Annotated bibliography on

Hydrology and Hydrogeology of the Aquifers

Prepared by:

Naser Almarri

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Technical Services Department

National Scientific & Technical Information Center
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Introduction

Aquifers are essential underground reservoirs of water stored within porous rock or sediment layers. Hydrogeology studies the geological characteristics of aquifers, including their formation, structure, porosity, permeability, and the movement of groundwater within them. Hydrology complements this by examining the overall dynamics of water within aquifers, including recharge rates, water quality, and interactions with surface water bodies. Together, hydrogeology and hydrology play pivotal roles in managing and sustaining groundwater resources, assessing risks such as contamination, and ensuring effective water resource management for various human and ecological needs. The annotated bibliography aims to assist the Water Research Center, and especially the Water Resources Development and Management (WRDM) program by providing a list of most recent articles that cover the topic: Hydrology and hydrogeology of the aquifers.

This annotated bibliography contains articles' abstracts from 2024.

E-resources used: Web of Science.

Contact NSTIC to request full-text articles.

Articles' Abstracts

1. Banks, E., Noorduijn, S., Post, V., Munday, T., Sorensen, C., Cahill, K., … Batelaan, O. (2024). Island hydrogeology in the tropics: Constraining a 3D variable-density groundwater flow and solute transport model with geophysics. JOURNAL OF HYDROLOGY, 635, Article 131037.

Abstract: Saltwater intrusion is the greatest risk to coastal community water supplies where they are dependent on fresh groundwater as the main source of supply. For small, fractured bedrock island aquifers, the fresh groundwater lens dynamics and transition zone geometry are complex. This study investigated the impacts of projected increases in groundwater pumping on a fresh groundwater lens to evaluate changes to the lens geometry and localized up-coning from the deeper, more saline aquifers beneath a small bedrock island in the tropics. A combination of traditional hydrogeological datasets and an airborne electromagnetic survey were used to develop a three-dimensional density-dependent groundwater flow and solute transport model using the SEAWAT code. This investigation represents one of very few studies that have taken such an approach. The model was calibrated using observed groundwater hydraulic heads and chloride concentration data, and calculated chloride values based on bulk conductivity measurements determined from inverted geophysical data. A staged calibration approach was adopted, firstly assessing the time-average lens extent and geometry, and secondly considering the seasonal groundwater level response. In the calibration, the geophysical data helped constrain the lens geometry in the absence of hydraulic head and chloride data. The calibrated model was used to test scenarios where groundwater pumping rates were increased above the current demand of 452 m3 d-1, showing that the lens is likely to be stable, i.e., its available storage is not expected to contract excessively, for extraction rates of up to 3,000 m3 d-1. The combined use of geophysical data and a numerical modeling approach was advantageous in investigating the lens characteristics. It also demonstrated how these techniques can be used together to evaluate coastal water resources and to manage water supply risks for coastal communities. The study demonstrated that the freshwater lens can likely support the freshwater demands of the remote community, and is a preferred option compared with high-cost and more complicated options such as seawater desalination and managed aquifer recharge.

2. Chilaka, C., Rinehart, A., Wang, H., & Ward, F. (2024). Sustaining aquifers hydrologically, economically, and institutionally: Policy analysis of the Ogallala in New Mexico. SCIENCE OF THE TOTAL ENVIRONMENT, 921, Article 170727.

Abstract: Groundwater discharge exceeding recharge threatens sustainable aquifer water use internationally. Interest remains high in discovering more hydrologically sustainable and economically affordable measures to protect these aquifers. Previous research has conducted various aquifer assessments. Some work has investigated costs and benefits of various plans that would limit aquifer pumping. Despite notable advances in this kind of analysis, little published work to date has unified these elements into a science -based integrated framework to inform more sustainable aquifer policy design. This work's novel contribution is to integrate analysis of hydrology, economics, institutions, and policy into a unified scientific framework to inform choices on more sustainable pumping strategies while protecting economic activity for agricultural and urban water -using sectors. It does so by conceptualizing, formulating, designing, and applying a mathematical programming framework to replicate historically observed pumping patterns in parts of the Southern and Central High Plains Ogallala Aquifer region in New Mexico, USA. We first calibrated the optimization framework to replicate the historically observed data. We then go on to identify least cost pumping caps that would have partly restored the aquifer to its 2014 level by 2020, while comparing the performance of four other partial aquifer protection policy measures. Findings indicate a surprisingly low cost that could have been incurred to partially protect the aquifer over that period. However, these low costs are complicated by (1) decreasing water quality outside of the irrigated regions and (2) focusing of lateral inputs to a narrower zone of depression around the irrigated regions. These findings carry important implications for identifying more sustainable aquifer management plans internationally. The work's importance comes from its capacity to inform policy debates over a range of water shortage sharing plans, while respecting institutional constraints governing equitable burden sharing.

3. Chmielarski, M., Dogramaci, S., Cook, P., Skrzypek, G., Jackson, A., Tredwell, M., & McCallum, J. (2024). Identifying the influence of episodic events on groundwater recharge in semi-arid environments using environmental tracers. JOURNAL OF HYDROLOGY, 633, Article 130848.

Abstract: Informing groundwater recharge in arid environments is both challenging and necessary for understanding complex and changing water systems, and for making well-informed aquifer management decisions. The difficulty with interpreting aquifer recharge in arid environments lies in the sporadic and often unpredictable recharge opportunities. There is a gap between theoretical groundwater age distributions based on the physics of groundwater flow and the interpretation of real groundwater age tracer data. This gap is amplified in transient environments. This study uses a deconvolution approach constrained by probable recharge events to interpret variable groundwater recharge in the Weeli Wolli Creek alluvial fan, in the semi -arid Pilbara region. This approach is paired with spatial correlation to establish relationships between wells, making space a proxy for time in the recharge interpretation. Spatial correlation also helps address the data density requirement of deconvolution. The resulting model was able to identify specific events in the last 100 years as contributors to recharge, as well as highlighting effects of mine dewatering in the catchment. In addition, spatial interpretations showed water recharging along specific channels in the fan, and showed active channels varying over time. This level of detail in groundwater recharge studies is a move toward more meaningful environmental interpretation and aquifer planning.

4. Delottier, H., Schilling, O., & Therrien, R. (2024). Assessing the impact of surface water and groundwater interactions for regional-scale simulations of water table elevation. JOURNAL OF HYDROLOGY, 639, Article 131641.

Abstract: Groundwater flow models are increasingly considered for the regional scale simulation of hydraulic heads and water table elevation. In the most complete conflguration, models explicitly simulate two-way interactions between surface water (SW) and groundwater (GW) to reproduce and forecast both SW and GW water levels. In most regional scale groundwater models, however, SW-GW interactions are represented by simplifled boundary conditions that only allow one-way interaction from SW to GW, neglecting most of the dynamic exchange fluxes between SW and GW. To evaluate the potential consequences of such simpliflcations on the simulation of regional GW levels, we compare two models on a

36,900 km2 regional aquifer system in Southern Quebec. One model explicitly simulates both SW and GW flow with two-way SW-GW feedback and the other model only simulates GW flow with a surface boundary flux to represent a one-way interaction with the land surface. Both models are developed with the same numerical code to ensure that the only differences are the representation of SW water flow and SW-GW feedback. The one-way model simulates overall deeper water tables because it removes all exflltrated groundwater from the system once it exits the subsurface, therefore not allowing exflltrating groundwater to re-inflltrate. This effect is most pronounced in areas where the water table is close to the surface and for low-flow periods. The inclusion of two-way feedback also reduces the sensitivity of simulated GW levels to the magnitude of the hydraulic conductivity. This result highlights the need for additional data on other system states to improve the calibration of regional scale models that explicitly simulate two-way SW-GW interactions.

5. Dupuy, M., Garel, E., Chatton, E., Labasque, T., Mattei, A., Santoni, S., … Huneau, F. (2024). Using natural gas content of groundwater to improve the understanding of complex thermo-mineral spring systems. JOURNAL OF HYDROLOGY, 634, Article 130956.

Abstract: The varied gaseous composition of thermo-mineral waters emerging in a non -active zone reflects the diversity and complexity of groundwater pathways and provides important insights into their hydrogeological behaviours. The investigated geochemical content of complex thermo-mineral springs revealed the need to use dissolved gas contents as part of a multi -tracer approach to discriminate processes, geogenic (water-gas-rock interactions), abiotic (geological confinement, flow paths) and biotic activity influencing geochemical of groundwater along regional pathways. Irrespective of the dissolved element content or the water type, examining the overall concentration of dissolved gases enables an effective delineation of regional groundwater flow paths. Using dissolved gas content further contributed to the circumvention of some analytical challenges associated with conventional isotopic or geochemical techniques, often linked to the high concentration of elements such as iron, sulfate, sulfide or other naturally occurring elements content. The primary objectives are to analyse the gas composition of individual springs, to identify the origin of these gases in the groundwater, and to use this gas composition to improve the understanding of the flow patterns contributing to the geochemical diversity observed at the surface. From field investigations in

a geologically and structurally complex area of Eastern Corsica (France), three types of gas contents are identified: (type 1) CH4 & H2S-rich, (type 2) N2 -rich and (type 3) CO2-rich. The study of these dissolved gases highlights that the wide geochemical diversity of thermo-mineral waters observed here is not only related to the mineralogical composition of the local aquifer but also involves strong and cumulative interactions along deep regional circulation pathways. This approach also reveals a common deep crustal gaseous influence characterised by N2 production, which interacts during up flow with groundwater and then with the local metamorphic or sedimentary rock matrix. The groundwater's isotopic and geochemical contents are then altered by local lithologies encountered through both abiotic and biotic interactions. Finally, at shallow depths, phreatic groundwater can add its geochemical and isotopic footprint and dilute this complex mixture before groundwater emerges as mineral spring. This paper answers the primary objectives yet further demonstrates that using dissolved gas as a tracer of groundwater flow paths allows a deeper interpretation of surface geochemical and isotopic observations, distinguishes local from regional flow paths, and provides information about processes at the origin of groundwater diversity. The combination of tools presented in this paper (i.e., geochemical, dissolved gas, and isotopic tools) allows the establishment of a reliable regional groundwater flow scheme for thermo-mineral waters in a non -active zone. This scheme is essential to improve thermo-mineral water management, and protection to ensure their sustainable quality in front of increasing anthropogenic and climatic pressures.

6. Ibarra-Alejos, O., Ventura-Houle, R., Morales, J., Macías, B., & Heyer, L. (2024). Analysis of isoscapes (δD, $\delta^{18}O$ and tritium) in groundwater in the semiarid northeast region of Mexico. HYDROGEOLOGY JOURNAL.

Abstract: Arid and semiarid zones often lack surface water sources. Since aquifers are the only source of water supply in these zones, they are at risk of overexploitation. In understanding the behavior and dynamics of aquifers within the hydrological cycle, isotope hydrology is a useful tool. The objective of this study was to develop a conceptual hydrogeological model in the arid zone associated with the Tula-Bustamante aquifer, Mexico. Stable deuterium (delta D), oxygen-18 (delta O-18) and tritium isotopes were used to investigate the hydrogeological processes and dynamics in the aquifer to identify the recharge zones and the origin and residence time of groundwater. Precipitation data for the region indicate that the study area

went through a dry season, with 2017 being the year with the least rainfall in the 20-year study period. The analysis of the delta D and delta O-18 groundwater isoscapes (maps of values) for 2016 and 2017 show that the main aquifer recharge zone is in the eastern part, in the mountainous area of the Sierra Madre Oriental. Tritium distribution indicates that the region has mixed and premodern waters. In addition, hydrological analyses results, in conjunction with the stable isotope values obtained, suggest a fast hydrological flow. The results of this research made it possible to generate a suitable hydrogeological model of the aquifer, which can be used as a groundwater resource management tool to prevent overexploitation.

7. Jiménez-Valera, J., Alhama, I., & Duque, C. (2024). Advanced type curves for vertical groundwater flow estimation from temperature profiles. Applications to real scenarios. JOURNAL OF HYDROLOGY, 631, Article 130860.

Abstract: Groundwater discharge or recharge in aquifers can be obtained from the analysis of temperature profiles, a costefficient method widely applied in hydrogeology. In this study we proposed a set of type curves that can be used for estimating the vertical velocity flow, and have the potential to allow, in certain cases, the assessment of the thermal diffusivity of the soil matrix. The solutions, represented graphically, establish the dependencies of the basic parameters involved in the process: groundwater velocity, thermal conductivity, specific heat, aquifer depth and harmonic temperature period. Using the non-dimensionalization technique, the mentioned parameters were organized in dimensionless groups which are verified by numerical simulations. For the estimates of the groundwater velocity, transient temperature-depth measurements or steady state amplitudes of the harmonic oscillation were used as input data. In this last case, a particular type curve solution allows us to assess the depth from which temperature oscillations have a negligible amplitude compared to the amplitude at the ground surface. The resulting dependencies have been applied to estimate the groundwater velocity in real aquifers and laboratory experiences.

8. Kpegli, K., Alassane, A., Zouari, K., Ofterdinger, U., Araguas, L., Alou, G., … Boukari, M. (2024). Delineation of a conceptual groundwater flow model of the Kandi basin in Benin (West Africa): Insights from isotopes, piezometric and hydrological investigations. JOURNAL OF HYDROLOGY-REGIONAL STUDIES, 53, Article 101804.

Abstract: Study region: The hydrogeological Kandi basin, the Benin's sector of the transboundary Iullumeden basin, located in northern Benin, West Africa Study focus: In many parts of the world, groundwater resources constitute the main, if not the only, source of potable water available to address a growing demand for numerous uses. And yet, a basic understanding of the hydrogeology of many critical groundwater systems is lacking in many instances. Only when severe groundwater depletion or serious groundwater quality issues arise is the attention paid to the lack of specific groundwater studies. This study targets the Kandi basin, a similar to 8700 km2 hydrogeological basin located in northern Benin, which is the primary source of potable water for its inhabitants, but its hydrogeological functioning remains unclear. We conducted isotopic and hydrogeological investigations in this basin from 2013 to 2019 to characterize groundwater recharge processes and delineate flow patterns. The resulting hydrological and geochemical data have been integrated and interpreted using tools including mapping tools. New hydrological insights for the region: This study has identified the preferential groundwater recharge areas and characterized the main groundwater flow paths. Predominant areas of groundwater dischage into surface water, regardless of the seasons, were detected and areas where the surface-groundwater interflows are season-dependent were discriminated. The main findings presented in this paper are expected to provide a baseline for further in-depth hydrogeological investigations, namely groundwater flow modeling that will help understand the impacts of various groundwater withdrawals and climate changes on the groundwater resources availability of this basin.

9. Ma, L., Sun, X., Qian, J., Wang, W., Deng, Y., & Fang, Y. (2024). Identification of high-permeability and water-rich zones in a fractured karst water source area based on the hydraulic tomography method. JOURNAL OF HYDROLOGY, 629, Article 130648.

Abstract: Determining the spatial hydraulic parameters of aquifers is of paramount importance for the development and utilization of groundwater in water source areas. However, most

methods are unable to accurately characterize the heterogeneity of aquifers because of the influences of complex geology, hydrogeology, structure and insufficient information. Hydraulic tomography (HT) is an effective and robust method for hydraulic parameter inversion to characterize heterogeneity. In this study, a two-dimensional HT model was established to simulate hydraulic parameter fields for a fractured karst aquifer in the Zhangji water source area (Xuzhou city, China). Steady-state hydraulic tomography (SSHT) and transient hydraulic tomography (THT) with different prior information conditions were applied to determine the high-permeability area and water-rich zones, and to infer possible locations of karst conduits and strong runoff paths in the water source area. The results indicate that: (1) THT can better reveal larger-scale heterogeneous characteristics of hydraulic properties compared to SSHT. The hydraulic conductivity distribution estimated by THT correlates well with the geological conditions of the area, especially in identifying water-rich zones formed by faults and other formations. (2) When combined with geological conditions, HT possesses the ability to identify strong runoff paths in fractured karst aquifers. (3) Accurate prior information, which is more relevant to the head response information, is conducive to obtaining more acceptable HT results. (4) THT can simultaneously identify high-permeability and high-storage zones, and the analysis of the overlap of these two regions has the potential to predict underground water reservoirs, which is of the utmost importance for the development and utilization of groundwater resources in water source areas.

10. Mohammed, M., Szabó, N., Alao, J., & Szucs, P. (2024). Geophysical characterization of groundwater aquifers in the Western Debrecen area, Hungary: insights from gravity, magnetotelluric, and electrical resistivity tomography. SUSTAINABLE WATER RESOURCES MANAGEMENT, 10, Article 67.

Abstract: The recent study followed a multi-methodological approach integrating gravity, magnetotelluric (MT), and electrical resistivity tomography (ERT) to investigate the geometry and hydrological characteristics of the main hydrostratigraphical units in the Western Debrecen area, Eastern Hungary. The integration of these methods aims to delineate potential zones for groundwater development and guide effective extraction strategies. In the gravity investigation, the Bouguer anomaly map undergoes spectral analysis for the separation of shallow and deep features, offering a preliminary indication of basement rock depth. Subsequently, gravity data inversion is employed to map variations in basement rock topography, revealing a basin

structure, with sediment thicknesses extending up to 2 km. On the other hand, the MT data are modeled using the 1D Occam inversion algorithm to validate the results of the gravity data analysis. This inversion, constrained with lithological logs is further utilized to delineate the main hydrostratigraphical units in the study area. Accordingly, four units are identified, including the Nagyalfold Aquifer, Algyo and Endrodi Aquitards, the Badenian Aquifer, and the Pre-Neogene Aquitard. Consequently, Dar Zarrouk parameters based transmissivity and the hydraulic conductivity of the aquifer units are measured. The Nagyalfold aquifer showed a hydraulic conductivity that ranged between 7.9 and 11.9 m/day, while the Badenian aquifer showed an average hydraulic conductivity of 13.1 m/day. The ERT data are employed to map the spatial distribution of the depth to the water table. The shallow water table is observed in regions characterized by an elevated thickness of sedimentary rocks, attributed to their high specific capacity. Integrating these hydrogeophysical methods provided a comprehensive understanding of the subsurface hydrology and enabled better-informed decision-making for groundwater development.

11. Navarro-Farfán, M., García-Romero, L., Martínez-Cinco, M., Hernández-Hernández, M., & Sánchez-Quispe, S. (2024). Comparison between MODFLOW Groundwater Modeling with Traditional and Distributed Recharge. HYDROLOGY, 11, Article 9.

Abstract: Groundwater models serve the function of predicting and analyzing aquifer behavior. They require input information, such as hydrogeological parameters like hydraulic conductivity and storage coefficient, which are used to calibrate the model, and elementary actions that include recharge and extracted volumes. There are cases in which it is insufficient to know the homogeneous recharge entering through the surface basin, referred to as traditional recharge, since, in many instances, the distribution is altered by changes in land use. For this reason, based on the geomorphological characteristics of the basin, weighting is proposed for sites with greater recharge capacity. The present work shows a solution to the recharge distribution using the potential groundwater recharge (PGR) map, which is formed by weighting spatially distributed information: (i) drainage, (ii) precipitation, (iii) land use, (iv) geological faults, (v) soil type, (vi) slope, and (vii) hydrogeology. A comparison is made between groundwater modeling using traditional recharge and PGR recharge. It is noted that the modeling perform similarly for both recharges, and the errors do not exceed 5% absolute error, which validates the model's reliability. This manuscript demonstrates how to model and

calibrate groundwater in aquifers with scarce information and variable recharge, making it reproducible.

12. Perumal, M., Sekar, S., & Carvalho, P. (2024). Global Investigations of Seawater Intrusion (SWI) in Coastal Groundwaters in the Last Two Decades (2000-2020): A Bibliometric Analysis. SUSTAINABILITY, 16, Article 1266.

Abstract: Seawater intrusion represents the flow of seawater through coastal aquifers, but it also affects surface water bodies such as channels, canals, and wetlands. Transitional water volumes, variable density and salinity distributions, and heterogeneous hydraulic properties describe coastal aquifers which are present in complex environments. The relationships between water density and salinity, climatic variations, groundwater pumps, and sea level fluctuations provide complex hydrological conditions related to the distribution of dissolved salts. This review will focus on (i) systematic evaluation of global SWI areas assessed by different methodologies and author contributions, (ii) SWI identified areas across the world using publication results, and (iii) bibliometric analysis of SWI publications for evaluation of the current status in coastal zone management, including the research gaps that are published in the Journal of Hydrology (5.91%), Environmental Geology (3.41%), Hydrogeology Journal (3.20%), Science of the Total Environment (1.60%), Water Resources Research (1.50%), Arabian Journal of Geosciences (1.30%), Environmental Earth Sciences (1.20%), Advances in Water Resources (1.10%), Applied Geochemistry (1.10%), Water Resources Management (1.0%), and Hydrological Processes (0.8%), a collection representing 30.59% (94 articles) of the total peer-reviewed scientific products of the past two decades focusing on the use of the present status of SWI in coastal aquifers, estuaries, and lagoons.

13. Pouliaris, C., Stika, M., Foglia, L., Schüth, C., & Kallioras, A. (2024). Insights on modelling of karstic aquifers: A new methodology for the integration of fracture data in groundwater flow modelling. ENVIRONMENTAL MODELLING & SOFTWARE, 177, Article 106056.

Abstract: Groundwater resources have been extensively exploited in many areas around the globe for providing good quality water for drinking and other purposes. Groundwater flow models have been widely used as management, evaluation and prediction tools on many

occasions, however, in the case of karstic aquifers, the use of modelling tools is often a task with increased complexity. In the light of this constrain, a new methodology for implementing field data into mathematical models developed for simulating flow in karstic aquifers is presented. The aim is to combine an existing groundwater flow model, field data and the MODFLOW CFP code to develop a model that adequately simulates the hydrological processes in the karstic aquifer. Results show that MODFLOW CFP can be used to model areas where karstic aquifers are developed, providing decisive information about hydrological processes taking place in these aquifers.

14. Robertson, D., Fu, G., Barron, O., Hodgson, G., & Schepen, A. (2024). A new approach of coupled long-range forecasts for streamflow and groundwater level. JOURNAL OF HYDROLOGY, 631, Article 130837.

Abstract: Methods to produce seasonal to annual forecasts of surface and groundwater availability have been developed and implemented nationally and globally. Such forecasts allow water managers to create effective irrigation schedules and better plan and manage water supply. However, one limitation of existing approaches that the forecasts of surface streamflow and groundwater are independent and therefore neglect inter-variable correlations that allow for reliable forecasting of total water availability. In this study, we develop an approach to jointly forecast streamflow and groundwater level and demonstrate its performance for the Lockyer Valley, Australia, where both surface water and groundwater are critical for irrigation. Informed by analysis of the processes influencing dynamics of groundwater levels in the alluvial aquifer (as a substitute to available groundwater storage) and streamflow dynamics, an existing hydrological model is adapted to better represent the ephemeral nature of streamflow in the catchment and also to simulate changes in groundwater levels. The modified hydrological model is then integrated into a statistical-dynamical forecasting framework to jointly forecast streamflow and groundwater level. Verification results indicate that forecasts skilful to lead times of up to 3 months for streamflow and 12 months for groundwater levels, even though rainfall forecasts are not skilful beyond the first month. Forecasts for both streamflow and groundwater are also statistically reliable with low bias. The approach developed can be extended to forecast the spatial distribution of groundwater levels across a large region, as well as be used to infill missing groundwater observations.

15. Schiavo, M. (2024). Numerical impact of variable volumes of Monte Carlo simulations of heterogeneous conductivity fields in groundwater flow models. JOURNAL OF HYDROLOGY, 634, Article 131072.

Abstract: The knowledge of aquifer systems, their geological setting, their structure, and subsequent modeling is highly uncertain and is usually faced through Monte Carlo-based methods in hydrogeology. One of the most important uncertainty sources for groundwater models is represented by input hydraulic conductivities, related to the aquifer's structure. There are no specific rules when simulating hydraulic conductivity fields within Monte Carlo frameworks to instruct numerical models, and information about employed conductivity fields and their numerical convergence is often not given. This technical work aims to fill this gap by investigating the impact of employing conductivity information upon different volumes of Monte Carlo simulations applied to a real case study. Thus, this work estimates the minimum volumes of Monte Carlo hydraulic conductivity fields to be employed in groundwater flow models for achieving numerically stable (i) boundary conditions, (ii) global model performances, and (iii) local ones such as simulated hydraulic heads. The present results aim to be indicative of similar hydrogeological settings and will serve as a basis for more complex ones and for investigating transport problems.

16. Tobin, B., Miller, B., Niemiller, M., & Erhardt, A. (2024). Expanding Karst Groundwater Tracing Techniques: Incorporating Population Genetic and Isotopic Data to Enhance Flow-Path Characterization. HYDROLOGY, 11, Article 23.

Abstract: Karst aquifers are unique among groundwater systems because of variable permeability and flow-path organization changes resulting from dissolution processes. Over time, changes in flow-path connectivity complicate interpretations of conduit network evolution in karst hydrogeology. Natural and artificial tracer techniques have long provided critical information for protecting karst aquifers and understanding the potential impacts on ecosystems and human populations. Conventional tracer methods are useful in karst hydrogeologic studies for delineating flow paths and defining recharge, storage, and discharge properties. However, these methods only provide snapshots of the current conditions and do not provide sufficient information to understand the changes in interconnection or larger-scale evolution of flow paths in the aquifer over time. With advances in population genetics, it is possible to assess population connectivity, which may provide greater insights into complex

groundwater flow paths. To assess this potential, we combined the more traditional approaches collected in this and associated studies, including artificial (dye) and natural (geochemistry, isotopes, and discharge) tracers, with the population genetic data of a groundwater crustacean to determine whether these data can provide insights into seasonal or longer changes in connections between conduits. The data collected included dye trace, hydrographs, geochemistry, and asellid isopod (Caecidotea bicrenenta) population genetics in Fern Cave, AL, USA, a 25 km-long cave system. Combined, these data show the connections between two separate flow paths during flood events as the downstream populations of isopods belonging to the same subpopulation were measured in both systems. Additionally, the sub-populations found in higher elevations of the cave suggest a highly interconnected unsaturated zone that allows for genetic movement in the vadose zone. Although upstream populations show some similarities in genetics, hydrologic barriers, in the form of large waterfalls, likely separate populations within the same stream.

17. Toulier, A., Join, J., Stamenoff, P., Benoit, Y., Lebeau, G., Gautier, M., … Ah-Peng, C. (2024). ERORUN-STAFOR: A collaborative observatory for the multidisciplinary study of the critical zone processes in a tropical volcanic watershed including a Tropical Montane Cloud Forest. HYDROLOGICAL PROCESSES, 38, Article e15061.

Abstract: Tropical volcanic islands are biodiversity hotspots where the Critical Zone (CZ) still remains poorly studied. In such steep topographic environments associated with extreme climatic events (cyclones), deployment and maintenance of monitoring equipment is highly challenging. While a few Critical Zone Observatories (CZOS) are located in tropical volcanic regions, none of them includes a Tropical Montane Cloud Forest (TMCF) at the watershed scale. We present here the dataset of the first observatory from the French network of critical zone observatories (OZCAR) located in an insular tropical and volcanic context, integrating a 'Tropical Montane Cloud Forest': The ERORUN-STAFOR observatory. This collaborative observatory is located in the northern part of La Reunion island (Indian Ocean) within the 45.0 km2 watershed of Riviere des Pluies (i.e., Rainfall river) which hosts the TMCF of Plaines des Fougeres, one of the best preserved natural habitats in La Reunion Island. Since 2014, the ERORUN-STAFOR monitoring in collaboration with local partners collected a multidisciplinary dataset with a constant improvement of the instrumentation over time. At the watershed scale and in its vicinity, the ERORUN-STAFOR observatory includes 10

measurement stations covering the upstream, midstream and downstream part of the watershed. The stations record a total of 48 different variables through continuous (sensors) or periodic (sampling) monitoring. The dataset consists of continuous time series variables related to (i) meteorology, including precipitation, air temperature, relative humidity, wind speed and direction, net radiation, atmospheric pressure, cloud water flux, irradiance, leaf wetness and soil temperature, (ii) hydrology, including water level and temperature, discharge and electrical conductivity (EC) of stream, (iii) hydrogeology, including (ground)water level, water temperature and EC in two piezometers and one horizontally drilled groundwater gallery completed by soil moisture measurements under the canopy. The dataset is completed by periodic time series variables related to (iv) hydrogeochemistry, including field parameters and water analysis results. The periodic sampling survey provides chemical and isotopic compositions of rainfall, groundwater, and stream water at different locations of this watershed. The ERORUN-STAFOR monitoring dataset extends from 2014 to 2022 with an acquisition frequency from 10 min to hourly for the sensor variables and from weekly to monthly frequency for the sampling. Despite the frequent maintenance of the monitoring sites, several data gaps exist due to the remote location of some sites and instrument destruction by cyclones. Preliminary results show that the Riviere des Pluies watershed is characterized by high annual precipitation (>3000 mm y(-1)) and a fast hydrologic response to precipitation (approximate to 2 h basin lag time). The long-term evolution of the deep groundwater recharge is mainly driven by the occurrence of cyclone events with a seasonal groundwater response. The water chemical results support existing hydrogeological conceptual models suggesting a deep infiltration of the upstream infiltrated rainfall. The TMCF of Plaine des Fougeres shows a high water storage capacity (>2000% for the Bryophytes) that makes this one a significant input of water to groundwater recharge which still needs to be quantified. This observatory is a unique research site in an insular volcanic tropical environment offering three windows of observation for the study of critical zone processes through upstream-midstream-downstream measurements sites. This high-resolution dataset is valuable to assess the response of volcanic tropical watersheds and aquifers at both event and long-term scales (i.e., global change). It will also provide insights in the hydrogeological conceptual model of volcanic islands, including the significant role of the TMCFs in the recharge processes as well as the watershed hydrosedimentary responses to extreme climatic events and their respective evolution under changing climatic conditions.

18. Yang, J., Pan, Y., Zhang, C., Gong, H., Xu, L., Huang, Z., & Lu, S. (2024). Comparison of groundwater storage changes over losing and gaining aquifers of China using GRACE satellites, modeling and in-situ observations. SCIENCE OF THE TOTAL ENVIRONMENT, 938, Article 173514.

Abstract: Groundwater depletion in intensively exploited aquifers of China has been widely recognized, whereas an overall examination of groundwater storage (GWS) changes over major aquifers remains challenging due to limited data and notable uncertainties. Here, we present a study to explore GWS changes over eighteen major aquifers covering an area of 1,680,000 km(2) in China using data obtained from the Gravity Recovery and Climate Experiments (GRACE), global models, and in-situ groundwater level observations. The analysis aims to reveal the discrepancy in annual trends, amplitudes, and phases associated with GWS changes among different aquifers. It is found that GWS changes in the studied aquifers represent a spatial pattern of 'Wet-gets-more, Dry-gets-less'. An overall decreasing trend of -4.65 +/- 0.34 km(3)/yr is observed by GRACE from 2005 to 2016, consisting of a significant ($p < 0.05$) increase of 47.28 +/- 3.48 km(3) in 7 aquifers and decrease of 103.56 +/- 2.4 km(3) (similar to 2.6 times the full storage capacity of the Three Gorges Reservoir) in 10 aquifers summed over the 12 years. The annual GWS normally reaches a peak in late July with an area-weighted average annual amplitude of 19 mm, showing notable discrepancy in phases and amplitudes between the losing aquifers (12 mm in middle August) in northern China and gaining aquifers (28 mm in early July) mostly in southern China. GRACE estimates are generally comparable, but can be notably different, with the results obtained from model simulations and in-situ observations at aquifer scale, with the area-weighted average correlation coefficients of 0.6 and 0.5, respectively. This study highlights different GWS changes of losing and gaining aquifers in response to coupled impacts of hydrogeology, climate and human interventions, and calls for divergent adaptions in regional groundwater management.

19. Zaryab, A., Farahmand, A., Jafari, Z., Ali, S., Alijani, F., & Nassery, H. (2024). Geochemical evolution of spring waters in carbonate dominated aquifer in Upper Shirin Tagab sub-basin, northern Afghanistan. GROUNDWATER FOR SUSTAINABLE DEVELOPMENT, 25, Article 101102.

Abstract: Spring waters originates from carbonate aquifers provides substantial water for drinking and widely used for irrigation in Afghanistan. Thus, understanding hydrogeochemical evolution in carbonate dominated aquifer is important for sustainable groundwater resource management in the country. Therefore, in this study, water from springs and dug wells from carbonate dominated aquifers were investigated to study hydrogeochemical evolution in Upper Shirin Tagab sub -basin, Northern Afghanistan. This study reveals that water in the area mainly belongs to Ca-Mg-HCO3 facies type in Upper part and Mg-(Na, Ca)-SO4-(HCO3, Cl) in the lower part. The hydrogeochemical processes in the aquifer were found to be governed by dissolution of carbonate, gypsum and halite minerals. Results shows that the chemical composition of springs is primarily controlled by local geology and water -rock interactions of limestone and dolomite with minor effects of silicate weathering. The delta 2D-H2O and delta 18O-H2O of springs water shows wide variations and found in the range of -64.4 ‰ to -52.6 ‰ and -10.1 ‰ to -8.6 ‰, respectively. Stable isotopes of water indicate that the water in the study area receive recharge from infiltration of recent precipitation and showing less evaporative enrichment of heavier isotopes. Overall, the quality of groundwater is safe for drinking with respect to WHO guidelines but the aquifer is suspectable to anthropogenic contamination such as sewage sludge, excessive nutrients, sulfate and pathogens. Furthermore, findings of this study will be helpful for decision makers to develop a sustainable water resource management in Shirin Tagab sub -basin in Northern Afghanistan.

20. Zhuang, C., Lü, C., Yan, L., Li, Y., Zhou, Z., Wang, J., … Illman, W. (2024). Pumping-induced Well Hydraulics and Groundwater Budget in a Leaky Aquifer System with Vertical Heterogeneity in Aquitard Hydraulic Properties. ACTA GEOLOGICA SINICA-ENGLISH EDITION, 98, 477-490.

Abstract: In groundwater hydrology, aquitard heterogeneity is often less considered compared to aquifers, despite its significant impact on groundwater hydraulics and groundwater resources evaluation. A semi-analytical solution is derived for pumping-induced well hydraulics and groundwater budget with consideration of vertical heterogeneity in aquitard hydraulic

conductivity (K) and specific storage (Ss). The proposed new solution is innovative in its partitioning of the aquitard into multiple homogeneous sub-layers to enable consideration of various forms of vertically heterogeneous K or Ss. Two scenarios of analytical investigations are explored: one is the presence of aquitard interlayers with distinct K or Ss values, a common field-scale occurrence; another is an exponentially depth-decaying aquitard Ss, a regional-scale phenomenon supported by statistical analysis. Analytical investigations reveal that a low-K interlayer can significantly increase aquifer drawdown and enhance aquifer/aquitard depletion; a high-Ss interlayer can noticeably reduce aquifer drawdown and increase aquitard depletion. Locations of low-K or high-Ss interlayers also significantly impact well hydraulics and groundwater budget. In the context of an exponentially depth-decaying aquitard Ss, a larger decay exponent can enhance aquifer drawdown. When using current models with a vertically homogeneous aquitard, half the sum of the geometric and harmonic means of exponentially depth-decaying aquitard Ss should be used to calculate aquitard depletion and unconfined aquifer leakage.

Contact NSTIC for Full Texts:

Naser Almarri

nmarri@kisr.edu.kw

Ext. 9545