based on geological-hydrogeological criteria to identify potentially suitable regions and to exclude areas that are not promising for the application of specific MAR systems;
3. Specific (suitability) mapping to rank sites and find the best available site for a selected MAR technique.

Analysis of suitability maps helped delineate a Hungarian pilot area where the feasibility of a selected MAR scheme could be investigated. A feasibility study is performed related to an underground dam in SE Hungary in the Maros alluvial fan. The low relief and moderately warm and dry climate mean land use is predominantly for agriculture, however due to a sparse natural surface water network there is an increasing demand for irrigation groundwater.

An integrated interpretation of borehole logs and geophysical maps reveal the geological setting comprises thick Quaternary layers built up from an alluvial complex comprising several fluvial sequences of the ancient River Maros. Interconnected aquifers form a unified hydraulic system in the changing fluvial facies. Paleo riverbeds are the best suited shallow aquifers for a potential underground dam. An area in the vicinity of Medgyesbodzás and Csanádapáca was selected as the final pilot site based on an evaluation of the available data, preliminary field observations and geophysical profiles.

An ongoing feasibility study includes geoelectric surveys, special core penetration probe tests, hydro-geochemical and isotope hydrogeology investigations together with in-situ hydrogeological measurements. A numerical 3D hydrogeological model helps test and support evaluation of different scenarios assessing the potential effects and viability of the proposed underground dam. A risk assessment and cost benefit analysis are also carried out in addition to the geological-hydrogeological pilot site characterization.

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456

Long-Term Environmental Benefits Of The Soil Aquifer Treatment (Sat) Scheme In Agon-Coutainville (Normandy, France)

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Environmental benefits, ecosystem support and recreational services are critical aims of the Agon- Coutainville coastal area in Normandy, France. Soil Aquifer Treatment (SAT) scheme is used in addition to the WasteWater Treatment Plant (WWTP, with a 35300inh.eq treatment capacity) as a polishing step before discharge of secondary treated wastewater (STWW) to sea in an area where shellfish are commercially grown and in an estuary known for tourism.

STWW is infiltrated using surface method at a rate of 730.103m3/y into a sandy aquifer through three reed beds. Ecosystem protection was the primary purpose of this SAT system. There is a clear tendency of reclaimed water use being applied in water spreading systems with some level of SAT, in order to take advantage of the natural additional treatment in the subsurface. The difficulty is to assess this level of treatment.

In Agon-Coutainville, a monitoring plan has been in operation since 2005 for nutrients and micro- pollutants in the discharge from the WWTP and in groundwater (five observation wells) near the intermittently operated infiltration basins, and this has been agreed with national and local regulators and representatives of local government. This involves public annual reporting and reporting of any exceptions beyond the standards.

For understanding the interactions which exist among environmental, social, and economic pillars in an effort to better understand the consequences of this SAT scheme, 9 sustainable indicators and 1 levelised cost have been proposed and rated by Zengh et al. (2021). Environmental Sustainability Indicators (water quantity and quality, ecosystem services and stressors) and Social Sustainability Indicators (security human health, communinity-participation-education-justice). Based on careful consideration of the monitored data, the experts rated the SAT scheme of Agon-Coutainville as good in sustainability. The levelised cost of this SAT scheme is around 1.10US$ /m3 to be added to the WWTP which, without SAT scheme, would have discharged directly into rivers and sea.

Increasingly, this SAT scheme is also seen as a solution to enhance environmental goals, and where multiple goals can be achieved with single systems, this appears to be an added advantage as deter saline intrusion and provide freshwater for irrigation in saline environment.

457

Assessment Of Saltwater Intrusion Using Integrated Geophysical And Hydrochemical Methods In Three Selected Part Of Alluvial Aquifer Of Mateur Plain, Northeastern Tunisia

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Assessment of saltwater intrusion using integrated geophysical and hydrochemical methods in three selected part of Alluvial Aquifer of Mateur plain, Northeastern Tunisia

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The alluvial aquifer of Mateur plain Northeastern Tunisia suffers from several problems like salinity. This study presents an assessment of saltwater intrusion in Mateur plain using a combined electrical resistivity tomography (ERT) and groundwater physicochemical analysis. We used Syscal R1 Plus Switch 72 system resistivity with an array of 72 steel electrodes, a Schlumberger method with a constant 5 m electrode spacing to obtain deep information.

The software RES2DINV was utilized to get the true resistivity value in 2D covering 3 different places. We carried out the field survey in June 2019. The model obtained revealed a significant impact of saltwater intrusion from the nearby lagoon, the Bizerte lagoon-Ichkeul lake complex, indicated by low-resistivity structures generally below 20 Ωm. For Hydrochemical analyses, we collected 32 groundwater samples from bore wells. We measured parameters and major ions following the quality procedures in place. We interpreted our results using geochemical plots, ionic ratios, water quality indices. pH values within the groundwater ranged from 6.2 to 7.9. the value of EC was between 6.42 mS/cm and 12.45 mS/cm.

The highest value of EC was next to Ichkeul Lake. Spatial distribution of the groundwater salinity (g/l) highlights the danger of salinity which affects the groundwater of the alluvial aquifer. The hydrochemical analysis of the groundwater and ERT 2D profiles indicates a probable partial mixing of the groundwater with seawater.

Keywords: Mateur plain, electrical resistivity tomography (ERT), alluvial aquifer, hydrochemical.

458

A Methodological Approach For The Effective Infiltration Assessment In A Coastal Groundwater

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Saltwater intrusion is a crucial environmental problem in coastal areas. The preservation and proper management of water resources is essential in these systems. Climate change can affect natural recharge of aquifers and sea level variation. However, the relative vulnerability of coastal aquifers to groundwater extraction and sea-level rise need to be considered in order to quantify which of these factors have the most significant impact and better manage groundwater to protect it from saltwater intrusion. The trend of saline intrusion will be simulated in the test area of the Muravera plain in Sardinia (Italy). In this area, the natural hydrodynamic equilibrium between groundwater, surface-water and seawater has been deeply modified by the construction of two dams across the Flumendosa river and the development of agriculture, tourism and aquaculture activities along the coast. In this work, the possible future scenarios of natural recharge of the aquifers in relation to climate change will be assessed through the use of Soil Water Balance (SWB) code. Moreover, the vulnerability of coastal aquifers to saltwater intrusion and variation in natural groundwater discharge caused by rising sea levels and in relation to abstraction will be examined. Monitoring systems of hydrogeological, geochemical and isotopic indicators will be designed to improve the qualitative and quantitative knowledge of groundwater in relation to the impact that climate change will have on the natural recharge of aquifers. These strategies could be extended at a regional level on coastal aquifers with similar hydrogeological behaviour.

458

A Methodological Approach For The Effective Infiltration Assessment In A Coastal Groundwater

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Saltwater intrusion is a crucial environmental problem in coastal areas. The preservation and proper management of water resources is essential in these systems. Climate change can affect natural recharge of aquifers and sea level variation. However, the relative vulnerability of coastal aquifers to groundwater extraction and sea-level rise need to be considered in order to quantify which of these factors have the most significant impact and better manage groundwater to protect it from saltwater intrusion. The trend of saline intrusion will be simulated in the test area of the Muravera plain in Sardinia (Italy). In this area, the natural hydrodynamic equilibrium between groundwater, surface-water and seawater has been deeply modified by the construction of two dams across the Flumendosa river and the development of agriculture, tourism and aquaculture activities along the coast. In this work, the possible future scenarios of natural recharge of the aquifers in relation to climate change will be assessed through the use of Soil Water Balance (SWB) code. Moreover, the vulnerability of coastal aquifers to saltwater intrusion and variation in natural groundwater discharge caused by rising sea levels and in relation to abstraction will be examined. Monitoring systems of hydrogeological, geochemical and isotopic indicators will be designed to improve the qualitative and quantitative knowledge of groundwater in relation to the impact that climate change will have on the natural recharge of aquifers. These strategies could be extended at a regional level on coastal aquifers with similar hydrogeological behaviour.

459

Parameter Estimation Of Regional Groundwater Models: Some Pitfalls And A Few Tips

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When dealing with regional groundwater model, the essential step of parameter estimation presents a number of challenges originating from the heterogeneity of geological formations, the sparsity of observations and the implementation of the algorithm itself. The issue deserves some attention as it determines the value and robustness of model outcomes, which can eventually have some interest for decision making. The implementation of parameter estimation algorithms for ill- posed, highly parameterized inverse problems requires a bunch of somewhat subjective choices: the algorithm itself, but also a number of adjustments which sometimes lead to another, time consuming, “trial and error” process.

We conducted the parameter estimation of an extensive, multilayered groundwater model in Aquitaine (France) with the Gauss-Levenberg-Marquardt algorithm as implemented in the PEST Software. The estimation of distributed parameters (hydraulic conductivities and storage) was conducted with pilot points. An optimum strategy was developed for the seeding of pilot points so as to maximize data assimilation while minimizing the number of parameters. The solution was stabilized with mathematical (singular value decomposition) and Tikhonov regularizations (preferred value and homogeneity).

We investigated the trade-off between the integrity of sensitivities and the numerical burden of more accurate numerical solutions are more robust derivation schemes. The final outcome was successful but came at a cost. We discuss the caveats of such a strategy and provide a number of recommendations to facilitate the replication of such projects in the future.

460

Channeling Resources During Droughts Through Deep Learning-Based Analysis Of Satellite Imagery Data

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As droughts become more frequent and severe due to climate change, the protection of groundwater is increasingly crucial. For example, recent droughts in the state of California in the United States reveal the importance of groundwater and the danger of overusing it in the irrigation of crops.

To aid local governments, non-profit organizations, and other governance structures in channeling resources and personnel to areas that are affected by droughts in order to preserve aquifers and provide relief to residents and ecosystems, we propose the deployment of deep learning-based systems that are trained on multitemporal satellite imagery. Machine learning models like convolutional neural networks (CNNs), especially when trained on imagery data sources like earth observation data and even social media data, have proven to be key assets in assessing natural hazards and mitigating or adapting to their occurrences. Namely, we use the ResNet CNN architecture and train on satellite imagery captured before and after the droughts. In this manner, corresponding pairs of images are included as training data.

The output of the model is a classification integer from 0 to 5 representing the severity of the drought in the image, which can be further segmented into image “crops.” When deployed, this artificial intelligence-powered technology seeks to provide quickly-sourced, enhanced information to policymakers that aids in the allocation of resources, humanitarian response, and disaster recovery.

Prior to deployment, the interpretability of our deep learning models should be further studied, which encompasses gaining a deeper understanding of the inner decision making processes of the algorithm.

461

Assessment Of Groundwater Recharge Rates Under Projected Climate Change In Arid And Semiarid Tunisia

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In arid and semiarid regions groundwater often represents the major water resource. In these regions, the demand for water is constantly increasing. Recharge is an important term in the groundwater balance. But climate change is expected to slow the level of recharge by 10% to 30% by 2070.

The present paper aims to study the impact of climate change on groundwater recharge rates using climate and numerical modelling. For this purpose, we chose two groundwater systems located in Northeast and central Tunisia: Korba and Kasserine aquifer system.

Korba coastal aquifer (Area=438 km²), located in the Cap Bon Peninsula (mean precipitation is 450 mm and mean annual evapotranspiration is 1100 mm), is overexploited for agricultural purposes. the Kasserine Aquifer System (KAS) Located in an arid region in Central Tunisia (mean precipitation is 300 mm and mean annual evapotranspiration is 1233 mm), is a transboundary aquifer extending into the northeast of Algeria. The main regional reservoir of the KAS is the deep Miocene sandstone representing the most available source of water supply in the area.

In both study sites, a numerical modelling method (HYDRUS-1D) was applied to estimate the present diffuse recharge rates using climatic and soil field investigation campaigns dataset. Three and four soil profiles, representing different recharge zones, were selected for Korba and the KAS groundwater systems respectively. Daily mean temperature and precipitation were extracted from 11 regional climate models forced by general circulation model (GCM-RCMs) issued from EURO-CORDEX project. EURO-CORDEX provides the most recent high resolution climate projections for the European domain with a 0.11° resolution (horizontal grid spacing of ~12 km). The period 1970–2000 corresponds to the historical model simulation. Climate projection were performed over the future periods 2040–2070 and 2070–2100, with two radiative concentration pathway RCP 8.5 and RCP 4.5. Quantile Mapping was adopted as the Bias Correction approach for the projected raw daily GCM output. Results presented herein, are related to recharge rates simulated with HYDRUS1D for the KAS using 4 GCM-RCMs outputs. The remaining calculations are ongoing. For Korba aquifer, the calculated yearly aerial recharge rate, using HYDRUS-1D, ranged from 0.7 to 6.2 %. For the KAS, model calculations showed that recent recharge rates were between 0.6 mmyear-1 to 20 mmyear-1, representing a groundwater recharge percentage between 0.2% and 6.7%.

Projected recharge rates showed decrease reaching 180% for some models and profiles but in other cases it showed an increase of 122 %.

462

Assessing The Impact Of Human Activity, Managed Aquifer Recharge And Climate Change Scenarios On Groundwater Nitrate In South Portugal

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Agricultural practices in south of Portugal have developed strongly in the 1970's leading to an high increase of groundwater resources abstraction over the past decades, as well as aquifer salinization and contamination by nitrates.

The highest levels of contamination (reaching up to 300 mg/L of nitrate in groundwater) are observed in the Campina de Faro multi-layered Aquifer System (M12) located in the western part of the drainage basin of the Ria Formosa lagoon, an ecologically sensitive and economically important wetland. Despite the implementation of the EU Nitrates Directive since 1997, nitrate levels are still high in some locations, constituting a threat to the ecological status of the Ria Formosa coastal lagoon, where the M12 naturally discharges.

In the current study a groundwater flow and nitrate transport model was developed and used to assess how nitrate transport is controlled by intrinsic properties, human activities and implemented restoration measures. Additionally, the model is also used to assess the impact of Managed Aquifer Recharge (MAR) methodologies on the nitrate contamination distribution, in particular, two MAR scenarios: a) scattered large well infiltration of rainwater intercepted from greenhouses and; b) enhancing in-channel riverbed infiltration.

Results show that the response of the M12 to the implementation of good agricultural practices in compliance with the European policies is very slow, indicating that good qualitative status would be impossible to reach by the required EU deadlines (i.e. 2027). Integration of climate change scenarios into the transport model reveals that despite the implementation of restoration measures, there could be a retardation of the nitrate levels decrease in the upper aquifer as a result of enhanced evapoconcentration caused by lower recharge, higher water demands and incomplete mixing within the aquifer.

As for MAR scenarios simulated in the model, scenario a) large well infiltration, shows that the injection of the available water does have a positive impact in decreasing nitrate concentration, but this effect appears to be noticed only in the vicinity of the injection points. As the additional infiltration is spread out over M12, impacts are localised and the change in water budget is insufficient to create significant increases in hydraulic gradient. Regarding b)

Enhancing riverbed infiltration, on the other hand has significant impact, reducing time to compliance at some observation points by up to 20 years, however, this effect is more impactful in observation wells near the river, whereas wells further away are less impacted.

463

Contribution Of Geophysical And Hydrochemical Methods Unto Characterization Of Groundwater Emergences Exploited For Irrigation : Case Of The Irrigated Lowland Of Sindou In Burkina Faso

August Kinglo, Student members SAURET ELIE, INERA

The objective of this study is to contribute to the improvement of knowledge on groundwater emergences in order to ensure a sustainable management of spring water in the Sindou lowland in Burkina Faso. The choice of the study site is justified on the one hand by its geological context, straddling sedimentary and crystalline formations, and on the other hand by the presence of natural water sources. It was therefore necessary to explain the conditions of emergence of the groundwater as well as the origin of the spring water, which are currently poorly known. To this end, geophysical investigations such as very low frequency (VLF) electromagnetic prospecting and spontaneous polarisation were carried out. The electromagnetic prospecting made it possible to obtain a 2D image of the conductivity of the subsoil and to highlight fracture zones. Spontaneous polarisation was used to detect anomalies generated by the vertical emergence of water in the fractures (Zhou W., 1999). These geophysical approaches coupled with geological, hydrogeological and geomorphological data have made it possible to explain the conditions of emergence of these water sources. With regard to the determination of the origin of the spring waters, the classical methods of hydrochemical study of the waters, such as the study of the hydrochemical facies of the waters thanks to the Piper diagram, the calculation of the saturation index IS (dolomite and calcite), and the study of the relative ages of the waters have made it possible to determine the characteristics of these spring waters and their origin.

The results obtained highlighted three different types of springs, including the Hillslope springs, represented by spring group 1 (S4-S5-S6- S10), present in the very hilly northern part of the perimeter, the overflow springs or Mound Form, represented by spring group 2 (S1-S2-S3-S7-S8-S9-S11), located near the interface between the sedimentary and crystalline zones, and the depression springs, represented by spring S12, appearing as a result of the meeting between the static level of the surface water table and the natural ground.

464

Contribution Of Hydrochemistry And Multivariate Statistics Unto Characterization Of The Quality Of Irrigation Water : The Case Of Sindou Peaks Irrigated Area In Burkina Faso

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The objective of this study is to mobilise information on the qualitative state of the spring water and the surface water of the irrigated perimeter of the Sindou peaks. A total of thirteen (13) samples were taken in 1.5 litre PET bottles at the end of the dry season. The transport and storage conditions were carried out according to standard methods for water testing (WHO, 2011). The analysed data were validated using best-fit models. The interpretation of the analytical data shows that CaMg- HCO3 is the dominant hydrochemical facies in the study area. The percentage of sodium, SAR, osmotic pressure and dry residue indicate that the analysed samples are in the allowable sodium risk category for agricultural applications, and that most of the samples fall in the C1S1 range, indicating low salinity and low sodium water that can be used for irrigation on almost all soil types. However, the presence of a certain degree of cations, iron anions and heavy metals indicates that the perimeter waters could change the quality of these waters in the near future. Finally, three processes governing mineralization were identified using multivariate statistics (PCA). These include natural, anthropogenic and redox mineralisation.

465

Surface Water Modelling In The R'Dom River Basin Using Gis Technique And Swat + Model

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Title: Surface Water Modelling in the R'Dom River Basin using GIS Technique and SWAT + Model Abdennabi ALITANE*1, Ali ESSAHLAOUI2, Ann VAN GRIENSVEN3, James Celray

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In the hydrological cycle, Surface water is one of the important components. Many processes such as natural and anthropogenic processes (climate change, population growth, industrial growth and land use/land cover change, etc.) affect the interaction exchange between cycle water phases at Atmosphere, surface water and groundwater. The geographical information system (GIS) is used for generating land cover/land use data and soil series. Soil and Water Assessment Tool + Model (SWAT+) integrated with Geographic Information System (SIG) was used to simulate the streamflow concentration on daily bases of R'Dom River Basin (1938 km2) situated in the north of Morocco for the period from 2000 to 2014 including a two years warm up period (2000/2002) . SWAT + is physics-based, computationally efficient, and has the capability to simulate continually over long periods. The Distributed hydrologic Model subdivides the watershed into sub-catchments and each sub-catchment further divided into Hydrologic Response Units (HRU).

The model was calibrated and validated for streamflow using observed data for the periods of 2002-2009 and 2010-2014 respectively. The NSE estimates for the calibration and validation period are estimated to be 0.56 and 0.53, respectively; similarly, the R2 estimates for the calibration and validation period are estimated to be 0.85 and 0.83, respectively, indicating a good relationship between modeled streamflow and observed streamflow at the daily scale. The result of water balance for the whole simulation period shows the potential evapotranspiration (PET) around about 1089 which is calculated using Penman-Monteith. The annual average of rainfall is 445.28 mm, where the evapotranspiration (ET) represents 69.6 % of the rainfall and 18.71 % is lost by the total flow and the percolation represented by 11.69 % from the rainfall.

Keywords: Surface Water, R'Dom River Basin, GIS, SWAT + Model, and streamflow

466

The Thau Hydrosystem Under Surveillance: An Observatory To Prevent Seawater Intrusion In The Submarine Vise Spring (Balaruc-Les-Bains, France)

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The Balaruc-les-Bains peninsula is subject to seawater intrusion intrusion phenomena by the sudden and prolonged inversion of the flow through the submarine Vise karst spring (the so-called "inversac" phenomenon). The inversion process spreads saltwater from the Thau lagoon downstream of the karst aquifer developed in Upper Jurassic limestones. This process modifies the local field of hydraulic heads and groundwater quality. Nevertheless, the preservation of the quality of these groundwaters and their uses (drinking water, thermalism...) is crucial. Such preservation requires a better understanding and prevention of the inversion process which already occurred 7 times over the last 50 years.

For this purpose, an observatory has been installed over the territory since 2019. Offshore in the Thau lagoon, the submarine Vise spring was equipped with flow recording devices as well as electrical conductivity and temperature monitoring sensors. Onshore but close to the spring, three boreholes of 45 m, 168 m and 300 m deep each were drilled near an existing thermal borehole, and a new borehole including fiber-optic distributed temperature sensing (FO-DTS) is currently under completion.

Sub-hourly observations of pressure, electrical conductivity and temperature in these boreholes and in the lagoon, as well as synoptic measurement campaigns focused on groundwater chemistry, complete a monitoring network of about twenty boreholes and springs spread accross the territory.

Thanks to this observatory, the last inversion process which started on November 28th could be characterized with a high temporal resolution on a dense monitoring network. This monitoring network allowed to follow: the sudden rise of the water level in the wells (more than 2 m locally) and changes of temperature and salinity associated with the transport of salt water in the karstic aquifer. Overall, this observatory provides valuable observations that helps better understand inversion processes drivers, which up till now remained overlooked.

467

Assessment Of Transient Variations And Effective Management Geotechnologies For Mine Drainage From Enugu Coal Fields, Southeastern Nigeria

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Coal, an important energy resource, has been explored and exploited from the Enugu area, southeastern Nigerian, since early last century.

The mining activities, inevitably, have not only generated unprotected and untreated spoils (rejects) but also liquid effluents that are allowed to freely invade the contiguous unmined areas and settlements with dire consequences to the environment. In addition, the mining pits and underground shafts are known to be prone to excessive flooding due to uncontrolled groundwater influx, a geotechnical adverse situation that often culminate in straining mining budget and impairing mine safety protocols. The economic implications of mine water evacuation and the environmental problems associated with drainage discharges predicate the need for the evaluation of the hydrochemical characteristics, transient modification patterns and sustainable treatment technologies. The hydrochemical facies of the mine drainage is examined with the view of elucidating the ambient geologic and hydrogeologic processes and to access sustainable remediation options to the groundwater incursion and acidic effluents. The method adopted for the investigations included field mapping and hydrochemical analysis of mine effluents over a two years period. The results of the hydrochemical analyses were compared with standard specifications, a priori measured data and with their variation in seasons. The Enugu coal field contains one hydrostratigraphic system in which multiple aquifer units of sandstone are interdigited with shale and/or coal seam aquitards. The units exchange groundwater through the ubiquitous fracture and fault systems as evidenced by the similarity in gross hydrochemical character of water from the coal fields. However, the facies demonstrate significant variations with data reported over two decades ago and with seasons both of which have significant implications on mine water genesis. The mine water originate from groundwater flow and rainfall recharge through the aquifers and flow dynamics is influenced by the fractures which act as drains before the water is intercepted by the mine tunnels, pits and shafts. The rate of reaction and hydrochemical activities varies within the mine and with seasons, so does the chemistry of the resulting water. Since groundwater influx into the mines cannot be prevented, considering the hydraulics of the area, it is advised that for economic reasons, that treatment is the most practical solution to mine draining problem. Analyses of treatment options show that the environmental effect of the mine water may be reduced and eventually eliminated by treating and recycling it for use.

468

Hydrogeochemical And Isotopic Characterization Of The Middle Magdalena Valley Basin, Colombia

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The Middle Magdalena Valley Basin is an important economic development band where a significant percentage of the Colombian GDP is produced. Activities such as agriculture, livestock, oil and gas industry are developed there. Water requirements of these activities are provided by surface water and groundwater. The pollution and unavailability during dry seasons of surface water have turned groundwater into a reliable source for more than five decades.

From the geological point of view, the north part of the Middle Magdalena basin is a sedimentary sequence that endured drastic environmental transitions: from continental to marine during the Mesozoic and then back to continental in the early Cenozoic.

Nevertheless, there is no proper management of the aquifers because the technical and scientific knowledge of this resource is limited. During the dry and wet seasons about 300 water samples were collected (rain, springs, rivers, wetlands, and wells from 10 to 350 m depth). Major ions, stable isotopes (2H, 18O, 87Sr/86Sr), CFC, and 3H were analyzed.

Compositional Data Analysis (CoDA) techniques were implemented on the hydrochemical data before a multivariate statistical analysis (MSA) based on a hierarchical cluster and a principal component analysis (HCA and PCA). As result, two main clusters were grouped. Less mineralization at the southern zone (where the Cenozoic formation outcrops) with Na+ - HCO3- water type compared with the northern tendency (in the alluvial quaternary formation) with Ca2+ - HCO3- water type. The CoDA-PCA grouped southern cluster to the Cl+, probably as the influence of the precipitation which is about twice than in the north. The northern cluster is associated with silicate weathering from fragments of igneous rocks transported in the alluvium fan close to the eastern Colombian range.

Stable isotopes were grouped close to the local meteoric line (built with rainy samples) even the deepest wells. It suggests that recharge by precipitation is the main inlet on the whole Valley.

However, seasonality is reflected in the isotopic composition and is used to identify transit times and surface-groundwater interactions. It was confirmed through the age estimation based on CFC-11 and CFC-113 concentrations in water samples collected in the shallow wells (less than 60 m depth) which was less than 30 years. On the other hand, 87Sr/86Sr measured in the deepest wells displays connections with the Magdalena River and the influence of the rocks at the east.

469

Economic Potential And Geochemical Exploration Significance Of Brine Discharges In Abakaliki Fold Belt, Southeastern Nigeria

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Brines (saline water) incident in Abakaliki fold belt and other inland rift systems in the Benue trough as surface natural discharges from springs and lakes as well as in excavations used for metallic ore mining. The brines are allowed to freely discharge into the basins with dire environmental impact on land, surface and ground waters, ecological receptors and human health risks. The economic and technical viable remediation option of the impacts of brines spurred the view for envisaging the potential for economic utilization of the saliferous waters. Hydrochemical analyses of the brines has enabled the evaluation of the geothermal energy potential, industrial mineral resource estimation and geochemical exploration significance. The results show surface temperatures that range from 31 o C to 46 o C and calculated estimate of geothermal gradient varies from 44 to 61+ 2o CKm _1 and heat flow ranges from 50 to 76 + 5 mWm_2 . The gradient values are higher than minimum of 40 o ckm_1 recommended for low ethalpy geothermal resource. Infact, high gradient is even expected at increasing depth because of the proximity to igneous intrusion, pyroclasics (volcanic rocks)and ore bodies which are potential heat sources. Geothermometric assessment using the hydrochemical and isotope parameters show good comparison with mineral equilibration temperatures reported for other existing low enthalpy geothermal brines. Similarly, a comparison of the hydrochemical facies concentration of the brines with the chemistry of brines known for use in production of industrial chemicals indicates that the concentrations of Li,Cl, Na and Br are highly favourble for use for in the production of industrial chemicals. However, the hydrochemical facies of the brines show some significant spatial variations in concentrations distribution within the basin. The spatial vitiations are prominent with hydrochemical facies. of Br, Ba, SO4, Ca, Mg and TDS. The trends in the spatial variations in the concentration of hydrochemical facies coincide with the clustering patterns of known deposits of metallic ore and thus, constitute an important criterion for locating subtle or unknown ore deposit or their differentiation within the basin.

471

Effective Monitoring Of Emerging Organic Compounds In European Groundwater

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In Europe, emerging organic compounds (EOCs) in groundwater is a growing research area. Prioritisation for monitoring EOCs in Europe was formalised in 2019 through the development of the first voluntary groundwater watch list (GWWL). In parallel, HOVER - WP8 "Effective monitoring of emerging contaminants: development and validation of new assessment methods" (H2020 co- funded project) put together 7 active eurogeosurveys stimulated by developing a consistent approach to groundwater monitoring for EOCs in term of sampling, site selection, monitoring strategy and methodology including analytical technics. The aim in Europe is to develop a unified strategy for the classification, and prioritisation of EOCs to be monitored in groundwater.

Groundwater occurrence data in the peer reviewed literature for Europe has not been reviewed to date. The first task of the HOVER – WP8 project was to compile evidence from the recent published studies from across Europe, since 2012, when the last major literature global review of EOCs in groundwater took place. It was complemented by a questionnaire circulated to all eurogeosurveys in order to gain an overview of any published and unpublished work previously undertaken on organic compounds of emerging concern in groundwater. Thirty-nine studies were identified for review based on specific selection criteria (geography, publication date, sample size>10, inclusion of EOCs data) and 30 organisations that completed the questionnaire. The two most frequently detected EOCs, carbamazepine and caffeine, occurred in groundwater at concentrations of up to 2.3 and 14.8 µg/L, respectively. The most frequently published and unpublished category of compounds were 'Pharmaceuticals'; a highly studied group with 135 compounds; and 'Perfluorinated compounds'.

The use of analytical methods is not uniform across Europe, and this inevitably influences the current assessment of EOCs in groundwater. A correlation between the number of compounds analysed for, and the number detected in groundwater highlights the need for further studies, especially larger-scale harmonized studies throughout Europe. A sampling and analysing test for 20 EOCs in 4 groundwater sites by 3 laboratories also reveals the limited robustness of EOCs results when concentrations are reported close to the limit of quantification. It is urgent to better estimate sampling and analytical uncertainties and to consider it when reusing EOCs data. For the development of EU and national regulation, further work is required to understand and interpret the occurrence and impacts of EOCs in groundwater throughout Europe and elsewhere.

473

Large-Scale Non-Stationary Geostatistical Modeling In Surface And Subsurface Hydrology

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Early applications of geostatistics in hydrology have largely focused on modeling spatial variation in relatively small domains (1-100km). With climate change, there is an increasing need to model physical processes at a much larger scale (100-1000km); likewise, the geostatistical methodology needs to be expanded and adapted to that scale. Almost by definition, such large-scale modeling is a problem of non-stationarity, the change of statistical variation in space-time. Traditionally, this was addressed through trend functions, covariates or by means of non-stationary covariance models.

These methods fall short when the variation is much drastic and the inference problem covering 1000s of km with billion cell models. Using two case studies in hydrology, I illustrate some new concepts that can address the non-stationary challenge. The first case study pertains to the spatial interpolation of the bedrock topography of the Thwaites glacier in Antarctica. Predicting the ice movement of this glacier is critical to the prediction of sea level changes in the next 50-100 years. Such ice movement is function of the bedrock topography and sedimentological variation of the substrate. To map such topography, radar flight line data are acquired over a 2000 x 2000 km area. I illustrate how multiple-point geostatistics with training images acquired from the Artic allow for a realistic interpolation. The non-stationary variation in the choice of the training images stitched together using a Bayesian model selection drives the non-stationarity in the spatial interpolation. In a second case, I illustrate the use of non-stationary level set functions in the interpolation of paleo- valley aquifers from AEM data for the Musgrave region in Australia. Here a method McMC algorithm is develop that gradual perturbs a flat surface over a 500 x 500 km area to match the geophysical data as well as create realistic connectivity in the paleo-valley structure.

476

The Isotopic Fingerprints Of Salinization - A Process-Oriented Approach

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Groundwater salinization in coastal aquifers of the Mediterranean is an omnipresent risk to the water supply. There are different generic pathways of groundwater salinization. The fast and reliable identification, reconstruction, and early detection of groundwater salinization processes are essential to remediation measures. Stable isotopes have been used in many instances to identify geochemical sources, evaporation processes, mixing of different water types, and in some cases also geochemical processes linked to salinization. Within the MEDSAL initiative, a review of stable isotope patterns related to salinization, including a wide range of light and heavy isotopes, has been undertaken. Geochemical modeling of salinization paths with PhreeqC and Geochemical Workbench has been carried out to derive indicators and fingerprints of salinization. These types have analyzed for their stable isotope fingerprints using the stable isotopes of hydrogen, oxygen, carbon, boron, sulfate, and strontium in combination with residence time indicators such as tritium, carbon -14, SF6 and radium isotopes. As a result, seven different generic process patterns of salinization have been found. For each pattern, geochemical pathways and indicators are supported and validated by stable isotope and residence time markers. Besides the apparent salinization sources of rock-salt dissolution, mixing with or up-coning of seawater and brines with or without ion-exchange, and soil salinization that each have a present and paleo-type, two new patterns of salinization can be identified. Solute trapping emerges in basins that have lost their natural drainage and solute discharge and accumulate dissolved weathering products. Specific salinization patterns also arise from geothermal systems' residual waters or from contact with secondary fracture filling in fractured aquifers. In rare cases serpentinite weathering with water extraction at a high rock to water volume ratio can produce extreme geochemical salinization types. Within the MEDSAL initiative, this identification approach has been applied to experimental coastal aquifers, each characterized by salinization. In each of the study areas, the dominant salinization type is identified as a basis for remediation or risk reduction measures.

477

Sustainable Groundwater Management In Ancient Greece - Lessons Learnt From Archeohydrogeology

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The ancient temple of Hera on the island of Samos in eastern Greece has been built on the alluvial fan of the Imbrassos river. The archeology and hydrogeology of the site have been studied in an interdisciplinary project. Archeological studies involved the reconstruction and analysis of ancient wells, water collection and pipe systems, and especially the analysis of structures to capture and collect groundwater from the alluvial fan. At the same time, the site has been equipped with modern monitoring devices to capture the response of the system the seasonal rainfall, flood occurrence.

Groundwater levels have been monitored in ancient wells and remnants of hydraulic infrastructures. Current recharge rates have been reconstructed from stable isotope profiles. The source and relative contribution of groundwater to the ancient water supply have been identified using geochemistry, stable isotopes, and inverse compartment mixing models. Finally, a groundwater model of the entire study area has been developed to investigate the response to extreme climate and hydrological events. The picture emerging from this interdisciplinary archeo-hydrogeological study contains several inspiring elements regarding sustainable water management practice in ancient Greece. All wells have been constructed in a way that prevents up-coning and intrusion of seawater. The bottom of wells at the site of Hera's temple has been found at 0.05 m above sea level. Modern groundwater wells in the same area not obeying this construction principle are affected by groundwater salinization and require abstraction management and monitoring. The ancient system had been designed as an overflow system resilient to salinization.

Groundwater modeling has shown that the site is highly resilient to droughts and can provide groundwater supply even after prolonged droughts lasting more than 15 years—the resilience results from the selection in the convergence zone of several basins and aquifers. A complex system of pipes connecting wells to the most proficient springs and aquifers provided water. Archeological evidence and historical dating of these structures give deep insights into paleo-water levels during operation. The cooperation between archeologists and hydrogeologists helps to understand paleo-hydrogeological conditions and reveals water management techniques applicable to modern systems.

478

Seasonal Variability Of Pesticides In Surface And Drinking Water Wells In The Annual Cycle In Western Poland, And Potential Health Risk Assessment

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Drinking water wells on a riverbank filtration site are exposed to plant protection product contaminations infiltrating from the contaminated river. At the Mosina-Krajkowo well field in Poland pesticide contaminations of the Warta river and riverbank filtration water (wells and observation wells) in the annual cycle were examined. 25 of the 164 tested pesticides were detected. The highest concentrations occurred in the river water and were reduced on the flow path from the river to the wells. Only the most persistent substances were detected at the farthest points from the river.

During the study period, seasonal changes in pesticide concentrations and differences in the occurring substances were noticed. The most substances and the highest concentrations were detected in May 2018, the least substances and the lowest concentrations in February 2018. Based on the research, periods of increased exposure of water to pollution (mainly spring) were indicated. The periods were combined with increased chemical plant protection and more rainfall. The dominant group of pesticides was herbicides, which is in the line with the worldwide trend. In the highest concentrations in surface and riverbank filtration water occurred 7 pesticides: isoproturon, nicosulfuron, imidacloprid, terbuthylazine, chlorotoluron, S-metalachlor, and prometryn, mainly toxic and persistent. Some of the detected substances (isoproturon, prometryn and simazine are banned in the European Union. Pesticides are widely used in the research area, so a potential health risk assessment was performed. The values of hazard quotients (HQs) do not exceed 1, which does not mean a significant risk for human health. The highest values of HQs were noted for common fungicide tebuconazole.

479

Fractured Rocks Of Central Chile Coast: Insight Groundwater Exploration By Means Of Topological Approach

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Central Chile (30°-36°S) is currently experiencing water scarcity due to a prolongate drought that led to the overexploitation of alluvial aquifers. Rainfall decreases by 25% to 45% and river's flow by up to 90%, revealing the need of an efficient water resource management and of a deep understanding of the hydrogeological systems.

Efforts are being focused on the search for new water sources, especially in no conventional geological settings and unexplored areas, such as the coastal areas of Central Chile that are fast growing in terms of population and agricultural activities. Chile's coastline is 6435 km and has not been the subject of in-depth hydrogeological studies despite the increasing anthropic pressure. Literature and technical reports indicate piezometric levels variations and biological pollution occur suggesting depletion of groundwater resources for drinking water supply.

We started new studies to determine the hydrogeological potential and to assess the role of fractured rocks in groundwater circulation and storage of the coastal area of Central Chile. With this purpose, a topological and fracture analyses were carried out in the Laguna Verde area (~33.1°S), a peninsula area made up by a Jurassic diorite affected by N120E-oriented long-lived regional-scale faults, inherent from pre-Andean tectonic stages.

Preliminary results indicate that the dominant fracture orientation is N120-150E, which intersect with a secondary family of fractures (N50E), increasing fracture connectivity in the coastal zone. These orientations result from a strong structural control of the long-lived regional-scale faults in the diorite basement. Recent published studies in the Western Andean Front pointed out that faults with similar orientation are preferential conduits for groundwater allowing the recharge from Andes to alluvial aquifers. This finding may be latter transposed to Laguna Verde area. The N120-150E- oriented fractures could be so considered as a predominant control of the anisotropic hydraulic properties governing both fresh groundwater and sea-water intrusion transfers, promoted by the natural and/or anthropic influences in the Central Chile coastal areas. Nevertheless, a deeper assessment of faults control on groundwater in coastal area is needed because of the complex geological setting and to promote a suitable water resources management.

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480

Optimized Approach For Groundwater Management For Drinking Water - Application To A 10 Million Cubic Metres /Year Well Field (South Of Bordeaux – France)

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In southwestern France, all drinking water supplying the conurbation of Bordeaux originates from groundwater (springs and well fields). Today, two major aquifers supply this demand: the 'Oligocene aquifer' and the 'Eocene aquifer'; historically, the first one is the main resource for Bordeaux. In recent decades, the proportion of water abstracted from boreholes in the Oligocene aquifer has increased by 10 M m³/year from 1975 to 2005, while since the early 1990s the production from the Eocene aquifer decreased in the same proportions. Considering the increased water demand due to this population increase (8% between 2011 and 2016) and the potential impact of climate change on the flowrate of springs, Bordeaux must increase its drinking-water production capacity while ensuring the sustainability of the groundwater resource.

This study aims at determining the best way for a sustainable exploitation of a well field south of Bordeaux, while minimizing the impact on groundwater resources by using optimization and hydrogeological-surrogate models in addition to the regional hydrogeological multilayer model developed at BRGM with the MARTHE® groundwater-flow software program. The general structure of the model contained 720,093 cells of 100x100 m size in six layers (four aquifers and two confining layers). It will help evaluating the feasibility of using surrogate models for optimizing pumping rates of a well field over a regional multilayer aquifer. This optimization approach investigates a much larger number of combinaitions than the classic trial-and-error approach. It is carried out by the CAPUCINE® software, which follows two strategies:

- Strategy 1: Optimization under constraints considering the management requirements of an existing well field (maximum drawdown, maximum pumping rate of each well);
- Strategy 2: Optimization to study the opportunity of drilling and exploiting new wells while taking advantage of the existing water-supply pipe network.

Though it is usually considered that preserving groundwater quality necessarily implies restricted exploitation, this works shows that other exploitation strategies can reach this objective with a significant gain in the total extracted volume without creating new wells. Well-by-well analysis of the results shows that real-life tests can be carried out, first test show results in accordance with simulations.

Moreover, two alternative configurations, incorporating the creation of new wells, were tested for maximizing the capacity of the well field and optimizing the effective capactity of the existing pipe network. Substantial gains are expected from those configurations, reaching an additional 2.2 to 5.5 M m^3/year.

482

Preliminary Assessment Of Sediment Transport And Associated Bacteriological Contamination In A Mountainous Rural Karst Area (Sierra De Ubrique, S Spain)

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In rural karst areas, where agricultural and cattle activities are developed and quite often urban waste waters are not properly treated, the high probability of groundwater pollution occurrence together with the high vulnerability of carbonate aquifers poses a potential risk for human health. Sierra de Ubrique is a karstified carbonate aquifer system developed in Jurassic limestones and dolostones located in one of the wettest regions in Spain (NE of Cádiz province). This karst aquifer is recharged by rainfall infiltration through karst features, but also from concentrated runoff trough Villaluenga shaft which is connected to a well-developed karst network with several syphons.

Groundwater discharge, which is mainly produced through three karst springs (Algarrobal and Cornicabra -permanent- and Garciago -overflow-), is also used for drinking water supply of Ubrique town (17,000 inhabitants). During flooding conditions, high turbidity events at the two permanent springs (up to 350 NTU) are simultaneous to maximum discharge, hindering the exploitation of groundwater for human consumption. This work aims to identify and characterize the main contamination sources and to understand the role of sediment transport in the occurrence of polluted groundwater episodes. For that purpose, a complete climate and groundwater monitoring network has been installed including a weather station and field devices for continuous record of physical-chemical parameters (discharge, electrical conductivity, water temperature, turbidity and tryptophan-like-fluorescence -TLF-). Additionally, numerous surface and groundwater sampling campaigns (December 2020 to March 2021) were performed to take samples for chemical and bacteriological determinations. The obtained results allowed the identification of different contamination types of anthropogenic origin as (1) organic (poorly treated waste waters, fecal remains from cattle activity and food factories) and (2) inorganic (leakage of waste water of storm tanks). The response times in output signals of the two main springs, maximum thresholds of pollutants and statistical correlations among specific chemical/bacteriological-like parameters lead to explain the main contaminant transport mechanisms, which greatly differ in the examined karst connections. Even though, the influence of the concentrated recharge is clear in both of the springs, as clayey sediments from the shaft catchment erosion and its remobilization from inside the system serve as the main transport vector for contaminants, so that pathogens and trace metals mainly travel attached to particles through adsorption and biding processes. The main outcomes and the methodology applied in this research will be transferable to intensely karstified areas worldwide where karst groundwater represents the main water source for urban development.

484

Unreaveling Hidraulic Connection Of Coastal Aquifers To The Sea From Responses To Tidal Fluctuations

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Seawater intrusion and other contamination from the sea are a common issue in coastal aquifers under human pressure. Their negative effects could be avoided by pumping in those wells with worst hydraulic connection. The hydraulic connectivity indicates the existence of geological materials that facilitate the flow of water and reduce its transit time.

Hydraulic connectivity can be defined qualitatively through natural tests in which the variation of the piezometric level is observed as a function of the variation of the tide. The more the signal recorded in the well resembles the tidal signal, in terms of amplitude and frequency, the greater the hydraulic connectivity.

However, it is common in coastal aquifers to observe hydromechanical effects due to the semi-daily variation of the tide. The variations that occur in the piezometric levels due to hydromechanical effects do not necessarily indicate a hydraulic connection, since they are transmitted as a pressure wave due to the elastic properties of the aquifer.

In this work, a methodology to compare the hydraulic connection of coastal wells is presented. This methodology is based on the different response that hydraulic and hydro-mechanical effects have on the aquifer (see Figure 1).

Sea tides can be decomposed in harmonics with a wide range of frequencies, from low (months) to high-frequencies (days or hours). The response of coastal aquifers to each harmonic encloses a different kind of information according to the harmonic frequency. Hydraulic effects are assumed to be observed only in low-frequency waves, while high-frequency waves only reflect hydromechanical behavior. The proposed methodology suggests focusing on low-frequency harmonics to stablish the hydraulic connection of the aquifer to the sea. An application of this methodology is presented for the aquifer system of the Matanza-Riachuelo river basin and its connection to La Plata river.

485

A Webtool For The 3D Conceptualization And Animation Of Groundwater Flow Systems

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It is often difficult to communicate groundwater-related aspects (fast vs. slow groundwater circulation, mineralization processes, contamination paths, etc.) to people without a basic hydrogeological knowledge. The description of groundwater flow systems is particularly difficult in complex geological environments, and this may lead to differences in interpretation and understanding. Either, conceptual models are highly schematized and static, or dynamic models are too sophisticated, and request hydrogeological skills to understand processes. In order to better explain the various hydrogeological processes in a given aquifer system to stakeholders, a webtool (interactive 3D-animation) to visualize conceptual models of groundwater flow-systems in 3D has been developed as an extension to visualkarsys.com within the frame of a joint-project between Danone Waters, SISKA and I4DS. This is designed for all types of hydrogeological settings, and can address different timescales (few days event, seasonal regimes, long term trends) and spatial scales. The aim of this webtool is to explicitly show how groundwater flows (infiltration to unsaturated zone, flowpaths in the saturated zone) through complex heterogeneous aquifer systems (high- contrasted permeabilities, thick unsaturated zones, cascading aquifers, multi-layers aquifers, etc.) as those tapped by Danone Waters worldwide.

Input rainfall is generated as falling 3D drops which may be spatialized at a certain location or extrapolated over the whole project area. When touching the ground surface, 3D drops are converted into particles which may runoff and/or infiltrate depending on the hydraulic conductivity of the geological layer. Particles infiltrate vertically through the unsaturated zone until penetrating the saturated zone or until reaching the basement of the aquifer. In that case, particles follow the topography of the aquifer basement before penetrating the saturated zone. In this zone, particles organize as a flows field and converge toward the main outlets (springs or tapped/artesian drillholes). Tools for representing residence time and mineralization processes are also available.

Users may parameterize the timescale, the precipitation rate as well as a series of more global parameters (ET and P versus elevation, etc.). Animation scenarios may be saved and later retrieved by all users having the permissions to access the project. From a technical point of view, the webtool is built on a per-project basis which can be shared between users. Frontend functionalities are based on the Angular 7 web framework (TypeScript) and 3D animations run with threeJS. Functionalities of the webtool will be presented on the operating test site of the Pasuaran volcanic aquifer (Eastern Java, Indonesia).

486

A Way To Use Karst Groundwater For Managed Aquifer Recharge (Mar)

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The amount of persistent pollutants in groundwater is increasing worldwide, especially where agriculture, industry and urban development are intensive. Therefore, a significant number of wells showing contaminant concentrations beyond recommended/limit values must be closed. The problem may be strengthened in some areas exposed to temporary groundwater shortage due to climate change. Managed Aquifer Recharge (MAR) combined with resources of karst aquifers may represent a promising solution. In Switzerland, the major part of drinking water is taken from alluvial aquifers in lowland settings, with a high anthropogenic pressure. Besides, karst environment represents a significant water resources, which was not extensively used given the frequently high bacterial and turbidity loads related to recharge events. However, as karst regions are less exposed to intense agriculture the level of persistent pollutants is relatively low in related groundwater.

A large portion of karst is situated in the Jura Mountains, directly north-west of the Swiss lowland. A project is being carried out to assess the potential of using karst water at the foothill of the Jura Mountains as a source for MAR. This comprises the mixing with impacted groundwater in alluvial porous aquifers in order to improve their quality, and the use of deeper carbonate aquifers as storage reservoir. So far, MAR approaches were implemented in Switzerland only in highly populated regions (Basel, Zurich, Geneva), using surface waters for recharging alluvial aquifers. The actual project on karst groundwater is therefore novel for Switzerland and may be pathbreaking for other regions with karst adjacent to lowland aquifers.

For this project, a regional assessment of all water resources related to karst was carried out, including deep groundwater in carbonate rocks (down to a depth of 500 meters below ground). The well-established KARSYS approach, including the 3D modelling of carbonate aquifers, was systematically applied in order to characterize the aquifer structure, roughly quantify the respective resources, as well as identifying potential locations for withdrawal or artificial recharge.

50 potential targets, which could potentially be used for MAR, were identified over an area of ~1000 km2. The assessed water amount is larger than 3*107 Mm3/an, i.e. a water supply for ~500'000 inhabitants. The next objective in the study is to develop specific MAR scenarios according to local hydrogeological settings and demands.

These findings highlight that even in countries with significant natural groundwater recharge, such as Switzerland, MAR can be a promising solution, especially in the case of groundwater quality problems.

488

Contribution Of Geophysical And Hydrochemical Methods Unto Characterization Of Groundwater Emergences Exploited For Irrigation : Case Of The Irrigated Lowland Of Sindou In Burkina Faso

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The objective of this study is to contribute to the improvement of knowledge on groundwater emergences in order to ensure a sustainable management of spring water in the Sindou lowland in Burkina Faso. The choice of the study site is justified on the one hand by its geological context, straddling sedimentary and crystalline formations, and on the other hand by the presence of natural water sources. It was therefore necessary to explain the conditions of emergence of the groundwater as well as the origin of the spring water, which are currently poorly known. To this end, geophysical investigations such as very low frequency (VLF) electromagnetic prospecting and spontaneous polarisation were carried out. The electromagnetic prospecting made it possible to obtain a 2D image of the conductivity of the subsoil and to highlight fracture zones. Spontaneous polarisation was used to detect anomalies generated by the vertical emergence of water in the fractures (Zhou W., 1999). These geophysical approaches coupled with geological, hydrogeological and geomorphological data have made it possible to explain the conditions of emergence of these water sources. With regard to the determination of the origin of the spring waters, the classical methods of hydrochemical study of the waters, such as the study of the hydrochemical facies of the waters thanks to the Piper diagram, the calculation of the saturation index IS (dolomite and calcite), and the study of the relative ages of the waters have made it possible to determine the characteristics of these spring waters and their origin. The results obtained highlighted three different types of springs, including the Hillslope springs, represented by spring group 1 (S4-S5-S6- S10), present in the very hilly northern part of the perimeter, the overflow springs or Mound Form, represented by spring group 2 (S1-S2-S3-S7-S8-S9-S11), located near the interface between the sedimentary and crystalline zones, and the depression springs, represented by spring S12, appearing as a result of the meeting between the static level of the surface water table and the natural ground.

489

Results From Groundwater Monitoring In Denmark, Nitrate And Pesticides

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Pesticides and nitrate poses the greatest threats to Groundwater quality in Denmark. For nitrate, the monitoring shows decreasing concentrations. For pesticides, the situa-tion is more complex. Some improvement is found, but new substances are recently found to give rise to substantial impact on the groundwater resource.

The Danish case is a strong example of the potential of the science policy interface to develop better resource efficiency. In Denmark groundwater is synonym with drink-ing water. 100 % of all drinking water comes from groundwater. To preserve this highly valued resource a national strategy for sustainable abstraction and groundwater protection has developed over the last 50 years.

Monitoring of groundwater poses the challenge that we a priori do not know much about the geology or the chemical composition of the groundwater before we establish the monitoring well. We largely depend on conceptual models that incorporate our general geochemical understanding.

The Danish Monitoring originates from 1987. 30 years' time series are available for nitrate and other major ions as well as pesticides, trace metals and a range of organic pollutants. Groundwater dating in the monitoring wells has proved to be a strong tool when interpreting the collected data. Trend reversal for nitrate in oxic groundwater on a national scale indicates changes in land use and reduction in nitrate leaching.

The improved groundwater quality is due to regulation through the consecutive Dan-ish Action Plans that have been introduced to comply with national environmental ob-jectives as well as the objectives in the Nitrates Directive and the Water Framework Directive.

Locally, nitrate trend analyses in monitoring wells have shown a more varied pattern with both upward and downward nitrate trends underpinning the need for supplemen-tary site-specific groundwater protection initiatives.

For pesticides, data was divided into subsets of different depth and concentrations . For some pesticides, it was possible to asses a change in groundwater quality over time that could be linked to policy measures.

Recently screening programs pesticides and metabolites have dramatically changed the pattern of pesticides found in groundwater and water work wells. Substances that in the first 25 years of monitoring was not accounted for are commonly found. As an example Desphenyl Chloridazon was found in 23 % of 2,456 water work wells and 8,3 of these had concentrations above the drinking water standard of 0,1 µg/l.

490

Hydrogeochemistry And Isotopic Study To Determine Surface Water Level Rise Mechanism Of Lake Batur, Bali Island, Indonesia

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Batur Lake as a closed-volcanic system lake shows a unique hydrogeochemical and isotopic characteristics compared to other volcanic lakes. The lake is located at Kintamani, Bangli at the northern part of Bali Island, Indonesia. The lake is part of the UNESCO Global Geopark Site. The water from Batur Lake has a pH of 9 with a TDS of 1100 mg/L and a heavier stable water isotope ratio than other volcanic lakes in Bali Island. The hydrogeochemical and isotopic characteristics are resembling to the characteristics of the hot springs in the vicinity of Batur Lake. This shows the contribution of magmatic fluid to the water of Batur Lake which is more dominant than the meteoric water. Indications of the influence of magmatic fluid on the lake water are also seen from the measurement of the radioisotope 222Rn concentration along the rim boundary which shows a pattern of increasing during the measurement cycle. Hydrometeorological analysis around the lake does not show any relationship between water level fluctuations with changes of rainfall and evapotranspiration rates. On the other hand, volcano-tectonic activities of the Mount Batur Complex at Batur Lake show a significance correlation with fluctuations of the water level. Previous researchers discovered a hydrothermal overpressure activity below the surface. This mechanism is responsible to the formation of permeable zone which then develop the conduit for fluid flow from deep subsurface. This confirms the suspicion of the influence of volcano-magmatic water on the fluctuation of the water level of Lake Batur.

492

Determination Of Tectonic And Non-Tectonic Structures And Their Influence On Groundwater Resources Of Mekelle Area, Tigray

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Mekelle is located in the northern part of Ethiopia and is mainly covered by Mesozoic sedimentary succession and late-coming magmatic rocks (dolerite) found in the form of swarms of sills and dykes. The area is characterized by the presence of different kinds of fractures and needs detail structural geological investigation. The main objective of this study was to determine tectonic and non-tectonic structures and the link with the structure of the groundwater reservoir. The methods that were employed aim at the measurement of the entire geological structures. From satellite images and ground measurements, the general orientation is computed to be N55°W/75°SW. Mekelle area has two aquifers, upper (first) aquifer and lower (second) aquifer; those aquifers are separated by a dolerite sill (aquitard). The fractures and faults have become the main source of recharge area to the lower aquifer. The upper aquifer is composed of shale with limestone intercalation and recharged by rainfall. Regionally, Mekelle's main fault results from tectonic impact. And hence, measurements, having nearly the same orientation are supposed to be genetically linked with it. Mekelle area comprises genetically distinct structural features. Some are developed immediately after the solidification of the rocks (non-tectonic structures) and others are developed much later than the rocks (tectonic structures). A series of measurements have been collected from the entire study area and are categorized into five trends. These are: N89°E, S60°E, N55°E, N16°E, and N12°W. The minor faults and dykes have an orientation of S60°E or N60°W, which coincides with the geometry of the Mekelle fault. The E-W or N89°E aligned fractures have a kind of riddle shear appearance with the Mekelle fault. Moreover, these fractures are found in all types of rocks indicating that they are formed much later than the dolerite. For this reason, these two structures are interpreted as tectonic origin fractures. On the other hand, all other joints do not have any link with the regional or local geological structures, and they are also mainly confined with the carbonate rocks and are absent in the dolerites. From these basic two reasons, they are non-tectonic in nature. Hence, it can be concluded that both tectonic and non-tectonic structures serve as a conduit for groundwater recharge. The features could also lead to challenges in terms of quality, mostly when the surface water includes pollutants.

493

Assessment Of Groundwater Contamination By Pesticides Using The Pwc Model In Júcar River Basin

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Pesticides are commonly used to control weeds and prevent nondesirable grow of algae, fungi and bacteria in many agricultural applications. Despite its highly negative effects on human health, environmental modeling of this kind of pesticide in the groundwater is not commonly done in real situations. Predicting the fate of pesticides released into the natural environment is necessary to anticipate and minimize adverse effects both at close and long distances from the contamination source. A number of models have been developed to predict the behavior, mobility, and persistence of pesticides. These models should account for key hydrological and agricultural processes, such as crop growth, pesticide application patterns, transformation processes and field management practices.

This work shows results obtained by the Pesticide Water Calculator (PWC) model to simulate the behavior of pesticides. PWC model is used as a standard pesticide simulation model in USA and in this work it has been used to simulate the fate and transport of chlorpyrifos in the unsaturated zone of the aquifer. The model uses a whole set of parameters to solve a modified version of the mass transport equation considering the combined effect of advection, dispersion and reactive transport processes. PWC is used to estimate the daily concentrations of pesticides in Júcar River Basin (Spain).

Results of the PWC model obtained in this study represents a crucial first step towards the development of a pesticide risk assessment in Júcar River Basin (Spain). Results show that numerical simulation is a valid tool for the analysis and prediction of the fate and transport of pesticides in the groundwater.

494

Jo.In Hydrocafe Project: Connecting And Giving Visibility To Early Career Hydrogeologists In The Online World

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The COVID19 pandemic caused a strong disruption to the scientific community, delaying research activities and preventing the celebration of traditional, in-person, conferences, and meetings.

However, the community rapidly adapted creating and expanding online channels for communication, and, since last year, we have seen an unpredicted growth of online meetings, workshops, and webinars. As a side benefit, the use of online platforms provided access for many researchers to initiatives that, otherwise, would be unachievable because of travel, accommodation, and registration costs. A new type of hybrid events, with a mix of online and in-person, could be the norm for years to come, with the advantage, as a side effect, of reducing our carbon footprint.

Jo.in Hydrocafe was launched with the idea of encouraging young and early career researchers and professionals in hydrogeology to present and share their work taking advantage of the new online platforms. The initiative aims to promote a faster track for dissemination, in a more informal way, to many young hydrogeologists around the world for which assistance to national or international conferences or publication in peer-reviewed journals is not always achievable for economic or other reasons, such as the change of institution after finishing their degrees. In addition, Jo.in Hydrocafe aims to create a network of young hydrogeologists, fostering collaboration among researchers in different countries around the world.

In the first edition of Jo.in Hydrocafe, supported by the Spanish Chapter of the IAH, 26 early career hydrogeologists from 10 different countries and 23 institutions presented their work in the 13 sessions celebrated live in YouTube. The topics covered in the first edition represented the main research subfields in hydrogeology and were mainly the results from academic works developed during Master and Doctoral degrees. By providing an online platform for dissemination out of the traditional channels, fresh graduates had the opportunity to share the results to an international audience without the requirement to attend an international conference or have the results submitted and reviewed for publication.

Given the great acceptance of the first edition and the existing waiting list of participants, the need of continuing with this project was clear. The Second Edition of Jo.in Hydrocafe, 2021-2022 will start in September 2021 with a new set of young researchers from all over the world. The sessions from the First Edition can be found in the webpage of the IAH Spanish Chapter (http://www.aih-ge.org/jo- in-hydrocafe/) and in the YouTube repository (https://www.youtube.com/c/JoinHydrocafe).

495

The Impact Of Climate Variability On Groundwater Temperature Of The Piedmont Po Plain (Nw Italy): Spatio-Temporal Analyses

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It's now recognized that a global climate change is taking place, leading to an increase in temperatures and a variation in precipitation regime, also affecting groundwater (GW) (Taylor et al., 2013).

In this study we want to evaluate how climate variability affects GW temperature (GWT) in the Piedmont Po plain (NW Italy).

The Piedmont Po plain covers the 27% of the whole region and it's the most important GW reservoir of Piedmont. It consists, from top to bottom, by Alluvial deposit complex (lower Pleistocene- Holocene), that hosts a shallow unconfined aquifer, the "Villafranchiano" transitional complex (late Pliocene-early Pleistocene), that hosts a multilayered aquifer, and a Marine complex (Pliocene) hosting a confined aquifer.

For this research, 41 wells in the shallow aquifer and 20 weather stations were selected throughout the Piedmont Po plain area, and GW and air temperature parameters were analysed for the period 2010-2019.

Both GWT and air temperature (AT) data were firstly studied with basic statistical analysis (mean, maxima, minima) and then with the Mann-Kendall and Theil-Sen methods to evaluate the trend.

The AT monthly mean data have a mean increase of 1,69 °C/10years; the monthly mean GWT also show a general increase in all the plain, with a mean of 0.85 °C/10years.

Then to compare water and air temperature, the Voronoi polygons method was used on QGis by centring the polygons on the weather stations. From this comparison, it was possible to highlight that in most cases (37 on 41, thus 90% of the analysed couples of temperature data) there is a greater increase in the monthly mean AT than in the monthly mean GWT.

The same behaviour was observed for the monthly minima and maxima GW and AT.

These results testify a greater resilience of GWT to climate variability. Future insights will be a detailed analysis of the factors influencing the more or less evident increase in GWT in relation to AT (e.g. depth of the water table, position of the monitoring well, position of the probe inside the well).

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496

Multi-Isotopic Assessment Of Potential Chloroform Remediation By A Combined Treatment Of Alkaline-Activated Persulphate In Alkaline Recharge Water Interception Trenches

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Chloroform (CF) is one of the highest-ranked halogenated volatile organic compounds in the most recent priority list of hazardous substances ATSDR, in 2019. Due to its extended use by the industry, accidental leakages or improper disposal, it is an ubiquitous environmental pollutant which can form Dense Non-Aqueous Phase Liquids (DNAPLs) at inaccessible parts of the subsoil. Persulphate (PS) injection-based In Situ Chemical Oxidation (ISCO) is a commonly applied technique for the remediation of such contaminated sites, but inducing a long-lasting alkaline activation of PS is challenging. In our contaminated site near Barcelona (NE Spain), these alkaline conditions have been already created by two recharge water interception trenches filled with concrete-based construction wastes and around 30% CF alkaline hydrolysis was previously proved by compound-specific stable isotope analysis (CSIA).

The present study aims to evaluate the use of CF (13C and 37Cl) and sulphate as a degradation product of PS (34S and 18O) isotopic data for assessing i) the remediation efficiency and ii) the oxidant consumption, respectively, during an ISCO treatment by commercial alkaline-activated persulphate (i.e., PersulfOx®) in combination with the mentioned alkaline recharge water interception trenches before its application in the field.

Firstly, laboratory batch experiments with distilled water allowed to determine the C and Cl isotopic fractionation (ε$_C$, ε$_{Cl}$ and Λ) of CF for the reaction with PersulfOx® and the isotopic pattern of sulphate produced. Secondly, the same but reproducing the field conditions, prepared with real contaminated infiltration water (e.g. containing geogenic sulphate) and crushed solid particles from the materials filling the interception trenches, allowed to investigate how the conditions of trench water could influence CF oxidation and other processes potentially interfering during the field application.

Preliminary results showed a significant difference between the CF dual C-Cl isotope slope (Λ) with PersulfOx® in distilled water and those available in the literature for CF oxidation with thermally- activated persulphate, alkaline hydrolysis, or reductive dechlorination. This fact would open its use to distinguish CF remediation by ISCO treatments against anaerobic biodegradation in field studies. However, unexpectedly, the CF Λdetermined for the experiments resembling the field conditions differed from the first one and it was similar to Outer-Sphere Single Electron Transfer (OS-SET) or reductive dechlorination, suggesting that the hydrochemistry of the trenches might affect the radicals formation and therefore the CF degradation mechanisms in the field.

497

Imagine Living In A World With No Groundwater

Ineke Kalwij, The Groundwater Project
Ineke Kalwij, The Groundwater Project

Groundwater is undisputedly the most important freshwater resource for humanity and ecosystems, yet this resource is greatly misunderstood and undervalued, which has contributed to the current concerning state of groundwater globally. The groundwater problem is complex and complicated, rooted in the combination of aquifer depletion and groundwater pollution, further aggravated by the ballooning global population and related increase in water demand. What needs to change in order to bring groundwater on a trajectory of sustainable use?

The Groundwater Project is an ambitious global initiative, driven by volunteers and collaborations, committed to contribute to advancement in groundwater education and awareness, embedded in five realms of learning, covering all levels of education ranging from children to groundwater experts. Its philosophy is that everyone should have free access to high quality groundwater knowledge. With this approach the Groundwater Project cross cuts boundaries to be unencumbered with the limitations inherent in academia, government, and commercial publishing, with one vision in mind: empowering citizens by providing knowledge tools for developing groundwater sustainably for humanity and ecosystems.

498

Considering Climate Variability In The Water-Energy Nexus In South Portugal

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There is a lack of research relating predictions of climate extremes and their socio-economic impacts on the water-energy nexus. Arid and semi-arid regions already experiencing a drying tendency, like the Algarve, will undoubtedly benefit the most from the potential prediction of recurrent droughts associated with climate patterns. Moreover, research on climate-driven variability in the water and energy sectors is required to drive adaptative policies to climate change and boost cross-sectorial synergies.

This study identifies possible policy measures based on the role of climate patterns, namely the North Atlantic Oscillation (NAO) and East Atlantic pattern (EA), on the water-energy nexus in southern Portugal (Algarve region).

Water at surface reservoirs and aquifers and solar and wind energy potentials do not share the same dominant variability scales, but their interrelationships have implications for leveraging the use of renewable energy in the water sector, particularly through water pumping efficiency gains. Coupling or synchronizations between opposite phases of NAO and EA correspond to extremes in water availability. Recent advances in the seasonal and long- term predictability of NAO and EA climate patterns can help to improve drought resilience and groundwater sustainability and have huge potential benefits in the water-energy nexus.

Groundwater depletion due to over pumping and reliance on cheap non-renewable energy sources for desalination are risks that arise from neglecting the water-energy synergies. In the Algarve, solar energy is the best adapted to the interannual variability in the water sector and the most viable solution to reduce the vulnerability of energy demand to drought. Policies promoting solar based technologies, in particular for groundwater pumping for irrigation, are one of several measures to better integrate energy and water management. Yet, there is a need for holistic and integrated management of water and energy resources to support renewable energy infrastructure. Additional measures such as adaptive planning, legal incentives, and flexible water allocation mechanisms are recommended to achieve the goals of the European Green Deal and the WFD-RBMP. We acknowledge funding by FCT-UIBD/50019/2020.

499

Groundwater Drought Monitoring In The Algarve Region

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In many water-stressed regions like southern Portugal aquifers are traditionally used as security systems against water shortages but increasing water demand and exacerbated withdrawals during drought result in quantitative and qualitative pressures that menace their sustainability. Future projections of more frequent and severe drought events emphasize the key role of groundwater in climate adaptation and call for the need of better understanding and monitoring of groundwater drought (GD). Very often the main source of uncertainty in the quantitative assessment of groundwater is abstraction. In order to evaluate the impact of abstraction on drought, first we need to understand the main features of groundwater drought, and the mechanisms of drought propagation as it translates from the atmosphere through the soil and finally to aquifers. The GDMaP project will be the first study dedicated to a regional-scale assessment of GD in Portugal. It contemplates groundwater in-situ observations as well as state-of-the-art remote-sensing data and abstraction information which are rarely considered in an integrated way.

The Algarve is an ideal pilot region to test the project methodologies given the crucial importance of groundwater and availability of good quality datasets in the area. We plan to use abstraction and climate data to distinguish the impacts of anthropogenic activities from the effects of natural climate forcing. Then, we intend to compare conditions in the Algarve case-study area to regions with similar issues, climate and drought mitigation strategies. The results will contribute elucidate the impact of abstraction and drought within critical aquifer systems in semi-arid regions.

The project comprises the quantification of GD by computing the standardized groundwater level index (SGI) from in-situ piezometric records. Comparison of the SGI with other standardized indices of drought, like the SP, allows quantifying important aspects of drought propagation as well as establishing a classification of GD typologies. State-of-the-art remote-sensing data (e.g. NOAA- AVHRR, MODIS, SPOT, Sentinel-2, GRACE) will be used to derive new GD indicators and estimate abstraction. Some of these products have already shown good potential to complement groundwater in-situ observations in Iberia. However, their potential for GD detection and in particular the value of hybrid versions of satellite-derived indices to monitor drought needs further research and will be tested for the first time over the study area. We acknowledge funding by FCT- UIBD/50019/2020.

500

Validation Of Grace Satellite Data For Water Resources Management In Iberia

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This study evaluates the performance of several GRACE products in Iberia using the closure of the water budget. The work is structured in three parts: (1) The first is an assessment of different GRACE products using a water budget analysis based on precipitation, evapotranspiration and runoff obtained from public databases and re-analysis datasets. The aim is to determine which GRACE solution provides the best closure of the water budget, first in Iberia and then in Portugal; (2) The second examines the match between GRACE-derived groundwater storage and in-situ groundwater level measurements obtained from a set of 51 piezometers, distributed across 12 aquifers in Portugal. We apply a robust optimization method for estimating aquifer storage parameters, similar to the proposed by Sun et al. (2010), to obtain estimates of the storativity or specific yield distribution in the region. The optimization problem is formulated to explicitly account for uncertainty in both remotely sensed and in-situ data by incorporating bounds on data variations; (3) Finally, groundwater time series are decomposed into trends, seasonal and residual components at an individual aquifer basis. This decomposition is of interest from the point of view of water resource management, since knowledge of water storage fluctuations is essential to establish relationships between water scarcity, climate forcing and human intervention. Data from ground- station observations (piezometric records, E-OBS and GRUN grids), land-surface models (GLEAM) and atmospheric reanalysis (ERA5) indicate that the main components of the water budget in Iberia are precipitation and evapotranspiration, contributing to approximately 63% and 32%, respectively, of the total water storage changes in Iberia. Among the 5 GRACE products tested in this study, the one that produces the best fit to the closure of the water budget in Iberia is the CSR Mascon. It is concluded that GRACE provides a consistent representation of the hydrological cycle and thus, can be used as an aid in monitoring climate-related water mass transports in the study regions. We acknowledge funding by FCT-UIBD/50019/2020.

501

Changes In The Hydrochemical And Isotopic Composition Of Epiperidotitic Springs Of The Ronda Peridotites (Southern Spain) Under Wet And Dry Conditions

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The Ronda peridotites are one of the largest outcrops of subcontinental mantle peridotite in the world. They consist of several massifs exposed in the mountain ranges of Sierra Bermeja and Sierra de Tolox (Ronda massif, ~300 km²), Sierra Alpujata (Ojén massif ~70 km²), and Sierra de Aguas (Carratraca massif ~60 km²). The massifs are mainly composed of lherzolites, minor harzburgites and dunites, and exhibit a variety of serpentinite rocks. Although peridotites, as any other hard rock, are not considered classical aquifers, to date several tenths of springs have been recognized to drain the rainfall (and snow) infiltration. So far, two types of springs have been distinguished with significantly different chemical characteristics. On the one hand, a minor group of springs present hyper alkaline waters (pH above 10), slight thermalism, CHδfluxes, and chemical compositions characteristic of COδOδclosed environments (Ca-OH type) associated with deep flows. On the other hand, epiperidotitic springs drain shallow groundwater in contact with the surface outcrops and exhibit lower pH (7-8) and mineralization. This study focuses on the hydrochemical and isotopic variations observed at the epiperidotitic springs located in one of the mountain ranges: Sierra de Tolox. Mg- HCOδis the prevailing hydrochemical facies, and Mg²δand Si (HδiOδ) are the most abundant ions. Seasonal changes can be observed throughout the sampling campaigns.

The lowest mineralization is exhibited in the wettest period: lower electrical conductivity (CE), Si (H_4SiO_4), HCO_3^- and Mg^{2+} coupled with higher total organic carbon (TOC) and pH, indicating heavy recharge and dilution of ions of the groundwater. Conversely, in drier periods and the start of the rainfall season, the water chemistry shows the most significant variations and interaction with the host rock. Especially the dissolution of Mg minerals (such as pyroxenes, olivines and serpentines) seems to explain the high $Mg^{2+}$and Si (H_4SiO_4) contents of the water. The stable isotopes δ^2H and $\delta^{18}O$ in all the water samples indicate their meteoric origin. However, the most depleted values and lowest variation are shown in the wettest periods, in agreement with the amount and temperature effect. Similarly, stable isotope C composition of dissolved inorganic carbon ($\delta^{13}C$-DIC) presents the most enriched values in the wet period, close to the atmospheric composition, confirming the recent infiltration and shorter transit time of the waters.

502

Flopyparser: Convert Modflow Input Files To Python

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Are you using Python scripts to model groundwater with MODFLOW? This software might help! Flopyparser uses MODFLOW input files to generate a neat Python script to interface with MODFLOW. The generated Python script contains all the Flopy code to write and run the MODFLOW input files. All packages and parameters are explicitly defined and a parameter description is provided from the flopy documentation. Currently MF2005, MT3D, and SEAWAT are fully supported, and support for MODFLOW 6 can be expected in the near future. The software is continuously tested to ensure that the Python scripts are valid. Use cases include:

- Collaborate with others
- Publish your groundwater model
- Clean up your messy Python code
- Migrate from a GUI to Python.

Flopyparser is a wrapper around the load functions of flopy, it therefore requires little maintenance and directly supports all packages that are supported by flopy. Ideas for new features are highly appreciated! Repository: github.com/bdestombe/python-flopy-parser

503

Inferring Aquitard Hydraulic Conductivity Using Transient Temperature-Depth Profiles Impacted By Ground Surface Warming

Victor Bense, Wageningen University and Research
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Aquitard hydraulic properties are notoriously difficult to assess, yet accurate aquitard hydraulic conductivity estimates are critical to quantify recharge and discharge to and from semi-confined aquifer systems via hydraulic head gradients. Such flux quantification is required to evaluate the risks of aquifer exploitation by groundwater abstraction and aquifer vulnerability to surface contamination. In this study, we compare existing hydraulic conductivity estimates for a regionally important aquitard obtained through traditional methods to those inferred from long-term hydraulic head monitoring and thermally-derived vertical groundwater fluxes (0.04--0.25 m/y). We estimate the fluxes using numerical modeling to analyse the propagation of decadal climate signals into temperature-depth profiles. Results reveal that climate-disturbed temperature-depth profiles paired with multi-level head data can yield accurate vertical fluxes and aquitard hydraulic conductivity.

This approach for characterizing groundwater systems and quantifying flows to and from sedimentary aquifers is more efficient and may be more accurate than conventional methods.

504

The Sealink Research Project: Submarine Groundwater Discharge (Sgd) Affecting Coral Reef Health Around Semi-Arid Islands In The Dutch Caribbean

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It is not always appreciated that submarine groundwater discharge (SGD) can exceed surface hydrological fluxes into marine environments around tropical islands. Moreover, SGD can negatively impact marine ecosystems in places where groundwater is polluted by terrestrial sources. SGD carrying unwanted pollutants (e.g., nitrates) to the marine environment has been poorly studied, especially in semi-arid climates where SGD fluxes are relatively small and often only detected through indirect measurements.

We will study the hydrogeology of the semi-arid tropical Caribbean island of Curaçao, where coral reef health has been deteriorating over the past decades. Previous hydrogeological measurements suggest the presence of groundwater fluxes towards the ocean through karst conduits, though quantitative data are currently lacking.

Field measurements will be conducted across a range of locations representing the various geological settings present on Curaçao in order to define a water balance of the island. Soil infiltration measurements will be performed for different soil types across the island and rainfall, stream discharge and groundwater level fluctuations will be monitored to determine hydrogeological responses after rainfall events. Geophysical (Electrical Resistivity Tomography) surveys will be carried out to detect and map potential flow paths in the island's karstic geology. Marine geophysical surveys will be performed to detect locations of submarine groundwater discharge onto the coral reefs. The field measurements will serve as input for a hydrogeological model of Curaçao in MODFLOW.

This project is part of the interdisciplinary SEALINK project, comprising nine PhD projects from different Dutch universities and research institutes. Together, SEALINK aims to elucidate the link between terrestrial processes and coral reef health in semi-arid tropical islands.

505

Hydrogeologic Interactions: Analytic Element Method And A Nearly Exact, Open-Source Framework

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A novel methodology is presented to study hydrologic and geologic interactions across interfaces and boundaries of both aquifer and soil features with nearly exact computational precision. This formulation utilizes a parsimonious representation of a modeling domain, by disretizing hydrogeologic features, each with its own geometry and mathematical representation. A framework to formulate the interactions amongst hydrogeologic features is presented following Steward (2020), "Analytic Element Method: Complex Interactions of Boundaries and Interfaces".

Examples illustrate that interface and boundary conditions for problems in both saturated groundwater and the unsaturated vadose zone are met with nearly exact precision.

Open-source solutions are available (at the Oxford University Press companion site) to a wide range of hydrogeological problems, including hydrologic flows and related applications in electrical conduction, wave propagation, and elastic deformation. The methods are broadly adaptable to achieve predictive capacity across interdisciplinary perspectives and fields of study in earth sciences.

506

Spatio-Temporal Dynamics Of Nitrate Leaching Through The Vadose Zone

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To address excessive nitrate concentrations in groundwater, agricultural practices are frequently adapted. However, the projects often fail to meet expectations regarding water quality improvement in the aquifers. One of the reasons is an underestimation of the time lag between an intervention on the surface and the response in the aquifer. While biogeochemical memory effects in the topsoil have been addressed in numerous research projects, the transit time and the related delay through the vadose zone has received less attention, especially for more complex geological settings.

In this study, we investigated nitrate transport across the entire unsaturated zone of six meters depth under an active arable field. We installed a Vadose Zone Monitoring System (VMS) to identify relevant nitrate leaching processes under a crop rotation from 2019-21, consisting of silage maize after plowing the grass-clover ley, spelt and canola. The sampling ports were located in 172, 311, 451 and 590 cm vertical depth. We characterised the dynamics of water flow and N transport based on precipitation and soil moisture measurements, a bromide tracer test, and via the analysis of N ions (NO3-, NO2-, NH4+) and stable isotopes in precipitation and soil pore water (δ2H-H2O, δ18O- H2O, δ18O-NO3-, δ15N-NO3-).

The spatio-temporal concentrations were in stark contrast to what is expected if nitrate-rich water from the winter leaching period successively migrates downward. Specifically, the nitrate level strongly decreased from the 1st to the 2nd level but was higher again in levels 3 and 4. In these deeper levels, nitrate concentrations rapidly dropped at the beginning of the leaching period and increased during summer, contrary to what was observed in pore water below the topsoil. These patterns can be explained by denitrification at the 2nd level located in a clay-rich horizon and a combination of preferential and matrix flow that brings down in alternation water with lower (due to denitrification) and higher (due to leaching of topsoil) than average nitrate concentrations. This leads to short-term concentration variations that overlap the long-term concentration trend. The tracer data provided further evidence that flow processes at different time scales overlap as indicated by constant stable isotope ratios of water throughout the year but yet the arrival of bromide at >400cm depth within a few months.

The study highlights the benefit for vadose zone monitoring combined with natural and acritical tracer methods to understand the temporal dynamics of nitrate input into groundwater.

507

Geothermal Exploration On Neighborhood Scale - Potentials And Limitations

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Shallow geothermal energy use and aquifer thermal energy storage bear great potential to path the way towards the decarbonization of the building sector. This is especially true for the existing building stock for which passive house standards can hardly be achieved during refurbishments.

While the thermal use of the shallow subsurface for space heating, warm water supply and seasonal heat storage is standard in countries like the Netherlands, its uptake in many other countries is yet rare. Reasons for this are manifold. One significant obstacle in the sustainable planning and operation of geothermal systems on neighborhood scale is the often-encountered limited availability of exploration data, foremost information about the spatial distribution of thermal and hydraulic conductivity. In this study, we critically evaluate the suitability of well-established as well as novel approaches to determine the variability of relevant parameters on neighborhood scale to overcome this obstacle. Based on a round-robin test, we exemplarily investigate the suitability and application limits of thermal response testing for the characterization of a complex shallow sedimentary deposit. In addition, we present first results of a study aiming to derive the spatial distribution of thermal and hydraulic conductivity by using surface electrical resistivity tomography data and vertical high- resolution in-situ direct push-based profiling data.

508

Trying To Understand The Complexity Of The Groundwater-System In The Fractured Volcanic Basalts Of The Faroe Islands – A Brief Overview

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As of today, municipalities and industries in the Faroe Islands rely mostly on surface water as their main freshwater supply. Groundwater has had little geological interest in the past, perhaps due to the naturally wet climate and abundance of rainwater in the region. But a steadily growing population, an increase in visiting tourists during the drier summer months, and a larger number of industries relying on huge daily supplies of freshwater, are pressing the need for a thorough understanding and sustainable management of the groundwater resources in the fractured volcanic basalts of the islands.

Groundwater, a subject long since explored in most countries around the world, is still in its infancy in the Faroes Islands. Up until now fresh water supply has come from surface waters and a few natural springs. In an attempt to initiate research on the subject, an industrial PhD-project has been funded by the Faroese Research Council and the private Faroese aquaculture company Hiddenfjord with the aim of exploring for groundwater for use in onshore aquaculture farming. Even though the project merely touches the surface of this complex subject, hopefully one of the positive side effects will be further research and a sharing of knowledge on the subject with other industries and municipalities around the country. The close to 700 ground-source-heat-pump-systems (GSHP) wells drilled on the islands during the last 10-15 years show clear evidence of an active groundwater- system and the question therefore no longer is if there is groundwater, but rather if it can sustain both a growing public, a changing climate, as well as new industries relying on fresh water for their production.

This study provides a brief overview of what the PhD-project has achieved since its launch in 2018, the main focus of study being in the area around the onshore aquaculture facilities on the island of Vágoy, where geological fieldwork, porosity and permeability tests, examination of larger structural elements on satellite data and drilling of the first groundwater test-well in the Faroe Islands have been completed. The resulting data have been compared to existing geological knowledge and data from GSHP wells from around the country.

Are the resulting data enough to give a thorough understanding of the groundwater system? What studies should be initiated on the Faroe Islands in order to manage this precious resource in a healthy and sustainable manner in the years to come?

510

Modeling Of Slug Tests In Fluvio-Glacial Unconfined Aquifer

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Unconfined aquifers formed of unconsolidated porous and permeable sediments deposited by river system known as fluvio-glacial alluvial deposits comprise sand and gravel, interspersed with boulders, cobbles and pebbles. The occurrence of pebbles, cobbles, and boulders may be random and scattered in the sand and gravel matrix forming the aquifer. Such aquifers are commonly encountered in Canada and the USA as well as abroad.

When performing field permeability tests in such aquifers, careful determination of the geological setting is essential for proper assessment of likely cobble and boulder concentrations and distributions located around the test well, in the zone impacted by the test. Failure to do so may seriously impact the test results and lead to erroneous data interpretations.

Physical modeling of slug test in a homogeneous unconfined aquifer is carried out in a reliable reduced scale physical setting under laboratory conditions developed at the Royal Military College of Canada. The values of the saturated hydraulic conductivity obtained from the physical modeling are in good agreement with the constant head permeameter results.

The Finite element numerical model was calibrated using the physical modeling results and therefore used in testing of the effect of cobbles under different configurations in the region around the test well screen. The resulting test data show the impact of cobbles on the calculated values of the hydraulic conductivity. This poster describes all the details of the physical and the numerical models and discuss the results obtained.

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