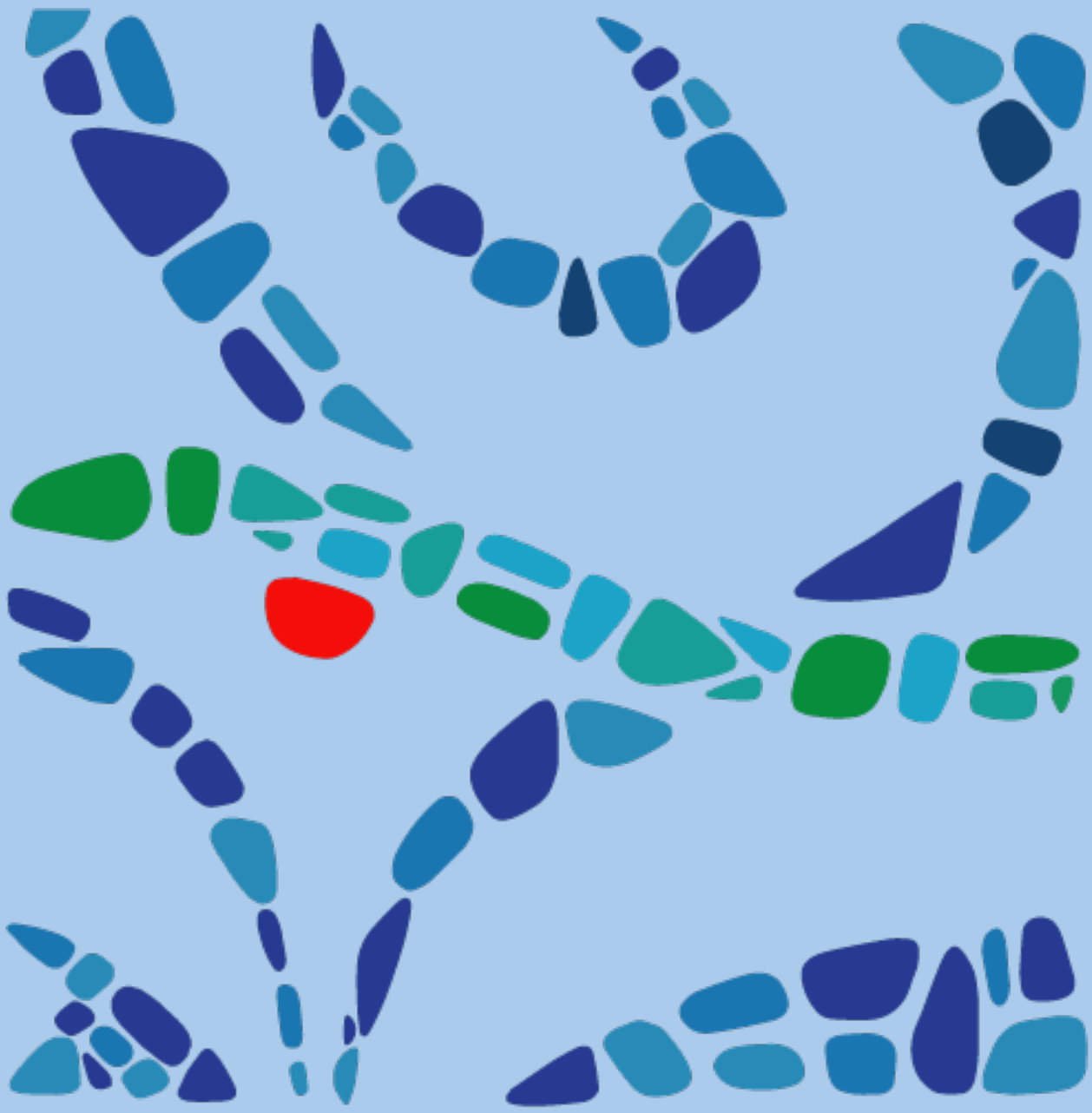
Proceedings of the 28th Salt Water Intrusion Meeting 2025

Integrating Land and Ocean Approaches In the Study of Coastal Groundwater

2 - 6 June 2025, Barcelona, Spain

Eds.: Albert Folch and Marc Diego-Feliu



Salt Water Intrusion Meeting 2025

SWIM 2025

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PREFACE

Salt Water Intrusion Meeting 2025

Integrating Land and Ocean Approaches in the Study of Coastal Groundwater

The Salt Water Intrusion Meeting (SWIM) is a prestigious biennial scientific conference that has been held in different countries since its inception in 1968. For decades, SWIM has served as a pivotal event for scientists and experts dedicated to understanding and addressing the challenges of seawater intrusion and salinization in coastal aquifers worldwide. Tackling these issues requires multidisciplinary collaboration, drawing from chemistry, engineering, geology, geophysics, mathematics, physics, hydrology, and water resources management.

The 28th edition of SWIM, which took place from June 2–6, 2025, in Barcelona, Catalonia, embraced an ambitious vision: integrating land and ocean approaches in the study of coastal groundwater. This edition placed a greater emphasis on linking seawater intrusion (SWI) and submarine groundwater discharge (SGD).

Our goal was to foster engaging discussions bridging diverse interfaces:

- From land to ocean, highlighting the connections between terrestrial and marine systems.
- Across spatial scales, from the pore level to the aquifer and basin scales.
- Across disciplines, bringing together hydrology, oceanography, geophysics, and engineering to explore innovative, state-of-the-art techniques both onshore and offshore.

Barcelona provided an ideal setting for this memorable edition of SWIM. Nestled along the shores of the Mediterranean Sea, the city offered a rich maritime history, a vibrant cultural landscape, and a leading position as a hub for hydrology, ocean sciences, and coastal research.

We were thrilled to bring this new chapter of the Salt Water Intrusion Meeting to life—one that broadened perspectives, sparked meaningful discussions, and fostered collaboration among scientists and professionals from around the globe.

Thank you for joining us in Barcelona for such an inspiring and unforgettable experience!

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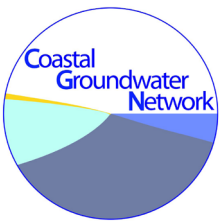

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Salt Water Intrusion Congress (SWIM 2025)

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LARGE-SCALE 3D GROUNDWATER MODELLING USING IMOD-WQ AND GLOBAL DATASETS - A CASE STUDY FOR THE AUSTRALIAN CONTINENT AND PAPUA NEW GUINEA

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ABSTRACT

Groundwater plays a crucial role in drinking water supply, agricultural and industrial production, and ecosystem stability worldwide. Preserving both groundwater quantity and quality while facing future anthropogenic and natural threats (i.e. aquifer overexploitation and climate change impacts) is therefore crucial. In recent years several attempts have been made to build a global groundwater model based on global datasets and using a combination of high-performance computing and parallel numerical code. One of the main limitations of this approach has been the simplified schematization of hydrogeological heterogeneity in these groundwater models.

Therefore, our study aims to increase the complexity of the hydrogeological schematizations of continental to global-scale groundwater models. To this end, we divide the globe into large-scale groundwater regions and apply a novel approach to estimate the regional-scale hydrogeological makeup of large-scale groundwater models. Three main lithological layers are defined, the most recently deposited unconsolidated sediments represent the top model layer while the second layer consists of older unconsolidated sediments. The third lithological layer consists of sedimentary rock formations, whose depth and type are defined from available global datasets. Additionally, we further split these three lithological layers into several sub-layers representing the heterogeneous conditions (e.g. clay or sandy sub-layers). The resulting geological model is then used as a base to build a groundwater and variable density flow model, set up with the parallel iMOD-WQ code. This allows us to simulate complex large-scale groundwater processes and provide a better understanding of large-scale groundwater flow and salinity patterns.

The presented methodology was applied to create a groundwater model spanning the Australian continent, Papua New Guinea island and the continental shelf connecting these two landmasses. By applying this methodology to other regions around the world we can eventually create a new global groundwater model with higher and more realistic hydrogeological complexity and thus provide valuable insight into global groundwater flow patterns and input into Earth system models where groundwater processes are often largely simplified or neglected.

Keywords: *groundwater salinity, large-scale models, regional geological modelling, global datasets, reproducibility*

Salt Water Intrusion Congress (SWIM 2025)

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Management Of Coastal Aquifers In The Mediterranean Using Innovative Modeling And Data Collection Techniques

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ABSTRACT

The coastal regions of the Mediterranean Sea rely heavily on groundwater, but excessive use for drinking water and agriculture is leading to depletion, salinization, drought, and subsidence. This disrupts ecosystem services and threatens water security for both people and nature. Climate change, shifting precipitation patterns, and sea-level rise are intensifying the crisis, impacting agriculture, the economy, ecology, and public health. A thorough understanding of coastal groundwater vulnerability is essential for sustainable development. Innovative modeling tools and data-driven insights would help stakeholders understand and address the impacts of human activities and climate change on groundwater. In this project, initiated by UNESCO under the GEF ID#9686: “Management of Coastal Aquifers and related Ecosystems in the Mediterranean”, we will develop models that can simulate complex hydrogeological processes, predicting the extent and impact of saltwater intrusion on freshwater resources under various scenarios, while also identify features like Fresh Offshore Groundwater and Submarine Groundwater Discharge (as important for ecosystems).

Developments of parallel open-source SEAWAT (10.1016/j.advwatres.2021.103976) has indicated a breakthrough in variable-density groundwater flow and salt transport modelling. Now, huge models can be split into multiple (practically at least tens of) partitions and executed in parallel, leading to enormous reduction in computation time, and thus, making it possible to simulate groundwater salinity dynamics over a full glacial-interglacial cycle (viz. approx. 125 kyears). Given high performance computing facilities (supercomputers), this opens possibilities in building (high temporal and spatial scale) Large-scale Coastal Groundwater Models (LCGMs). An increasing number of open-source global hydrogeological datasets available on web portals will be used. Open-source tools (e.g., Python) will incorporate these datasets, like HydroBASINS (global-watershed-boundaries), CoPerm (geological parameters), and GEBCO (global DEM), as input into the models. In addition, AI Large Language Models data-mining techniques will make it possible to retrieve hydrogeological data (e.g., borelogs, salinity values) from articles as well as grey literature. Additionally, innovative groundwater salinity data collection techniques using Airborne EM surveys and citizen-science generated data using smartphone apps and web portals will be added too. Tools like ArchPy are used for transferring e.g., borelogs to 3D geology and salinity measures to 3D ‘present’ fields of groundwater salinity.

We have started with a (coarse) model (14 model layers, plus 10 million cells) of the entire Mediterranean Sea area doing some paleo-geographical analysis. The focus is on five priority coastal aquifers in six countries, making country-level (local) models at a higher resolution.

These models provide first order approximations of groundwater conditions in data scarce large-scale regions, despite simplifications and uncertainties related to hydrogeological data availability.

Keywords: Coastal aquifers; Freshwater resources, Mediterranean Sea area, Variable-density groundwater flow; Numerical model

Salt Water Intrusion Congress (SWIM 2025)

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MODELING SEAWATER INTRUSION IN COASTAL AQUIFERS WITH PHYSICS INFORMED NEURAL NETWORKS

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ABSTRACT

Seawater intrusion is one of the most important challenges facing groundwater resources in coastal zones. Modeling tools have become irreplaceable tools that are widely used to understand seawater intrusion processes and to improve groundwater management in coastal aquifers by providing insights into sustainable consumption and better decision-making.

With the increasing usage of Artificial intelligence in all aspects of scientific applications and the incredible results, seawater intrusion could be one of the topics that AI, and machine learning could significantly help. Machine learning can provide reliable predictions by learning from available datasets. Despite the numerous advantages of the machine learning models, there is one major drawback, they rely on a vast amount of data, which is often costly and unreachable in several scientific domains, in hydrogeology. Furthermore, conventional neural network functions are called "black boxes" which means they lack interpretability and may not generalize well in unseen data. These drawbacks can limit these machine-learning models in real-world applications.

In response to these challenges, physics-informed neural networks (PINNs) have been implemented as an innovative approach that integrates physical laws directly into the training process of neural networks. Unlike conventional machine learning models that depend solely on data, PINNs incorporate governing mathematical equations, such as differential equations into the network's loss function. By embedding these physical constraints, PINNs are capable of learning solutions that do not rely on data and a model build that can understand the principal physics of the problem. In fact, physics helps constrain the learning domain, ensuring that the model's predictions are consistent with the fundamental laws of physics. Because of these advantages, PINNs have received considerable attention in scientific modeling, especially in areas where data scarcity is a significant issue.

To the best of our knowledge, PINNs approach has never been applied to seawater intrusion. This study addresses this gap and aims at evaluating the performance of PINNs for seawater intrusion in coastal aquifers. The Henry problem, a widely used hypothetical model, describing seawater intrusion in coastal aquifers, is employed in this context. The study's results showed that standard physics-informed neural networks successfully captured crucial aspects of saltwater intrusion, highlighting the effectiveness of this method in hydrogeological modeling.

While this method is effective for modeling seawater intrusion using PINNs, it faces challenges when dealing with complex problems, especially in transitioning from a wider to a narrow mixing zone. A key finding of this research is that transfer learning, applying knowledge from simpler cases to more complex ones, can help improve results.

Keywords: Modelling seawater intrusion; Henry problem; PINNs; transfer learning

Salt Water Intrusion Congress (SWIM 2025)

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MODELING TIDAL INFLUENCE IN GROUNDWATER MODELS WITH LARGE TIME STEPS

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ABSTRACT

As groundwater flow is generally slow, most groundwater models use time steps larger than one day. These models are used to quantify the influence of groundwater recharge, pumping or changes to the surface water system. Groundwater models are also used to calculate the influence of sea level rise.

In alluvial coastal areas, the sea is an important boundary condition. In tidal areas with a shallow slope of the beach, part of the beach only inundates during high tides. The flow resistance of the phreatic aquifer retains the infiltrated seawater. This results in a groundwater level that is higher than mean sea level. Therefore, it can be challenging to incorporate the influence of tides in a groundwater model with time steps larger than the tidal period (just over 12 hours).

Several methods to schematize the sea boundary condition have been developed by others in the past. In our research, we explore some of the most practical methods in a MODFLOW 6 groundwater model, from simple (just using mean sea level and a constant resistance) to complex (spatial and temporal variation of the boundary properties). Models with larger time steps and different schematizations are compared to models with smaller time steps and a varying location of the sea, focusing mainly on water quantity. We will use synthetic cross-sectional models in which we can vary the slope of the beach, the aquifer transmissivity and the amplitude of the tides.

We will also test the methods on a simplified model of one of the Dutch Wadden Islands, with large natural areas that only flood at high tides. Modelled heads are compared to available head measurements close to the sea. Practical guidelines to schematize the sea boundary condition and possible pitfalls when modeling sea level rise are presented.

Keywords: *boundary condition, numerical modeling, tidal influence, time steps*

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OFF TO A GOOD START: FINDING THE INITIAL CONCENTRATION IN GROUNDWATER MODELS

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ABSTRACT

Groundwater models are often used to predict the effect of climate change and (over)exploitation of aquifers. In the past 10 years, developments in software and hardware made it possible to create complex 3D models that include density dependent flow and transport of chloride. These models are used to simulate the effects of climate change (i.e. sea level rise) and (over)exploitation of aquifers, with respect to ground water heads and chloride transport. However, these predictions (and especially the speed of changes) are highly dependent on the three-dimensional starting concentration. In many cases this is more important than the hydraulic parameters or boundary conditions, especially when predicting the salinization of drinking water wells. We will show the importance of the initial chloride concentration with a few synthetic and real-world examples. We propose a method to derive a three-dimensional chloride distribution using a combination of different types of data:

- (airborne) geophysics
- Water samples
- Bore logs

We show how the coupled groundwater model itself can be used to create a physically plausible starting concentration that matches current and historical measurements, and which combination(s) of measurements are the most effective in reducing the uncertainty of the predictions.

Keywords: *Groundwater Modelling, Sea Water Intrusion, Salinization*

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REDUCED-ORDER SEAWATER INTRUSION MODELING WITH A NEW FORMULATION FOR INTERFACE FLOW IN MULTI-LAYER SYSTEMS

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ABSTRACT

Changes in sea-level, precipitation patterns, and water usage impact groundwater flow and seawater intrusion in coastal aquifers. Reduced-order models are favored for rapid, large-scale simulations as they are based on relevant physical processes, but avoid overly complex, data intensive, and computationally expensive techniques. Reduced-order models are intended for screening-level assessments of seawater intrusion impacts to freshwater resources and to quickly assess future impacts of seawater intrusion due to sea-level rise. A popular reduced-order model for coastal aquifers is an interface flow model, in which an interface separates freshwater from saltwater. An interface formulation is capable of simulating the movement of the freshwater, the saltwater, and the elevation of the interface with much lower computational effort than variable-density models for coupled flow and transport. We developed a new control-volume finite-difference formulation based on a water balance of both the freshwater zone and the saltwater zone in combination with a continuity condition at the interface. The numerical formulation is fully implicit, uses upstream weighting of the freshwater and saltwater thicknesses, and solves for the freshwater head, and (optionally) for the saltwater head simultaneously using Newton's method. As the formulation is fully implicit, it allows for the use of large time steps to quickly compute the final steady state position of the interface, which is useful for many applications. Several example models will be presented

simulating transient interface movement for advancing and receding interfaces in multi-layer systems, including a comparison to the results of a variable density model. The formulation has been implemented in Python (for multi-layer cross-sectional simulations) and is being implemented in a new MODFLOW 6 package and in Aquaveo's Groundwater Modeling System (GMS) graphical user interface.

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REQUIREMENTS FOR MODELING WELL SALINIZATION WITH VARIABLE-DENSITY SUBMODELS DERIVED FROM DENSITY-INVARIANT REGIONAL MODELS

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ABSTRACT

Modeling salinization of wells in semi-confined aquifers with a fresh-salt interface presents many challenges. Accurately modeling of upconing and the salinity of extracted groundwater under variable-density conditions requires a fine spatial and temporal discretization, which is computationally prohibitive at a regional scale. A common practical approach to address this challenge is to use larger-scale models to derive boundary conditions for locally refined models. In this way the effects of regional topography or seasonality can be accounted for in the local model. Transfering the heads and fluxes calculated with the regional model to the smaller submodel is not a trivial task, especially when the regional groundwater models do not include salt transport and variable density flow.

This research aims to answer the following questions. How do you determine the appropriate dimensions and resolution of the locally refined model? What errors are introduced when boundary conditions derived from a constant-density regional groundwater model are applied to a local variable-density model? How to account for the density effects that occur in the local model but not in the regional model?

To investigate these questions a synthetic regional Modflow 6 model is used. The regional model includes hydrological processes such as groundwater recharge, ground- and surface water interaction, wells and variable density flow. Extraction wells are simulated at a number of key locations in the model that differ in, for example, the depth to the interface and the geohydrological layer structure. The effect of neglecting variable-density flow is investigated using this model. A constant-density version of this model is also created.

Locally refined models are constructed at the well locations. The effects of model size, resolution and boundary conditions on the simulated extraction water salinity and strategies for translating the heads and fluxes from the density-invariant version of the regional model to boundary conditions for the local models are investigated. The lessons learned will be presented as practical guidelines for building submodels for well salinization based on models of regional flow systems.

Keywords: *Well salinization, numerical modelling, variable-density flow, Modflow 6*

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SEA WATER INTRUSION ON THE LLOBREGAT DELTA: THE IMPACT OF UNDERGROUND INFRASTRUCTURE AND HYDRAULIC BARRIER

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ABSTRACT

Approximately 40% of the world's population currently inhabits coastal urban areas—a figure projected to grow steadily in the coming years. In light of this increasing urban concentration along coastlines, coastal aquifers emerge as key freshwater reserves, particularly in arid and semi-arid zones, where their importance becomes even more pronounced during drought events.

A representative example of an urban coastal aquifer is the Llobregat Delta, which has supplied water to the city of Barcelona and its metropolitan area for over a century. Since the 1960s, due to urban, demographic, and industrial expansion, the aquifer has been subjected to systematic overexploitation, which has favoured a progressive advance of salt water intrusion (SWI). During the same period, numerous underground infrastructures have been built, including railway tunnels with associated drainage systems and retaining walls, as well as an enclosed inner port dock confined by retaining walls. These elements may have acted as intensifying factors for SWI. In 2007, a positive hydraulic barrier was implemented using reclaimed water, with injection wells placed in close proximity to the port dock, to counteract the intrusion. To date, however, the influence of these infrastructures on SWI—and their potential interference with the functioning of the barrier—has never been quantified.

The study is structured around four groups of simulations. The first group includes a transient simulation under a real scenario with infrastructures and another under a hypothetical scenario without them. This initial stage aims to quantify the total accumulated impact in terms of seawater intrusion, with special emphasis on identifying localized effects that may compromise the performance of the hydraulic barrier. The second group consists of a series of additive simulations in which each infrastructure is incorporated incrementally, following chronological order, starting from the hypothetical no-infrastructure scenario. These simulations are designed to quantify the specific contribution of each structure to the overall impact. Once both the total

and individual impacts have been assessed, the cumulative effect of the hydraulic barrier is determined by comparing the real scenario with another simulation that excludes the barrier. Finally, based on the areas where the barrier proves less effective—and considering the influence of nearby infrastructures—two proposals are developed: (a) an extension of the existing positive barrier and (b) a mixed barrier combining injection and pumping wells to address the identified shortcomings.

Preliminary results point to a significant and synergistic contribution of infrastructures to SWI in the Llobregat Delta: the dock appears to act as a primary entry point for seawater, with its effect amplified by the drainage cones of nearby tunnels. Additionally, seepage from the dock seems to be undermining the hydraulic barrier's effectiveness in the Zona Franca area under its current configuration. Nevertheless, the barrier has shown an overall positive impact in mitigating the intrusion. A mixed barrier, featuring a set of extraction wells surrounding the dock, would likely achieve a greater reversal of SWI than a positive barrier alone.

This study offers a methodological framework for addressing similar challenges in urban coastal aquifers, while underscoring the need to consider both the impact of adjacent infrastructures and a thorough geological assessment before implementing a positive hydraulic barrier as a mitigation measure against seawater intrusion.

Keywords: Urban coastal aquifer, Sea water intrusion, Tunnels, Inner dock, Positive hydraulic barrier, Mixed hydraulic barrier

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TIDAL AREA MORPHOLOGY AND THE IMPACT OF SEA LEVEL RISE ON GROUNDWATER SYSTEMS

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INTRODUCTION

About 25% of the Netherlands is situated below sea level and pumps are needed to keep the area dry for living and agriculture. These areas are called 'polders'. The first polders originate from around 1000 AD when the reclamation of land from the sea and lakes started in the Dutch coastal area. In these low-lying reclaimed salt marshes, upward seepage of saline groundwater salinizes surface waters and shallow groundwater (De Louw, 2013).

The last few years, the opposite of reclamation is happening (de-reclamation); i.e. vulnerable agricultural land is given back to the sea to restore tidal salt marshes. Perkpolder was the first de-reclaimed polder which was established in 2015. De Louw et al., (2016) described the effectiveness of a mitigation measure called SEEPCAT, a self-flowing seepage system, in Perkpolder to protect a freshwater lens from this local sea level rise.

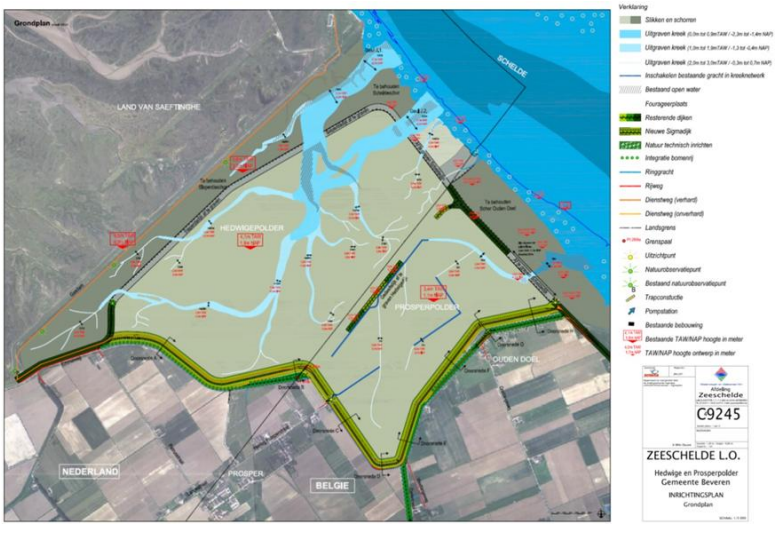

Figure 1. Design map of new tidal area with tidal creeks. The light green area was agricultural area and since 28 October 2022 tidal area.

In October 2022 a much larger polder area 'Hedwige-Prosperpolder' of about 5 km^2 situated on the Dutch-Belgium border was de-reclaimed and transformed into a tidal area (see Figure 1). The realization of the open connection to the sea can be seen as a local sea level rise for the adjacent agricultural area. The average tidal fluctuation of the estuary water flowing into the new tidal area fluctuates between -2.0m below to 2.8m above mean current sea level (MSL). Figure 2 shows a conceptualized cross section through the new tidal area and the agricultural area. The average surface level of the new tidal aera is ~1.8m above sea level and will inundate two times per day. The tidal area is incised by (man-made) tidal creeks through which filling of the tidal area with seawater occurs and deflating during low tide, twice a day.

The question arises, how will the morphology of the tidal area and tidal creeks affect the aquifer heads in and outside the tidal area resulting from filling and deflating of the area and subsequently affecting the groundwater system in the agricultural area. Besides the morphology also the hydrogeological composition of the tidal area will affect the propagation of tides to the aquifer.

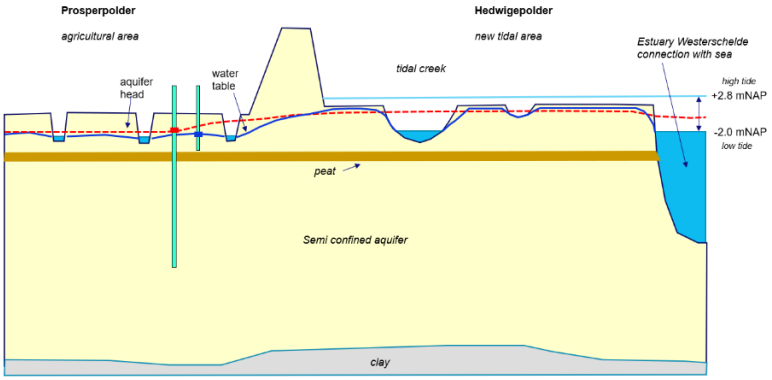

Figure 2. Conceptual hydrogeological cross section showing new tidal area in the east with the connection to the sea via the Westerschelde Estuary and the agricultural area in the west.

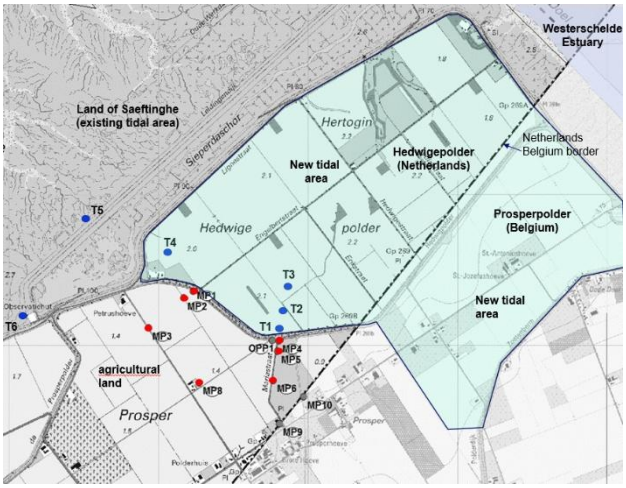

Figure 3. Groundwater monitoring network in the agricultural area (in red) and in (new) tidal area (in blue). The area indicated in green is the new tidal area with open connection to the sea since 28 October 2022.

METHODS

A detailed monitoring network outside the Hedwigepolder was installed to determine the reference groundwater situation and monitor the effects of the new tidal area on the groundwater system in the adjacent agricultural area. At 7 locations at different distances to the tidal area (former Hedwigepolder) the hydraulic head in the aquifer and water table are measured every hour with automatic monitoring devices. At these locations the fresh-saline interface (salinity – depth profile) is measured every year with the EM-SlimFlex. The monitoring campaign was started in 2015 and since October 2022 effects of the local sea level rise are being measured. Half year before opening the connection with the sea, piezometers were installed in the tidal area with screens at 2-3m, 6-7m and 14-15m depth to monitor the propagation of the tidal effects in the aquifer. Time series analysis was performed using Pastas (Collenteur at al., 2019) to filter out effects of precipitation, evapotranspiration, and drainage in the time series to isolate effects from the opening of the connection to the sea. A groundwater model (in MODFLOW) was built to reproduce the monitoring results and to simulate effects of measures to mitigate effects of (local) sea level rise. Model results are not described in this paper but will be presented during the presentation in June.

RESULTS

Figure 4 shows the time series of the hydraulic head in red (screen depth 14-15m) and phreatic water table (screen depth 2-3m), before and after the establishment of the open connection to the sea of the new tidal area. It is clearly visible that after the connection was established the hydraulic head increased ~0.30m and the tidal groundwater fluctuation increased from <1cm to 20 to 45cm. The phreatic water table doesn't show any effect of the opening since it is dominantly controlled by the intensive drainage network in the agricultural area. The aquifer hydraulic heads were about ~0.7m higher than the water table before opening, showing a permanent upward groundwater

seepage situation. After opening this head difference increases to ~1.0m indicating that seepage fluxes increased with ~40%.

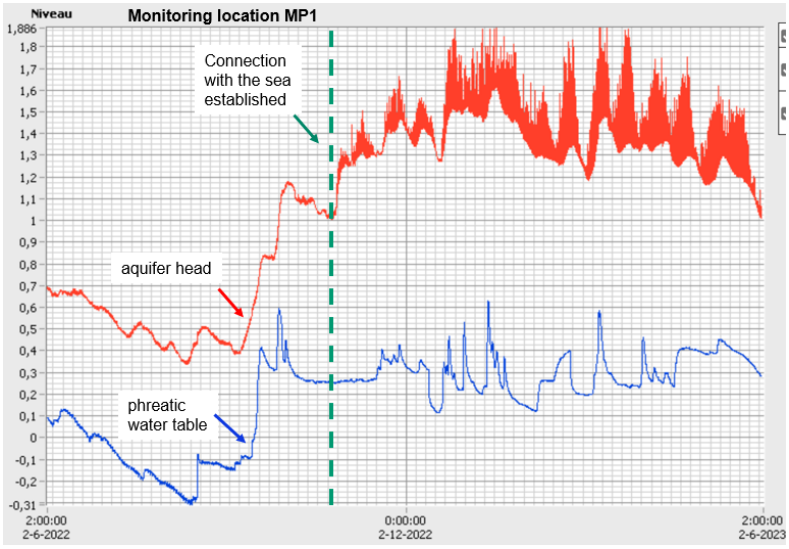

Figure 4. Measured hydraulic head and phreatic water table time for MP1 in the agricultural area, at 100 meters from the new tidal area.

A time series model was derived from 7 years of data of the reference situation (see Figure 5-top) applied for the entire period including the period after opening. The deviation (trend) between observed and simulated time series indicates effects other than meteorology and drainage, in this case the opening of the connection to the sea. Figure 5 shows that the hydraulic head increased ~0.30m due to the opening but the effect decreases after February 2023. The exact cause is not yet found and longer timeseries are required. The timeseries analysis clearly shows no effect for the phreatic water table (see Figure 5-bottom).

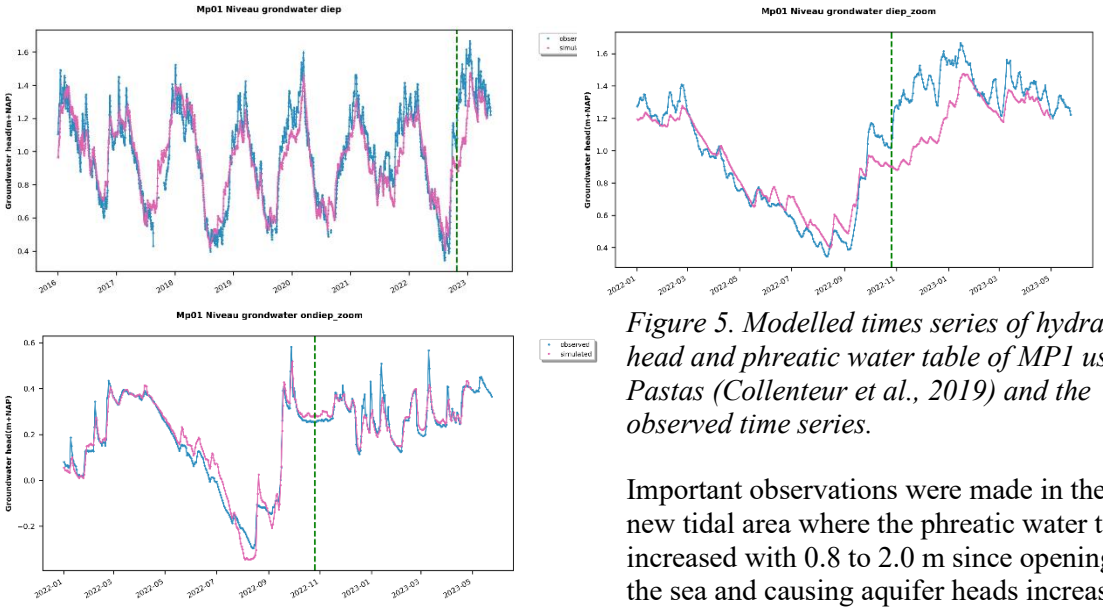

Figure 5. Modelled times series of hydraulic head and phreatic water table of MP1 using Pastas (Collenteur et al., 2019) and the observed time series.

Important observations were made in the new tidal area where the phreatic water table increased with 0.8 to 2.0 m since opening to the sea and causing aquifer heads increase as well. Figure 6 shows for monitoring location T1 increases of ~1.5m for the phreatic water table, ~0.8m for the aquifer head at 6-7m depth and ~0.6m for the aquifer head at 14-15m. The situation in the tidal area changed from upward seepage before to infiltration after opening the connection to the sea. The measurements clearly show the increases of the phreatic water table during high tide reaching the surface water stages of the high tide. But, during low tide the phreatic water table stay at the surface level, at a level of about 1.9m MSL (see T2 and T4 in Figure 6). Although sand deposits in the tidal area are permeable, the time during low tide is too short and the drainage capacity of the creeks too low to significantly drain the groundwater. Monitoring location T3 is located at short distance (< 20 m) from a tidal creek and shows a much better drainage and lowering of the phreatic water table. In February 2023 a sudden drop is visible when a new opening of tidal area was

established, and a lowering trend is visible causing by a constantly eroding creek increasing its drainage capacity. The sedimentation and erosion processes are still far from in equilibrium.

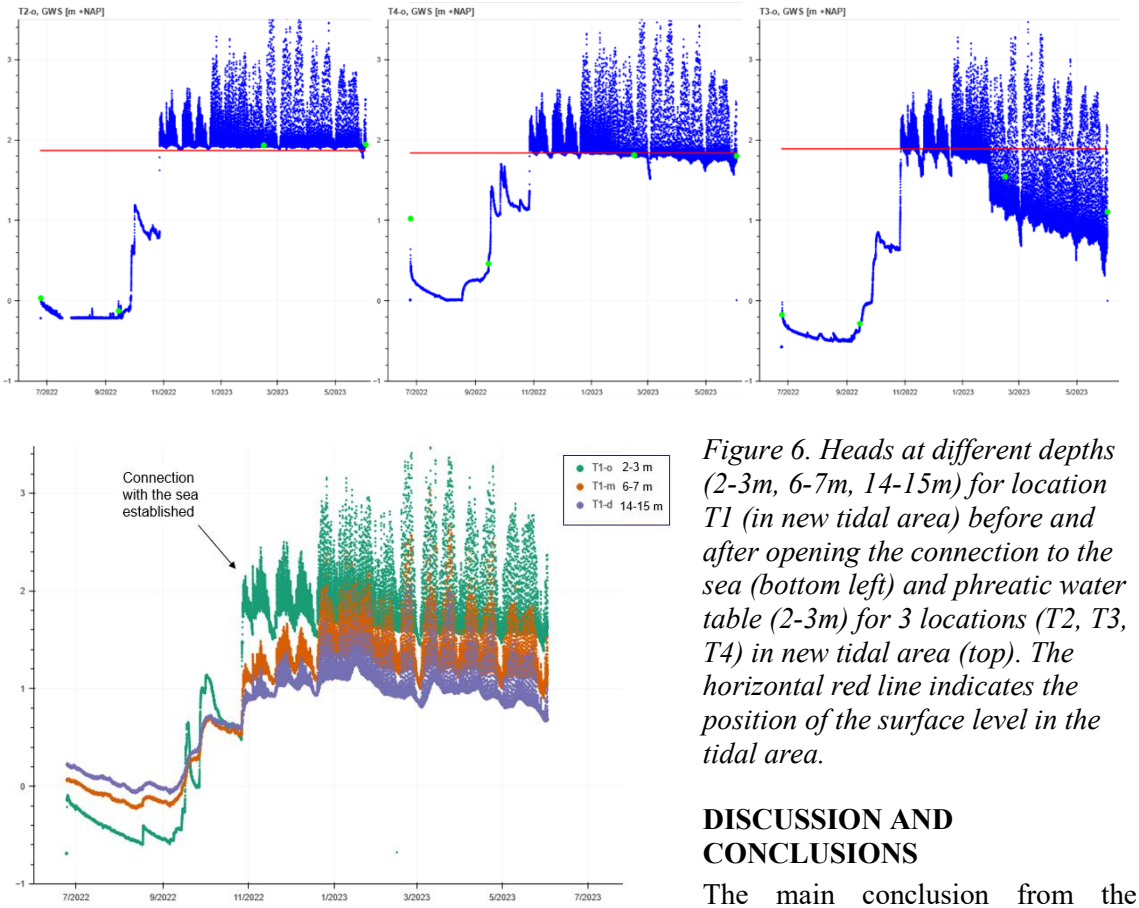

Figure 6. Heads at different depths (2-3m, 6-7m, 14-15m) for location T1 (in new tidal area) before and after opening the connection to the sea (bottom left) and phreatic water table (2-3m) for 3 locations (T2, T3, T4) in new tidal area (top). The horizontal red line indicates the position of the surface level in the tidal area.

DISCUSSION AND CONCLUSIONS

The main conclusion from the measurements so far is that phreatic groundwater levels in the tidal area will stay at the surface during low tide due to the short period of low tide available for groundwater to be drained. This has large consequences for the effect on the hydraulic heads in the tidal area and head propagation to the agricultural area caused by (local) sea level rise. In fact, the effect of the sea level is not the average of high and low tide (which is approximately 0 m MSL) but the space and time-weighted average of high tide (water levels above surface level in the tidal area during a certain time) and the water table at the surface during low tide. So, the water pressure in the tidal area caused by this local sea level rise is not 0 m MSL but >2.0 m MSL which is a huge difference.

The monitoring results showed that for tidal flat areas, the impact of a sea level rise on groundwater systems is highly dependent on the surface elevation of tidal area (morphology of the tidal area) and the drainage capacity of the tidal creeks. And this should always be taken into account when calculating effects of sea level rise on groundwater systems when the coastal zone contains tidal flats.

REFERENCES

Collenteur, R.A., Bakker, M., Caljé, R., Klop, S.A., Schaars, F. (2019) Pastas: open source software for the analysis of groundwater time series. Groundwater. doi: 10.1111/gwat.12925.

De Louw, P.G.B., 2013. Saline seepage in deltaic areas. Preferential groundwater discharge through boils and interactions between thin rainwater lenses and upward saline seepage. PhD thesis, Vrije Universiteit Amsterdam. ISBN/EAN 9789461085429.

De Louw, P.G.B., et al. (2016). A self-flowing seepage system to protect a freshwater lens from local sea level rise. Pages 67-70 from: Werner, A.D. (ed.) (2016), Proceedings of the 24th Salt Water Intrusion Meeting and the 4th Asia-Pacific Coastal Aquifer Management Meeting, 4-8 July, 2016, Cairns, Australia.

Salt Water Intrusion Congress (SWIM 2025)

June 2-6, 2025, Barcelona, Spain

ASSESSING THE ROLE OF SUBMARINE GROUNDWATER DISCHARGE IN COASTAL ECOSYSTEMS USING COMPOSITIONAL DATA ANALYSIS: INSIGHTS FROM THE CATALAN COAST.

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ABSTRACT

Submarine Groundwater Discharge (SGD) has emerged as a critical factor in understanding sea-land interactions in coastal regions. SGD involves the release of nutrient-rich groundwater and recirculated seawater into marine environments, playing a vital but poorly understood role in coastal ecosystems. This process is especially significant in the oligotrophic Mediterranean Sea, where low nutrient levels make SGD a key driver of ecological dynamics in the sea-land transition zone. This study investigates the impact of SGD along the Catalan coast in the Western Mediterranean, a densely populated area where land-sea interactions and SGD effects on marine ecosystems are likely substantial. Using a 23-year dataset, the research aims to link SGD to coastal water quality by analyzing inorganic nutrient composition (NO3, NO2, NH4, PO4, and SiO4) and salinity at 70 coastal stations. A Compositional Data Analysis (CoDA) approach is employed to identify SGD locations and assess their influence. The study also considers land-based hydrogeological factors, such as aquifer characteristics, and explores relationships between nutrient composition and biological indicators, particularly chlorophyll levels, which reflect photosynthetic activity and potential ecological responses to SGD-driven nutrient changes. This approach, which takes into account the compositional structure of the data, enhances the identification of SGD locations and facilitates a deeper understanding of their ecological impacts. The findings from this study offer valuable insights that could support the design of more effective strategies for the management and conservation of coastal ecosystems.

Acknowledgments:

Acknowledgments This work was funded by the Spanish Government grant PID2022-140862OB-C21 and PID2021- 125380OB-I00 funded by MCIN/AEI/10.13039/501100011033 and by ERDF A way of making Europe. This study was also funded by of the Horizon Europe GES4SEAS project HORIZON-CL6- 2021-BIODIV-01-04.

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BIOGEOCHEMICAL TRANSFORMATIONS OF ANTHROPIZED *VERSUS* PRISTINE CONTINENTAL GROUNDWATERS IN SUBTERRANEAN ESTUARIES

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ABSTRACT (300 WORDS)

The intense biogeochemical reactivity of the freshwater-seawater mixing interface inside coastal aquifers (also called subterranean estuaries; STEs) alters the chemical composition of groundwater before its discharge into coastal waters. However, human activities on land and at the shore may also alter the role of STEs as chemical modulators in the land-to-ocean transfer of solutes. Here, we evaluate how these systems transform the composition of anthropized and pristine continental groundwaters by examining the levels and reactivity of oxygen, nutrients and dissolved organic matter (DOM) quantity and quality in porewaters of two urban STEs (one internally oxygenated due to a human-derived gravel layer and the other anoxic) and one from a local National Park considered pristine but under similar geological, hydrological and oceanographic contexts and comparing them with the composition of the surrounding continental groundwaters. Continental groundwaters surrounding urban STEs exhibited nitrate levels two orders of magnitude higher than those from the National Park, while the latter doubled DOM levels compared to the urban sites. This contrast was reflected in the composition of the terrestrial freshwater discharge tube entering STEs, enriched with DOM in the pristine STE and with nitrate in the oxygenated urban STE. Yet, comparison between measured concentrations and conservative mixing lines revealed that most DOM was produced within the pristine STE. No groundwater-borne nitrate was detected in the anoxic urban STE interior, which contrasted with the enhanced nitrogen transport through the gravel layer of the oxygenated

urban STE. Close to the seepage face, interaction between terrestrial brackish groundwater and the oxygen and coastal organic matter sourced by tidally-driven recirculated seawater fueled the production of phosphate, dissolved inorganic nitrogen and aromatic DOM through benthic reactivity. This study reveals how despite anthropogenic impacts on continental groundwaters, the biogeochemistry of STEs is the main driver of the composition of the discharged porewater.

Keywords: *(maximum 5 keywords): Subterranean estuary, Anthropogenic impact, Submarine groundwater discharge, sandy seepage face, seawater recirculation*

Acknowledgements: *This work was financed by the projects SUBACID (funded by the Irish Research Council and the European Union's Horizon 2020 Research and Innovation Program under the Marie Skłodowska-Curie grant agreement No. 713279 through the CAROLINE program, CLNE/2017/210), MicroSub (Parques Nacionales, 2595/2020) and Integrounds (TED2021-130020B-C21). E. Calvo-Martin received funding from the Spanish government through the FPU PhD grant number FPU20/04707.*

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DIGGING INTO THE ROLE OF MICROORGANISMS IN MEDITERRANEAN COASTAL AQUIFERS

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Submarine groundwater discharge (SGD) is a key global process that delivers significant amounts of nutrients and other solutes to coastal oceans, profoundly impacting marine ecosystems. Both the quality of groundwater and the effects of SGD are shaped by biogeochemical processes occurring at the land-sea interface, many of which are mediated by microorganisms inhabiting the transition zones where freshwater mixes with seawater. However, studies on SGD and subterranean estuaries have largely overlooked the microbial component, leading to an incomplete understanding of the functioning of coastal aquifers and their relevance for coastal ecosystems.

Integrating microbial information into SGD research is challenging, as it requires interdisciplinary approaches (ecology, hydrology, geochemistry) and cross-ecosystem perspectives, given that subterranean estuaries act as connectors between terrestrial, freshwater, and marine systems. In recent years, we have characterized microbial

communities from various coastal aquifers along the Spanish coast to gain insight into their poorly known microbial inhabitants, and to better understand their role in regulating SGD quality and its consequences in the marine environment. Our results reveal that coastal groundwater communities are extremely diverse and heterogeneous, exhibiting a unique composition as they share very few species with connected freshwater, sediment, and seawater microbial communities. They harbor many potentially unknown species and metabolisms, and are dominated by some poorly known groups such as Patescibacteria and Nanoarchaeota, which might be mobilized to the sea via SGD. Ongoing research targeting microbial functional genes will allow to characterize the functional potential of these communities to elucidate their role in modulating nutrient fluxes to the sea.

Keywords: coastal aquifers, submarine groundwater discharge, microbial communities, microbial dispersal

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DRIVERS OF NITROGEN AND PHOSPHOROUS TRANSFORMATIONS IN SUBMARINE GROUNDWATER DISCHARGE (SGD) OF A MEDITERRANEAN COASTAL AQUIFER

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ABSTRACT

A comprehensive understanding of chemical exchange mechanisms is essential for advancing research on coastal groundwater biogeochemistry. Submarine groundwater discharge (SGD) is driven by forces acting on different temporal and spatial scales, with significant influence from a variety of geological contexts and numerous terrestrial and marine dynamics. These factors play a crucial role in transforming dissolved compounds before they are released into the coastal ocean.

This research aims to conceptualize and characterize the main drivers in biogeochemical dynamics and processes associated with the SGD in a karst environment in the Mediterranean region. Conducted at Aiguadolç Beach in Garraf County, northeast Spain, the study enhances the identification and quantification of various SGD pathways and their role in nutrient

transformations. A multimethodological approach is employed, incorporating field techniques such as Amphibious Electrical Resistivity Tomography (AERT), manual piezometers, and seepage meter sampling. Additionally, hydrogeochemical and microbiological sampling was integrated to identify the drivers and mechanisms of biogeochemical processes.

Previous results reveal a unique geochemical signature in each pathway, with nutrient concentrations in groundwater samples at the study site ranging from 0.06 to 1.00 µmol·L^{-1} for phosphate, 18 to 52 µmol·L^{-1} for silicate, 0.02 to 0.84 µmol·L^{-1} for nitrite, 1.4 to 230 µmol·L^{-1} for nitrate, and 85 to 410 µmol·L^{-1} for ammonium. Samples from the diffusive area exhibited lower variability, with narrower ranges of dissolved inorganic phosphorous (DIP) (0.06–0.21 µM), dissolved silicate (DSi) (19–32 µM) and dissolved inorganic nitrogen (DIN) (120–230 µM) compared to the focused discharge area, which displayed greater dispersion (DIP: 0.07–1.00 µM; DSi: 19–52 µM; DIN: 90–380 µM) due to the area's heterogeneity and the variety of discharge processes. Ammonium was the predominant species of inorganic nitrogen in all groundwater samples; however, the submarine spring samples indicated a higher proportion of nitrate in this area.

During a field campaign in January 2025, a detailed biogeochemical characterization was conducted to better understand the complexities of nitrogen and phosphorus transformations along these SGD flows.

Keywords: *biogeochemical processes, coastal biogeochemistry, SGD, subterranean estuary*

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GROUNDWATER DISCHARGE AND HYDROLOGICAL CONNECTIONS IN A COASTAL FISHPOND

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ABSTRACT

The He'eia Fishpond is an 800-year old Native Hawaiian aquaculture system that has relied on stream and groundwater inputs of silica, nitrogen, and phosphorus for productivity. Decades of land-use and water management changes in the watershed altered water and nutrient fluxes threatening the pond's water quality and food-web. In order to quantify fluxes during current variable hydrological and tidal conditions, we contrasted stream and groundwater discharge and nutrient inputs in dry and wet seasons, during and after intense rain events and droughts as well as perigean spring tides. We used spatial radon surveys and temporally continuous radon measurements to better understand groundwater discharge patterns. The largest uncertainty in the radon mass balance models was the pond's spatially and temporally variable residence time and resulting atmospheric evasion and radon decay correction. Using a triangulation method, we were able to subdivide the pond and evaluate SGD spatial patterns and changes across the different sampling periods in each parcel. We identified SGD hotspots along the landward margin of the pond but also on the outer, ocean side of the pond wall. In addition, temporal analysis revealed that SGD is higher at rising tides and is also higher at spring tides/higher ocean water levels. Contrary to how tidal pumping has been described in the literature, SGD at low tide is limited. Not until the coastal aquifer is lifted by tides do we observe increased SGD both on daily tidal and on neap-spring tidal time scales. The connection of the tidal cycle and the water level in the coastal aquifer affects the water flow paths and seems to be an important driver of

SGD into the pond.

Keywords: *submarine groundwater discharge, tidal pumping, coastal aquifer, nutrient fluxes across the land-ocean interface*

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IDENTIFICATION OF SUBMARINE GROUNDWATER DISCHARGE ZONES AS THERMAL REFUGIA FOR EELGRASS RESTORATION

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ABSTRACT

The Peconic Estuary (Long Island, NY, USA) has experienced eelgrass retreat over the past two decades towards inlets or areas with increased ocean exchange, where water temperatures are cooler, similar to much of the US east coast. This project aims to identify shoreline segments where submarine groundwater discharge may provide cool water temperature refugia during the summer and to conduct eelgrass restoration in these areas. Here, we report on the identification and mapping of submarine groundwater discharge zones. We conducted airborne thermal infrared (TIR) flights over the Peconic Estuary in August and December 2023 to identify shoreline segments susceptible to submarine groundwater discharge. The presence of groundwater in the TIR imagery was validated through in-situ seawater mapping along the coast of temperature, salinity, radium, and radon-222, which are natural groundwater tracers. Results indicate significant TIR surface water anomalies throughout the Peconic Estuary, with reduced salinity and elevated radioisotope signatures. Two shoreline areas identified during summer were used for eelgrass test planting. Repeat TIR and radon measurements in winter confirmed the stability of submarine groundwater discharge as a potential thermal refugia zone. Intertidal and submarine groundwaters collected within these TIR zones further demonstrated enrichment of inorganic nutrients that varied with the seasonal migration of the freshwater-saltwater interface. This project serves as a model for eelgrass habitat restoration and implementation efforts in estuaries affected by groundwater inputs.

Keywords: *submarine groundwater discharge, remote sensing, radon, radium, nutrients*

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IMPACT OF SUBMARINE GROUNDWATER DISCHARGE ON MICROBIAL PLANKTON IN A TIDAL CRYSTALLINE COASTAL SYSTEM

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ABSTRACT

Submarine groundwater discharge (SGD) has been largely ignored in the tidal crystalline coast of the Atlantic arc of the Iberian Peninsula despite it can contribute to eutrophication of coastal waters. The Ría de Vigo is a productive coastal inlet, located in the northwest of the Iberian Peninsula. Coastal upwelling is considered the main allochthonous nutrient source to the Ría de Vigo, while SGD may represent up to 23% of riverine discharge to the system. Regardless of the magnitude of SGD to this coastal inlet, its impact on marine microbial dynamics remains unknown. Within this context, we assessed the response of marine microbial plankton growth (based on changes in phytoplankton and bacterial biomass) and taxonomic community composition (assessed using 16S and 18S rRNA gene metabarcoding) to SGD inputs of different magnitude and nature during the dry and the wet seasons by mixing seawater with different proportions (5%, 10%, and 20%) of porewater obtained from three subterranean estuaries in the Ría de Vigo (Cesantes, Panxón, and O Vao). Seawater and porewater controls were included to compare growth and community structure in the endmembers and in the mixed treatments. Phytoplankton growth was stimulated by porewater addition up to ca. 4-fold compared to the seawater control, while bacterial responses ranged from 0.8 to 1.4-fold. There was a clear spatial and temporal variability in the response patterns, related to the chemical composition of

the porewaters. In the dry period, phytoplankton response to SGD was proportional to total dissolved nitrogen. During the wet period, prokaryote response to SGD was inversely proportional to nitrite concentration, suggesting a potential inhibitory effect. Our results highlight the variability of the impacts of SDG on coastal waters as well as the differential impact on phytoplankton and bacteria which might alter the services provided by the microbial community in this productive ecosystem.

Keywords: *(maximum 5 keywords)*

Microbial communities, subterranean estuaries, phytoplankton, bacteria, Ría de Vigo.

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MICROBIAL COMMUNITY STRUCTURING AND NITROGEN TRANSFORMATIONS ALONG A MEDITERRANEAN SUBTERRANEAN ESTUARY

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ABSTRACT

Submarine Groundwater Discharge (SGD) supplies large amounts of solutes to the ocean. In coastal areas, the confluence of fresh and saline groundwater results in subterranean estuaries (STEs), biogeochemically active sites in which biogeochemical transformations mediated by microbes can control SGD-driven nutrient fluxes to the ocean. However, the understanding of microbial communities inhabiting these areas and of their functional capabilities remains very limited. Our aim was to explore the spatio-temporal variations in abundance, heterotrophic activity, taxonomical composition and functional capabilities of prokaryotic communities within a Mediterranean STE characterized by pronounced physicochemical gradients. For this purpose, we collected groundwater samples from several piezometers (depths 6 – 22m) covering the

entire salinity gradient along a transect perpendicular to the shoreline in two hydrological seasons.

Our results show large spatial variations in prokaryote abundance and activity, as well as in microbial composition following gradients in salinity, nutrient availability and dissolved organic carbon concentration. qPCR analysis of functional genes involved in nitrification (amoA) and denitrification (nirK and nirS) unveiled significant spatial variability, indicating different microbial niches influencing nitrogen transformations through the STE. Conversely, communities were less variable between both seasons, suggesting temporal stability. Our findings highlight the high spatial heterogeneity in the microbial communities, in terms of biomass, activity, taxonomical composition and their role in nitrogen transformations throughout the coastal aquifer. This variability highlights the importance of conducting detailed spatial analyses for a more comprehensive understanding of the microbial contribution to SGD-driven biogeochemical processes in these key ecosystems.

Keywords: *Submarine Groundwater Discharge, subterranean estuary, microbial communities, microbial functionality, nitrogen cycle.*

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SPATIOTEMPORAL VARIABILITY AND ECOLOGICAL IMPACT OF A MEDITERRANEAN SUBTERRANEAN ESTUARY ON COASTAL MICROBIAL COMMUNITIES

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ABSTRACT

With their permeable sandy substrates, beaches represent potential hot spots of subterranean mixing between fresh groundwater and intruding seawater, resulting in the formation of subterranean estuaries (STE) that discharge into coastal waters. Current scientific challenges consist in characterizing microbially mediated biogeochemical transformations occurring in STE and their spatiotemporal variability, as well as evaluating the potential of such nutrient-rich groundwaters to contribute to coastal food web functioning in case of ground water discharge.

The hydrological and biogeochemical spatiotemporal variability of a French Mediterranean superficial STE was evaluated through nine sampling campaigns conducted in 2023 and 2024. Salinity ranged from 1 to 40, with a diversity of situations suggesting sea water intrusion as well as of discharge into coastal seawater. Based on salinity in nearby seawater, discharge of groundwater was estimated to represent up to 8.5% of coastal water. Along with these variable conditions, water residence time in the STE was estimated to range between 1 and 20 days thanks to the analysis of radium isotopes. Oxygenation levels varied from near saturation to anoxia. Macronutrients concentrations were very high compared to sea water, especially in ammonium and phosphates (up to 220 and 7µM, respectively), as well as in dissolved organic and inorganic carbon (up to 1.5 and 33 mM, respectively). The sensitivity of the microbial basis of the coastal planktonic foodweb to representative groundwater discharges representing observations at our study site were evaluated experimentally. For that, coastal seawater and its natural microbial community was exposed to 0-20 % of groundwater. Dose-response modelling revealed lowest observed effect concentrations down to 0.1% after 24h for phytoplankton and nearly linear responses to the proportion of groundwater. Heterotrophic prokaryotes also appeared stimulated within 2 days for more than 5% of groundwater added. The coastal microbial community thus appeared highly sensitive to estimated groundwater discharge levels.

The abstract must contain the full emails and affiliations of all author/s. Abstracts can only be accepted on the understanding that the work will be presented at the Conference. One presentation per registered author will be allowed.

Keywords: subterranean estuary, submarine groundwater discharge, hydrology, macronutrients, microbial sensitivity

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THE EFFECT OF SALT WATER INTRUSION AND SUBMARINE GROUNDWATER DISCHARGE ON DISSOLVED OXYGEN CONCENTRATIONS IN ESTUARINE AND COASTAL WATERS

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ABSTRACT

The twin forces of salt water intrusion (SWI) and submarine groundwater discharge (SGD) cause biogeochemical reactions in subterranean estuaries. A primary reaction is the oxidation of biogenic carbon, which releases CO_2, nutrients, metals, and other byproducts. In freshwater aquifers dissolved oxygen (DO) is the primary oxidizing agent, but its low concentration (~0.28 mmol/L at saturation) limits its capacity to oxidize carbon. In freshwater aquifers oxidation largely ceases when the inherently low concentrations of oxidizing agents are exhausted. SWI supplies high concentrations of sulfate, an oxidizing agent with 200 times the oxidation capacity of dissolved oxygen in full strength seawater. The byproducts of sulfate oxidation of biogenic carbon include sulfide, ammonia, reduced metals, dissolved organic carbon and nitrogen, and radionuclide tracers, especially radium isotopes. SGD carries these reduced byproducts to coastal waters, where they may be quickly oxidized and substantially reduce the DO concentration in receiving waters. If the DO concentration falls to <60% saturation (~ 60 mmol/L), many marine organisms become stressed. Severe oxygen depletion – called hypoxia – occurs when DO concentrations fall below 30% saturation (~30 mmol/L). Such low concentrations kill or displace many organisms. Today I will focus on this often-overlooked mechanism contributing to coastal and estuarine hypoxia: the oxygen demand created by oxygen-depleting substances entering the system from coastal aquifers. I call this SGD oxygen demand (SGD-OD). This poorly recognized aspect of SWI-SGD interactions may have large implications. Today I will review documented cases at estuarine and coastal sites where SGD-OD may cause or accelerate hypoxic conditions. Without continued aeration with atmospheric oxygen, the study sites would have experienced prolonged hypoxic conditions due to SGD-OD. The presence of hydrogen sulfide supplied by SGD also impacts the ecosystem as it is poisons most organisms. Increases of SWI will exacerbate these problems.

Keywords: sea water intrusion, submarine groundwater discharge, disolved oxygen, hypoxia, radium isotopes

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THE OVERLOOKED ROLE OF TERRESTRIAL GROUNDWATER IN COASTAL WETLAND RESILIENCE

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ABSTRACT

Coastal wetlands form at the dynamic interface between terrestrial and marine environments. To date, most research has focused on ocean inundation as a driver of ecosystem productivity, health, and biogeochemical cycling. While the ocean's influence is undeniably important, terrestrial aquifers also interact with coastal wetlands along their upland and subsurface boundaries. However, the role of terrestrial groundwater in modulating coastal wetland ecosystem dynamics has scarcely been investigated, potentially limiting the efficacy of ecosystem projections in a changing future. Here, we investigate drivers of coastal wetland redox potential, a key indicator of sediment biogeochemistry, reflecting oxic/anoxic transitions that shape wetland resilience. Using wavelet and mutual information analyses at seven coastal wetland sites across the United States, we evaluate the influence of wetland water level, terrestrial groundwater level, and meteorological factors on coastal wetland redox potential. Results show that, across all sites, terrestrial groundwater level was the dominant control on coastal wetland redox potential. The strong link between terrestrial aquifers and coastal wetland redox potential observed here contrasts with the traditional paradigm of ocean inundation as the primary ecosystem modulator and suggests that coastal aquifers are a key driver of biogeochemical processes. This upland-marsh connectivity also indicates that changes in coastal aquifers, such as drought or pumping, may affect the biogeochemical conditions and future resilience of coastal wetlands.

Keywords: *coastal groundwater, coastal wetland, hydrologic connectivity, biogeochemistry*

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GLOBAL FLUXES OF RECIRCULATED SUBMARINE GROUNDWATER DISCHARGE INDIVIDUAL COMPONENTS

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ABSTRACT

Submarine groundwater discharge (SGD) consists of freshwater SGD (FSGD) and recirculated saline SGD (RSGD). FSGD contributes approximately 0.5-1% of the influx from rivers to the ocean (Liu et al., 2020; Luijendijk et al., 2020), but it has significant implications for coastal water chemistry and ecology. RSGD is several orders of magnitude higher than FSGD, and does not directly impact the ocean water budget. Due to water-rock interactions, RSGD exhibits a distinct chemical composition compared to seawater. As a result, it plays a crucial role in coastal ecology and the ocean's solute budget (Santos et al., 2021).

RSGD is driven by several mechanisms, including density-driven, tidal-driven, and wave-driven circulations, each with different spatial and temporal scales. Wave-driven fluxes are short-term, while density-driven fluxes are long-term, and tidal-driven fluxes are intermediate. Different water-rock interactions exhibit varying reaction rates; those with low reaction rates are not reflected in short-term fluxes.

This study quantifies global density-driven and tidal-driven RSGD fluxes. The fluxes were calculated using numerical simulations, sensitivity analysis of geohydrological parameters, and upscaling to a global scale using a hydraulic parameter database and bilinear interpolation. Results indicate that higher hydraulic conductivity increases the density-driven circulation and reduces tidal-driven nearshore circulation. An increase in hydraulic gradient has no significant impact on density-driven circulation, while it slightly decreases short-term nearshore circulation.

The estimated global fluxes are 1380 km^3/yr for density-driven RSGD (accounting for heterogeneity effects), 250 km^3/yr for tidal-driven circulation, and 385 km^3/yr for tidal pumping. Using a typical enrichment, calcium flux to the ocean by the density-driven RSGD may be comparable to the riverine calcium input. The results enable the identification of "hotspots." For instance, the Mediterranean Sea and the Caribbean Sea are "hotspots" of density-driven RSGD, while the East Coast of Africa, the west coast of India, and Oceania are "hotspots" of tidal-driven RSGD.

Keywords: *Saline SGD, numerical modeling, global fluxes*

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GROUNDWATER-DRIVEN NUTRIENT INPUTS TO MAR MENOR COASTAL LAGOON: AN OVERLOOKED DRIVER OF ECOSYSTEM DEGRADATION

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ABSTRACT

Coastal lagoons are systems with great ecological importance that support valuable ecosystem services. However, their restricted connection to the sea favors the accumulation of pollutants, making them vulnerable to external inputs. Mar Menor (SE Spain), the largest hypersaline lagoon in southern Europe, has recently suffered several eutrophication events linked to nutrient inputs. The lagoon is connected to an unconfined Quaternary aquifer, artificially recharged by irrigation from agriculture. Submarine Groundwater Discharge (SGD) flows through this nutrient-rich aquifer, acting as a transfer mechanism of solutes from land to sea. However, its contribution to the Mar Menor nutrient budget remains unknown. SGD comprises different

pathways: fresh terrestrial discharge, long-scale seawater recirculation through the sediments, and short-scale porewater exchange (PEX). The chemical composition of each one is strongly shaped by its origin, groundwater transit time, and biogeochemical reactions occurring in the coastal aquifer before discharging into the ocean. In this study, we aim to quantify the contribution of each SGD pathway to the nutrient budget of the lagoon. We performed 3 intensive campaigns in March, July, and November 2021, where we estimated the magnitude of each SGD pathway and the associated nutrient fluxes (NO3−, NO2−, NH4+, Si(OH)4, PO43−). Our results suggest that recirculated SGD represents up to 99% of total groundwater inputs to the lagoon, and short-scale flows significantly increase in summer. A preliminary calculation of the PEX-derived nutrient release to the water column is estimated to be comparable to or exceed all other nutrient sources, emerging as the main source of these pollutants. This can be particularly important in summer, coinciding with eutrophication events. In addition, it seems to be predominantly enriched in reduced species such as NH4+, increasing oxygen demand in the lagoon. Resolving the SGD contribution to the nutrient budget is critical for predicting water quality in lagoonal ecosystems.

Keywords: Submarine Groundwater Discharge, nutrient fluxes, coastal aquifer, radium isotopes

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INFLOW OF METALS THROUGH SUBMARINE GROUNDWATER DISCHARGE IN THE VIGO ESTUARY AND INFLUENCE ON THE LEVELS FOUND IN RECEIVING WATERS

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ABSTRACT

Groundwater is an important source of solutes from land to coastal waters. This input is most relevant even in areas where there are no continuous inputs through river channels. However, until recently, this input has not attracted much interest and studies have been scarce. The present work aims to show the importance of the input of metals associated with submarine groundwater discharge (SGD) in a coastal system such as the Ría de Vigo (Galicia, Spain). For this purpose, two samplings were carried out at different times of the year during the rainy (March 2024) and dry seasons (July 2023). Samples were taken from 8 intertidal subterranean estuaries, 7 wells and 3 rivers. In addition, coastal waters were sampled along the entire coastline of the estuary, and two central stations further away from the coast.

Looking at the coastal samples, the levels of radon, a tracer of groundwater input, were three times higher during the rainy season. However, this input was only reflected in increased levels of Mn, Fe and Co, while the remaining metals (Ni, Cr, Cu, Zn, As, Cd and Pb) show a negative or no correlation with radon.

Comparing the levels of metals between the three input sources considered in this study (wells, subterranean estuaries and rivers the highest values of Cr, Fe, Mn, Co, As, Cd and Pb were associated with subterranean estuaries, while the values of Ni, Cu and Zn were higher in wells.

This study shows that the importance of metal inputs through SGD can be equal or greater in importance to inputs through rivers and is therefore a source to be considered when studying biogeochemical cycles of metals in coastal areas.

Keywords: *Vigo Ría, metals, submarine groundwater discharge, intertidal estuaries*

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QUANTIFYING POREWATER EXCHANGE: UNDERSTANDING NUTRIENT AND METAL CYCLING IN MAR MENOR LAGOON

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ABSTRACT

Coastal lagoons serve as vital ecosystems, preserving a rich diversity of flora and fauna while also holding significant economic value through their extensive use for productive and recreational activities. Mar Menor is one of the largest Mediterranean coastal lagoons and has experienced severe anthropogenic pressures. Decades of mining, agriculture, and urban development in its watershed have increased the fluxes of nutrients and contaminants to the lagoon, leading to ecological degradation, including eutrophication and hypoxia events. Understanding the origin and fluxes of nutrient in the Mar Menor coastal lagoon is essential for mitigating the negative effects of eutrophication. While surface water runoff has been widely studied and Submarine Groundwater Discharge (SGD) has gained increasing attention in recent years, there is still limited understanding of alternative pathways, including short-scale recirculation, known as porewater exchange (PEX). Previous findings derived from Ra mass balances in Mar Menor suggest that PEX is a major source of nutrients to the lagoon, especially during the summer months. Our study aims to directly quantify PEX fluxes to the lagoon using the $^{224}Ra/^{228}Th$ disequilibrium method in surface sediments. Multiple sediment cores were collected in different seasons to assess PEX fluxes throughout the year. Preliminary assessments estimate a PEX flow on the order of 0.0741 cm day^{-1} consistent with previous values derived from the Ra mass balance approach. Preliminary results indicate a gradual increase in PEX fluxes approaching summer, with a peak during the warmest months. In addition, the associated nutrient and metal fluxes have been quantified, highlighting PEX as a significant contributor to the solute input into the lagoon, a key factor in the ongoing ecological degradation of this ecosystem.

Keywords: (Porewater Exchange, $^{224}Ra/^{228}Th$ disequilibrium, PEX, Mar Menor)

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QUANTIFYING SUBMARINE GROUNDWATER DISCHARGE CONTRIBUTIONS TO THE OCEANIC CARBON BUDGET

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ABSTRACT

Coastal aquifers act as dynamic interfaces between terrestrial and marine systems, regulating the exchange of water and solutes through submarine groundwater discharge (SGD). While riverine fluxes of dissolved inorganic carbon (DIC) and total alkalinity (TA) have been extensively studied, the contributions of both fresh groundwater discharge and recirculated seawater remain poorly constrained. These overlooked pathways are particularly relevant in the context of saltwater intrusion (SWI), where mixing processes and biogeochemical transformations within subterranean estuaries reshape coastal carbon fluxes.

By compiling and analyzing a global dataset of coastal groundwater compositions, we quantify DIC and TA fluxes via both fresh SGD and saline recirculation. Our findings reveal that SGD delivers DIC and TA to the ocean at magnitudes comparable to riverine inputs, with global DIC fluxes from SGD estimated at **3.6 ± 0.6 Tmol y^{-1}** (15–30% of the riverine flux) and TA fluxes at **2.6 ± 0.5 Tmol y^{-1}** (~10% of the riverine contribution). Notably, DIC concentrations frequently exceed TA due to non-conservative behavior in subterranean estuaries, highlighting the complex interplay between hydrological mixing, carbonate dissolution, and microbial activity.

A key innovation in our approach is the simultaneous evaluation of TA and DIC in the same groundwater samples, allowing for a refined understanding of how SWI influences carbon cycling in coastal aquifers. By distinguishing flux contributions based on aquifer lithology, we provide new insights into the abiotic and biotic drivers of carbonate system variability. These results underscore the need to integrate SGD processes into global carbon budget models and further explore their role in modulating marine biogeochemistry.

Keywords: *Carbon cycle, Submarine Groundwater discharge (SGD), Coastal aquifer, Seawater recirculation*

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SUBMARINE GROUNDWATER DISCHARGE A SOURCE OF TOTAL MERCURY AT CABRERA ARCHIPELAGO NATIONAL PARK AND RÍA DE VIGO

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ABSTRACT

Submarine groundwater discharge (SGD) is an important yet understudied pathway for mercury (Hg) transport to coastal waters. This study examines SGD as a source of total mercury (THg) and methylmercury (MeHg) in two distinct Spanish coastal systems: the Cabrera Archipelago National Park (Balearic Islands, Spain) and the Vigo Ría (Galicia, Spain). Seasonal variations in Hg concentrations were analyzed in different water compartments, including wells, seawater, porewater, and river water, to assess the influence of SGD on Hg cycling.

THg concentrations ranged from 2.5 to 213.2 pM, with significantly higher levels in wells (median: 95.4 pM in summer, 78.9 pM in winter) compared to porewater (6.5 pM in summer, 5.5 pM in winter) and seawater (1.5 pM in summer, 1.0 pM in winter). Similarly, in Vigo, THg was highest in wells (4.5 pM in summer and 6.6 in winter) and porewater (6.8 pM in summer, 2.7 in summer) and, with lower levels in seawater (1.9 pM in summer, 1.2 pM in winter). A negative correlation between THg and salinity, along with a positive correlation with radium isotopes, suggests that SGD significantly contributes to Hg inputs in both coastal regions. MeHg concentrations in Cabrera ranged from 0.04 to 1.8 pM, with the highest values in wells (0.56 pM

in summer), followed by porewater (0.11 pM) and seawater (0.13 pM). While SGD was a major source of THg, no significant correlation was found between MeHg and SGD indicators, suggesting additional biogeochemical controls on Hg methylation.

This study highlights submarine groundwater discharge (SGD) as a significant source of total mercury (THg) in coastal waters. THg and MeHg levels are influenced by hydrological and biogeochemical processes. Understanding Hg transport and transformation is crucial due to its ecological and health risks. Future research should quantify SGD contributions and microbial methylation processes.

Keywords: *Submarine groundwater discharge, groundwater,mercury, porewater*

The Influence of Lake Kinneret Level Fluctuations on Saltwater Intrusion Through Lacustrine Groundwater Discharge

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Abstract

Lake Kinneret (the Sea of Galilee) is a key freshwater source in the water-scarce Eastern Mediterranean. However, its relatively high salinity (~260 mg Cl/L) poses challenges for agriculture, groundwater quality, and drinking water supply in Israel and Jordan. Salts enter the lake through onshore and offshore saline springs (point sources) and seepages from surrounding sediments (non-point sources). Fluctuations in lake and groundwater levels alter the hydraulic gradient, affecting Lacustrine Groundwater Discharge (LGD). However, the impact of these changes on brine discharge and shallow groundwater salinity remains poorly understood. To investigate these processes, shallow (~1 m) monitoring wells were hand-dug along the shore near the Kinneret Limnological Laboratory. Groundwater was monitored using sensors (every 15 minutes) and water sampling (biweekly). Sensors recorded electrical conductivity (EC), water level, temperature, dissolved oxygen (DO), and pH, while water samples were analyzed for major ions, trace elements, and water isotopes ($\delta^{18}O$, $\delta^{2}H$). Results show that as lake levels rose and flooded the monitoring area, groundwater salinity increased. Chemical and isotopic analyses revealed two distinct water sources: a fresh end-member (Lake Kinneret water) and a saline end-member, which is a mixture of a non-Ca-chloridic brine (not abundant around the lake) and fresh groundwater with a light isotopic signature. Since the saline end-member is located beneath the lake, it contributes to well salinization when the lake level rises and inundates the area. This occurs because the lake, as the lowest hydraulic head in the region, directs brine flow toward it. This study demonstrates that lake level fluctuations influence brine discharge and groundwater mixing. The monitoring approach can be applied to similar lacustrine environments to distinguish water sources and LGD regimes, improving our understanding of saltwater intrusion in freshwater lakes.

Keywords: Lacustrine groundwater discharge, saltwater intrusion, salinization, geochemistry, water isotopes

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UNVEILING HIDDEN MERCURY AND METHYLMERCURY SOURCES: THE ROLE OF SUBMARINE GROUNDWATER DISCHARGE IN THE LARGEST WESTERN MEDITERRANEAN SEA COASTAL LAGOON

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ABSTRACT

Mercury (Hg) loads from Submarine Groundwater Discharge (SGD) may represent an understudied source of methylmercury (MeHg) to the ocean. SGD comprises three components: terrestrial fresh groundwater discharge, long-scale seawater recirculation through the sediments, and short-scale porewater exchange. Existing studies disagree on the SGD relevance as a source of Hg to the coastal ocean and rarely report the Hg fluxes supplied by the diYerent SGD components. Hence, we aimed to quantify the SGD-driven Hg fluxes to the Mar Menor, the largest coastal lagoon in western Mediterranean subject to polluted SGD. We measured dissolved total Hg (THg) and MeHg in lagoon waters, streams discharging to the lagoon and coastal porewaters during summer and autumn. Porewaters were enriched in both THg and MeHg compared to the lagoon. Lagoon shore waters and porewaters with high MeHg concentration and labile DOM were prone to MeHg formation. The input of THg through SGD to the Mar Menor lagoon (650 g THg yr-1) was an order of magnitude greater than the stream input and dominated by long-scale lagoon water recirculation. These findings have significant implications for the Hg budget in the region and raise awareness of the importance of legacy Hg remobilized by SGD in coastal areas.

KEYWORDS: Biogeochemistry, mercury budget, submarine groundwater discharge, coastal aquifer, Mar Menor

Salt Water Intrusion Congress (SWIM 2025)

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USING RADIUM ISOTOPES TO DETERMINE SEAWATER INTRUSION RATES

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ABSTRACT

Ra isotopes has been recently suggested as robust tools for the determination of residence times in the aquifer. Kiro et al. (2015) suggested that $^{226}Ra/^{223}Ra$ activity ratios should buildup to secular equilibrium, which is their radioactive parent activity ratios ($^{238}U/^{235}U$=21.7), within 5-6 half-lives of the long lived ^{226}Ra (8-10,000 years). Weinstein et al. (2021) studied saline water residing in a deep carbonate aquifer under the coastal plain of Israel. They suggested that the lower than secular equilibrium ratios in some of the water, up to 8-10 km from the sea, should be attributed to recent (<1000 years) seawater intrusion. This further implies relatively fast seawater circulation of up to >>10m yr^{-1}. A similar research of sub-permafrost groundwater in Svalbard also found water with low $^{226}Ra/^{223}Ra$ and determined residence times <1000 years for some of the water (Rotem et al. 2024). Notably, in both cases, some of the water showed $^{226}Ra/^{223}Ra$ significantly higher than the equilibrium ratios ($^{226}Ra/^{223}Ra$ up to 150), which is quite enigmatic. Recent work on saline ground ice (cryopegs) in Svalbard suggests that while the short-lived ^{223}Ra (half-life: 11.4 days) is mainly dependent on recoil and desorption from the wall-rock surface, the long-lived ^{226}Ra (1600 years) also builds-up by diffusion from inside the rocks, which if time allows may result in higher than equilibrium ratios. This further enhances our confidence in the low ages determined for the low $^{226}Ra/^{223}Ra$ water.

References

Kiro, Y., Weinstein, Y., Starinsky, A. and Yechieli, Y. 2015, Application of radon and radium isotopes to groundwater flow dynamics: an example from the Dead Sea, Chemical Geology 411, 155-171.

Rotem, D., Weinstein, Y., Christiansen, H.H., Sültenfuß, J. and Hodson, A. 2024, Ra isotope perspective on the hydrology and continuity of permafrost in the high Arctic, Science of The Total Environment 950, 175412.

Weinstein, Y., Friedheim, O., Odinzov, L., Harlavan, Y., Nuriel, P., Lazar, B. and Burg, A. 2021, Radium isotope dating of saline groundwater and implication to seawater intrusion in shallow and deep aquifers, Journal of Hydrology 598, 126412.

Keywords: *Ra isotopes, groundwater residence time, SWI rate, deep aquifers*

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ASR SYSTEMS IN SALINE AND BRACKISH GROUNDWATER: WELL (FIELD) DESIGN CONSIDERATIONS FOR OPTIMIZING THE INJECTION AND RECOVERY OF FRESHWATER

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ABSTRACT

In coastal areas, Aquifer Storage and Recovery (ASR) systems are increasingly relied upon to provide a sustainable freshwater supply. During the feasibility and design phases of such systems the focus typically lies on optimizing the recovery efficiency (RE) as a way of maximizing freshwater yield. However, for many practical cases the injectable volume of freshwater turns out to be a critical condition for the absolute volume of freshwater that can ultimately be recovered. This is particularly the case in low lying coastal areas and polders where high injection pressures cannot be applied due to shallow groundwater tables, particularly in areas with relatively thin overlying confining layers and seepage pressures due to the risk of integrity failure (ground ruptures). Here, several crucial aspects of well (field) design in such conditions were considered, as well as analytical and numerical approaches that can support optimization of recoverable freshwater volumes.

Results show that, for individual wells, the difference in density between the injected and native groundwater results in lower injection pressures gradients at the bottom of well screens. We show that depending on the conditions this can considerably affect injection rates and can negatively impact RE. Also, for shallow ASR systems in low lying polders, the risk of integrity failure may be such that partially penetrating wells set at depth below the overlying confining layer are to be preferred. Lastly, at the well field level, the spacing between wells is an important design criterion, as from a RE perspective a minimal spacing is preferred, however, overlapping injection pressures between wells can severely limit the injection rate.

Overall, the results of this study highlight that for the design of ASR systems in saline aquifers, maximizing freshwater yield requires careful balancing of possible trade offs between the RE and injection rate.

Keywords: *ASR, well design, freshwater, groundwater modelling*

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COASTAL AQUIFERS MANAGEMENT EVALUATION AND CLIMATE CHANGE ADAPTATION IN LIBYA

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ABSTRACT

Libya's coastal aquifers face significant challenges that threaten their sustainability and water security due to the heavy reliance on groundwater. Climate change significantly impacts the coastal region of Libya and its water resources, exacerbating existing challenges in this arid nation.

The country experiences extremely limited water availability, receiving an average of only 56 mm of rainfall annually with only a narrow zone along the coast receiving more than 100 mm per year, leading to a heavy reliance on non-renewable aquifers to meet the increasing demand. This has exacerbated water scarcity problems and caused very significant environmental concerns. Limited precipitation, higher evaporation rates and prolonged droughts diminish the recharge of aquifers, leading to increase the overextraction and consequently the formation of the depression cones and progressive seawater intrusion into these aquifers, particularly around Jifarah Plain basin, resulting in heightened salinity levels rendering them unsuitable for consumption and agriculture.

In some other coastal areas in Libya, the problem appears more complex. In recent years, Zliten, a coastal city in northwest of Libya, has faced a significant environmental crisis due to a mysterious groundwater upsurge flooding homes, roads, and agricultural lands, causing substantial damage of infrastructure and displacing numerous families. These areas are witnessing a rise in groundwater levels due to malfunction in the hydrological system, among of the suggested reasons is the large use of transported fossil water and, consequently, severe backflow, which has led to it mixing with sewage and causing polluted floods that threaten the environment and the population.

The combination of the impact of the climate change, overexploitation and poor management plan compounds Libya's water scarcity and impacts the ecosystems causing adverse effects on its biodiversity. Addressing these challenges requires comprehensive strategies that integrate sustainable water resource management and climate change adaptation measures to ensure long-term water security.

Keywords: *Coastal aquifers, overextraction, climate change, sustainability, groundwater management.*

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Enhancing Freshwater Supply for Agriculture on Texel Island: Aquifer Storage and Recovery in a Saline Aquifer Using Horizontal Wells

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ABSTRACT

The Zoete Toekomst Texel (Fresh Future Texel) project aims to improve freshwater availability for farmers on Texel Island, the Netherlands, where agriculture relies entirely on rainwater due to the lack of alternative freshwater sources. Increasing drought frequency and intensity, driven by climate change, pose a growing challenge to sustainable farming. Aquifer Storage and Recovery (ASR) offers a potential solution by capturing excess tile drainage water in winter, storing it in the subsurface for use during the growing season.

The project site's specific hydrogeological conditions -a thin aquifer (8-10 m), low hydraulic conductivity (2-5 m/d), and high groundwater salinity (25-35 mS/cm)- favour horizontal wells over conventional vertical wells for higher recovery efficiency. After extensive hydrogeological assessments, including exploration drilling, cone penetration tests, geophysical surveys (DUALEM, ERT, borehole logging), pumping tests, and water quality analysis, the ASR system design was optimized and various operational scenarios tested with density-dependent groundwater flow modelling using MODFLOW 6 with the BUY-package.

Between 2021 and 2024, four innovative horizontal wells (100-200 m screen length) were installed, each incorporating design improvements informed by operational experience and monitoring results at 13-16 m below ground surface using horizontal directional drilling (HDD), for infiltration and extraction in an initially saline aquifer. However, two wells were abandoned due to construction failures. The remaining two connect to a slow sand filter with granular activated carbon for removal of pesticides and nutrients, which processes tile drainage water from a 30-ha catchment area. After 2.5 years of operation, the system has faced multiple challenges, including unintended seepage from hydraulic fracturing, strict waterboard regulations and high sand filter clogging rates limiting infiltration capacity. Despite these setbacks, the operational horizontal wells are capable of infiltrating ~20,000 m^3/year, with 30-50% recovery within 1.6 mS/cm.

Monitoring at the second horizontal well (180 m) in its third operational cycle shows variable freshwater advance along the well during infiltration, likely due to aquifer heterogeneity and differences in screen resistance. Borehole resistivity (EM39) and electrical resistivity tomography (ERT) measurements confirm uneven freshwater distribution, reflecting localized

flow paths and storage within the saline aquifer.

A key innovation is the formation of a freshwater cooperation, where farmers jointly manage the system and share maintenance costs, improving cost-effectiveness. While challenges remain, this pilot provides valuable field-scale insights into horizontal ASR feasibility in saline environments, informing future applications.

Keywords: *(Aquifer Storage and Recovery, Horizontal Wells, Freshwater Management, Salinization, Climate Adaptation)*

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Experiences with Managed Aquifer Recharge for Agriculture in a Salinized Flemish Polder Area

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KEYWORDS

Belgium, climate change, adaptation, polder area, fresh water availability, creek ridge infiltration, level controlled drainage, interreg TOPSOIL project

ABSTRACT

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 dryer summers and wetter winters which forces water managers to seek adaptation strategies for the increasing seasonal imbalance. In the European TOPSOIL project (2015-2022) countries around the North Sea investigated the possibilities of using the topsoil to solve current and future water challenges. The Belgian part of the TOPSOIL project investigated the potential of local groundwater measures to tackle the effects of climate change. These measures mainly focus on increasing freshwater resources by using the Ghyben-Herzberg relationship between fresh and salt water.

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. A pilot has been constructed where creek ridge infiltration in combination with level controlled drainage is investigated. The system has been in place since 2022 and the project involved both modelling and measurements of its effects. Main goal of this pilot is to act as a demonstration project for agriculture and to analyse the economic and technical feasibility of creek ridge infiltration.

INTRODUCTION

The Belgian coastal zone is protected from the sea by densely populated dunes. The low-lying area behind the dunes is reclaimed land and lies less than 5 meters above mean sea level. In this so called ‘polder area’, agriculture is the main activity. Surface water is managed by a dense network of watercourses in which the desired water level, low in winter and high in summer, is controlled by weirs. Excess of surface water is discharged gravitationally to the sea during low tide.

Agriculture in the polder area depends on rainwater, surface water and groundwater. Fresh water is however scarce, especially in the western part of the coast. Droughts in recent years caused a temporary salinization of surface water and a rapid depletion of rainwater stocks. Groundwater reserves are limited due to a historical overexploitation of the

deep confined aquifer and the saline origin of the shallow aquifer. Additionally, the agricultural sector became more water dependent during the last 20 years due to a shift to a more intensive cultivation of cattle and crops. The situation is likely to deteriorate further due to climate change and sea level rise. Demand is increasing for sustainable solutions which contribute to a better local fresh water availability and a regional self-sufficiency.

FROM POTENTIAL MEASURES TO PILOT

Water balance studies of the Belgian coastal area (Antea, 2018) show there is enough water available but unevenly distributed throughout the year. Climate change will enhance this imbalance: winters are generally becoming rainier and summers drier. Moreover, sea level rise will shorten the time window to discharge surface water into the sea gravitationally and will increase flood risk from rivers during winter.

However, the polder landscape offers opportunities to buffer surface water and to increase the fresh water availability during summer. First, water levels are easy to control due to a dense network of watercourses. Second, the microtopography offers opportunities to infiltrate water. Based on the experience in the Netherlands (Oude Essink *et al.*, 2014; Pauw *et al.,* 2015) and the area's characteristics, three promising measures were selected: 1) creek ridge infiltration (MAR), 2) adaptive drainage and 3) surface water level control by weirs (De Louw *et al*, 2019). All three rely on the Ghyben-Herzberg principle for an unconfined coastal aquifer which states that the depth of the fresh-salt water interface depends on the height of the water table above sea level (Badon-Ghyben, 1888; Herzberg, 1901). Under perfect circumstances this means that a freshwater lens can grow 40 cm when the water table is raised by 1 cm. These three measures focus on exactly that: raising the water table.

Creek ridges are former tidal gullies filled with sand. They became small sandy ridges when land was reclaimed: the surrounding clayey soils were settled due to drainage and natural subsidence. The higher topography of these ridges led to higher groundwater tables above sea level and the development of fresh water lenses. The main fresh water lenses in the polder area are therefore situated along these creek ridges. Infiltration of excess 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 advantage of an adaptive drainage system compared to a conventional system is the possibility to control the drainage level in function of weather circumstances (climate adaptive drainage system). By setting a higher drainage level before drought, groundwater will be longer retained which lead to better soil water conditions. It also creates the opportunity to maintain a mean higher groundwater level throughout the year which could contribute to a further development of the freshwater lens.

The third measure is to manage groundwater levels indirectly by controlling surface water levels by weirs. Surface water levels are mainly set based on the prevention of flooding during winter (thus low water levels) and availability of fresh water during summer (high levels). In case of a good hydraulic connectivity, groundwater will respond on surface water levels. Today, surface water levels are mainly focussed on the prevention of flooding, but the droughts of recent years show that surface water levels are better not too low. There remains room for improvement. When mean surface water levels could be set higher throughout the year, groundwater levels will raise and freshwater lenses will grow. A higher groundwater table will also lead to better soil water conditions during the dry season.

The implementation of measures was discussed at workshops and during field visits. Finally, a collaboration was set up with a farmer to implement a creek ridge infiltration system in combination with level controlled drainage.

HYDROGEOLOGICAL CONDITIONS

The farm has a mixed livestock and uses phreatic groundwater from the creek ridge for the drinking water of the cattle. A horizontal well with a length of 300m and on a depth of 4m below surface level provides the necessary amount of water. The farmer is licensed to withdraw 6500 m^3 per year from the phreatic aquifer. Based on the available geological information in the area and the results of local field work, the shallow aquifer consists mainly of sand to a depth of 12 meters in the centre of the creek ridge and 3 meters on the edge. The top of the aquifer is covered by a thin clay layer (max. 1m). According to the airborne EM-results (Delsman *et al.*, 2019; Vandevelde *et al.,* 2018) and borehole geophysics, there is a freshwater lens with a thickness of 2.5 to 7.5 meter. Adjacent to the pilot location is a watercourse from which fresh water can be extracted for infiltration during winter. Based on the available data, this farm meets the conditions for a creek ridge infiltration system: there is a freshwater lens, the subsoil is suitable for infiltration and there is a water source available for infiltration. A research and monitoring plan and a concept design were drawn up for this

pilot location. Five piezometer wells were installed and an intensive monitoring campaign was set up to identify the seasonal behaviour of groundwater levels and variation in surface water quality.

LICENSE APPLICATION, MODELLING AND FINAL DESIGN

For infiltration, an environmental license was needed. As part of this process a groundwater model was used to investigate the environmental effects to the neighbouring parcels and to optimize the design of the installation (Kaandorp *et al.*, 2021). Neighbours were informed about the results of the modelling and objectives of the pilot installation. Finally, a license was obtained to build the installation and to infiltrate 72 m³ per day and 6500 m³ per year.

The density dependent groundwater model simulated the current situation and several scenarios. Main conclusions were that a maximum effect can be obtained on the groundwater level and freshening by combining infiltration and level adaptive drainage. Furthermore, it was found that the level adaptive drainage is an important steering factor regarding control of salinity distribution. The combination of both measures was expected to increase the freshwater lens but may cause changes in the adjacent parcels regarding fresh-salt water distribution. Model results were used to optimise the design of the installation.

The final design takes into account the presence of the horizontal well for groundwater abstraction. Twelve horizontal wells for infiltration, with a length of 250m, were installed above the abstraction well at a depth of 1.5m below surface level and cover a surface area of 2 hectares. To prevent negative effects of infiltration to the neighbouring parcels, the infiltration system is flanked by an adapted drainage system at both sides. A surface water intake was installed in the watercourse and leads the water to a technical room where a monitoring system, water treatment and electromechanical devices are present. An online monitoring and remote control system allows to intervene at any moment in time. The surface water intake is controlled by conductivity: when conductivity becomes too high, the pump stops automatically. The system therefore depends mainly on the winter season when there is enough fresh surface water available and the overall water quality meets the standards for infiltration.

INFILTRATION TESTS

After building of the installation (November 2021 till February 2022), the first infiltration test started in February 2022 and ended in March 2022. Monitoring results from the year before showed that surface water quality deteriorates starting from the end of March. A total of 34mm has been successfully infiltrated which corresponds with 14% of the annual groundwater recharge. Level controlled drainage ensured that there were no negative effects (raised groundwater levels) to the adjacent parcels. The rest of the year, water quality of the surface water was not suitable any more for infiltration due to pesticides and chloride concentrations.

To reduce the dependence on surface water quality and to enlarge the time window for infiltration, an additional water treatment on the infiltration water was installed at the beginning of 2023. A licensing process had to be undertaken prior to the installation of the activated carbon with sand filtration as pre-treatment. First results with this additional treatment are promising but further investigation is necessary to ensure that quality objectives are always guaranteed. Sand filtration removes the suspended solids and avoids clogging of the active carbon.

In June 2023, a second infiltration test was carried out which lasted one week. 17mm was infiltrated which corresponds with 7% of the annual groundwater recharge. In the dry period before start of the infiltration, groundwater levels dropped at a rate of 5mm per day due to evapotranspiration. After one week of infiltration, groundwater levels at the centre of the infiltration reached levels from 20 days before. Thus the infiltration could reverse the downward trend in groundwater level in the centre of the parcel and stabilised groundwater level at the boundary with adjacent parcels.

Due to the limited tests of the infiltration system, changes in fresh-saltwater distribution are not expected yet. Future behaviour of the fresh-salt water interface will be monitored by EM borehole measurements.

ECONOMICAL FEASIBILITY

A cost price analysis was carried out for the pilot to determine whether such a measure would be economically feasible. For this purpose, we looked at which water sources at the farm could be replaced by shallow groundwater extraction in combination with creek ridge infiltration. Subsequently, the cost price of the system was determined, including the required infiltration drains, the pump, electricity and control systems. Furthermore, costs such as electricity,

maintenance and taxes were all taken into account. Because the pilot only has as small water demand, the creek ridge infiltration system is not economically viable compared to the current situation. In case of a higher water demand, the cost price of the water from the infiltration system will fall sharply. In order to increase the demand for water and thereby reduce the cost price of the extracted water, an economical feasible system could be created through cooperation between several farmers. The exact costs and economic feasibility must always be considered per farm, since they are highly dependent on the local situation, geology and existing facilities. Other conditions to take into account are water quality, availability of a fresh water source and licensing.

CONCLUSIONS

First results show that combining creek ridge infiltration with level controlled drainage can be a promising measure to counter drought and increase the fresh water availability for agriculture in a coastal aquifer. Additional water treatment can be necessary to reach quality standards for infiltration during the year.

By drawing up a cost price analysis, the economic feasibility of the system could be determined on a local scale. Especially with a higher water demand, the price becomes attractive compared to other water sources.

REFERENCES

Antea. 2018. Waterbehoefte, -gebruik en -aanbod analyse van de kuststreek. Studie in opdracht van de Provincie West-Vlaanderen. (in Dutch)

Badon-Ghyben, W. 1888. Nota in Verband met de Voorgenomen Putboring Nabij Amsterdam. Tijdschr. Kon. Inst. Ing., Den Haag. (in Dutch)

Delsman, J., van Baaren, E., Vermaas, T., Karaoulis, M., Bootsma, H., de Louw, P., Pauw, P., Oude Essink, G., Dabekaussen, W., Van Camp, M., Walraevens, K., Vandenbohede, A., Teilmann, R., Thofte, S. 2019. TOPSOIL Airborne EM kartering van zoet en zout grondwater in Vlaanderen (FRESHEM Vlaanderen). Deelopdrachten 1, 2, en 3. Deltares-rapport 11200306-000-BGS-0011. Deltares, Universiteit Gent, De Watergroep, TNO, SkyTEM. (in Dutch)

De Louw, P., van Baaren, E., Kaandorp, V., Galvis Rodriguez, S., Dupon, E., Huits, D., van Camp, M., Walraevens, K., Vandenbohede, A. 2019. TOPSOIL - GO-FRESH Vlaanderen, Potenties om de zoetwaterbeschikbaarheid te verbeteren. Deltares-rapport 1200306-007-BGS-000. Deltares, Inagro, Universiteit Gent, De Watergroep. (in Dutch)

Herzberg, A. 1901. Die Wasserversorgung einiger Nordseebaden. Z. Gasbeleucht.Wasserversorg. 44:815–819, 824–844. (in German)

Kaandorp, V.P., de Louw, P.G.B, van Camp, M., Walraevens, K. 2021. Infiltratieproject Veurne, Technische nota en hydrogeologische studie. (in Dutch)

Oude Essink, G. H. P., Van Baaren, E. S., Zuurbier, K. G., Velstra, J., Veraart, J., Brouwer, W., Faneca Sànchez, M. Pauw . P.S., de Louw, P.G.B., Vreke, J., Schoevers, M. 2014. GO-FRESH: Valorisatie kansrijke oplossingen voor robuuste zoetwatervoorziening, KvK rapport. (in Dutch)

Pauw, P. S., Van Baaren, E. S., Visser, M., De Louw, P. G. B., & Oude Essink, G. H. P. 2015. Increasing a freshwater lens below a creek ridge using a controlled artificial recharge and drainage system: a case study in the Netherlands. Hydrogeology Journal. https://doi.org/10.1007/s10040-015-1264-z

Vandevelde, D., van Baaren, E., Delsman, J., Karaoulis, M., Oude Essink, G., de Louw, P., Vermaas, T., Pauw, P., de Kleine, M., Thofte, S., Teilmann, R., Walraevens, K., Van Camp, M., Huits, D., Dabekaussen, W., Gunnink, J. & Vandenbohede, A. 2018. Groundwater salinity mapping of the Belgian coastal zone to improve local freshwater storage availability. Proceedings, 25th Salt Water Intrusion Meeting, Gdansk, Poland.

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FEASIBILITY AND ENVIRONMENTAL IMPACTS OF SHALLOW BRACKISH GROUNDWATER ABSTRACTION AND BRINE REINJECTION IN THE COASTAL NETHERLANDS

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ABSTRACT

The availability of fresh groundwater in the coastal Netherlands is increasingly threatened by sea level rise, saltwater intrusion, and growing demands from industry, agriculture, and population expansion. One method used to bridge the gap in freshwater supply is reverse osmosis (RO) systems, which treat brackish or salinized groundwater. The challenge lies in the disposal of brine, the concentrate water produced during RO. For decades, one alternative has been the reinjection of the brine into deeper, highly salinized aquifers, based on the assumption that the area's several clay aquitards and depth-of-injection prevent any potential environmental impacts. However, the validity of these assumptions remains unclear.

This study examines the long-term feasibility and environmental implications of shallow brackish groundwater abstraction and subsequent brine reinjection in the coastal Netherlands through a modelling approach. We use as a case study the area of the Delfland water board, a coastal area in the west of the Netherlands that presents extensive groundwater salinization issues and freshwater competition between industry, horticulture and drinking water companies. Numerous abstraction-reinjection configurations are tested throughout the area using small, local-scale, fast running models in an HPC environment. These local models are based and feed from a spatially and temporally downscaled regional model of Delfland derived from LHM fresh-salt (the national variable density model of the Netherlands). We then evaluate the effects over the salt mass exfiltration, shallow and deep groundwater heads and saltwater interfaces. With this approach, we intend to find the technical and environmental limitations of these systems and their susceptibility to climate change over a large area.

Keywords: *Brine Reinjection, Groundwater Modelling, Groundwater management, Brackish Groundwater, Reverse Osmosis*

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FRESH WATER FROM A SALINE SUBSURFACE:

THE POTENTIAL FOR REGIONAL SCALE IMPLEMENTATION OF ASR TO ALLEVIATE WATER STRESS IN THE AGRICULTURAL AREA OF WOLPHAARTSDIJK, THE NETHERLANDS

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ABSTRACT

In summer, farmers in a large part of The Netherlands are fully rain water-dependent for the watering of their crops, as both surface and groundwater sources are brackish to saline. In winter an abundance of fresh surface water is rapidly discharged to keep the land dry. Here, regional implementation of aquifer storage and recovery (ASR) was considered to alleviate this temporal mismatch between supply and demand for the agricultural area of Wolphaartsdijk. Both the regional implementation as well as the sole availability of a highly saline (5 to 18 g Cl/l) aquifer provide challenging storage conditions.

The potential for ASR in the area was evaluated by determining the potential winter intake of surface water based on the available amount and injection constraints. Although the calculated total availability was abundant to overcome the seasonal mismatch, the injectable volume was limited to 30-60% due to the uneven temporal distribution of surface water winter discharge. Freshwater demand was estimated to be 25-50% of the injectable available volume, therefore putting a constraint on the minimum required ASR recovery efficiency (RE). Using numerical MODFLOW6 simulations, the achievable recovery efficiency was assessed considering the use of conventional fully penetrating wells (FPWs), horizontal directionally drilled wells (HDDWs) and vertical multiple partially penetrating wells (MPPWs). Simulation results indicated that for the aquifer conditions the use of FPWs is unsuitable, but that RE's of 20%-70% are achievable with MPPWs and HDDWs, strongly depending on subsurface conditions and the applied infiltration volume. Sufficiently high infiltration volumes, implicating a few larger ASR systems in the area rather than many small ones, could be sufficient to provide the required freshwater for the farmers in the Wolphaartsdijk area despite the challenging conditions. However, field testing is required to allow more accurate assessment of the location suitability and optimize design in such saline conditions.

Keywords: *ASR, regional freshwater availability, groundwater modelling*

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INNOVATIVE DRAINAGE AS A SOURCE OF FRESH WATER FOR AGRICULTURE IN BRACKISH AREAS

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ABSTRACT

Groundwater in low lying areas in the Netherlands is often brackish with thin rainwater lenses of one or several meters thickness. Agriculture in these fertile areas therefore has limited access to fresh water. To improve the fresh water availability on arable farms, innovations in drainage and storage systems are piloted.

On the island of Schouwen-Duiveland saline seepage fluxes are high giving little room for the storage of fresh water in the groundwater system. Two types of innovative tile drainage were tested. In one pilot, a controlled drainage system was installed where drain pipes are placed 40 cm deeper in the soil. This way, extra fresh water could be stored by pushing the fresh-salt interface downward and thickening the rainwater lens. At two other locations, double drainage was installed with both a shallow (80 cm b.g.l.) and deep (130 cm b.g.l.) drainage system. The deeper system was used to discharge saline seepage while the shallow system was used to harvest excess fresh water. Modelling and monitoring results show that about 50% of infiltrated rain water could be harvested and reused for irrigation during the growing season.

Discharge water from subsurface drainage systems is increasingly seen as a source of fresh water in brackish/saline environments in the Netherlands. In another pilot in a polder in the north of the country drainage water is collected, pre-treated to remove contaminants and then gravitationally infiltrated through a well in a subsurface sandy layer (19-25 m b.g.l.). During the growing season this water is pumped up and used for drip-irrigation. The whole system is monitored using piezometers, EC- and flowmeters, and results are brought together in a dashboard. Use of drain water creates the potential for a circular water system at arable farms where both fresh water and nutrients are collected, stored and reused.

Keywords: *fresh water availability, drainage, managed aquifer recharge, circular*

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LIFE REMAR PROJECT, RENATURALIZING TREATED WASTEWATER THROUGH MANAGED AQUIFER RECHARGE

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ABSTRACT

Water scarcity is a growing concern in Mediterranean coastal areas, where intensified groundwater extraction causes aquifer overexploitation and promotes seawater intrusion. The LIFE REMAR project (LIFE20 ENV/ES/000284) addresses this issue by repurposing treated wastewater from the Cambrils wastewater treatment plant (WWTP) to recharge the Plioquaternari Detrital Aquifer of Camp de Tarragona implementing a Managed Aquifer Recharge (MAR) system. The project employs a Soil-Aquifer Treatment (SAT) system with

reactive barriers composed of aquifer sediments and plant-derived organic matter. These barriers promote a sequence of redox states, increasing the number of sorption sites and promoting biodegradation of various pollutants, including contaminants of emerging concern, microplastics, pathogens, and antibiotic resistance genes. The system is designed to recharge 146,000 m^3 of water annually, approximately 4% of the WWTP effluent, mitigating aquifer depletion while improving treated wastewater and groundwater quality. Most nitrogen in the infiltration water, i.e. the WWTP effluent, primarily in ammonium form, undergoes microbiological nitrification and denitrification, decreasing nitrogen levels. Recharge has also significantly reduced nitrate concentrations directly beneath the basins, in the saturated zone, addressing the aquifer's initial poor qualitative state. Additionally, Escherichia coli concentrations in the infiltration water are also reduced during recharge. By increasing available freshwater resources and improving aquifer conditions, this project offers a sustainable strategy for managing coastal groundwater systems. The REMAR system contributes to protect water resources and to improve the quantitative and qualitative state of the aquifer. Results from this pilot study will inform the design of a larger-scale system implementation, which would lead to increased freshwater availability, restored submarine groundwater discharge areas and coastal ecosystems, and seawater intrusion mitigation, thus contributing to face water scarcity.

Acknowledgments
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Keywords: (maximum 5 keywords)
Infiltration
Coastal Aquifer
Managed Aquifer Recharge
Treated Wastewater Renaturalization
Seawater intrusion

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RECLAIMED WATER FOR MANAGED AQUIFER RECHARGE: A TOOL FOR WATER SECURITY IN BARCELONA

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ABSTRACT

In recent years, Barcelona has faced extreme water scarcity, with the city experiencing one of the most severe droughts in decades. This crisis has forced the local water utility to use groundwater reserves, since surface water availability was limited, to the point that reclaimed (treated) water from the city's tertiary wastewater treatment plant had to be released into the Llobregat River to maintain sufficient flow for both drinking water intake and ecological needs. Barcelona, like many other coastal cities, suffers from saline intrusion, especially in drought periods when groundwater abstraction is highest. The increased groundwater abstraction creates a negative hydraulic balance that pushes seawater intrusion further inland. The MARCLAIMED project addresses this challenge by a double recharge: excess reclaimed water through infiltration ponds and surface sand filtered water through a deep injection well, both sites on the same aquifer, which is used by the city water utility's well fields. This recharge increases the piezometric levels in the area near production wells, counteracting the drawdowns generated by groundwater abstraction. Additionally, the natural filtration of the reclaimed water through the aquifer enhances water quality stability and further purifies it by reducing pathogens, nutrients, and organic contaminants. The infiltration ponds are operational since April 2024 and include a 4000 m² decantation pond and a 5600 m² infiltration pond, with water quality monitored through 5 piezometers and 5 abstraction wells from the water utility, continuous CTD sensors and groundwater sampling every 6 weeks. Additionally infiltration also takes place through a deep injection well, monitored vía 5 piezómeters and 3 pumping wells. Preliminary results show increased piezometric levels and groundwater conductivity that align with the recharged water quality. Over the course of the project, so far 431.815 m3 of of reclaimed water have been infiltrated at the infiltration ponds, whilst 1.04 Mm3 of sand filtered water from the river have been recharged through the deep injection well, with the objetive of infiltrating 1 Mm³/year at each site. This showcases Managed Aquifer Recharge (MAR) as a crucial tool for improving water security in the region and a safe, effective pre-treatment method for reclaimed water. The aquifer recharge, available throughout the whole year and independent of rainfall events, raises piezometric levels creating a water buffer and making this coastal aquifer less vulnerable to overexploitation and saline intrusion, particularly during the increasingly frequent and severe droughts expected due to climate change.

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A NEW GROUNDWATER CLASSIFICATION FOR MANAGING SEAWATER INTRUSION IN THE MEDITERRANEAN AREA

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ABSTRACT

Groundwater salinization in coastal aquifers is primarily driven by seawater intrusion. However, attributing salinization exclusively to seawater intrusion may overlook other potential sources. Understanding whether salinization stems from seawater intrusion and identifying its onset are essential for effective groundwater management, yet there are no universally established threshold values for common indicators like chloride. This study introduces a novel groundwater classification based on 1,662 groundwater samples from five Mediterranean coastal aquifers in Greece, Italy, Turkey, and Tunisia. Despite their differences in size, geological formations, permeability, and salinization sources, these aquifers share common hydrogeochemical challenges. Cumulative probability plots for chloride and total dissolved solids (TDS) were used

to establish a threshold for the onset of seawater intrusion. Findings highlight chloride as a reliable non-reactive tracer for seawater intrusion, whereas TDS, being reactive, is less dependable. A chloride concentration of 200 mg/L was identified as the salinization threshold, corroborated by the newly proposed salinization facies classification. The findings also underscore the limitations of using TDS or electrical conductivity (EC) as standalone indicators of salinization. Furthermore, an analysis of nitrate and sulphate concentrations reveals that freshwater in coastal aquifers (Cl < 200 mg/L) are often affected by anthropogenic salinization rather than seawater intrusion. The presence of these pollutants indicates significant contributions from agricultural activities, wastewater infiltration, and other anthropogenic sources. This insight challenges the conventional focus on seawater intrusion as the primary concern for groundwater quality, emphasizing the need for comprehensive assessments that consider multiple sources of salinization. The proposed classification and threshold provide a robust framework for groundwater monitoring and sustainable management across Mediterranean vulnerable coastal aquifers.

Keywords: *chloride, nitrate, groundwater salinization, coastal aquifer, cumulative probability*

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ANCIENT SEAWATER TRAPPED WITHIN A TECTONICALLY UPLIFTED CHALK FORMATION

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ABSTRACT

Tectonically uplifted ancient seawater was found within an exposed chalk formation (Avdat Group, Israel) of Eocene age at the foothills of the Judean Mountains. This seawater, along with its diluted derivatives, was found at elevations of 200–300 m above mean sea level (aMSL), significantly higher than the maximum flooding surfaces recorded since the Eocene.

In contrast to modern-day seawater intrusion, which currently occurs along the Pleistocene alluvial fill of the Mediterranean coastal aquifer, the seawater trapped in the Avdat Formation shows no geochemical evidence of cation exchange. This is due to the absence of significant clay or organic material within the chalks. As a result, the trapped seawater has largely retained its original major ionic ratios. However, compared to standard seawater composition, it is enriched in Ca^{2+} and SO_4^{2-}, suggesting that the intruding seawater dissolved gypsum deposited during Miocene transgression-regression cycles.

A comparison with global records of ancient seawater compositions suggests that some of the trapped water dates back to the Eocene, indicating it is connate water (originating from the time of sedimentation). Other samples correspond to late Miocene seawater intrusions, representing interstitial water from later transgression-regression events. These seawater intrusions occurred prior to the final tectonic uplift that raised the region above sea level, fully exposing the Judean Mountains and their foothills.

Tectonic reconstructions indicate that this seawater has been preserved since at least the Miocene, despite direct exposure to meteoric precipitation and the significant uplift that brought it to its current elevation (~250 m aMSL)—well above recorded maximum sea levels. This preservation is attributed to the dual-permeability characteristics of the chalk: low matrix permeability combined with high fracture permeability. This permeability structure channeled rainfall into underlying formations, allowing only partial dilution of the porewater and preventing significant flow since the Early Pliocene.

Keywords: seawater-intrusion, interstitial-water, connate-water, cation-exchange, gypsum-dissolution

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ASSESSING THIN RAINWATER LENS VIABILITY UNDER CHANGING CLIMATE CONDITIONS

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ABSTRACT

Thin rainwater lenses are an essential water resource for agricultural areas in coastal regions, as they support crop growth by giving access to fresh water. They are formed when the upward movement of saline groundwater (seepage) prevents rainwater from infiltrating to greater depths. It is unknown how the disappearance of thin rainwater lenses will be exacerbated by more frequent (multi-year) droughts due to climate change. This study investigated the future viability of rainwater lenses and explored the conditions that enhance climate resilience in diverse spatial environments.

We developed a numerical model using SEAWAT to investigate rainwater lens dynamics and the impact of droughts on their viability. An extensive sensitivity analysis was conducted with varied climatological and environmental conditions, based on the Southwest Delta in the Netherlands, a region with over 600 km² of brackish to saline groundwater within 5 meters of the surface. Climate scenarios from the Dutch meteorological institute were used, that align with SSP pathways (SSP1-2.6, SSP2-4.5, and SSP5-8.5).

Our results demonstrate that thin rainwater lenses are less viable under future climate conditions. It emphasizes the importance of climate signals in determining rainwater lens viability alongside physical parameters such as tile-drainage configuration (drain levels and distance), seepage fluxes, and soil types. While thicker rainwater lenses are expected with wetter winter conditions, severe recharge deficits, particularly in late summer and early autumn, extend periods of rainwater lens absence. Under median conditions, soils with coarser textures, lower seepage rates, and deeper, more intensive drainage systems show reduced sensitivity to rainwater lens absence, enhancing climate resilience. Conversely, areas with elevated drainage levels, increased seepage rates, finer-textured soils, and greater drainage distances show heightened sensitivity. Dry-trending scenarios lead to extended periods without rainwater lenses while wet-trending scenarios limit the reduction in fresh drainwater volumes.

Keywords: *Rainwater lens, Climate change, Saline seepage, Tile-drained agricultural fields*

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ASSESSMENT OF GROUNDWATER SALINISATION AND NITRATE POLLUTION THROUGH STATISTICAL AND HYDROGEOCHEMICAL APPROACHES

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ABSTRACT

Groundwater in coastal aquifers of Mediterranean regions plays an essential role in sustaining ecosystems and human activities. Their geographical position and geomorphological characteristics make them vulnerable to hydro-climatic hazards, such as seawater intrusion, groundwater depletion and pollution, related to frequent and intense drought events, rising temperatures, intensive groundwater exploitation, and fertiliser use. To this end, the spatial and temporal evolution of groundwater salinization and nitrate pollution in the coastal karst aquifer of Salento, southern Italy, was investigated using multivariate statistical methods (Hierarchical Cluster Analysis and Factor Analysis) and hydrogeochemical techniques (Hydrogeochemical Facies Evolution) to classify groundwater samples and identify the main pollution processes. Additionally, Indicator Kriging was used to analyse nitrate pollution trends over a 25-year period. Results allowed the delineation of the main ongoing processes, i.e. groundwater salinisation and nitrate pollution, identifying the areas most affected. The salinisation process intensifies at the end of dry periods, where the lack of rainfall and the increase in water demand for irrigation lead to more significant withdrawals from wells. Nitrate pollution, conversely, cannot be easily attributed to specific sources based on the available data. Specific analyses (e.g., isotopic investigations) would be needed to clarify its origin. Nevertheless, the observed contamination is likely associated with anthropogenic pressures, considering the predominant agricultural land use characterizing the study area. Moreover, it is not possible to establish with certainty whether current concentrations have surpassed the peak related to the massive use of nitrogen fertilisers in the past. Statistical methods prove effective in identifying ongoing processes where continuous monitoring data are lacking. Finally, the results of the different techniques are superimposed, corroborating their effectiveness. Findings demonstrate the necessity of long-term monitoring and strategic water resource management to prevent further deterioration of water quality in vulnerable karst aquifers.

Keywords: *coastal aquifer, groundwater salinization, multivariate analysis, hydrogeochemical analysis, nitrate*

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DETAILED MONITORING AND SIMULATION OF GROUNDWATER SALINITY IN RESPONSE TO EXTRACTIONS IN A COASTAL AQUIFER, THE NETHERLANDS

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ABSTRACT

High-resolution three-dimensional variable-density groundwater flow and coupled salt transport models (abbreviated 3D-VD-FT models) are useful instruments to support coastal groundwater management strategies and to forecast impacts of climate change. However, the ability of 3D-VD-FT models to provide accurate groundwater salinity predictions depends on computational capabilities, availability of sufficient and adequate (high-resolution) data and understanding of groundwater salinity processes in the subsurface. Often, for instance, local aquifer heterogeneities are simplified in numerical models. In doing so, flow and transport are simplified, and consequently, local groundwater salinity changes become difficult to predict accurately.

New avenues in data acquisition and computational methods have opened up the possibility to greatly improve the accuracy of predictions. Recent developments in innovative geophysical monitoring methods are able to observe salinity and (indirect) flow velocities in detail. For instance, one can use automated measurements with Electrical Resistivity Tomography (abbreviated ERT) to intensively monitor salinity changes, and one can use measurements with Active Heating-Distributed Temperature Sensing (abbreviated AH-DTS) to monitor groundwater flow velocities.

In this research, we are examining to what extent the predictive capacity of 3D-VD-FT models can be improved when 3D-VD-FT models are integrated with data from ERT and AH-DTS measurements. To achieve this, we are developing a high-resolution 3D-VD-FT model calibrated with data from a scavenger well field study called the FRESHMAN pilot, located in Scheveningen, a district of the city The Hague, the Netherlands. Moreover, we are assessing the ability of the 3D-VD-FT model to reproduce observed groundwater salinity changes during multi-level groundwater extractions and impact of these extractions on upconing and downconing of fresh, brackish and saline groundwater. The FRESHMAN pilot allows for a unique view in the subsurface during groundwater extractions due to intensive monitoring by incorporating conventional hydrogeological monitoring methods and innovative geophysical monitoring techniques.

Keywords: Coastal aquifers; Variable-density groundwater flow; Numerical model; Brackish groundwater extraction; Field study

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DRONE ELECTROMAGNETICS FOR GROUNDWATER INVESTIGATIONS

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ABSTRACT

The importance of drone based investigations increased in geophysics during the last years. A milestone in that regard was the development of semi airborne electromagnetic (SAEM) surveys during the DESMEX project. In principle, grounded transmitters generate the EM signal, while the magnetic field is recorded at a drone, respectively. Although originally used for mineral exploration it is possible to adapt the method for groundwater investigations. The major advantage compared to other geophysical methods working on the local scale is that drone based SAEM deliver 3D models of the subsurface resistivity distribution.

The project Blue Transition aims to balance water and land use to minimize climate change effects. Investigations on pilot sites in Denmark, Netherlands, Sweden, Belgium, France and Germany are used to develop transnational solutions for water boards, farmers, authorities and society. In this framework, SAEM measurements were carried out in Minstedt (northern Germany) to investigate a deep salinization that infiltrate into a shallow aquifer.

Drone based SAEM measurements were conducted in autumn 2023, including four transmitter with corresponding flight lines, covering an area of approx. 4 km^2. The results show the saltwater intrusion as an anomaly with low el. resistivities. Comparisons with downhole chloride monitorings match with the inversion results as well as with information about the freshwater-saltwater boundary from the local water board. Further comparisons with airborne TEM measurements also deliver comparable results compared to SEAM results. In summary, drone-based SAEM is able to deliver 3D el. resistivity models on the local scale for saltwater investigations in a depth range of 20 – 200 m below the surface.

Keywords: *geophysics, EM, saltwater, drone*

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FEEDBACKS BETWEEN SALTWATER INTRUSION, PERMAFROST THAW, AND SOIL THERMAL PROPERTIES IN AN ARCTIC COASTAL SYSTEM

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ABSTRACT

Permafrost, or perennially frozen ground, and seasonally frozen ground in the Arctic modulate many processes such as landscape stability, hydrological conditions, and biogeochemistry of terrestrial and aquatic ecosystems. Permafrost conditions across the Arctic are changing due to climatic impacts like warming and hydrological intensification. Ocean dynamics such as sea level rise, sea ice loss, and increasing ocean surge frequency further threaten coastal permafrost through saltwater intrusion and increased erosion. Across the globe, saltwater intrusion has ecological and biogeochemical consequences, with additional implications for soil freezing point depression in high latitude environments. Models have identified some impacts of flooding and saltwater intrusion on coastal Arctic soil thermal conditions, however, integrative approaches are needed to understand the feedbacks between coastal flooding, tundra degradation, and permafrost thaw in situ. To assess consequences of saltwater intrusion in a coastal Arctic system, we used a combination of pore water salinity, thaw depth, multi-depth temperature probes, and geophysical methods, including electrical resistivity tomography and multi-frequency electromagnetic surveys. Areas with increased pore water salinity had degraded vegetation and greater active layer thickness. Geophysical surveys showed these areas had pronounced differences in ice-rich permafrost distributions, demonstrating the long-term impacts on coastal stability. Yearlong time series of soil temperature profiles across degradation states revealed further differences in soil thermal properties at both diel and seasonal scales. For

example, vegetated sites had up to 10°C cooler temperatures than the degraded sites throughout the soil profile during summer. We demonstrate that in addition to freezing point depression, feedbacks between ecological conditions or soil properties complicate the impacts of coastal flooding and saltwater intrusion across much of the coastal Arctic. Integrating multiple methods is critical for achieving a process-based understanding of the effects of saltwater intrusion on interacting ecological, hydrogeological, and thermal processes along permafrost-bound coastlines.

Keywords: *permafrost, storm surge, soil temperature,*

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GROUNDWATER FLOODINGS, STORM SURGES AND WIND DIRECTION: A SILENT THREAT IN COASTAL AREAS

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ABSTRACT

Global warming is expected to lead to rising mean sea level, as well as alter wind-wave dynamics (Hemer et al., 2013) and trigger more frequent and intense storm surges (Little et al., 2015). These phenomena will amplify the magnitude and frequency of extreme episodic rises of sea level and coastal flooding, resulting in increased shoreline erosion (Vitousek et al., 2017) and significant damage to coastal ecosystems (Little et all., 2015).

Storm surges travel toward the coast as shallow water waves (Idier et al., 2019), leading to the accumulation of seawater mass near the shore. As seawater levels rise, groundwater in low-lying areas can exceed the land surface, resulting in groundwater flooding. These events are often wrongly interpreted with surface water flooding, due to the complex nature of hydrodynamics in coastal aquifers.

The southeastern coast of Spain is highly exposed to powerful storms that can have a significant impact on both natural and urban areas (Molina et al., 2019). The present study focused on the specific case of the Motril (South-East Spain), where there was an increment in the frequency of flooding events over the past decade. Groundwater level data was obtained from 3 research wells near the shoreline and compared to different climate and oceanographic series to understand their interdependencies during coastal floodings. In addition, limnimetric level data was measured to study changes in the hydrodynamics of a wetland located a few hundred meters from the coastline (La Charca de Suárez) during floodings.

During the study period, various types of flooding were observed during strong winds. Several floods were caused by a rise in the groundwater level, occurring without precipitation or marine flooding. Time series analysis revealed that the wind direction was a key factor over the piezometric levels as well as the direction of the shoreline.

Keywords: *groundwater flooding, wind direction, low-lying coastal areas*

REFERENCES

Little, C. M. et al., 2015. Joint projections of US East Coast sea level and storm surge. Nat. Clim. Change, 5, 1114–1120.

Hemer, M. A., Fan, Y., Mori, N., Semedo, A., Wang, X. L., 2013. Projected changes in wave climate from a multi-model ensemble. Nat. Clim. Change, 3, 471–476.

Idier, D., Bertin, X., Thompson, P. et al., 2019. Interactions Between Mean Sea Level, Tide, Surge, Waves and Flooding: Mechanisms and Contributions to Sea Level Variations at the Coast. Surv. Geophys., 40, 1603–1630.

Molina, R., Manno, G., Lo Re, C., Anfuso, G., Ciraolo, G., 2019. Storm Energy Flux Characterization along the Mediterranean Coast of Andalusia (Spain). Water, 11, 509.

Impacts of Flood Mitigation Facilities on Groundwater Salinization in the Low-lying Coastal Estuary of Kujukuri Plain, Japan

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ABSTRACT

Low-lying coastal estuaries are particularly vulnerable to environmental threats including saline water intrusion and surge inundations. These risks are worsened by factors such as sea-level rise, excessive groundwater extraction, and extreme weather events, which threaten freshwater availability and coastal infrastructure. To mitigate inundation impacts, various facilities such as river embankments, pumping stations and drainage systems are implemented to manage water levels, to increase agricultural productivity, and to protect areas from flooding. Even though these facilities provide essential flood control, they may have unintended consequences on groundwater dynamics, potentially altering surface-subsurface water interactions and exacerbating salinization risks. To better understand these impacts, we aim to investigate how the flood mitigation facilities affect groundwater salinity in the low-lying estuary of Kujukuri plain, Japan, using a numerical approach, i.e., HydroGeoSphere. Due to ongoing land subsidence in this area, the pumping stations and ditch systems were built to prevent flooding and manage the resulting land surface elevation changes. Here, we developed scenarios to assess the effects of these mitigation facilities on groundwater salinization, considering (a) the case before land subsidence, and (b) the case where land subsidence occurs, using current elevation data and the addition of pumping stations. The simulation results show that when pumping stations work effectively, groundwater levels can be lower than the tidal river level, leading to seawater intrusion from the tidal river through subsurface. As a result, groundwater salinization extended further into the lowland areas on both sides of the tidal river. This finding indicates that mitigation facilities can effectively prevent inundation, yet they may worsen groundwater salinization. The study implies the importance of evaluating flood prevention strategies as their unexpected results could compromise groundwater resources.

Keyword: Low-lying Coastal Estuary, Groundwater Salinization, Numerical Approach, Flood Mitigation Facilities

Salt Water Intrusion Congress (SWIM 2025)

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INFLUENCE OF TREE MORTALITY ON SALT DISTRIBUTIONS IN CHANGING COASTAL ENVIRONMENTS

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ABSTRACT

In changing coastal environments, different driving forces can lead to freshwater salinization, which may cause vegetation mortality for low-saline tolerance plants and saltmarsh migration into uplands. Coastal flooding from storm surges and extreme high tides are fast forcing mechanisms that causes immediate responses in soil salinity. On the other hand, sea-level rise, which is relatively slow forcing, can lead to movement of saltwater inland and increase the salinity of the fresh groundwater system. Along the Delmarva Peninsula, USA, vegetation mortality and saltmarsh migration have been observed and monitored at six sites. In this work, a 3D HydroGeoSphere model is applied to a marsh-to-forest transition zone along the Atlantic Coastline in Virginia to study the effects of different forcings on salinity variations. Land surface depressions caused by uprooting of dead trees can change the soil properties and morphology. Preferential flow paths for saline floodwater infiltrating the subsurface can be caused by increased permeability of near-surface sediments. The resulting pits can also hold saline floodwater, potentially increasing the amount of salt infiltration. The current work investigates the influence of heterogeneity in permeability and land surface elevation caused by tree mortality and saltmarsh migration on saltwater intrusion to groundwater under both extreme events for storm surge sea-level rise. The work elucidates the integration of 3D groundwater-surface water interaction model and field measurement as well as the impact of permeability and morphology heterogeneity on saltwater intrusion and saltmarsh migration in changing coastal environments.

Keywords: *Saltwater intrusion, saltmarsh migration, heterogeneity, soil salinity*

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OPERATION AND DESIGN OF INFILTRATION GALLERIES IN THE PACIFIC

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ABSTRACT

Infiltration galleries, or skimming wells, are horizontal or inclined, perforated pipes used to extract fresh groundwater from many Pacific islands, particularly atolls. In this study, we reviewed the state of knowledge of infiltration galleries in the Pacific, including their design and performance, through engagement with hydrogeologists and operators from across the Pacific. The review summarized key infiltration gallery design elements, including layout, pipe characteristics and pumping rates, gallery performance (pumping rates and salinities), and other aspects. Several critical research gaps are identified, as well as critical knowledge about infiltration gallery design and operation that has thus far been reported only in engineering reports and other unpublished documents. A key design element of infiltration galleries should include the freshwater lost as discharge to the sea and through mixing with saltwater, because these are often overlooked in atoll island water-balance analyses. The insights gained from applying infiltration galleries to Pacific atolls offers opportunities for more widespread applications within continental aquifers, in particular to capture submarine fresh groundwater discharge that is otherwise lost through mixing with seawater and to mitigate seawater intrusion, thereby contributing to global groundwater management strategies.

The research included a workshop held at Kiritimati Island (Republic of Kiribati) in November 2023 with Pacific Island operators, hosted by the Pacific Community (Fiji). This workshop produced a summary of construction details and operational performance information, which was used as the basis for summarising design components of infiltration galleries, and to develop guidance on their future use, drawing on the collective experience of decades of trial-and-error throughout the Pacific.

Keywords: *Skimming well, Seawater intrusion, Up-coning, Freshwater lens, Groundwater management*

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Salinity Intrusion in a Tropical Agricultural Wetland of India

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ABSTRACT

Climate change and failure in the development project to control salinity intrusion adversely affects rice production and availability of reliable water in the Vembanad-Kol coastal agricultural wetland, a designated Ramsar site and a recognised globally important agricultural heritage system of India. Aquifers in the region has become saline. The wetland is surrounded by backwater, with most of the area lying one metre below sea level. Through generations, rice cultivation has been made possible by constructing dikes using local soil and pumping out water. The project to multiply crop production by preventing saline water intrusion results in large-scale salinity intrusion. Dispute developed between fishermen and farmers over the period of opening and closing of regulators during peak summer where there is no river runoff to displace saline water. Improper maintenance of the shutters permits leakage of saline water during high tide. Due to the failure in foreseeing the rising sea level and sand dune formation in the coast during monsoons, sea water enters the wetland through spillway. Rice production became half. Natural flushing is obstructed by the barrage and concentration of pollutants multiplied and the water resources became totally unsafe. Many native species of aquatic life and migratory birds have disappeared. Changing climate and rising sea level pose a new threat. Rainfall in the state is becoming highly seasonal, reducing the summer flow of rivers joining the wetland that is important in pushing away the saline water. Fall in rice production and deterioration of water quality leads to several socio-economic and health issues. A detailed investigation on the factors leading to increasing salinity in the wetland and a critical review of current strategies and policies for adaptation and mitigation has been made. Guidelines for an appropriate policy and strategy to save the wetlands agriculture from the salinity problem have been provided.

Keywords: *wetland, salinity, climate change, adaptation, policy*

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SALTWATER INTRUSION AND SALT MARSH MIGRATION IN A GEORGIA (USA) MARSH

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ABSTRACT

Salt marsh encroachment is a visible indicator of saltwater intrusion into the root zone in low-lying coastal areas. The rate of salt marsh migration does not track directly with sea level, however. Field observations from 1998 to 2022 at Sapelo Island, Georgia (USA), show that salt marsh migration occurred during droughts. Drought has the potential to affect salt marshes in multiple ways, including reduced infiltration of rainwater and reduced discharge of fresh groundwater from adjacent uplands to the marsh. To test these possibilities, we instrumented the field site in 2018 to record hydraulic head (every 20 minutes) and groundwater salinity (sporadically) in the root zone. We then developed a two-dimensional numerical model to simulate groundwater flow and salinity below the salt marsh from 1998 to 2022. Simulations revealed recurrent winter freshening of groundwater in the root zone in the high marsh, caused by winter expansion of the freshwater lens. In drought years, the simulated freshwater lens failed to expand, leading to higher salinities during the spring growth period. These kinds of seasonal variations in the size of the freshwater lens have implications for seasonal patterns in submarine groundwater discharge and salt water intrusion.

Keywords: *salt water intrusion, sea level rise, drought, salt marsh, freshwater lens*

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SEAWATER FLOODING AND SEA-LEVEL RISE INCREASE INLAND GROUNDWATER-SURFACE WATER EXCHANGES AND SALTWATER INTRUSION

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ABSTRACT

Coastal storms and sea-level rise will increase seawater flooding and saltwater intrusion in low-elevation coastal zones, such as small islands. High sea levels can elevate inland water tables via ocean-aquifer connections and cause groundwater flooding and salinization hazards. These subsurface hazards are often overlooked, but can intensify freshwater security challenges and drive ecosystem transgressions. Here, we use new field data and numerical simulations of groundwater flow and solute transport to evaluate how heavy rainfall, storm surge, and seawater infiltration during Hurricane Fiona (September 2022) and future sea-level rise impact beach and inland groundwater levels, freshwater pond areas, and saltwater intrusion on Sable Island National Park Reserve, Canada. Field data reveal heavy rainfall during Hurricane Fiona increased groundwater and pond levels before seawater flooded the beach. Seawater infiltration on flooded, low-elevation beaches caused a 1.8 m rise in beach groundwater levels, which in turn increased pond levels by 0.12 m without direct inputs from precipitation or seawater. Model simulations demonstrate that seawater infiltration on beaches flooded the subsurface and drove the observed inland groundwater rise that expanded the area of freshwater ponds by 174%. Simulations of projected sea-level rise show that seawater inundation will only flood a small area of land along the coast, while inland groundwater flooding may inundate up to 30 times more land area. Groundwater rise and flooding driven by sea-level rise decrease hydraulic gradients and increase saltwater intrusion via freshwater lens contraction. Together, results demonstrate that seawater inundation and sea-level rise paradoxically cause concurrent fresh surface water expansion but subsurface freshwater lens contraction. Our results provide new insights into drivers of spatiotemporal dynamics of island freshwater resources and highlight that unseen and often overlooked groundwater-surface water exchanges are critical for evaluating coastal flooding and groundwater salinization hazards in an age of intense storms and rising seas.

Keywords: *seawater flooding, sea-level rise, freshwater lens, groundwater-surface water interactions*

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SIMULATING GROUNDWATER MANAGEMENT SCENARIOS IN THE SALINIZED LUY RIVER AQUIFER SYSTEM UNDER CLIMATE CHANGE

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SHORT ARTICLE

Securing the sustainable utilization of potable water supplies is essential for global well-being (World Health Organization, 2017). Nonetheless, despite several efforts, the sustainable exploitation of groundwater resources has proven ineffective in many contexts due to overexploitation and contamination resulting from population growth, urbanization, industry, agricultural development, and climate change. This is particularly critical in coastal aquifers due to the risk of seawater intrusion. These causes contribute to a deterioration in water quality and a reduction in groundwater levels in numerous places (Hughes et al., 2011; Taylor et al., 2013; Cosgrove and Rijsberman, 2014).

Globally, groundwater management is based on the efficient and sustainable use of groundwater. Planning typically addresses three main management concerns: 1) adjust groundwater abstractions to meet future sustainable supply and demand requirements, considering other groundwater functions such as maintaining baseflow in rivers and recharge; 2) under acceptable extraction rates, an integrated aquifer system management should consider in which aquifer units to extract and how to optimize well locations; consider economic and social impact, local regulations, and changes in water quality (Zekâi Ş. 2015).

The term "climate change" is often used to denote global warming, characterized by the persistent rise in average world temperatures. In general, elevated average temperatures are resulting in more severe storms, droughts, and other climatic extremes (Summerhayes, 2015; Foster et al., 2017; IPCC, 2021). Variations will occur in the patterns and intensity of precipitation, evapotranspiration, and the timing of wet and dry seasons. The primary sources of groundwater recharge in aquifers are precipitation and interaction with surface water bodies. Consequently, any alteration in climate that directly influence precipitation and surface water would ultimately affect groundwater systems. Likewise, Climate Change is anticipated to influence water consumption, thereby increasing the necessity for groundwater extraction.

Seawater intrusion is especially probable when groundwater extraction causes water tables to fall below sea level, including upconing; however, fossil saltwater confined in clay can also significantly influence the distribution of seawater (Park et al., 2005; Bennetts et al., 2006; Werner et al., 2009). Climate change's disruption of the water cycle unavoidably affects seawater intrusion processes. Saltwater intrusion, global climate change, and sea level rise

significantly affect coastal towns regarding groundwater supply and water demand. The situation deteriorates further as the population increases over time.

The research conducted by Cong-Thi et al. (2021, 2024) and Pham et al. (2022, 2025a, 2025b) indicates that the Luy River aquifer system, situated in a semi-arid climate zone, is experiencing high salinity levels. The increasing population, along with industrial activities and agriculture, necessitates substantial freshwater resources. Moreover, the excessive extraction of groundwater from private wells by farmers may induce the migration of saltwater from deeper strata to shallower ones. The convergence of these challenges, alongside global climate change and rising sea levels, complicates groundwater management in the study area.

In this study, we used the model established by Pham et al. (2025b) to evaluate the effects of global climate change and sea-level rise on groundwater supplies. The configuration of hydrogeological units, boundary conditions, drainage systems, and rivers remained consistent. Furthermore, we calibrated the model parameters, including inflow flux boundary, river and drainage conductance, and hydraulic conductivity values, utilizing observation wells and water level measurements from two field campaigns conducted during both the rainy and dry seasons.

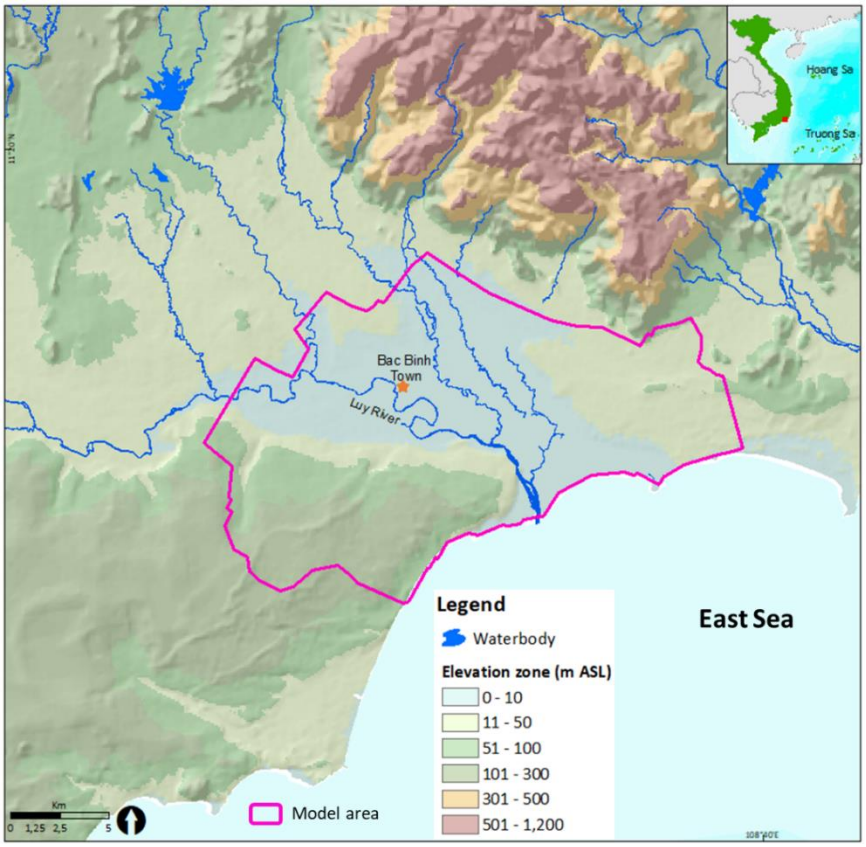

Figure 1. Map of the topography of the study area indicating the model boundary

We used the currently available salinity map from Cong-Thi (2024b) to establish the initial salt concentration for the model functioning at various densities. For sections with absent data, we estimated the initial salt concentration using water samples collected from deeper wells or alternative sources, including interviews conducted during the field operations. We utilized the salt concentration acquired from the 2019 field campaign in the Luy River estuary as the initial

salinity for the model. The starting salt concentration configuration for the model ranges from 0.45 to 35 kg/m³ for fresh and saltwater, respectively.

For the initial recharge, we used the values estimated from Pham et al. (2025a), while the initial sea level was taken from the average value recorded at Phu Quy station during the period 1980–2018. The recharge and sea level in the next 50 years were estimated from the climate change forecast reported in MONRE, 2021. The coupled density-dependent groundwater flow and transport model SEAWAT is used for our simulation. Several scenarios were simulated to evaluate the impact of global climate change and sea-level rise on groundwater resources.

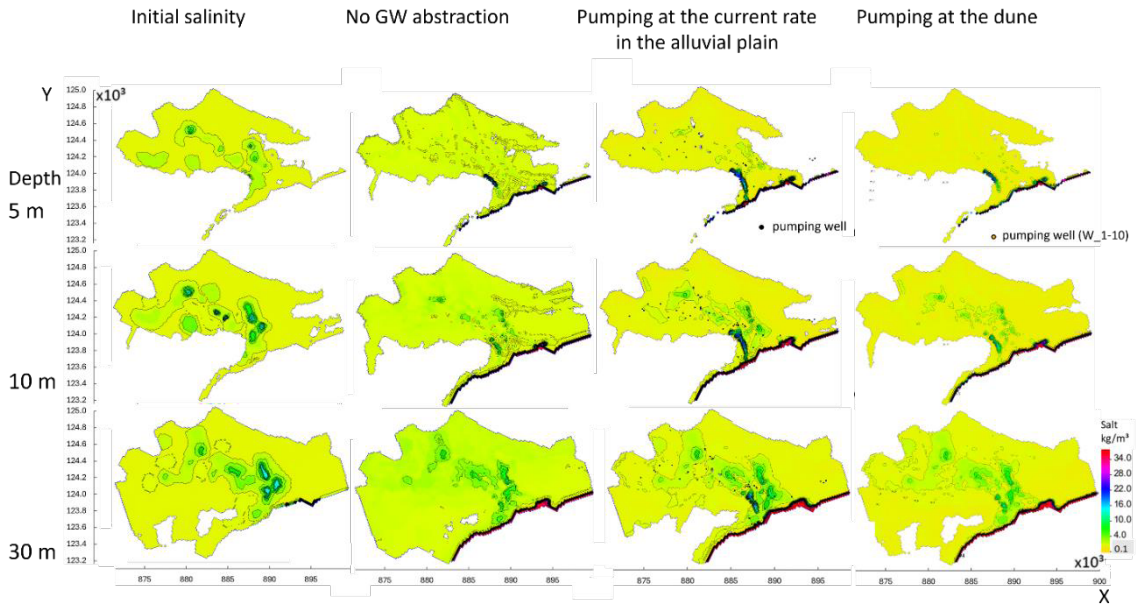

Figure 2. Salinity patterns at 0-5m depth, 5-10m depth, and 10-30m depth after a 50-year simulation under sea level rise and climate change in the different scenarios

The results (Figure 2) indicate that in the next 50 years, saline water will persist in the aquifers of the research area, aligning with the conclusions of Pham et al. (2022, 2025b). Seawater may encroach up to 1 km inland from the coastline if groundwater is extracted at the current rate, resulting in increased salt in the shallow aquifer. The dune systems possess significant potential for groundwater extraction in the region and will serve as a crucial resource, as they mitigate the issue of saltwater intrusion on the alluvial plain. Water should be preferentially sourced from these reservoirs, as they reduce the risk for further salinization. However, this requires the development of a regional groundwater management plan. The presence of saltwater in the bedrock remains an unknown. Groundwater extraction should therefore be preferentially integrated with managed aquifer recharge to prevent overexploitation of the resource. Comprehensive research should be conducted to evaluate the dune system's capacity to supply irrigation water to the town.

The findings of this study will aid government officials in evaluating groundwater resource capacities and implementing appropriate policies to ensure the long-term sustainability of groundwater in the research area.

Reference

1. Bennetts, D. A., Webb, J. A., Stone, D. J. M., & Hill, D. M. (2006). Understanding the salinisation process for groundwater in an area of south-eastern Australia, using hydrochemical and isotopic evidence. Journal of Hydrology, 323(1-4), 178-192.
2. Cosgrove, W. J., & Rijsberman, F. R. (2014). *World water vision: making water everybody's business*. Routledge.
3. Cong-Thi, D., Pham, D.L., Thibaut, R., Paepen, M., Ho, H.H., Nguyen, F., Hermans, T., (2021). Imaging the structure and the saltwater intrusion extent of the Luy River coastal aquifer (Binh Thuan, Vietnam) using electrical resistivity tomography. Water 13, 1743. https://doi.org/10.3390/w13131743.
4. Cong-Thi D., Pham, D.L., Caterina, D., Pauw, X. D., Dang, T.H., Ho, H.H., Nguyen, F., Hermans, T., (2024a) Quantifying salinity in heterogeneous coastal aquifers through ERT and IP: Insights from laboratory and field investigations. Journal of Contaminant Hydrology, 262 (2024) 104322. https://doi.org/10.1016/j.jconhyd.2024.104322
5. Cong-Thi, D. 2024b. Hydrogeophysical Characterization of Saltwater Intrusions in the Southern Central Region, Vietnam. Ph.D. thesis, Ghent University, Ghent, Belgium.
6. Foster, G. L., Royer, D. L., & Lunt, D. J. (2017). Future climate forcing potentially without precedent in the last 420 million years. *Nature communications*, *8*(1), 14845.
7. Hughes, T. P., Bellwood, D. R., Baird, A. H., Brodie, J., Bruno, J. F., & Pandolfi, J. M. (2011). Shifting base-lines, declining coral cover, and the erosion of reef resilience: comment on Sweatman et al.(2011). *Coral Reefs*, *30*, 653-660.
8. IPCC AR6 WG1 (2021). Chapter 11: Weather and climate extreme events in a changing climate. Eds. Seneviratne S. I., Zhang X,. Adnan M., Badi, W.
9. Summerhayes, C. P. (2015). *Earth's climate evolution*. John Wiley & Sons.
10. Taylor, R. G., Scanlon, B., Döll, P., Rodell, M., Van Beek, R., Wada, Y., ... & Treidel, H. (2013). Ground water and climate change. *Nature climate change*, *3*(4), 322-329.
11. Park, S.C., Yun, S.T., Chae, G.T., Yoo, I.S., Shin, K.S., Heo, C.H. and Lee, S.K., (2005). Regional hydrochemical study on salinization of coastal aquifers, western coastal area of South Korea. Journal of Hydrology, 313, 182-194.
12. Pham, D.L., Cong-Thi, D., Segers, T., Ho, H.H., Nguyen, F., Hermans, T., (2022) Groundwater Salinization and Freshening Processes in the Luy River Coastal Aquifer, Vietnam. Water, 14,
2358. https://doi.org/10.3390/w14152358
13. Pham, D.L., Cong-Thi, D., Ho, H.H., Nguyen, F., Hermans, T., (2025a). Estimating groundwater recharge in the downstream part of the Luy River catchment, Binh Thuan, Vietnam (In preparation).
14. Pham D.L., Paepen, M., Cong-Thi, D., Vandenbohede, A., Vu, T.T., Ho, H.H., Nguyen, F., Hermans, T., (2025b). Groundwater modelling to validate saltwater intrusion and freshening processes identified from hydrochemistry in a coastal groundwater system in Vietnam (In preparation)
15. Werner AD, Jakovovic D, Simmons CT. Experimental observations of saltwater up-coning. J Hydrol 2009; 373:230–41.
16. WHO Library Cataloguing-in-Publication Data, 2017. Guidelines for drinking-water quality: fourth edition incorporating the first addendum ISBN 978-92-4-154995-0.
17. Zekâi Şen, Water Science Basic Information, Editor(s), chapter 1 in Practical and Applied Hydrogeology, Elsevier, 2015, Pages 1-41, ISBN 9780128000755, https://doi.org/10.1016/B978-0-12-800075-5.00001-7.

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UNCERTAINTIES IN SALTWATER INTRUSION DUE TO MODEL PHYSICS AND PARAMETER DECISIONS

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ABSTRACT

Saltwater intrusion (SWI) driven by rising sea levels threatens coastal infrastructure and ecosystems. Modeling this process requires numerous decisions about model physics that introduce uncertainties in our estimation of SWI, but most modelling studies only quantify uncertainty due to parameter choices (for example, permeability) once the model physics has been constrained. Our goal was to evaluate both model and parameter uncertainty in estimating freshwater–saltwater interface movement due to sea level rise and climate-induced changes in groundwater recharge. We evaluate a 1D analytical (sharp-interface) solution, 2D and 3D sharp interface models, and fully coupled 2D flow and salt transport models in a synthetic coastal landscape that experiences 1 m of sea level rise and various changes in groundwater recharge. Sharp interface models use an experimental version of a new SWI package implemented in MODFLOW 6. The salt transport model simulates variable-density groundwater flow coupled with dispersive salt transport. Preliminary results indicate that hydraulic conductivity is the dominant source of uncertainty across all recharge conditions. Model selection uncertainty becomes more pronounced under specific recharge scenarios, including strongly drying and stable scenarios. These findings highlight the importance of constraining hydraulic conductivity to improve SWI predictions. Additionally, we identify parameter and data ranges where analytical and sharp interface models significantly deviate from the full numerical model, offering guidance for future SWI assessments.

Keywords: Saltwater Intrusion, coastal groundwater, groundwater modelling, uncertainty quantification, global sensitivity analysis

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UNTANGLING COMPLEXITY ACROSS THE CRITICAL ZONE AT THE LAND-SEA MARGIN

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ABSTRACT

Coastal systems are highly complex, hosting hydrological forcings that span waves to glacial cycles and interlinked ecological, biogeochemical, and geomorphological processes. These systems are also critical – as water supply to billions of people, hosts to valuable habitat, and outsized sequesterers of carbon – and vulnerable – as populations grow, sea level rises, and storms become more intense. Untangling these factors and quantifying feedbacks are essential for coastal system management and prediction of future change, yet the complexity poses a formidable challenge. How do we collect and integrate the data necessary to understand interconnected processes? Can we model these systems, and how do we balance principles of parsimony with process complexity? We present some examples and ideas for observational and modeling approaches to improve understanding and prediction of complex coastal processes in a changing climate.

Keywords: *Coastal Wetlands, Salinization, Climate Change, Coastal Resilience, Modeling*

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A REGIONAL-SCALE MODEL FOR ESTIMATING FRESH SUBMARINE GROUNDWATER DISCHARGE IN THE BALTIC SEA

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ABSTRACT

Submarine groundwater discharge (SGD) is an often-overlooked component of the global hydrological cycle, significantly influencing coastal water quality (Santos et al., 2021). Although multiple models and studies exist for estimating SGD, large-scale assessments remain scarce, especially in areas experiencing intensive anthropogenic pressures, such as the Baltic Sea. These pressures include large coastal populations and land-based pollution, which contribute to the increased risk of local marine environments (Reckermann et al., 2022). Moreover, SGD can act as a critical pathway for transporting pollutants including nutrients into marine environments (Zhang et al., 2024). However, the accurate regional scale estimation of SGD and its associated pollutant fluxes remains a challenge.

To address this challenge, we develop a novel openly accessible, user-friendly, three-dimensional groundwater flow modelling tool specifically designed to quantify fresh SGD and related pollution in the Baltic region. The model integrates high-resolution catchment-based water budgets, including infiltration, precipitation, recharge, runoff, and evapotranspiration with digital elevation data, climate inputs, and aquifer properties. The model performance will be validated through catchment-scale water balances. Once validated in the Baltic Sea context, this model framework can be easily adapted to other regions, with comparable hydrogeological and climatic conditions.

Planned future applications include examine how variations in climate, geology, and land use influence fresh SGD and the transport of both conventional and emerging pollutants. Future iterations of the model will incorporate density-dependent groundwater flow to address the effects of saltwater intrusion and saline SGD. By providing robust, spatially accurate estimates of SGD, this research offers a foundation for developing best management practices and targeted pollution mitigation strategies that consider local hydrogeological conditions.

Keywords: *Submarine Groundwater Discharge (SGD), Fresh SGD, Groundwater modelling, Pollution flux, Baltic Sea*

References

Reckermann, M., Omstedt, A., Soomere, T., Aigars, J., Akhtar, N., Bełdowska, M., Bełdowski, J., Cronin, T., Czub, M., Eero, M., Hyytiäinen, K.P., Jalkanen, J.P., Kiessling, A., Kjellström, E., Kuliński, K., Larsén, X.G., McCrackin, M., Meier, H.E.M., Oberbeckmann, S., Parnell, K., Pons-Seres De Brauwer, C., Poska, A., Saarinen, J., Szymczycha, B., Undeman, E., Wörman, A., Zorita, E., 2022. Human impacts and their interactions in the Baltic Sea region. Earth System Dynamics. https://doi.org/10.5194/esd-13-1-2022

Santos, I.R., Chen, X., Lecher, A.L., Sawyer, A.H., Moosdorf, N., Rodellas, V., Tamborski, J., Cho, H.M., Dimova, N., Sugimoto, R., Bonaglia, S., Li, H., Hajati, M.C., Li, L., 2021. Submarine groundwater discharge impacts on coastal nutrient biogeochemistry. Nat Rev Earth Environ. https://doi.org/10.1038/s43017-021-00152-0

Zhang, X., Li, H., Wang, X., Kuang, X., Zhang, Y., Xiao, K., Xu, C., 2024. A comprehensive analysis of submarine groundwater discharge and nutrient fluxes in the Bohai Sea, China. Water Res 253. https://doi.org/10.1016/j.watres.2024.121320

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ASSESSMENT OF OCEAN DYNAMICS ON GROUNDWATER DISCHARGE ACROSS AQUIFER TYPE THROUGH COUPLED OCEAN-GROUNDWATER MODELS

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ABSTRACT

Coastal zones are dynamic interfaces where groundwater-ocean interactions, such as seawater intrusion (SWI) and submarine groundwater discharge (SGD), critically influence water resource sustainability and ecosystem stability. While hydraulic properties like groundwater permeability and ocean tidal effects are well-studied, the impacts of other coastal physical properties—salinity, temperature, and turbulent diffusion—on these processes, particularly across different aquifer types, remain insufficiently explored.

This study employs a coupled Telemac-3D and MODFLOW6 model to comparatively analyze coastal groundwater dynamics in confined and unconfined aquifers under comparable geometries. Through systematic modulation of oceanic drivers - coastal salinity, coastal temperature, and turbulent diffusion parameters - we establish a controlled framework to: 1) quantify differential sensitivity of submarine groundwater discharge (SGD) and seawater intrusion (SWI) to individual marine forcing factors, and 2) characterize how aquifer confinement regulates the spatiotemporal evolution of groundwater-ocean exchange. This comparative framework reveals how geological architecture influences the balance of density-driven flow, advection, and dispersion at the terrestrial-marine interface.

This research seeks to improve understanding of coastal groundwater processes and support better management strategies for regions with varied aquifer types and environmental challenges.

Keywords: Coastal zone modeling, Coupled model, Telemac, Modflow6, Parameter sensitivity analysis

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COASTAL OCEANOGRAPHIC PROCESSES IN A SGD-AFFECTED AREA: ANALYTICAL MODELS AND DO-IT-YOURSELF SENSORS

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ABSTRACT

Submarine groundwater discharge (SGD) plays a crucial role in coastal oceanographic processes, influencing nutrient dynamics, salinity gradients, and biogeochemical cycles. Understanding these physical processes is essential for developing appropriate strategies for numerical modeling coupling and designing tailored hydrodynamic field campaigns.

This contribution explores the key coastal oceanographic processes associated with freshwater dispersion from SGD, emphasizing their varying spatial and temporal scales. The analysis is supported by recent oceanographic measurements conducted at an SGD-affected beach (Aiguadolç micro-tidal pocket beach, NW Mediterranean Sea), where groundwater discharge influences local hydrodynamics.

Additionally, this research examines the integration of Low-Cost and Do-It-Yourself (LC+DIY) instrumentation to monitor critical oceanographic parameters such as water levels, waves, temperature, and salinity. Several examples of LC+DIY sensors and their applications across different regions demonstrate their suitability for extensive data collection, particularly in SGD-affected areas with specific monitoring needs.

By combining theoretical and experimental approaches, this contribution aims to enhance our understanding of SGD-related coastal processes and encourage for the adoption of affordable sensor technologies in coastal oceanographic studies.

Keywords: *freshwater dilution, do-it-yourself sensors, estuarine circulation, Aiguadolç, NW Mediterranean Sea*

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EXPERIMENTAL AND NUMERICAL INVESTIGATION OF DNAPL TRANSPORT IN COASTAL AQUIFERS

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ABSTRACT

Dense non-aqueous phase liquids (DNAPLs) are organic pollutants that are insoluble in, and denser than, water, and have been discovered in aquifers underlying populated areas across the globe. The movement of DNAPLs in coastal aquifers, where tides and seawater create complicated flow paths, has received little attention. This study examines the movement of three different DNAPLs: TCE, CB and HFE, which differ in density and viscosity. Two-dimensional (cross-sectional) representations of coastal aquifers are adopted in both physical (sand tank) experiments and numerical modeling, which included the effects of both the seawater wedge and tides. The observations of DNAPLs responding to tides are the first physical experiments to do so. The results show that in isotropic and homogeneous aquifers, DNAPLs change the shape of the seawater wedge upon contact with it, pushing the toe seaward. The seawater wedge significantly expanded the area and increased the residual amounts of DNAPL trapped in the aquifer. The tide promoted seaward migration of the DNAPLs, tending to flush the DNAPL mass from the aquifer, although this had little effect on the volume of the aquifer containing mixtures of ambient groundwater and DNAPL. DNAPLs with lower density were more significantly affected by seawater and tides. The findings from this investigation show for the first time the opposing effects of seawater and tides on DNAPL migration in coastal aquifers.

Keywords: COMSOL; Sand tank; Tides; Trichloroethylene; Hydrofluoroether

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HIGH-RATE SUBMARINE GROUNDWATER DISCHARGE AND ITS INTERACTION WITH THE FRESHWATER-SEAWATER INTERFACE IN A COASTAL LIMESTONE AQUIFER

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ABSTRACT

Groundwater discharge from coastal limestone and karst aquifers plays a crucial role in global freshwater pathways and nutrient transport. The porous structure of these aquifers, with voids and cavities, leads to turbulent groundwater flow, making Darcy's law inapplicable. However, these discharge patterns remain poorly understood due to limitations in conventional measurement techniques. This study investigates submarine groundwater discharge (SGD) dynamics along the coast of Yoron Island, southern Japan, using an integrated monitoring approach. Electromagnetic flow meter, electrical resistivity surveys, and pressure monitoring were conducted to assess SGD variability in response to tidal cycles. The results highlight significant tidal influence on SGD behavior, with a pronounced hysteresis effect in efflux rates between low and high tides, suggesting complex seawater-freshwater mixing. Analysis of the hydraulic gradient between inland groundwater levels and tidal fluctuations provides additional insights into SGD mechanisms. Using observed SGD efflux rates and applying the Darcy–Weisbach equation, conduit characteristics within the limestone aquifer were estimated. The highest recorded SGD efflux rates exceeded 50 cm/s, among the highest reported in similar environments. These findings emphasize the need to refine hydrological models to account for non-Darcy flow dynamics in karst aquifers. This study demonstrates the effectiveness of electromagnetic seepage meters in capturing rapid SGD patterns in karst aquifers. The results contribute to a broader understanding of SGD pathways and their role in coastal water exchange, with implications for hydrological modeling and coastal ecosystem assessments.

Keywords: *(high-rate submarine groundwater discharge;* electromagnetic seepage meter; *limestone aquifer; direct measurement)*

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IMPACT OF SEA-LEVEL RISE AND TIDAL AMPLITUDE VARIATIONS ON SUBMARINE GROUNDWATER DISCHARGE IN COASTAL AQUIFERS

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ABSTRACT

Submarine groundwater discharge (SGD) is a crucial process linking terrestrial and marine environments, influencing coastal ecosystems, nutrient cycling, and water quality. Despite its importance, the long-term impacts of future sea-level rise and tidal amplitude changes on SGD remain poorly understood. This study employs a variable-density groundwater flow model to assess the effects of sea-level rise and tidal amplitude variations on both fresh and saline SGD in coastal aquifers. Through a comprehensive sensitivity analysis, we explore the impact of key hydrogeological parameters, including hydraulic conductivity, dispersivity, beach slope, and inland groundwater level or discharge. Our results indicate that saline SGD increases with increasing sea level and tidal amplitude, and that variations in tidal amplitude alone result in larger changes in nearshore saltwater SGD than sea level rise alone, which deserves more attention. Under constant head inland boundary conditions, both sea level rise and tidal amplitude amplification lead to a decrease in fresh SGD. These findings highlight the need to incorporate future sea-level rise and tidal amplitude changes in long-term SGD predictions, with significant implications for coastal water quality and ecosystem management.

Keywords: *Submarine Groundwater Discharge, Sea-Level Rise, Tidal Amplitude, Numerical Modelling, Coastal Aquifers*

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SIGNIFICANCE OF SUBMARINE GROUNDWATER DISCHARGE IN A SEMI-ENCLOSED BAY OF THE BALTIC SEA

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ABSTRACT

Submarine groundwater discharge (SGD) plays a crucial role in the exchange of water and substances across the land-ocean interface and thus for coastal biogeochemistry, yet its impact remains understudied in the Baltic Sea. This study investigates the hydrogeochemistry of SGD in the Bay of Puck, southern Baltic Sea, focusing on its spatial and seasonal variability, geochemical processes, and environmental implications. SGD, groundwater and seawater samples were collected at multiple sites during several campaigns between 2009 and 2021. A one-dimensional advection-diffusion model estimates SGD rates between 1.8×10^{-7} and 2.8×10^{-7} L cm^{-2} s^{-1} in coastal areas, while at offshore sites within pockmarks, SGD varies between 0.4×10^{-9} and 0.05×10^{-7} L cm^{-2} s^{-1}. These findings indicate that SGD is one of the most significant sources of freshwater in the study area.

SGD in Puck Bay is also a key source of dissolved inorganic carbon (DIC), alkalinity (AT), and nutrients, strongly influencing coastal biogeochemistry. Under hypoxic conditions, denitrification and sulfate reduction enhance AT and DIC production; however, concentrations then decrease by 32% and 37%, respectively, due to mixing, reoxidation, and CO_2 release. Additionally, SGD has a low pH and is undersaturated with respect to the forms of the aragonite and calcite minerals of $CaCO_3$. Therefore, SGD can potentially contribute to ocean acidification and affect the functioning of the calcifying invertebrates.

Moreover, SGD in the bay serves as a potential contamination pathway, with pharmaceuticals e.g. such as carbamazepine, sulfamethoxazole, and diclofenac detected in groundwater, SGD, and coastal seawater.

These findings underscore the necessity of incorporating SGD into regional water and nutrient budgets and call for further research to assess its ecological and chemical impacts on the coastal ecosystem and ecosystem services of the Baltic Sea.

Keywords: *pockmarks, dissolved inorganic carbon, alkalinity, nutrients, pharmaceuticals*

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VISUALISATION OF GROUNDWATER DYNAMICS AT THE LAND-SEA INTERFACE OF THE HETEROGENEOUS COASTAL AQUIFERS USING PHYSICAL MODELS

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ABSTRACT

The effect of tides and waves complicates groundwater flow dynamics in subterranean estuaries. Geological variations in coastal aquifers increase complexity and may affect flow dynamics differently than in homogeneous settings. Thus, intruding seawater might change how nutrients, contaminants, and metal fluxes of the terrestrial groundwater are transported through the intertidal mixing zones, how long these elements stay within the zones and what biogeochemical reactions can occur. Despite coastal aquifers being heavily influenced by natural geological heterogeneities, most previous submarine groundwater discharge (SGD) studies assumed homogeneous sediment conditions in both numerical and physical models. Moreover, most of the SGD studies accounting for aquifer heterogeneity are numerical studies. Additionally, detecting, tracking, and recording such intricate flow dynamics in the field are challenging. Examining the flow instabilities in artificial coastal aquifers with spatially distributed hydraulic conductivities allowed us to visually assess the coastal flow dynamics, thereby addressing this knowledge gap. We improved our physical sand tank configuration depending on previous successful laboratory experiments and incorporated aquifer heterogeneities - i) as a layer-cake and ii) as a bricks-like structure in this study. Our results imply that flow instabilities exist in heterogeneous configurations even if the size of the upper saline plume (USP) may shrink due to the presence of low hydraulic conductivity layers; especially for a gentle beach slope (1:12). However, lower hydraulic conductivity layers or compartments may hinder salt fingers from vertical penetration. Furthermore, it is evident that three-dimensionality plays a significant role even in narrow sand tanks. Although the scaling in physical models is different from that of real aquifers, the present work will help to assess the effect of heterogeneity on groundwater flow and transport in coastal aquifers. Furthermore, it will be useful in enhancing long-term water management strategies for coastal aquifers in the wake of climate change.

Keywords: *subterranean estuary (STE), submarine groundwater discharge (SGD), upper saline plume (USP), salt fingers, physical models*

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AN INTEGRATED APPROACH TO INVESTIGATE SEAWATER INTRUSION INTO A COASTAL FRESHWATER AQUIFER USING ELECTRICAL RESISTIVITY TOMOGRAPHY AND VERTICAL ELECTRICAL SOUNDING: A CASE STUDY IN CAPE COAST, GHANA.

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ABSTRACT

As developing countries grapple with the consequences of increasing population growth, industrialization, and climate change, the over-extraction of groundwater has become a critical issue. In response, this research was conducted using geophysical techniques to assess the vertical and lateral extent of saline intrusion into the coastal freshwater aquifers of Cape Coast, Ghana. Utilizing the Mangusta System MC 24/120E and a multifunctional digital resistivity/IP meter, 15 Electrical Resistivity Tomography (ERT) and 14 Vertical Electrical Sounding (VES) surveys were carried out along the southeast-northwest direction of the coastline. The ERT survey with profile lengths between 120-240m and a 5m dipole-dipole spacing interval, and the VES survey had Schlumberger configurations extending 50-80m. The classification of salinity level proves three resistivity zones exist: low resistivity (≤ 10 Ωm) interpreted as saline water; moderate resistivity (10 Ωm < x > 20 Ωm) suggested as brackish water and high resistivity (≥ 20 Ωm) interpreted as freshwater aquifer zone. The research findings indicate that the shallow aquifer zones are compromised by seawater intrusion at 4.25 km away from the shoreline. This is further corroborated by the geo-chemical analysis of groundwater samples, which shows a decreasing trend of salinity moving inland from the coastline. GIS maps interpolated for water parameters (EC, TDS, Cl & Na) indicate decreasing trends in saline intrusion inland from the shoreline. The study's visuals, including 2D/3D pseudo-sections of ERT, 3D block model, 2D cross-section & 1D resistivity model (VES), charts, and interpolated maps of groundwater sample parameters provide a clear implication of these significant findings to the affected areas.
In conclusion, integrated and sustainable water resources management strategies were adopted as the implementation model to combat global efforts to address water scarcity. These include exploring alternative water sources such as desalination and recycled water, which offer viable solutions to freshwater scarcity.

Keywords: *Seawater Intrusion, Electrical Resistivity Tomography, Vertical Electrical Sounding, Coastal Aquifer, Groundwater Sampling.*

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CHARACTERIZING THE SALINITY DISTRIBUTION AT THE BELGIAN COASTAL ZONE BY CONSTRAINING ELECTRICAL RESISTIVITY TOMOGRAPHY INVERSIONS USING CONE PENETRATION TESTS

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ABSTRACT

The influence of tidal forces on shallow coastal aquifers is reflected in the coastal groundwater distribution resulting in a upper saline plume at the Belgian coastal zone. Geo-electrical methods, sensitive to electrical conductivity, are often used to characterize and monitor this fresh-salt water transition zone. Lithological interpretations from only geo-electrical techniques are not straightforward since both clay-rich and saline zones result in low resistivity values. Correct lithological information is however needed since the groundwater distribution is influenced by the geological heterogeneity. Cone penetration tests (CPTs) help differentiate whether high conductivity zones in the ERT signal result from geological formations or variations in water quality.

Additionally, ERT inversion results are non-unique and may suffer from the impact of the regularization approach. To produce more realistic inversion results, constraints on subsurface geometry and resistivity are added to go beyond the standard smoothness-constrained approach. Structural constraints derived from CPTs are used to constrain the geometry of clay lenses. In addition, vertical variograms of CPT with electrical conductivity (CPT-E) are used to constrain geostatistically the inversion. Prior resistivity data from borehole electromagnetic measurements and CPT-E are used to further constrain ERT inversion.

By integrating geophysical and geotechnical methods, lithological cross-validation and constrained inversions, we improve the characterization of groundwater salinity patterns occurring at the sandy beach of De Panne (Belgium).

Keywords: *geophysics, geotechnics, geostatistics, inversion, subterranean estuary*

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Combining seepage meters and Amphibious Electric Resistivity Tomography to investigate pathways of Submarine Groundwater Discharge.

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ABSTRACT

Submarine groundwater discharge (SGD) plays a crucial role in coastal biogeochemistry, yet it is still challenging to accurately quantify water and solute fluxes driven by this process due to its complex hydrogeological dynamics. This work aims to improve the identification and independent quantification of different SGD pathways by combining the use of seepage meters

and Amphibious Electrical Resistivity Tomography (AERT) at a heterogeneous karstic system in the Mediterranean Sea. In the field, 5 AERT transects were surveyed along with 24 seepage meters, which provided a 3D view of the salinity distribution and direct discharge rate measurements, respectively. The integrated approach identified and quantified distinct SGD pathways, including beach-face recirculation, focused discharge, submarine springs, and diffusive discharge, each uniquely influencing SGD dynamics. Given that each pathway is characterized by specific geochemical signatures and discharge rates, nutrient fluxes supplied by different pathways varied significantly in magnitude. While diffusive discharge primarily facilitated the transport of fresh groundwater and ammonium, nitrate and phosphate were predominantly delivered to the coastal ocean through focused discharge, especially via submarine springs. The combined methodology proved more accurate for determining water and nutrient fluxes than straightforward extrapolations from averaged seepage meter rates, which were consistently 20 to 120% higher. This discrepancy highlights the need of combining qualitative and quantitative methods, particularly in geologically complex regions where multiple SGD pathways coexist.

Keywords: *Coastal aquifer, Submarine Groundwater Discharge, Geochemistry, Geophysics*

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COST ACTION OFF-SOURCE: MARINE GEOPHYSICAL EXPLORATION OF OFFSHORE FRESHENED GROUNDWATER: CHALLENGES AND INNOVATIONS

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ABSTRACT

The exploration of offshore freshened groundwater (OFG) has become an emerging field for marine geophysical methods in recent years. OFG is considered as a water body with a salinity less than seawater stored in near coastal sub-seafloor aquifers. OFG bodies may have formed under lowstand conditions, during one of the several middle-to-upper Pleistocene glacial periods when sea levels were up to 130 m below todays and fluvial systems flowed across continental shelves, causing the formation of offshore aquifers' systems. OFG may represent a substantial alternative water resource for water –stressed coastal regions. However, the global potential of OFG is highly unconstrained due to missing geophysical data. Hydroacoustic, seismic and electromagnetic methods have demonstrated their efficiency to delineate the volume and extent of OFG bodies in a number of case studies. The resistivity distribution derived from electromagnetic and electrical resistivity tomography methods can be related to pore water salinity, and aquifer geometries can be confined using high resolution seismic methods.

As part of the European Cooperation in Science and Technology (COST) Action OFF-SOURCE, we are working to identify the most practical and effective tools and methods for detecting and evaluating OFG. Drawing on published case studies and the group's expertise, we aim to address challenges and recommend improvements in instrumentation, data acquisition, and interpretation, with the goal of providing practical guidelines for OFG exploration strategies for both stakeholders and the scientific community.

Keywords: *(offshore freshened groundwater, marine seismic, marine electromagnetics, COST Action OFF-SOURCE)*

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High Resolution Downhole Resistivity Monitoring in Argentona (Catalunya, Spain) during the Gloria Storm (2020).

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ABSTRACT

High resolution downhole resistivity images have been recorded with the SMD monitoring device during the Gloria storm in January 2020 at the Argentona research site located about 20 km North of Barcelona. This research site is located 40 to 90 m from the seashore to study the Argentona coastal aquifer. It was developed by UPC (“*Universitat Politecnica de Catalunya*”) and CSIC (*“Consejo Superior de Investigaciones Cientificas”*) to compare the performance of different investigation methods and obtain new insights for the SWI and SGD scientific communities. Unlike most studies conducted elsewhere, Argentona offers a site little influenced by tides, which allows focusing on other physical driving forces on groundwater (waves, storms, groundwater table elevation, for example).

The SMD is constituted with an array of m-scale downhole electrodes designed to be interrogated automatically every 4 hours in a dipole-dipole mode. It was installed down to 18 meters in bentonite, 70 m from the shore and calibrated in January 2017, penetrating through the fresh to salt water interface located at 15 m depth. Early downhole resistivity images show that the bentonite took a little more than two months to wash away, a process accelerated by rainfall to which this galvanic electrical resistivity device is particularly sensitive. A total of 5 months of downhole resistivity data recorded with the SMD are presented, from December 2019 to April 2020, equating to a series of about 900 downhole resistivity records. The Gloria storm brought heavy rainfall, high winds and coastal flooding from January 19 to 21. The SMD, both from electrical resistivity and in a differential mode, shows in great details the impact of the storm on the fresh groundwater column, as well as that of sea water sprays in the top 4 m. Several other rainfall events of lesser magnitude also show the same downhole patterns.

Keywords: downhole geophysics, electrical properties, in-situ monitoring, salt water intrusion, storm.

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SALT WATER INTRUSION PROCESSES IN CLASTIC COASTAL AQUIFERS FROM DOWNHOLE GEOPHYSICS; THE CONTRIBUTION OF NMR PROFILES.

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ABSTRACT

Detailed downhole geophysical profiles have been recorded at dm-scale through clastic coastal aquifers from experimental sites located in the Roussillon basin (*Caballero et al., 2015*). With core analyses, this extensive downhole dataset provides a dm-scale view of salt water intrusion processes in clastic sediments with the downhole determination of pore water conductivity in each of the holes. This inversion arises from the joint analysis of resistivity and porosity, obtained for the latter with a Nuclear Magnetic Resonance (NMR) sonde (*Dlublac et al. 2013*). Below major sea water intrusion in shallow Holocene sediments (40 000 to 55000 µS/cm), the Pliocene sands are intruded along m-thick sands layers, in a way which departs from the traditional Ghyben-Herzberg model. From 50 m depth downward, the pore fluid conductivity reaches 10 000 to 27 000 µS/cm in an otherwise fresh water environment. These salinity peaks are often related to higher permeability horizons identified from NMR data. A salinity increase in adjacent clay-rich sediments is also obtained, apparently resulting from a more diffusive salinity intrusion process at dm-scale. This resistivity-based approach provides a new description of salt water intrusion processes in coastal aquifers sand-shale structures from passive margins. In a climate change context and from resistivity profiles repeated over time (or permanent downhole geophysical observatories), this new dynamic insight provides a high resolution means to closely follow in space and time sea water intrusion processes in coastal aquifers.

Caballero, Y., and Ladouche, B. (2015). Impact of climate change on groundwater in a confined Mediterranean aquifer. *Hydrol. Earth Syst. Sci. Discuss.*, *12*, 10109–10156.

Dlubac, K., R. Knight, Y.-Q. Song, N. Bachman, B. Grau, J. Cannia, and J. Williams (2013), Use of NMR logging to obtain estimates of hydraulic conductivity in the High plain aquifer, Nebraska USA, *Water Resour.Res.,*49,1871-1886.

Keywords: clastic coastal aquifer, downhole geophysics, electrical properties, nuclear magnetic resonance, in-situ monitoring

Salt Water Intrusion Congress (SWIM 2025)

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SALWATER-FRESHWATER INTERFACE: DIRECT INVERSION OF AIRBORNE EM DATA IN TERMS OF HYDRAULIC PARAMETERS

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ABSTRACT

Airborne Electromagnetics (AEM) is nowadays widely used worldwide to characterize the seawater-groundwater interface by inverting the AEM data in terms of electrical conductivity. Despite the effectiveness of this approach, the inversion in terms of electrical properties does not take into account the hydrogeological mechanism that determines the interface position. Furthermore, the standard approach in inverting AEM data is to use a 1D approximation in the data modelling, with the risk of creating severe artifacts in the interface mapping.

In this study we use hydrological modelling for constraining the geophysical inversion, modelling the freshwater-saltwater interface of costal aquifers in terms of hydrogeological properties and the AEM data with a full 3D solution of the AEM partial differential equation.

In particular, the interface flow below a strip island is modelled analytically as a function of: i) the island dimension; ii) the freshwater and groundwater densities; iii) the areal recharge; iv) the hydraulic conductivity. The corresponding AEM response is computed in 3D assigning the freshwater and groundwater electrical conductivities, and the AEM data are then inverted in 3D using as inversion parameters only the hydraulic conductivity and the freshwater/groundwater electrical conductivities. We believe that constraining the AEM geophysical inversion by hydrogeological modelling opens the way for a direct characterization of hydraulic parameters, as well as for a quantitative study of seawater/groundwater interactions in costal aquifers, both for characterizing seawater intrusion and submarine groundwater discharge.

Keywords: AEM, fresh-saline interface, hydrogeophysics, inversion, electromagnetic methods

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TIME-LAPSE AIRBORNE EM FOR MONITORING THE EVOLUTION OF A SALTWATER AQUIFER

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ABSTRACT

This work presents a novel time-lapse modelling scheme for Airborne Electromagnetics (AEM) monitoring datasets, applied to study the hydro-related evolution of the Bookpurnong floodplain in South Australia. Additionally, it introduces a new wide-ranging approach for this type of study, incorporating new processing, validation, and interpretation tools.

Time-Lapse studies are widespread in the literature but are not commonly applied to model EM data, particularly AEM data. This is likely due to the challenges of performing overlapping acquisitions with inductive systems. The key features of the new time-lapse scheme, which address these issues, include the definition of independent forward and model meshes. Additionally, a novel dedicated processing workflow for AEM monitoring is presented.

The results of the time-lapse geophysical models are evaluated with an Independent Hydrogeological Validation (IHV), designed to support the geophysical results validation and interpretation phases with hydrogeological assessment of the system.

At Bookpurnong, along a sector of the Murray River floodplain, multitemporal AEM survey were collected in 2015, 2022 and 2024, to study the groundwater system evolution over time. The time-lapse models show very small variations compared to the independent ones, while revealing sharply bounded variation zones over the floodplain. This demonstrates the effectiveness of the new time-lapse scheme, especially considering the discrepancies in data location and acquisition height among datasets.

The AEM models are first validated through comparison with resistivity borehole measurements. The models are ultimately validated and interpreted using the IHV approach, which revealed a direct correlation between the hydrological stress of the Murray River and the response of the shallow aquifers.

We believe that the time-lapse methodology developed in this work can be applied to AEM multitemporal studies for monitoring different processes, surpassing the results of single-time AEM investigations and providing a new dimension for studying large-scale processes with greater accuracy.

Key words: **Airborne Electromagnetic, AEM, Time Lapse Inversion, Hydrogeophysics**

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USING BOREHOLE AND SURFACE GEOELECTRICAL METHODS FOR THE OPTIMAL LOCATING COASTAL OBSERVATION WELL AND SALINITY MONITORING AT THE MICHMORET TEST SITE, ISRAEL

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ABSTRACT

The use of geoelectrical methods can add valuable data regarding water salinity prior drilling, especially in areas with fresh/ saline water interface (FSI).

The present geophysical study is part of a general research project studying the effect of pumping saline water from a nearshore borehole on the aquifer water quality and the FSI location. An important part of the project was to find the best location of an observation well at the vicinity of the existing pumping well. For this purpose, a combined high resolution electrical resistance tomography (ERT) and the time domain electromagnetic (TDEM) method were applied at the prospective drilling site.

The geophysical measurements delineated 2D resistivity profiles that clearly showed the FSI location in the phreatic sub-aquifer “A” and indicated the existence of sharp FSI in the sub aquifer “B” about 50 m east to the existing pumping well.

The results were confirmed with water samples that were taken during dry air drilling, EC test in the field and salinity Cl- lab test.

After drilling the observation well, 72 electrodes were installed around the borehole pipes in both sub-aquifers. They were connected to a novel low-cost do it yourself (DIY) geoelectric instrument, named “Ofer”, built for conducting time-lapse borehole ERT measurements and monitoring the salinity changes during the last two years.

The results show that the low-cost DIY instrumentation can provide reliable data with less than a 1% measurement error that is entirely sufficient for dependable FSI monitoring.

The monitoring results show different behavior of the sub-aquifers. While the salinity at the upper phreatic sub-aquifer shows similar variation in time at different depths, which follow atmospheric rains with about a month delay, the salinity at the bottom sub-aquifer demonstrates different behavior at different depths.

Keywords: *Hydrogeophysics;coastal aquifers; fresh-saline interface; seawater intrusion;low cost instruments.*

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A MANAGEMENT MODELLING APPROACH OF GROUNDWATER COASTAL RESOURCES AT SALINISATION RISK UNDER GLOBAL CHANGE

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ABSTRACT

Climate change and excessive groundwater extraction are major contributors to rising groundwater salinization due to seawater intrusion in coastal aquifers at global scale. In this framework, the aims to define a wide-applicable approach in which hydrological balance, boundary conditions, and irrigation water demand, defined over time considering climate change predictions, can integrated into a numerical model of the groundwater system could be considered a relevant scientific challenge.

This challenge was accepted defining a modelling approach that could be applied at global scale. The approach was tested in a selected coastal aquifer. The approach spans from the past, used to define steady or almost natural conditions for calibration purposes (1950-2000 in the test), to the future (2100), divided in decade steps. The water balance analysis is based on an inverse hydrogeological water balance approach. The future climate change predictions are used to assess variations in boundary conditions of the groundwater model concerning salinity and sea level, recharge, and inflow from upstream aquifers. The approach considers changes in agricultural activities, groundwater demand, and river stage. The regional model is generated using the MODFLOW code for the groundwater flow model and the SEAWAT code for the salt transport model. The test concerns the Metaponto coastal plain, in which a porous aquifer is at salinization risk due to seawater intrusion. In this way, different influences of climate change and human activities are combined to define a 3d view of groundwater depletion and salinization effects. Quantifying these potential effects or risks, adaptation scenarios with numerical assessments are outlined.

Keywords: *(maximum 5 keywords): climate change, groundwater management, seawater intrusion.*

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DEVELOPMENT OF A VARIABLE-DENSITY NUMERICAL MODEL FOR GROUNDWATER MANAGEMENT IN LAURA, MAJURO ATOLL, REPUBLIC OF THE MARSHALL ISLANDS

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ABSTRACT

Small islands are particularly susceptible to seawater intrusion, a problem intensified by climate change factors such as sea-level rise, prolonged droughts, and increased frequency of storm surges. These threats compromise their limited freshwater resources, making advanced variable-density numerical models essential tools for managing vulnerable aquifers.

This study presents a fully coupled 3D variable-density flow and transport model developed with COMSOL Multiphysics for groundwater management on Laura Island, Majuro Atoll in the Marshall Islands. The model incorporates the island's geometry and geology, including the innovative implementation of cross-shaped horizontal wells. These wells provide a more efficient and sustainable alternative for groundwater extraction in thin aquifers, reducing the risk of seawater intrusion compared to traditional vertical wells.

The model was calibrated to reproduce the historical freshwater lens response (2007–2022) under variations in recharge, sea level, and pumping. Future climate scenarios were simulated to assess three key threats: (i) prolonged drought, (ii) sea-level rise, and (iii) rapid flooding from storm surges. Each scenario evaluated changes in freshwater lens volume and recovery time.

An additional innovation is the incorporation of submarine groundwater discharge (SGD), a critical process in island hydrology influencing both water quantity and quality. By accounting for SGD, the model improves predictions of freshwater lens behavior under different climatic and human-induced stressors.

The model also captures the unique dynamics of storm surges, where seawater temporarily overlays the freshwater lens before rebalancing. This feature enhances understanding of how rapid flooding impacts groundwater availability and quality.

Overall, Laura Island has limited freshwater reserves, fluctuating around 2 hm^3. These reserves are highly sensitive to extreme conditions, responding rapidly to external stressors such as droughts or flooding. However, they also exhibit a fast recovery capacity, providing resilience against environmental changes.

Keywords: *Numerical modelling, Groundwater management, Climate change impact, Freshwater lens, Submarine Groundwater Discharge.*

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IMPACT OF URBANIZATION ON GROUNDWATER AVAILABILITY IN THE MASINGINI–MWANYANYA CATCHMENT FOREST, UNGUJA – ZANZIBAR (TANZANIA)

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ABSTRACT

The Island of Unguja in Zanzibar (Tanzania) has experienced accelerated urban development growth since early 90s`. These rapid land demands put additional stress on the country's ability to rebuild urban canters, cities and management of natural forest resources. The purpose of this study was to determine the impact of urbanization on groundwater catchment area at Masingini-Mwanyanya catchment forest reserves from 1992 to 2022. The study used remote sensed change detection approach to determine the Land Use Land Cover (LULC) changes under three decades of (1992 to 2022). Landsat images of 1992, 2002, 2012 and 2022 were used to determine these changes. In addition, paired samples t-test was conducted to determine the significant changes in mean population growth, urbanization and humidity. Results revealed that forest catchment areas have been decreased by 14.5% (i.e. from 8.3 km^2 in 1992 to 7.1 km^2 in 2022), while built up area has increased from 0 km^2 in 1992 to 1.7 km^2 in 2022 (indicating that the catchment area has been encroached at a rate of 0.05 km^2/year). Further results showed an existence of undesirable LULC evolution (i.e. persisted changes from forest to build up areas), posing significant threat and risk to the sustainable management of water resources and catchment forest reserves. The paired t test revealed a significant (at $p \leq 0.05$ or 95% confidence) changes of the urbanization, deforestation and humidity. Based on these results, the study recommended for more studies and upscaling of the existing findings, collaboration of the responsible authorities in intervening, re-demarcating and gazetting the new Masingi-Mwanyaya forest catchments area aiming to allow a sustainable use of groundwater resources.

Keywords: *Urbanization, Land Use, Catchment Areas, Groundwater, Remote Sensing*

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Impacts of Subsurface Dam Construction on Downstream Groundwater Levels and Salinity Dynamics in Coastal Aquifers

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ABSTRACT

Subsurface dams are a promising engineering solution for the development of groundwater resources around the world, particularly in mitigating seawater intrusion in coastal zones. However, their potential impacts on the groundwater environment have raised significant concerns. In this study, we employed a three-dimensional (3D), variable-density, unsaturated-saturated groundwater flow model to investigate the effects of a groundwater-storage-type subsurface dam, constructed within the freshwater zone of an unconfined coastal aquifer, on groundwater levels and salinity in the downstream area. The model results revealed that following the construction of the subsurface dam, groundwater levels downstream exhibited more pronounced fluctuations, characterized by phase advances, increased amplitudes, and higher frequencies, particularly after heavy rainfall events. Numerical simulations under various subsurface dam configurations further demonstrated that these fluctuations were amplified with a higher dam crest elevation or when the dam was positioned closer to the coast. Additionally, during the recharging period of the subsurface reservoir (i.e., the period from dam construction to groundwater level rise to the dam crest level), seawater in the downstream area intruded landward from its original position, posing at least a temporary threat to coastal water quality. A higher dam crest elevation extended the duration of seawater intrusion, while a dam located closer to the coast resulted in a greater horizontal extent of seawater intrusion. These findings can be useful for enhancing assessment methodologies and engineering designs of subsurface dams to mitigate these adverse impacts on the water environment.

Keywords: subsurface dams, numerical model, coastal aquifer

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IMPLICATIONS OF AQUIFER TYPE FOR HYDRO-ECONOMIC MANAGEMENT OF SEAWATER INTRUSION

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INTRODUCTION

Comprehensive management of seawater intrusion (SWI) requires collaboration between hydrologists and economists to achieve the best use of limited groundwater among alternative uses. Hydrology, extractor incentives, and institutional and policy factors all interact. Hydro-economic analysis informs SWI management in five ways.

First, economists argue that groundwater management is essential when there are potentially large spatial and temporal externalities arising from groundwater pumping. Externalities are external costs of pumping imposed on other extractors: increased future pumping costs from lower groundwater levels (pumping cost externality) and a cost arising from the reduction in future stock availability, whether quantity or quality (stock externality, or here, a seawater intrusion cost externality). Since externalities are by definition mediated through the physical environment, and not through market prices, the hydrological interlinkages between extractors are fundamental. Stock externalities, such as seawater intrusion cost externalities, are much more likely to create a large divergence between the optimal and common property rates of extraction and the resulting extent of SWI.

Furthermore, hydro-economic analysis reveals that the common property rate of SWI, where extractors make decentralized pumping decisions, is greater than the optimal rate of SWI and is thus economically inefficient. The divergence between the optimal and common property rates can be used to design spatial pumping fees to manage demand, which may be less expensive than structural solutions to protect or enhance supply. Since individual extractors make pumping decisions based on private incentives (benefits and costs), optimal demand management spatial pumping fees must internalize the costs that individual extractors impose on other extractors, termed common property externalities in economics; then decentralized pumping decisions will lead to the optimal rate of extraction and SWI.

Second, the dynamic-spatial structure of the externalities is different between the confined and unconfined SWI cases. Pumping fee policies appropriate for one type of aquifer are in general not appropriate for the other.

Third, failure to understand economic incentives of groundwater extractors can lead to excessive spending on technical solutions that overlying landowners will not support. To the landowners, the present value cost of funding the structural solution can be more than the present value benefits of slowing SWI. Understanding when the cost of continued SWI becomes greater than the cost of the structural solution can improve planning and the spending of resources designing structural solutions.

Fourth, the spatial-dynamic profile of the full marginal opportunity cost of water (equal to the marginal cost of extraction plus the marginal externality) can inform the design of economically efficient structural solutions, in particular, the location within the aquifer system that is the least-cost water source for transfer to intruded areas. Again, the functional form of the marginal externality is aquifer-type dependent, being the sum of marginal pumping cost externality and marginal SWI cost externality for confined aquifers, whereas this linearly additive decomposition is not possible for unconfined aquifers, in which the externalities are jointly produced, owing to underlying nonlinearities.

Fifth, SWI is economically efficient in some circumstances. In other words, banning or stopping SWI is more costly to the economy than allowing SWI to continue before reaching the optimal final steady state. The economic analysis of SWI examines the tradeoff between building a structural solution now or allowing SWI to occur and building a structural solution later. Since there is a time value of money characterized by an interest or discount rate, in present value terms delaying the construction of smaller capacity physical solution, allowing SWI to occur, and building a somewhat larger capacity physical solution later, can be less expensive.

HYDRO-ECONOMIC ANALYSIS FRAMEWORK

The hydro-economic analysis framework typically compares dynamic solutions of extraction under two institutional arrangements: 1) common property where each groundwater extractor maximizes their individual present value of net benefits (benefits minus cost), and 2) optimal extraction where a watermaster maximizes the present value of the net benefits for the whole aquifer. Comparison of these two cases reveals the spatial-dynamic externalities and the potential gains from optimal management. To simplify, consider a farming region where extractors are individual farms. In this case, benefits are revenues.[1]

COMMON PROPERTY EXTRACTION

Under common property institutions, each firm maximizes the present value of its private revenues minus costs

$$\max_{u(x,t)} \int_0^{\infty} e^{-rt} \left[R(u(x,t)) - C(u(x,t), g(x) - h(x,t)) \right] dt \tag{1}$$

subject to differential state equation constraints which describe both the water table or piezometric surface and the extent of SWI (rendering parts of the aquifer unsuitable for pumping) and where

R(pumping rate) = revenue function
C(pumping rate, lift) = cost function
$u(x,t)$ = pumping rate per unit area
$h(x,t)$ = water table or piezometric surface elevation
$g(x)$ = ground surface elevation

Economists represent the *marginal value* or *marginal revenue product* of water ($\partial R/\partial u$) in extractive uses with a demand curve. Downward sloping demand curves indicate that users allocate water to the highest value uses first and subsequently to lower value uses, or equivalently that the marginal value decreases as more water is used.

A firm's private marginal opportunity cost of pumping water has two components: *the marginal cost of extraction* ($\partial C/\partial u$) and the *private marginal user cost*, which accounts for the firm's own increased future pumping costs and reduction in future stock availability (quantity or quality) caused by its own pumping of a unit of groundwater stock.

Therefore, in dynamic common property models, each firm pumps until its marginal revenue product of water equals its marginal opportunity cost of pumping another unit of water. This study imposes the additional assumption of a very large number of small firms, which renders a single firm's private marginal user cost negligible. In this case, each firm's intertemporal profit maximization condition for all time t and all locations x reduces to

$$\frac{\partial R}{\partial u} = \frac{\partial C}{\partial u} \qquad \forall\, x \text{ and } t, \qquad \text{i.e. marginal revenue product = marginal pumping cost} \tag{2}$$

OPTIMAL EXTRACTION

Economists define the optimal extraction of a groundwater resources by the spatial-dynamic pattern of extraction that maximizes the present value of benefits minus costs,[2] (or revenue minus cost, here) for the whole aquifer of width w and inland length L.

$$\max_{u(x,t)} \int_0^{\infty} e^{-rt} \left[w \int_0^{L} \left[R(u(x,t)) - C(u(x,t), g(x) - h(x,t)) \right] dx \right] dt \tag{3}$$

subject to differential state equation constraints which describe both the water table or piezometric surface and the extent of SWI rendering parts of the aquifer unsuitable for pumping.

The first order condition for this maximization for confined aquifers has the form

$$\frac{\partial R}{\partial u} = \frac{\partial C}{\partial u} + MPCE + MSWICE \qquad \forall\, x \text{ and } t, \tag{4}$$

and the joint externality production form for unconfined aquifers is

$$\frac{\partial R}{\partial u} = \frac{\partial C}{\partial u} + ME(PC, SWI) \qquad \forall\, x \text{ and } t. \tag{5}$$

[1] For municipal water use, a benefit function can be derived from the demand function for water.
[2] Including in-situ uses, see for example Qureshi, Reeson, Reinelt, Borzovic and Whitten, 2012.

The descriptive first order condition solution of this dynamic optimization problem states that, at all times and locations, the marginal value of any unit of extracted water must equal its full marginal opportunity cost of that unit.

The full marginal opportunity cost consists of the actual marginal cost of extracting a unit of water ($\partial C/\partial u$) plus the present value of the increase in future marginal costs caused by the absence of that unit of water (what economists call the social user cost, Provencher and Burt, 1993). Future marginal costs increase for all extractors because pumping an additional unit of groundwater reduces the total aquifer stock which creates two consequences for both the extractor and all other users. First, lower stock increases the depth to groundwater and consequently increases pumping costs of all impacted users. Those costs that extractors impose on other extractors are external to the market and mediated by the physical environment, economists call these negative externalities. Economists define the marginal pumping cost externality (MPCE) as the present value of the change in future pumping costs imposed on all other extractors as a consequence of pumping a unit of water today. Second, lower stock reduces future availability and decreases extraction alternatives for all users. If the stock constraint ever becomes binding (due to its quantity or quality) on future pumping decisions, economists define a marginal stock externality (or marginal SWI cost externality, MSWICE, in the current case) as the present value of the loss in net value arising from the non-availability of groundwater stock caused by pumping a unit of water today. One consequence of the stock externality is that part of the full marginal opportunity cost of extracting water depends on its value in use. For example, if SWI eliminates the water supply for a particular piece of irrigated farm land, then the future net productive value from that land is lost, or decreases when alternative but more expensive water supply is available. With the assumption of a large number of small firms, the private user cost becomes negligible, and the social user cost becomes identified as the relevant externalities.

In Eq. (4) for confined aquifers, two additional terms appear compared to the common property case in Eq. (2). MPCE is the marginal pumping cost externality; this is the cost imposed by extractors on other extractors through the lowering of groundwater levels. MSWICE is the marginal SWI cost externality; this is the cost imposed by extractors on other extractors whose lands become intruded. Optimal extraction from society's perspective requires that these additional costs, ignored under common property, be taken into account in pumping quantity decisions.

In Eq. (5) for unconfined aquifers, the MPCE and the MSWICE are not additively separable but are jointly produced, and the spatial dynamic magnitude of this joint marginal externality can be inferred from the difference in numerically derived extraction rates between common property and optimal extraction cases utilizing knowledge of marginal extraction costs and marginal revenue product.

HYDRO-ECONOMIC MODELS OF CONFINED AND UNCONFINED AQUIFERS

Reinelt (2005) applies these principles to confined aquifers with a numerical optimization model, a freshwater fundamental flow equation, the rate of SWI determined by the negative gradient at the coastal interface, and a fixed water level inland boundary condition. Reinelt (2020) analytically derives spatial-dynamic first-order conditions for optimal extraction from a confined aquifer with SWI and characterizes the policy relevant spatial-dynamic externalities, while also remedying economic literature neglect of the physical realities of confined aquifers that generate spatial externalities even with homogeneous users and transmissivity by explicitly modeling the recharge region of the confined aquifer. Salt and freshwater regions are modeled by the fundamental flow equations with continuity of flow and pressure at a sharp interface. Since it is not possible to incorporate analytical models of the mixed water region, the shape of the interface is not estimated, but the average inland distance of the interface is estimated. The rate of SWI is determined by the negative gradient at the coast, which coupled with porosity determines the average extent of SWI. A simple model of an unconfined recharge region with appropriate continuity conditions with the confined aquifer is also included. Findings include that the marginal SWI cost externality decreases linearly with distance from the coast for all t, and derives conditions where the magnitude of the marginal SWI cost externality is greater than the marginal extraction cost leading to larger gains from optimal management.

Finally, three other economic models of SWI within unconfined aquifers illustrate the challenges of deriving analytical results for spatial-dynamic optimization models. Moreaux and Reynaud (2006) optimize a long-run static spatial equilibrium with endogenous well locations, pumping rates, and water transfers, but with "perfect hydraulic conductivity". While they derive spatial externalities consistent with their static equilibrium, they do not attempt to model the dynamics of extraction and SWI. Pitafi and Roumasset (2009) develop a dynamic optimization model with uniform water levels coupled with a ban on SWI and a seawater desalinization backstop, under increasing demand with existing and fixed well locations and depths. Kan et. al. (2010) analytically derive a steady-state condition, consisting of a fourth-order differential equation, for the spatial-dynamic problem assuming fixed well locations and distribution of depths, and a zero discount rate. They then numerically solve the complete spatial-dynamic model for nonzero discount rates. However, since they do not characterize the policy relevant spatial externalities for their steady state and

dynamic models, the policy implications for optimal management remain unclear.

The current research effort seeks to remedy the confusion arising in the literature about the spatial form of the SWI externality through comparison of results between confined and unconfined SWI without recognizing the very different mechanisms by which SWI occurs in each type of aquifer. Moreaux and Reynaud (2006) report a spatially uniform MSWICE (and thus pumping tax) for an unconfined aquifer and contrast with the linearly increasing tax of Green and Sunding (2000) based on the spatial contribution to SWI derived from a purely hydrological engineering simulation model. Unfortunately, Moreaux and Reynaud fail to mention that Green and Sunding analyze a confined aquifer.

The current research project numerically applies the above economic framework to unconfined aquifers to calculate the spatial-dynamic profile of the jointly produced marginal pumping cost and seawater intrusion cost externalities using similar geometry and revenue functions from previous research to isolate the effects of aquifer type. The model is implemented with MODFLOW SWI2 utilizing optimization algorithms in GWM. The profile of spatial-dynamic externalities in unconfined aquifers vary with transmissivity due to the length of time lags for inland pumping to impact coastal water levels, as well as the discount rate which economically values costs imposed at different times. While the jointly produced marginal pumping cost and SWI cost externalities cannot be decomposed, we conclude that the costs associated with SWI are the dominant effect by estimating the pumping cost externality for a related problem without SWI using a fixed freshwater boundary region to replace the sea.

CONCLUSION

The spatial dimension of SWI requires both expansion of the institutional dimensions of the typical economic analysis and re-interpretation of Provencher and Burt's (1993) taxonomy of the common property externality into a pumping cost externality and a stock externality. As seawater progressively intrudes under coastal lands, landowners in intruded areas can no longer exercise their water rights. Thus, the institutional analysis must be extended beyond the typical decision-making dimension—common property vs. watermaster—to consider the relaxation of the appurtenancy dimension of groundwater rights, restricting water pumping only for beneficial use on overlying lands, to consideration of intra-basin water transfers and the addition of structural transfer costs.

The characterization of the spatial-dynamic profile of the combined pumping cost externality and the SWI cost externality can be used to develop optimal management policy under either institutional structure. Under enforced appurtenancy, this profile implies the optimal spatial-dynamic tax/water charge policy. If water transfers are permitted, the spatial shape of the full opportunity cost of water, combined with transfer costs as a function of distance and volume, can be used to deduce the efficient structural design to transfer water to intruded areas, in particular identifying the least-cost source of transfer water within the aquifer system.

REFERENCES

Green, G. and D. Sunding (2000). "Designing Environmental Regulations: The Case of Seawater Intrusion." *Resource and Energy Economics* 22(January): 63-78.

Kan, I., A. Leizarowitz and Y. Tsur (2010). "Dynamic-spatial management of coastal aquifers." *Optimal Control Applications and Methods* 31(1): 29-41.

Moreaux, M. and A. Reynaud (2006). "Urban freshwater needs and spatial cost externalities for coastal aquifers: A theoretical approach." *Regional Science and Urban Economics* 36(2): 163-186.

Pitafi, B. A. and J. A. Roumasset (2009). "Pareto-Improving Water Management over Space and Time: The Honolulu Case." *American Journal of Agricultural Economics* 91(1): 138-153.

Provencher, B. and O. Burt (1993). "The Externalities Associated with the Common Property Exploitation of Groundwater." *Journal of Environmental Economics and Management* 24: 139-158.

Qureshi, M.E., A. Reeson, P. Reinelt, N. Brozovic and S. Whitten (2012). "Factors determining the economic value of groundwater." *Hydrogeology Journal* 20: 821–829.

Reinelt, P. (2005). "Seawater intrusion policy analysis with a numerical spatially heterogenous dynamic optimization model." *Water Resources Research* 41: W05006.

Reinelt, P. (2020). "Spatial-dynamic seawater intrusion and pumping cost externalities in a confined aquifer." *Resource and Energy Economics* 59(February): 101117.

Salt Water Intrusion Congress (SWIM 2025)

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INTEGRATED STRATEGIES FOR MITIGATING SALTWATER INTRUSION IN THE COASTAL AQUIFER OF MURAVERA (SOUTHEASTERN SARDINIA)

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Located in south-eastern Sardinia, the coastal aquifer of Muravera is a vital water resource for local supply and agricultural activities. However, it is subject to saltwater intrusion, a phenomenon exacerbated by excessive groundwater extraction, climate variations with prolonged drought periods, and high temperatures. This study aims to understand and mitigate the effects of salinisation through an integrated approach based on hydrogeological monitoring, numerical modelling, and sustainable water management strategies.

The first step included six field campaigns focused on data collection through flow measurements of the Flumendosa River and its tributaries, as well as physico-chemical analyses of both surface water and groundwater. Parameters such as electrical conductivity, salinity, pH, Eh, temperature, and dissolved oxygen were measured. Vertical logs were carried out in deep wells to analyse variations in electrical conductivity and other hydrochemical parameters with depth. Piezometric levels were continuously monitored through the installation of multiparameter dataloggers at strategic points across the plain, enabling the evaluation of seasonal recharge variations and saltwater interface oscillations. Furthermore, the installation of a tide gauge will allow for an assessment of the impact of tidal fluctuations on the aquifer's response.

The simulation phase involves the development of a density-dependent numerical model (freshwater–saltwater interface) to test passive and active management scenarios. The passive management approach will evaluate the effectiveness of reducing or suspending groundwater withdrawals, whereas the active management strategy will explore controlled artificial recharge (MAR – Managed Aquifer Recharge) to counteract saltwater intrusion and improve groundwater quality.

Finally, "control areas" will be identified, where multiparameter dataloggers will continuously monitor electrical conductivity, triggering early warning systems should critical thresholds be exceeded. The aim is to develop a sustainable management system, ensuring the protection of the aquifer and the restoration of degraded agricultural land.

Keywords: Saltwater intrusion; Numerical modelling; Managed Aquifer recharge; Hydrogeological monitoring; Climate change impact

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MULTI-METHOD APPROACH FOR QUANTIFYNG THE FRESH SALINE INTERFACE DYNAMICS IN CONFINED SUB-AQUIFER DUE TO A NEGATIVE HYDRAULIC BARRIER

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ABSTRACT

Seawater intrusion (SWI) into coastal aquifers is a global issue influenced by freshwater pumping. One way to mitigate SWI is through a negative hydraulic barrier, which pumps saline groundwater (SGW) beneath the Fresh-Saline Interface (FSI) to counter excessive freshwater withdrawal. This study focused on the Israeli coastal aquifer in Michmoret, a complex, heterogeneous system of sandstone, limy sandstone, and silty shale with five sub-aquifers, four of which are confined. Within this area, two saline water pumping wells were operational and served as a negative hydraulic barrier (fig.1 & 2).

Our research investigated the FSI dynamics affected by the negative hydraulic barrier in the area. we monitored the site for 2.5 years deploying a multi-method approach. Two observation wells equipped with electric conductivity (EC) and temperature probes provided continuous data, while seasonal geochemical sampling assessed water-rock interactions. Geophysical methods further explored subsurface conditions. Data integration into a FEFLOW-based numerical model allowed simulation of various saline and freshwater pumping scenarios.

Our data showed an overall freshening trend during the pumping periods (~10%), with short-term FSI shifts correlating to SGW extraction rates, which can provide insights for potential SGW desalination processes. Additionally, the numerical model employed, after successfully replicating the observed trends, was used to model unbalanced SGW pumping and its influence over the FSI dynamics. The model provided insights into the potential of reducing SWI in a complex aquifer system influenced by a negative hydraulic barrier, thereby offering a valuable approach for sustainable groundwater management in coastal regions and emphasizes the potential of SGW pumping as a negative barrier.

Keywords: *fresh saline interface, coastal aquifers, negative hydraulic barrier, numeric modelling, groundwater dynamics.*

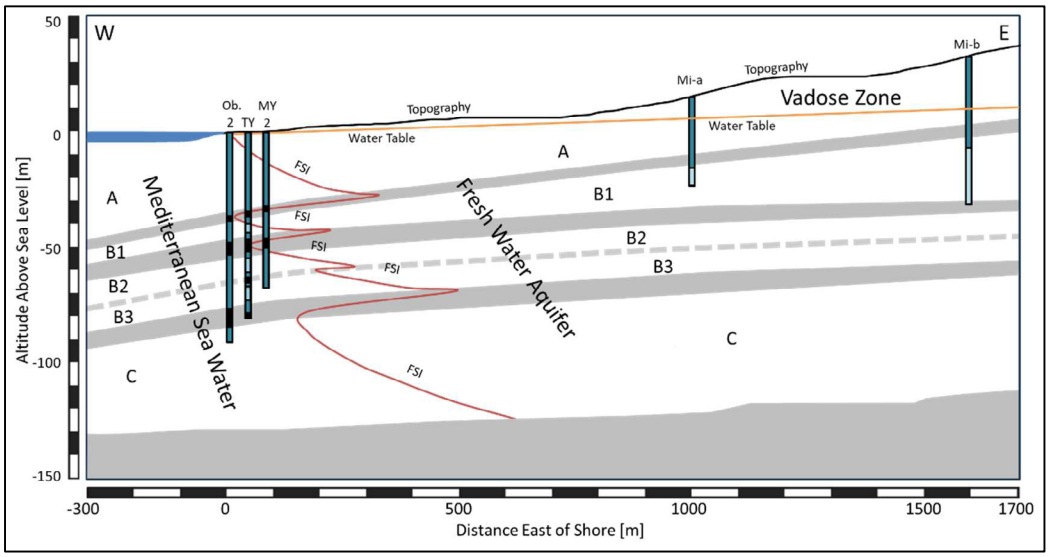

Figure 1 - Lithological and hydrological cross-section of the Michmoret area. The section illustrates the five sub-aquifers (A, B1, B2, B3, and C), that are separated by low permeability layers (in grey). The distribution of saline and fresh groundwater is depicted, separated by the FSI. The FSI is schematically represented by a red line, while the water table is denoted by an orange line. Five wells are depicted, the pumping well, Tsabey Yam (TY) pump at a rate of 180 m^3/ h. Well characteristics are illustrated as follows: Black segments indicate depths where the technical logs reveal low permeability layers. Light blue sections represent perforated areas in pumping wells.

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OBSERVATION AND NUMERICAL MODELING OF REVERSIBILITY OF SEAWATER INTRUSION IN A COASTAL CARBONATE AQUIFER

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ABSTRACT

Due to climate change and human activities, more than 500 coastal cities around the world are under threat of seawater intrusion (SWI). Understanding the mechanism and influencing factors of the reverse process of SWI - seawater retreat (SWR) process is critical for SWI prevention and control. Groundwater salinity variations over the past 50 years showed a fast SWI process and the following SWR process indicated by overall salinity decrease in the coast karst aquifer in the Dalian Peninsula, northeast China. Cross-sectional variable-density flow and transport simulations using equivalent porous medium (EPM) model, dual-domain (DDM) model and the EPM with a single discrete feature representative of conduit flow (EPM-DF) are conducted to understand the SWI reversibility related to the characteristics of the flow system, including aquifer parameters and seaside boundary conditions. Large dispersity combined with a low salinity concentration at the sea boundary are necessary in the EPM and DDM models to produce a fast SWI and low salinity concentration as observed. The enhanced dispersion in the DDM model enhances the mixing in the transition zone (TZ) and produces more obvious seasonal variation but longer SWR process compared to the EPM model. The EPM-DF model produces significant salinity seasonal variation during the SWI process and a fast decrease in the SWR process. The overall fast system response but low peak concentration during the SWI might be attributed to the highly heterogeneous characteristics of the karst aquifer system, which produces a wide front edge of TZ as observed. The dispersion-dominated EPM and DDM models produced higher degree of SWI reversibility compared to the EPM-DF model, as indicated by the weaker lag effects between groundwater levels and salinity concentration. Moreover, the SWI reversibility may arise not only from the heterogeneous characteristics of the karstic aquifer system but also from the rate for rise in the inland groundwater level during the seasonal variation cycle. An overall SWR process can be divided into two stages: the first stage with rapid decrease in salinity concentration but small changes in toe associated with TZ widening and the second stage with rapid toe retreat during aquifer flushing. The flushing of the brine leakage from the solar salt field may extend the SWR process. Considering this relatively longer water quality response time than the time span in general groundwater management plans, a reasonable objective and how maintain the hydraulic head during the SWI controlling have been of a great concern to the coastal groundwater management.

OBSERVED SALINITY VARIATIONS

The monitored salinity concentrations in wells indicate that the coastal aquifer system has undergone three SWI-SWR cycles from the 1960 s to the 2000 s (Fig. 1). The temporal variations of salinity concentration demonstrate a primary SWI process before 1982 and an overall SWR process from 1983 to 2010. Although the SWR process after 1982 had been interrupted by drought and repeated SWI, the groundwater Cl concentration had shown overall declining trend after abstraction reduction.

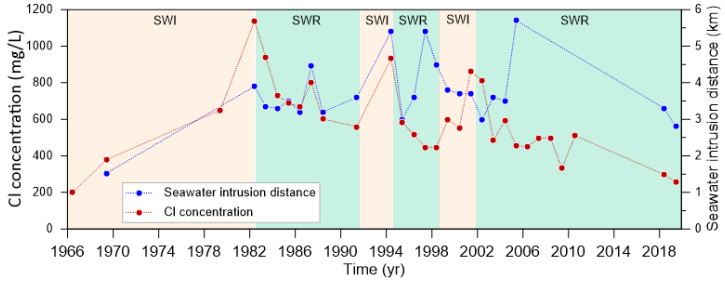

Figure. 1. Temporal variations in average Cl concentration from eight wells and seawater intrusion distance with Cl concentration greater than 250 mg/L from 1966 to 2019 in the Daweijia area. (Data from 1966 to 2010 are from Song, 2013, Han et al., 2015. Data in 2018 and 2019 are from Wang et al., 2021).

MODELING APPROACHES

A 2D synthetic model is constructed along a cross-section orienting along a flow line extending from the coast to a position far enough inland to ensure that the heads would not be influenced by the depression cone associated with the well field. In predevelopment condition, flow originating northeast of the well field flows toward the sea (Fig. 2a). The purpose of the modeling is to obtain a conceptual understanding of the flow system and to assess the importance of various boundary conditions and aquifer hydraulic parameters. Considering the simplified 2D model and limited information of the karst aquifer, the model cannot fully reproduce or predict the real SWI process. Nevertheless, the dimensions of the cross section, the inland groundwater temporal variations and the hydraulic parameters are chosen so that the model can represent the flow system as much as possible. Besides the lateral intruded seawater, the leakage of brackish water from the solar salt field near the coast is believed to be another important salt source. S The influence of the leakage of brine water from the solar salt field is assessed in the modeling. The effects of varied pumping rate in the well field are simulated in the model by specifying a head boundary based on monitored data. Therefore, the head variations in the aquifer are caused by hydraulic pressure propagation from the well field and salinity concentration change. To further simplify the model, the recharge from precipitation, groundwater evaporation and the influence of privately owned irrigation wells are not simulated in the model, assuming that their effects have been reflected in the observed groundwater level variations and incorporated in the boundary conditions.

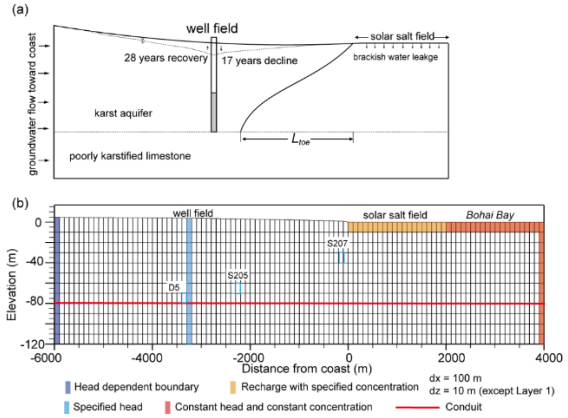

Figure. 2. (a) Conceptual model for land region (not scaled); (b) Model grid discretization and boundary conditions in the cross-sectional model. Zero of the x-coordinate is the coastline located at the landward boundary of the saltern. The locations of municipal water supply well D5, irrigation wells S205 and S207 with 10 m-length screens are shown.

The aquifer system is simulated in the model by three hydrogeologic units representing the shallow Quaternary aquifer, the karst aquifer and the poorly karstified limestone units. Despite of absence of detailed information of the conduit system in the karst aquifer, three generally applied conceptualization approaches are utilized to investigate the dominant transport behavior and possible conceptual models: the equivalent porous medium (EPM) model, the dual-domain (DDM) model and the EPM with a single discrete feature representative of conduit flow (EPM-DF). The EPM model has been applied to seawater intrusion problem in poorly karstified aquifers where the groundwater flow is relatively uniform. In this study, the EPM and DDM models are compared to illustrate effects of mixing related with high heterogeneity on the SWI and SWR processes; and the EPM-DF model is used to test the influence of a single conduit on salinity profiles.

RESULTS AND DISCUSSION

Intrusion distance and width of the transition zone

The front edge of the transition zone (TZ) is represented by the TDS concentration isochron of 0.44 g/L, assuming linear mixing of seawater and freshwater. The width of the TZ can be defined as the distance between the 0.44 g/L and 2 g/L TDS concentration isochlors. The intrusion distance is the distance from the coast to the position of the saltwater wedge "toe" along the −80 m-elevation line. The simulated toe position and TZ in 1982 and 2010 are compared in Fig. 6. The simulated intrusion distance of 3.4–4.3 km in 1982 is close to the reported value (3.9 km) (Fig. 3a). During the following 28 years of SWR process, the intrusion distance simulated by the EPM and DDM models only decreases by 1.3–1.4 km (Fig. 3b). However, the toe position simulated by the EPM-DF has moved back to a position near the coast.

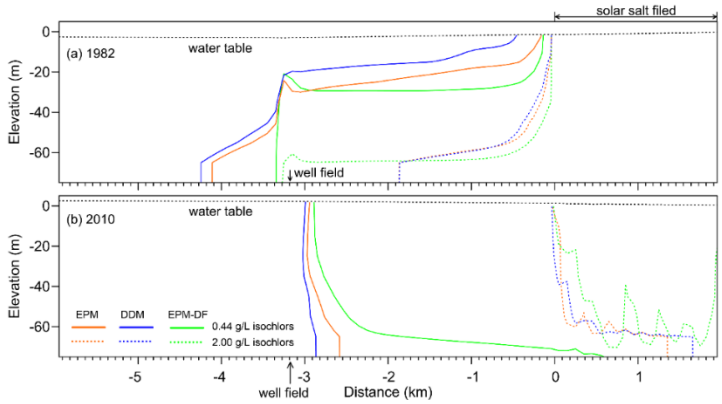

Figure. 3. Movement of fresh-salt groundwater interface and transition zone widening during the SWR processes demonstrated by comparing the salinity concentration isochlors of 0.44 g/L (Cl as 250 mg/L) (solid lines) and 2.00 g/L (dashed lines) for (a) 1982 and (b) 2010 simulated by three models. The positions of the simulated groundwater table at the end of 1982 and 2010 are shown as black dash line.

Movement of the fresh-salt groundwater interface shows persistent water table salinization during the SWR process, which is generally caused by active SWI process (Badaruddin et al., 2017). The water table salinization is accompanied by a remarkable TZ widening in this case. The seaside edge of the TZ moves faster than the fresh-salt groundwater interface during the SWR process. Consequently, the TZ width continues to increase over a period during the SWR process particularly for the shallow aquifer, resulting in a much steeper fresh-salt groundwater interface compared with the SWI process. Simulation of the SWR processes shows that the TZ width reaches a peak magnitude and remains for some time during the SWR period. When water table salinization is over, the buoyancy force is small and the intrusion distance decreases gradually to its initial state. The transient behavior of the TZ can extend the salinity flushing duration after inland groundwater level recovery.

Timescale of the SWR process

The time lag of salinity flushing behind head recovery and the required hydraulic head for triggering the salinity decline is controlled by buoyancy driving force or density gradient associated with the TZ width. The TZ width has the opposite effect on the SWI and SWR processes. The dispersion-dominated transport of salinity slows down the SWI process with a wide TZ but result in higher degree of SWI reversibility. Fig. 4 shows the simulated temporal variations of normalized salinity concentration and toe with respect to their maximum values during the SWI/SWR processes. The periods during which the salinity concentration decreases from its peak value to the Cl threshold concentration (250 mg/L) are compared across the three models to represent different durations of salinity flushing process. Salinity temporal variations simulated by the EPM and DDM models clearly show that the time required for salinity flushing process is much longer than that of salinizing progress (Figs. 4a and 4b). The EPM-DF model produces a nearly symmetrical changes in salinity concentration changes in the SWI and SWR processes in wells located in and nearby the conduit system (Fig. 4c). Comparing the simulated variations in salinity concentration and toe length by the three models suggests that the timescale of the SWR process is dominated by the aquifer characteristics. Differences in the timescales of SWI/SWR processes are usually manifested by the variable toe moving rates during these processes. As a real SWI case, the high toe moving rate before reaching the longest length indicates that the SWI was still in its early stage and far from achieving a steady sate. It can be confirmed that the time required for the subsequent salinity flushing process is longer than that for the early stage of the SWI process.

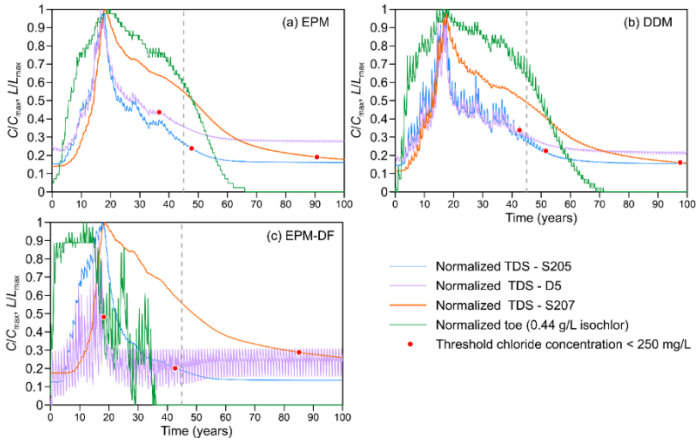

Figure 4. Normalized salinity concentration breakthrough curves for wells D5, S205 and S207, as well as normalized toe position from the coast simulated by the (a) EPM model, the (b) DDM model and the (c) EPM-DF model. Vertical dashed line indicates the year of 2010 when groundwater pumping was ceased.

CONCLUSIONS

The simulated salinity concentration changes in wells and toe length variations in the SWR indicate that the full SWR process can be divided into two stages: a TZ widening stage and a following aquifer flushing stage. In the first phase, the TZ widening leads to a much steeper fresh-salt groundwater interface compared with the SWI process. Although salinity concentration in the TZ can decrease fast, the response of toe length responses is slow. When the TZ widening is nearly over, the buoyancy force is small and the fresh-salt groundwater interface gradually retreats to its initial state, indicating the aquifer is being flushed. The studied aquifer experienced a TZ widening process from 1982 to 2010, which can explain the discrepancy between the observed changes in salt concentration and SWI distance. We recommend improving the present monitoring networks and applying advanced monitoring techniques to cover the entire transition zone and the SWI/SWR processes. It is necessary to provide effective information for hydrological modeling and management purposes.

REFERENCES

Han, D., Post, V.E., Song, X., 2015. Groundwater salinization processes and reversibility of seawater intrusion in coastal carbonate aquifers. J. Hydrol. 531, 1067-1080.

Cao G., Han, D., 2024. Reversibility of seawater intrusion in a coastal aquifer: Insights from long-term field observation and numerical modeling. J.Hydrol.638. 131470.

Badaruddin, S., Werner, A.D., Morgan, L.K., 2017. Characteristics of active seawater intrusion. J. Hydrol. 551, 632-647.

Hutchings, William C., David L. Tarbox. A model of seawater intrusion in surficial and confined aquifers of northeast Florida. The Second International Conference on Saltwater Intrusion and Coastal Aquifers-Monitoring, Modeling, and Management. Mérida, Yucatán, México, March 30-April 2. 2003.

Michael, H.A., Mulligan, A.E., Harvey, C.F., 2005. Seasonal oscillations in water exchange between aquifers and the coastal ocean. Nature 436(7054), 1145-1148.

Wang, H., Ni, J., Song, Q., Li, C., Wang, F., Cao, Y., 2021. Analysis of coastal groundwater hydrochemistry evolution based on groundwater flow system division. J. Hydrol. 601, 126631.

Song, Q., 2013. Status quo of seawater intrusion in Daweijia Karst water source of Dalian, China. Journal of Chengdu University of Technology (Science & Technology Edition) 40(3), 348-352. (in Chinese with English abstract)

Yang, J., 2011. Hydrogeochemical Reactions in Seawater Intrusion Process in Daweijia Water Source Area, Dalian City. Thesis (in Chinese with English abstract). Jilin University, Changchun, China.

Wu, Q., Jin, Y., Li, D., Xia, Y., 1994. The mechanisms of seawater intrusion of karst groundwater system in Daweijia, Dalian City and the countermeasures of its control. The Chinese Journal of Geological Hazard and Control 5(1), 64-68. (in Chinese with English abstract)

Salt Water Intrusion Congress (SWIM 2025)

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Origin of Shifting Chloride Concentrations Near a Well Field

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ABSTRACT

The Dutch drinking water company Vitens assesses possibilities to expand one of their well fields near the land reclamation of Southern Flevoland. The expansion may lead to an increased risk of salinization. In 1989, a map of the depth of the freshwater/saltwater interface was completed from Vertical Electrical Sounding (VES) measurements and recently new measurements were taken.

The measurements show that the depth of the freshwater/saltwater interface found in the VES measurements has shifted towards the extraction. A groundwater model was created to look into the hydrological characteristics of the freshwater/saltwater interface, in particular the chloride concentration of the raw pumped water. The model is used to analyse the causes of the observed changes in chloride concentration and to explore the effects of changes in the pumping regime along with the uncertainties involved.

We use a groundwater flow model combined with a groundwater transport model from the MODFLOW-6 framework. The models are set up with publicly available data of the geology, hydraulic conductivity, chloride concentrations, surface water, surface elevation and extraction wells. Various scenarios were run including one with a model period of 2000 years to find the origin of high saline areas.

The results show the influence of the pumping rates and the land reclamation on the advective transport of salt water. Also the sensitivity of the model to some of the hydrological parameters is evaluated, such as hydraulic conductivity, start concentration and surface water. Furthermore, the results of the long model run provide an explanation for the salt water presence in the otherwise fresh water aquifer.

Keywords: *groundwater transport model origin salt*

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BEDROCK WEATHERING CONTROLS ON THE GEOMETRY OF THE FRESHWATER LENS IN SMALL TROPICAL VOLCANIC ISLANDS: CASE STUDY OF WALLIS ISLAND, SOUTH-WEST PACIFIC

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ABSTRACT

In tropical basaltic volcanic islands, aquifers' hydraulic properties are largely controlled by the intensity of weathering of volcanic rocks, which in turns dictates groundwater gradients and the geometry and thickness of the freshwater lens. We explore the role of spatial variability in downward weathering affecting basaltic lavas and tuff cones of different ages on the extent and geometry of the freshwater lens in Wallis Island, Territory of the Wallis and Futuna Islands, South-West Pacific, which is relied upon for water supply, and which some wells are locally subject to saline intrusion. Geological, hydraulic and geophysical data were integrated in a 3D numerical variable-density groundwater model of the island. Data and model results showed that deeper weathering affects older lava flows non-uniformly depending on the island's tectonic setting and suggested the existence locally of younger un-weathered lavas overlying deeply weathered lavas. Hydraulic conductivities range from 10^{-2} m/s in un-weathered lavas to 10^{-4} m/s in the most deeply weathered rocks. Higher groundwater salinities and lower water table were observed and modelled in wells located in young un-weathered lavas, or in old lavas with shallow weathering regardless their distance to the shoreline. Deeply weathered lavas are therefore less vulnerable to saltwater intrusion. Locally, the existence of low permeability tuff cones, more prone to weathering, also act as relative barrier to saline intrusion. Findings are consistent with the history of development and operation of the well fields located across these different units.

Keywords: *small tropical basaltic islands; freshwater lens; bedrock weathering; geological heterogeneity; saltwater intrusion*

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CONTAMINANT TRANSPORT AND CHAOTIC MIXING IN HETEROGENEOUS COASTAL AQUIFERS UNDER TIDAL FORCING

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ABSTRACT

This study explores how tidal forcing and aquifer heterogeneity influence contaminant transport in coastal aquifers. Numerical simulations of density-dependent flow and solute transport were conducted in a three-dimensional, heterogeneous coastal aquifer subjected to tidal forcing. Advective transport was then analysed using particle tracking, tracing contaminants from both freshwater and seawater sources. Poincaré sections reveal that the interaction between tidal dynamics and aquifer heterogeneity induces chaotic and periodic orbits in the coastal salinity transition zone, leading to persistent contaminant trapping. The stochastic analysis further shows that greater heterogeneity enhances both trapping and mixing entropy while reducing segregation intensity, indicating that chaotic orbits promote mixing between contaminants from freshwater and seawater domains. These findings highlight two key processes in the transition zone: (1) contaminant trapping, which prolongs residence times and potentially increases long-term contamination risks, and (2) chaotic mixing, which promotes chemical and biological interactions.

Keywords: *(maximum 5 keywords)*

Coastal aquifer, heterogeneity, tides, chaotic mixing, particle tracking

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IMPLICATIONS OF INLAND BOUNDARY CONDITIONS WHEN MODELING SEA-LEVEL-RISE SCENARIOS

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ABSTRACT

Sea level rise (SLR) driven by climate change is widely recognized as a key factor contributing to increased saltwater intrusion (SWI) in coastal aquifers. However, the extent of SWI caused by SLR depends on how inland freshwater boundary conditions are defined. Previous studies have demonstrated that models utilizing head-controlled (HC) freshwater boundary conditions predict significant additional SWI, while those employing flux-controlled (FC) boundary conditions suggest negligible additional intrusion. Despite these contrasting outcomes, the broader hydrological effects of inland boundary conditions on coastal water balance have not been thoroughly investigated. In this study, we apply a well-established field-scale conceptual model to systematically analyze the hydrological implications of different inland freshwater boundary conditions in coastal aquifers experiencing SLR. Our findings indicate that coastal aquifers respond differently depending on boundary conditions: i) under HC conditions, aquifers exhibit a *flux-decline effect*, where freshwater fluxes, including submarine groundwater discharge, decrease over time, and ii) under FC conditions, aquifers experience a *head-lift effect*, where freshwater heads rise in response to SLR. Additionally, our results reveal that HC aquifers undergo prolonged transients in salt wedge movement, indicating a delayed response to historical sea-level changes. The flux-decline effect in HC systems alters the overall coastal hydrological balance of both aquifers and catchments, necessitating comprehensive hydrological assessments to accurately evaluate freshwater availability. Conversely, FC systems maintain mass balance and do not experience hydrological water balance alterations. However, the head-lift effect in FC aquifers can contribute to surface inundation in low-lying

regions with topographic limitations. Our study enhances the understanding of SWI mechanisms and highlights the hydrological consequences of inland boundary conditions when assessing the impacts of SLR on coastal aquifers and freshwater sustainability.

Keywords: *(Coastal aquifer, sea-level-rise, boundary conditions, saltwater intrusion)*

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MODELING SALTWATER INTRUSION SCENARIOS FOR COASTAL AQUIFERS IN NORTHERN GERMANY AND TURKEY

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ABSTRACT

3d regional density-driven flow models of heterogeneous aquifer systems at the German North Sea Coast and the Antalya region in Turkey are set up within the joint project "Implementing strategic development goals in coastal aquifer management" (go-CAM, see Schöniger et al 2022). The development of the freshwater-saltwater interface is simulated for various climate and pumping scenarios up to 2100.

Groundwater flow simulations are performed with the finite volume code d³f++ (distributed density-driven flow) that has been developed since 1995 with focussing on the modeling of large, complex, strongly density-influenced aquifer systems over long time periods.

INTRODUCTION

The project go-CAM (2017-2021) was a joint project of seven German institutions including research institutes as well a local water supplying company and consultants. It was funded by the German Federal Ministry of Education and Research (02WGR1427B). The main objective was the development, implementation and application of a multicriteria governance optimization for sustainable water use in various coastal regions around the world.

Modern hydrological, hydrogeological and geological models were forming the basis for estimating water resources in coastal regions. Two regional-scale density-driven flow models have been set up using the code d³f++ with the objective of forecasting the impact of various climatic and demographic scenarios on the freshwater availability. The models are based on detailed geological data, a hydrological water balance model (PANTA RHEI, Meon et al. 2012) as well as data from geophysics (Siemon et al. 2020). Various scenarios regarding the impact of sea-level rise and changing recharge- and well pumping conditions were simulated. The modeling results were transferred into practice using the CAM dialogue platform (Schöniger et al 2022) that provides the basis for a multicriteria decision analysis.

HYDROGEOLOGICAL MODELING

Figure 1 (right) shows the Sandelermöns model area of about 1,000 km² at the German North Sea coast, consisting of marshlands in the North and the Geest in the South. Up to some hundred years ago, the marshlands were flooded by seawater. Therefore, a in huge part of the area the aquifers lead saline groundwaters. Three waterworks Sandelermöns, Feldhausen and Kleinhorsten, situated in the Geest, are competing for pumping concessions and worrying about the close-by saline water. The hydrogeological structure model was provided by the Oldenburg East Frisian Water Company (OOWV). Six formations are distinguished, starting with a thick layer of fluvial sands at the bottom, followed by small fields of Tergast clay and a continuous layer of melt-water sands. The top of the model consists primarily of

pleistocene clay/silt ("Lauenburg Ton"), till, superficial sands and holocene marsh sediments, all of them with varying thicknesses and distributions. The extremely flat structured model geometry (depth 145 m only) and grid were set up with ProMesh (Reiter 2020). The lateral model boundaries are located on watersheds or perpendicular to the isohypses and therefore considered impermeable for flow and transport, just like the bottom of the model. For the coastal boundary a hydrostatic pressure boundary condition for seawater and a salt concentration of 35 g/l (NaCl) are chosen. For the upper boundary, spatial and temporal varying freshwater recharge rates for the recent state and various scenarios were simulated by the hydrological model PANTA RHEI. 147 polygonal recharge zones were distinguished (see figure 1). Six different recharge scenarios were computed based on the IPCC climate scenarios RCP 4.5 and RCP 8.5.

The north-eastern region of the model domain is characterized by a dense net of small draining ditches and rivers conducting water to the coastal pumping stations in the dikes to keep the groundwater level below land surface. This drainage plays a crucial role in the hydraulic regime. The model contains the 51 pumping wells of the waterworks and 36 private wells. 285 gauges could be used for calibration. The saline waters detected by measures far from the shoreline are not explainable by the hydraulic situation but only as a result of former inundations before the areas were protected by dikes. Therefore, the initial condition for the salt concentration, resulting from airborne electromagnetic (AEM) data, was essential for the simulation of the scenarios. This data was provided by the Leibniz Institute for Applied Geophysics and measured by the Federal Institute for Geoscience and Natural Resources (BGR).

The six recharge scenarios were simulated over the period from 2017 to 2100 with the density-driven groundwater flow model d³f++. Additionally, they were combined with a sea-level rise of 0.5 m (RCP 4.5) or 1.0 m (RCP 8.5) and two freshwater exploitation scenarios.

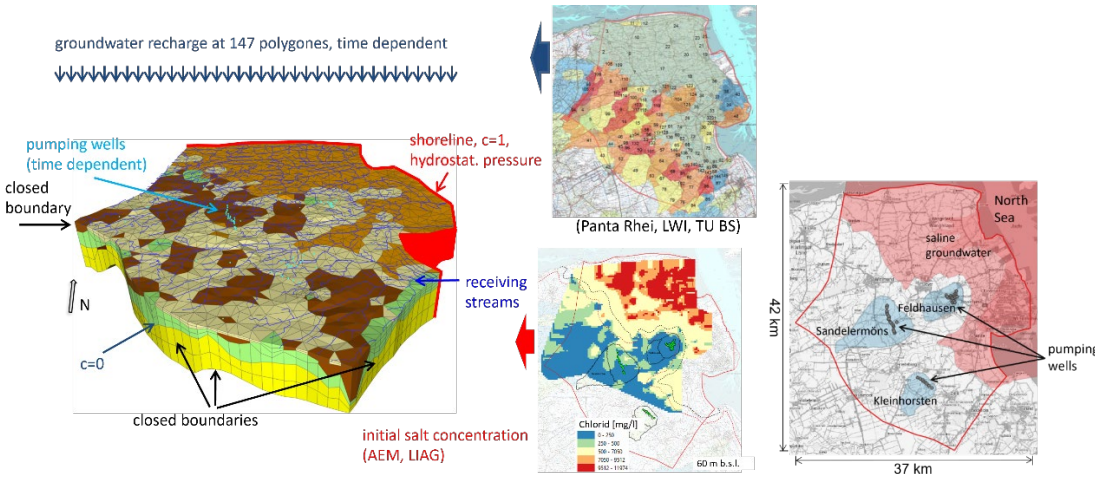

Figure 1: Sandelermöns: 3d hydrogeological model (30x vertically scaled) with coarse grid, rivers, pumping wells, recharge map, initial concentration and catchment areas of the waterworks

The data used for the Antalya model were provided by the University of Antalya, based on an existing study (personal communication). For groundwater modeling the so-called lower basin with an area of about 604 km² was chosen. This basin is bounded by watersheds. Only the southern, coastal line boundary to the Mediterranean Sea allows flow and saltwater transport. In contrast to the German North Sea coast, this model region is situated in a mountainous terrain with steep slopes to the shoreline. There exist only few gauges, no AEM data, nor pumping scenarios are provided by the water suppliers.

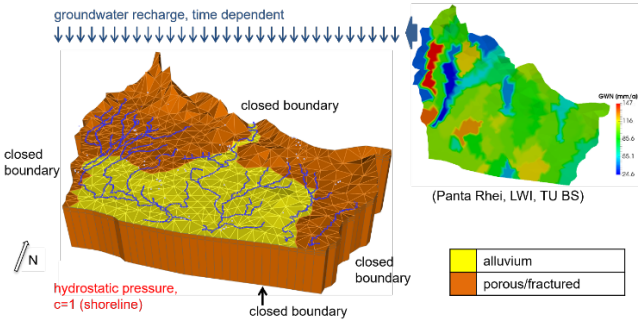

Figure 3 Antalya: Hydrogeological model with boundary conditions

Because of the very poor data situation, in the hydrogeological structure model only two layers are distinguished, a relatively thick lower layer and the alluvium with a thickness up to 40 m above it. The model contains 58 pumping wells with e depth up to 265 m and a network of receiving streams with Köprüçay as the huge main river, see Figure 3. The six recharge scenarios were computed with PANTE RHEI analogously to the Sandelermöns model, and the same climate scenarios were simulated with d³f++.

METHODS

For the density-driven flow simulations the finite volume code d³f++ (Fein 1999, Schneider 2020) is used. This code may be used for groundwater flow and transport modeling in porous as well as in fractured media, including options for modeling salt- and heat transport and the transport of radionuclides or other pollutants.

d³f++ is based on the UG4 toolbox (Vogel et al. 2014). The use of modern numerical methods such as geometric and algebraic multigrid methods and their parallelisation enables simulations over long time periods with feasible computational effort.

In d³f++, the equation system describing thermohaline flow is solved, consisting of the mass conservation of the fluid, the mass conservation of the brine, and energy conservation. The flow velocity follows Darcy's law. Fluid density and viscosity are depending on salt mass fraction and temperature. For the modeling of free groundwater surfaces, the time dependent position of the groundwater table is described as the zero set of a level set function (Frolkovič 2012). Some recent developed features of d³f++ are phase-field methods, the coupling with river flow and the modeling of freezing and thawing processes.

RESULTS

Our task in this project was the simulation of density-driven groundwater flow and the prediction of the impact of sea-level rise and changing recharge- and well pumping conditions for various scenarios up to 2100. The modeling results had to be transferred to the CAM dialogue platform. Firstly, the groundwater models had to be calibrated using recharge data and measured groundwater heads for 1970-2016. In the second step the 12 (Sandelermöns) or 6 (Antalya) scenarios were simulated.

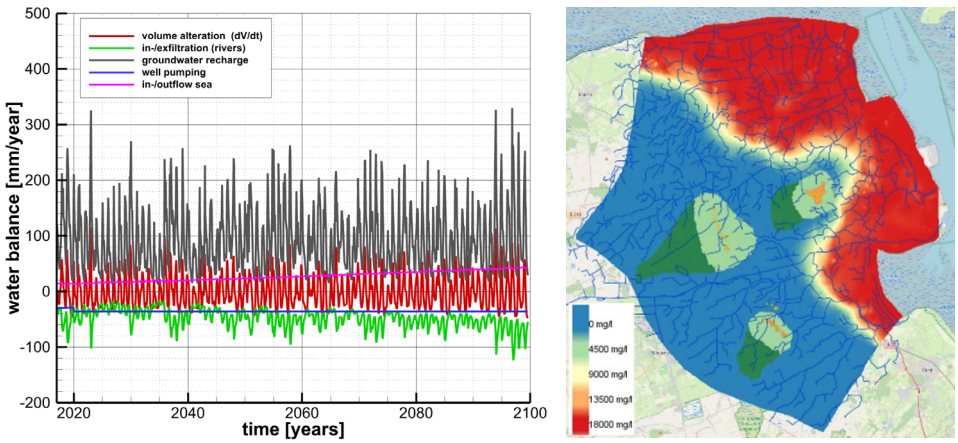

Figure 4 Sandelermöns: Water balance and chloride concentration 2100 (CAM-tool) 60 m b.s.l. for RCP-scenario 4.5, version 1, lower freshwater exploitation

The simulations were performed at GMG level 2 with 1.4 million of grid elements. In the case of Sandelermöns, as results of the scenario simulations could be observed that changes in the groundwater heads remain in the range of centimeters, whereas the chloride concentrations are changing over the whole simulation period, for RCP scenario 8.5 much more than for scenario 4.5. It was observed that recharge rates and river drainage of freshwater is much more influencing the results than well pumping, which plays a less important role, see figure 4. The main part of the recharge volume discharges into the receiving waters and is transported to the sea. On the other hand, the prognosticated sea-level rise leads to a significant increase of saltwater intrusion from the North Sea.

In the Antalya region we have a completely other hydraulic situation than in the German coastal region because of the large elevation differences. A considerable groundwater flow to the main river Köprüçay can be observed. The results show a huge amount of river draining to the Mediterranean Sea, see figure 5. The upper aquifer indicates an outflow of groundwater to the sea, whereas in deeper regions an inflow of seawater occurs. The results of the scenario simulations

show only small differences, and the effect of sea-level rise is much lower than in the Sandelermöns model. The threshold of potable water is moving landwards, and it can be expected, that this effect will become much stronger in case of the overexploitation of the aquifers.

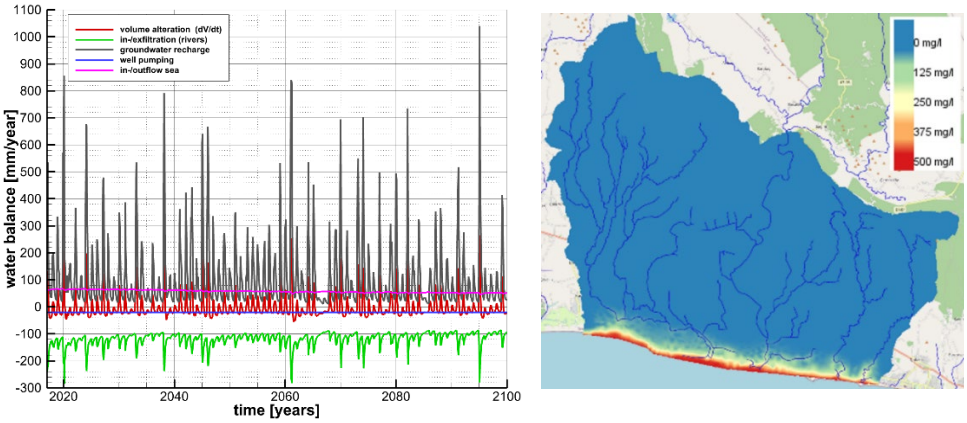

Figure 5 Antalya: Water balance and chloride concentration 2100 60 m b.s.l. for RCP-scenario 4.5, version 1

DISCUSSION AND CONCLUSIONS

The main result of these works was predicting the situation of the freshwater-saltwater interface and the groundwater heads for two very different model areas and 12 climate and groundwater abstraction scenarios until 2100. In case of Sandelermöns could be concluded, that the pumping wells of the waterwork of interest (with the same name) are not threatened by saltwater intrusion in this period even if the pumping rates are significantly increased.

The reliability of density-dependent groundwater simulations depends crucially on the availability of hydrogeological input data, measures of groundwater heads and conductivities, recharge data, river gauges and also the well pumping data of the local water suppliers. In case of coastal lowlands like in the Sandelermöns region, it is important to have more gauges and, at the other hand, data of the pumping stations at the overflow of the dikes to quantify the exfiltration by the drainage ditches. To use these data properly, future groundwater models should be coupled directly with surface water run-off models, what even requires more data.

The quality of scenario predictions is additionally depending on a careful model calibration, a diligent modeling of the physical effects (i. e. density dependence) as well as a high numerical accuracy.

REFERENCES

Frolkovič, P.: Application of level set method for groundwater flow with moving boundary, Adv. Wat. Res. 2012

Meon, G., K. Förster, M. Gelleszun, G. Riedel. 2012. Zukünftige Entwicklung von Wasserhaushalt und Hochwasser. In: NLWKN (Hg.): Globaler Klimawandel. Wasserwirtschaftliche Folgeabschätzungen. Oberirdische Gewässer (33).

Reiter, S., Logashenko, D., Vogel, A., Wittum, G.: Mesh generation for thin layered domains and its application to parallel multigrid simulation of groundwater flow. Comp. Vis. Sci. 23, 2 (2020). DOI: 10.1007/s00791-020-00322-5

Schneider, A., Conen, N., Gehrke, A., Hilbert, J., Knodel, M., Kröhn, K.-P., Lampe, M., Larisch, L., Lemke, B., Nägel., A., Schön, T., Salfelder, F., Stepniewskin, M., Wittum, G., Zhao, H.: Hydrogeological Modelling at a Regional Scale, FKZ 02E11809A-B (BMWi), Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, GRS-750, Braunschweig, 2023.

Schöniger, H. M., Langmann, T. et al. (2022): Implementing strategic development goals in coastal aquifer management. Final report of the GRoW joint project go-CAM (BMBF, 02WGR1427B). https://bmbf-grow.de/de/system/files?file=document/Schlussbericht_%20go-CAM_final_reduziert.pdf

Siemon, B., Ibs-von Seht, M., Steuer, A., Deus, N., Wiederhold, H.:Airborne Electromagnetic, Magnetic, and Radiometric Surveys at the German North Sea Coast Applied to Groundwater and Soil Investigations. Remote Sensing 12 (10), 1629, 2020.

Vogel, A., Reiter, S., Rupp, M., Nägel, A., Wittum, G.: UG 4: A novel flexible software system for simulating PDE based models on high performance computers. Computing and Visualization in Science 16 (4), 165-179, 2014.

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MULTI-MILLENNIA REACTIVE TRANSPORT MODELLING TO ELUCIDATE SEAWATER INTRUSION DYNAMICS IN THE AMSTERDAM WATER SUPPLY DUNE AREA

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ABSTRACT

The coastal area of the Netherlands has experienced multiple phases of seawater intrusion, starting with the predominantly vertical salinization driven by density differences that occurred when the formerly exposed land surface became flooded by the sea at around 6000 years before present (BP). Small freshwater lenses developed when the coastline stabilized and beach ridges formed at approximately 3500 BP. These lenses coalesced and deepened after the dune belt became established about 1000 years ago. The mixing and outflow of brackish water in the transition zone drove circulation of seawater beneath the lenses. This natural flow pattern became disrupted when land drainage resulted in lower water levels in the hinterland. Then, during the first half of the twentieth century, over-abstraction caused seawater intrusion and up-coning until the adverse effects were mitigated by artificial recharge starting in 1957.

In this contribution we simulate these processes in a reactive transport model in the Amsterdam Water Supply area. The model is based on an earlier SEAWAT model by Nienhuis et al (2014) and takes into account variable-density flow and solute transport in a cross-section across the freshwater lens. The simulation starts 3500 BP and considers the changing boundary conditions as well as the main geochemical processes, being mineral equilibria, cation exchange and organic matter transformations. The latter were included to assess the fate of radiocarbon (^{14}C). Using this tracer, Stuyfzand et al. (2025) identified bodies of intruded seawater of different ages along the modelled transect.

By comparing the model results to the measured radiocarbon ages, as well as to the chemical characteristics of both the fresh and saline groundwater in the area, we were able to provide new insights into the paleohydrological developments of the area. We found that, while remnants of brackish groundwater dating back millennia have also been preserved, the main thrust for seawater intrusion was the reclamation of the Haarlemmermeer Lake in 1850 and the over-exploitation of the freshwater lens in the first half of the 20th century. The model results also indicate that the development of the freshwater lens starting 1000 BP caused a temporary reversal of the flow direction in the saltwater wedge, turning seawater intrusion into submarine groundwater discharge. The simulated age distribution generally matches the pattern of the radiocarbon ages of the groundwater samples.

Keywords: *Seawater intrusion, Reactive transport modelling, Netherlands, Paleohydrology*

REFERENCES

Nienhuis, P., T. Olsthoorn & P. Kamps (2014) Hydrological history of Amsterdam Water Supply Dunes simulated with a 2D cross-section model. Proceedings of the 23th Salt Water Intrusion Meeting, Husum, Germany, 2014.

Stuyfzand P.J., P.R. Nienhuis & V.E.A. Post (2025) Radiocarbon Age Dating Of Coastal Seawater Intruding Beneath A Large Freshwater Lens. Proceedings of the 28th Salt Water Intrusion Meeting, Barcelona, Spain, 2025.

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SALTWATER INTRUSION MODELING ON SMALL ISLANDS: INSIGHTS INTO SUBMARINE GROUNDWATER DISCHARGE AS A MAJOR NUTRIENT PATHWAY FOR PHOSPHATE ACCUMULATION AFFECTING CORAL REEFS

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ABSTRACT

The study examines saltwater intrusion and freshwater lens dynamics on Kuroshima Island, a small cattle-farming community of roughly 200 people, located in the Yaeyama Island group in southern Okinawa, Japan. The island's Ryukyu limestone geology, along with its known elevation and precipitation data, provided the foundation for developing a single-layer SWI model using MODFLOW 6 and FloPy. The objective was to estimate freshwater lens thickness, track saltwater intrusion under tidal influence, and identify coastal zones of significant submarine groundwater discharge that potentially could be responsible for high phosphate levels deposited in the surrounding coral reefs. Parameter optimization, incorporating combinations of hydraulic conductivity, precipitation, and tidally varying well groundwater levels, helped refine the model. Resistivity surveys and continuous well groundwater level measurements were employed to verify freshwater thickness and validate model predictions. The results suggest that simple models informed by basic elevation and precipitation data can effectively simulate island hydrogeology, even in the absence of complex geological survey information. This is limited to islands with neither extraction nor injection of groundwater. Our findings pinpointed concentrated submarine groundwater discharge along the island's northeastern margin, likely contributing to the high phosphate levels accumulating in nearby coral reefs. Moving forward, we aim to investigate model limitations across varying island scales and determine optimal data requirements for reliable simulation.

Keywords: *(islands; freshwater lens; submarine groundwater discharge; coral reefs; phosphate)*

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SIMULATION OF HYDROBIOGEOCHEMICAL PROCESSES WITHIN THE SUBTERRANEAN ESTUARY AT A REAL HIGH-ENERGY BEACH

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ABSTRACT

A comprehensive multi-component reactive transport model is being developed to explain hydrochemical observations in a subterranean estuary (STE) below a real high-energy beach. The aim of the modelling is to explore and quantify the individual boundary condition effects on the hydrochemical processes and related water quality changes within the STE. It is still work in progress. The reactive transport model is based on an existing conservative flow and transport model calibrated against measured hydraulic heads, seasonal temperatures, and apparent Tritium/Helium groundwater ages. The reactive transport model considers the degradation of organic matter and the corresponding terminal electron acceptor processes (TEAPs) aerobic respiration, nitrate reduction, as well as sulfate and iron reduction. Calcite, siderite and FeS precipitation/dissolution were also included. The model further considers temperature dependent reaction kinetics of the TEAPs. The observed distribution of dissolved ferrous iron, alkalinity, pH, and ammonium could be well replicated, while the simulated patterns and dynamics of dissolved oxygen and nitrate were less accurate. The observed and simulated iron concentrations in the tide-induced upper saline plume (USP) and its fringes were up to 25 µmol/L. In the freshwater dominated zones of the STE, lower simulated iron concentrations of ~1 µmol/L were found, in line with field observations from the freshwater lens. The increased iron concentrations within the seawater affected zones of the STE was caused by the increased solubility of iron-bearing minerals as a result of elevated ionic strength. Within the USP, iron-oxide precipitation occurred at the thin redox boundary from nitrate- and iron reduction due to hydrodynamic dispersion. The location of this redox boundary shifted with time in response to the seawater infiltration dynamics depending on oceanic forcing.

Keywords: *high-energy beach, subterranean estuary, reactive transport modelling*

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STABLE STRONTIUM AND MAGNESIUM ISOTOPES BEHAVIOR IN COASTAL AQUIFERS DURING LONG-TERM SEAWATER CIRCULATION

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ABSTRACT

Groundwater-derived solute and isotope fluxes to the ocean, once deemed subordinate, have emerged as significant contributors to ocean chemistry. The chemical composition of these coastal aquifer groundwaters is affected by mixing between fresh and saline water bodies and by water-rock interactions. The latter also depend on the residence time of the intruding seawater and its flow paths. This study delves into the chemical dynamics of a carbonate-rich silicate aquifer at the Nitzanim Nature Reserve in Israel, unraveling the behavior of stable strontium and magnesium isotopes in the context of groundwater flow and water-rock interactions.

Notably, calcium, potassium, sodium, and strontium concentrations exhibit non-conservative behavior, contrasting with the conservative nature of magnesium. Our comprehensive approach integrates both magnesium and strontium isotopes, offering a holistic understanding of coastal aquifer dynamics. Strontium, akin to calcium and distinguished by its stable isotopes, enriches insights into the intricate processes governing these aquifers, contributing to a comprehensive comprehension of marine strontium dynamics.

Focusing on magnesium isotopes, our δ26Mg data (ranging from -1.46 to -0.82‰) reveals depletion compared to the conservative mixing line. Proximity to the coast mirrors seawater values, becoming more negative along the salt-water flow path from the sea into the aquifer over centuries. Estimating the contribution of long-term circulated submarine groundwater discharge (SGD) to the magnesium isotope budget emphasizes its magnitude (-2 Tmol yr-1 · ‰), comparable to rivers (-1.4 Tmol yr-1 · ‰).This underscores the necessity of linking isotope values to flows on diverse time scales within coastal aquifers, emphasizing water-rock interaction and residence time in determining the isotopic composition of terrestrially-derived solute fluxes to the ocean.

Our unique methodology connects isotopic values to flows on different time scales, providing crucial insights into the contribution of coastal aquifers to the marine isotope system. This study lays the groundwork for understanding the global badget by incorporating both magnesium and strontium isotopic systems.

Keywords: *Submarine Groundwater Discharge (SGD), Magnesium Isotopes, Stable strontium Isotopes, Water-Rock Interactions (WRI), Coastal Aquifers*

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THE NETHERLANDS NATIONWIDE VARIABLE DENSITY GROUNDWATER MODEL LHM FRESH-SALT: INSIGHTS FROM 5 YEARS OF APPLICATION

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ABSTRACT

Numerical modeling has proved itself to be an indispensable tool to support policy making with quantitative estimates. Be it of the effects of future changes or the effectiveness of proposed measures or strategies. This is no different for coastal hydrogeology, where numerical modelling has been in use for decades to predict future freshwater availability, support well design, and model the effects of climate change and sea level rise. However, due to the calculation times generally associated with coupled variable density groundwater flow and salt transport models, these models have been generally applied at the local to regional scale.

In 2020, we developed a nationwide variable density groundwater flow and salt transport model for the Netherlands, the LHM fresh-salt. The model makes use of a parallelized version of SEAWAT, and was built using a reproducible scripted workflow. Model parameters are based on the existing Netherlands' nationwide regular groundwater flow model LHM, with additional procedures put in place to resolve transport-specific problematic parameter combinations. The resulting model consists of over 31M active cells, calculation time originally was about 75 minutes per year on 24 CPUs.

Five years on, the LHM fresh-salt model has undergone several version updates, has been used in studies ranging from national policy studies, investigating effects of sea level rise scenarios for the Netherlands and defining National Groundwater Reserves, to more regional scale studies investigating possible brackish groundwater extraction or optimizing regional water management. We experienced that the readily availability of the LHM fresh-salt model spurred its use, while both user trust and version updating benefited from its reproducible construction. Future developments include changing to the MODFLOW6 framework and further incorporating the LHM fresh-salt model in the wider LHM model framework.

Keywords: *Numerical modeling, National variable density model, Sea level rise*

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DYNAMICS OF STRATIFICATION AND TURBULENT MIXING IN A MEDITERRANEAN COASTAL BAY

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ABSTRACT

Estuaries and coastal bays are directly connected to the open sea, making them particularly vulnerable to rising sea levels, erosion, saltwater intrusion, freshwater consumption, and variations in river discharge. These challenges are especially relevant for the highly stratified, microtidal bays of the Ebro Delta (NW Mediterranean). This contribution aims to quantify the turbulent dynamics governing mixing and momentum transport in Fangar Bay, key factors in understanding estuarine circulation. The bay's hydrodynamics are primarily driven by local wind events and modulated by water column stratification, which is influenced by freshwater inputs and oscillatory motions. The research investigate the relative contributions of wind-induced entrainment from the surface layer and shear-driven turbulent kinetic energy (TKE) production at the pycnocline as key mechanisms of vertical mixing. Additionally, we examine whether strong stratification suppresses turbulence and limits TKE generation or how turbulence evolves during highly energetic episodes. By analyzing velocity and density profiles, this study provides insights into the role of stratification in modulating turbulence near the pycnocline, contributing to a better understanding of mixing processes in stratified coastal environments. These findings are valuable for improving monitoring strategies of estuarine-coastal aquifer interactions and understand the physical process that occurs in the groundwater-seawater exchange.

Keywords: *turbulence; estuary; mixing; hydrodynamics; TKE*

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GROUNDWATER VULNERABILITY TO SEAWATER INTRUSION IN THE COASTAL ZONE OF POLAND

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ABSTRACT

The proposed research aims to develop and test a new approach for assessing vulnerability of coastal aquifers to seawater intrusion to coastal flooding and pumping hazards, separately, along the Polish Baltic coast (an area of 9530 km^2 with groundwater occurring mostly in complex multi-aquifer systems).

Two overlay index methods were developed: the INTRUS$_{FLD}$ method, tailored to determine the vulnerability of the shallow aquifer (the first aquifer below the ground surface) to seawater intrusion resulting from coastal flooding and the INTRUS$_{EXPL}$ method to assess the vulnerability of the main (exploited) aquifer to seawater intrusion, considering groundwater pumping. An overlay index structure has been used in both cases assigning ratings and weights to several representative factors. All the analysis were processed using GIS tools, and the results are presented with a final map that categorize the groundwater vulnerability to seawater intrusion into four classes, ranging from low to high. The data for the analysis were obtained from various sources, mainly from hydrogeological databases managed by the Polish Geological Survey.

The results show significant heterogeneity in groundwater vulnerability to seawater intrusion in the Polish coastal area. Approximately 807 km² of coastal aquifers were found to be highly vulnerable to seawater flooding, and approximately 496 km² are highly vulnerable due to groundwater extraction. We will also present the concept of improved vulnerability index which is currently developed in the framework of DATASET project (www.datasetw4all.info). The new approach includes vulnerability to salinization and leaching of agricultural pollutants and will be applied to the study area.

This research was funded by the Polish Hydrogeological Survey, in the frame work of the task no. 31: Identification of seawater intrusion or saline ascension processes in the coastal zone of Poland.
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Keywords: *seawater intrusion, groundwater vulnerability, coastal aquifer, Baltic Sea*

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INFLUENCE OF METEO-MARINE FORCINGS ON GROUNDWATER LEVEL FLUCTUATIONS OF A COASTAL MULTI LAYER AQUIFER

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ABSTRACT

A multi-layered aquifer made up of alluvial formations from the Quaternary, overlying levels of Pliocene sands and clays is located beneath the Roussillon plain (Perpignan, France). Covering an area of 800 km² and up to 300 m thick on land, this aquifer extends several dozen kilometres beneath the Mediterranean Sea. It contains a freshwater resource which, at a greater or lesser distance from the shoreline, is likely to be mixed with seawater. A hydro-geophysical observatory (Dem'Mer) has been set up along the coastline for monitoring the piezometric and physicochemical (conductivity, temperature) behavior of the groundwater flowing through the various permeable levels described within this multi-layer aquifer.

The time series of groundwater levels obtained from this observatory for several years have been processed using spectral analysis to explore the seasonal to daily influence of meteo-marine forcings (seawater level, tides, storms) on groundwater flows. Complementary, cross-correlation and coherence analyses have been performed to identify how the different signals are organised over time. This work provides field evidence of the influence of storm waves forces at sea bottom, water level at the shoreline and tide on the piezometric fluctuations in the aquifer nearby the coast. The results obtained constitute constraints that can be incorporated into the modelling work currently underway on this aquifer.

Keywords: *(coastal aquifer ; hydro-geophysical observatory ; groundwater fluctuation ; marine forcing; spectral analysis)*

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Innovative approach to the monitoring of the freshwater-saltwater interface

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The Mean Sea Level Aquifer systems in the Maltese islands develop within the Lower Coralline Limestone formation as a floating lens of groundwater in direct lateral and vertical contact with the bounding sea water. The structure of these freshwater lens groundwater bodies presents an elongated lower lens horizon which accounts for most of their groundwater storage capacity. This lower horizon is also more sensitive to groundwater level changes, with changes in the level of the freshwater-saltwater interface being augmented compared to changes in the piezometric level. The broadening of the interface in a transition zone is an important factor influencing storage capacity of the freshwater lens. Hence, monitoring of the lower points of the aquifer is essential to understanding the volume and response of the system over time.

A new monitoring approach was developed by the Energy and Water Agency (EWA) in collaboration with Korea Institute of Geosciences and Mineral Resources (KIGAM), to monitor changes within the transition zone and better understand the status of the freshwater body. A spatially representative network of twenty deep uncased boreholes traversing the freshwater lens has been commissioned, and in each station two interface probes were set to float at specific densities. The probes are made up of a housing which supports a pressure sensor and sets the density at which they float. The probes are set to float at salinity ranges of 17000 µS/cm and 35000 µS/cm which are assumed to represent the upper and lower limits of the transition zone.

The network has been operational since October 2023 and has provided crucial insights into

how the freshwater lens is responding to various factors, including drought periods, climate change and groundwater abstraction. Early results have highlighted changes in the deeper sections of the freshwater lens due to natural and anthropogenic pressures, which were previously undetectable with traditional approach to monitoring groundwater status through groundwater level monitoring. This network offers valuable information about the relationship between the thickness of the freshwater lens and groundwater usage.

This network allows for the analysis of the transition zone response to changes in groundwater levels over time, provide guidance to modelling, and enables a more comprehensive groundwater protection strategy in view of the emerging challenges and increased pressures resulting from climate change.

Keywords: *saltwater intrusion monitoring, interface monitoring, innovative monitoring technique*

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INTEGRATING DIRECT AND INDIRECT SALINITY MEASUREMENTS TO MAP THE EVOLUTION OF THE FRESHWATER LENS IN THE AMSTERDAM WATER SUPPLY DUNES

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ABSTRACT

This study demonstrates the integration of diverse data sources to map the dynamic interface between fresh and saline groundwater in the coastal dune system of the Amsterdam Water Supply Dunes (AWD) in The Netherlands. We showcase the value of long-term direct groundwater salinity monitoring and explore the complementary benefits of indirect salinity measurements, including groundwater electrical conductivity (EC), borehole geophysics, and airborne electromagnetic surveys.

The Amsterdam Water Supply Dunes (AWD) have been used for drinking water production for more than 170 years, initially mining the natural freshwater lens. To meet the growing demand, Managed Aquifer Recharge (MAR) with pre-treated river water was implemented approximately 70 years ago. A dense network of monitoring wells, established over time, allows for regular sampling and chloride concentration measurements at various depths. The wells are regularly sampled and the chloride concentrations at different depths are determined. These long-term datasets, some of them spanning over a century, enable the reconstruction of the fresh/saline groundwater interface's behavior, which has been significantly influenced by the dynamic history of groundwater abstraction and recharge.

We demonstrate that indirect salinity measurements provide valuable complementary data to direct chloride measurements:

1. Borehole geophysical measurements, using permanent electrode cables and electromagnetic downhole probes, offer high-resolution vertical salinity distribution profiles.

2. A single airborne electromagnetic survey facilitates spatial interpolation of the fresh/saline interface between groundwater point measurements.
3. We evaluate the reliability of using simple electrical conductivity (EC) measurements of groundwater samples as a cost-effective alternative to direct chloride analyses for determining groundwater salinity.

Furthermore, we present a validated methodology for mapping the extent of the artificially infiltrated river water and distinguishing it from the native dune freshwater using natural tracers chloride, and Br/Cl and $^{18}O/^{16}O$ ratios:

	Threshold value	
Native dune water	**Cl** > 70 mg/l <	**Artificially infiltrated river water**
	Cl/Br < 400 < for 350 – 450: $^{18}O/^{16}O$ is leading	
	$^{18}O/^{16}O$ < -8 ‰ V-SMOW <	

Keywords: *monitoring; freshwater lens*

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REAL-TIME FLUX MONITORING: THE EXTRA DIMENSION FOR COASTAL GROUNDWATER MANAGEMENT

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ABSTRACT

If we can track groundwater flux in a phreatic coastal aquifer in real-time, can we improve the management of water extraction at high risk of saline intrusion? A question we're answering at Dunea, a drinking water utility in the Netherlands, by installing a network of fifteen novel underground flux sensors and additional sensors linked to telemetry across the drinking water extraction area for real-time watershed monitoring. The flux sensors are installed in dedicated monitoring wells and measure the darcy velocity and direction of groundwater flow, which are real-time transmitted and interpreted into possible actions. Flux ranges from less than 1 cm/day up to 4m/day can be attained with the network.

At the specific site, due to nature-based dune fortification (sand motor) and the presence of a post WWII bombing dump site in the dunes, the groundwater catchment faces multiple risks to be managed at this dynamic interface. Therefore drainage wells have historically been installed along the coastline, pumping and discharging saline groundwater to keep these risks oriented towards the coastline and the watershed between the catchment and the dump site. The prevention of contamination reaching the catchment is vital to safeguard the entire installation.

The goal of the project is to enhance existing insights into groundwater dynamics, ensure resilient and sustainable production in response to increased demand and climate change, while minimizing additional costs. The network will help to optimize pumping regimes at coastal and inland areas to prevent either further saline intrusion or loss of infiltrated fresh water to the sea. At the same time the system will be operating as a real-time early warning system so remedial actions can be undertaken when flux sensors indicate potential harmful velocities and/or orientations, safeguarding future sustainable and resilient drinking water production.

Keywords: *groundwater flux, real-time monitoring, sustainable water extraction*

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BIOGENIC CARBONATE DISSOLUTION IN COASTAL PERMEABLE SEDIMENTS

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ABSTRACT

The increase in biogenic carbonate dissolution in coastal sediments is an expected response to current ocean acidification. However, the interaction between the continent, coastal sediments, the atmosphere, and the ocean establishes complex controls on the carbonate system, indicating that ongoing open ocean acidification cannot be directly applied to coastal environments. Understanding the factors influencing the preservation of biogenic carbonates in coastal areas is crucial for carbon cycling, as 50% of these carbonates are found in coastal sediments. This study evaluates carbonate dissolution in permeable sediments across different locations. While attention is given to surface water acidification and its impact over net $CaCO_3$ dissolution dynamics in sediments, results demonstrate a stronger correlation of $CaCO_3$ dissolution rates with porewater composition. On average, a pH difference of 0.2 units exists between surface seawater and porewater in the studied sites. Moreover, the arrival of continental groundwater to these systems, forming the so-called subterranean estuaries, further exacerbates the non-dependency of biogenic carbonate stability in relation to carbonate system properties of the overlying waters. The findings also suggest that biogenic carbonate dissolution/precipitation rates are strongly modulated by benthic metabolism and regulated by daily light-dark cycles. During daylight hours, net calcification dominates, whereas net dissolution occurs in darkness, independently of the pH of the overlying water. Metabolic respiration rates from various studies exhibit moderate positive correlations with dissolution rates in the darkness, whereas the relationship between net primary production (NPP) and dissolution in light conditions vanishes. Continental groundwater commonly transports land-derived carbonate system properties and, depending on its composition, can promote pH decline and calcium carbonate undersaturation, thereby promoting carbonate dissolution. Benthic metabolism along the continental groundwater flow path and within the subterranean estuary also contributes to the variation in porewater pH, further shaping the carbonate system of the local porewaters and benthic $CaCO_3$ stability.

Keywords: *biogenic carbonate dissolution, subterranean estuary, groundwater, coastal sands, benthic metabolism*

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DISSOLVED ORGANIC MATTER MOBILITY AND RETENTION IN A HIGH-ENERGY SUBTERRANEAN ESTUARY

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ABSTRACT

Permeable sandy sediments beneath high-energy beaches are potent biogeochemical reactors with high organic matter turnover rates. Despite their role in nutrient and trace metal cycles, little is known about their function in trapping and mobilizing dissolved organic matter (DOM). To explore DOM-solid phase interactions, we analyzed the molecular composition of water- and acid-leachable sedimentary DOM down to 24m in a subterranean estuary (STE) on Spiekeroog Island, German North Sea, using fluorescence spectroscopy and FT-ICR-MS. We also examined the coprecipitation of DOM and Fe^{3+} (oxy)hydroxides in STE porewaters containing reduced Fe2+ exposed to air. About 10% of total organic carbon was leachable as DOC in both treatments. Finer sediments with higher Fe and Al content retained more DOC. Water leachates contained aliphatic, nitrogen-rich compounds likely from marine sources, while acid leachates were more varied, including oxidized aromatic and labile compounds, likely from terrestrial and marine sources. Fe-DOM coprecipitation induced molecular composition changes, but DOC removal was within analytical uncertainties, and molecular fractionation varied across sampling periods. Thus, DOM-Fe coagulation at redox zones of deep beach STEs may be low and influenced by transport-driven changes in porewater chemistry. Overall, terrigenous DOM is preferentially retained in sediments, while the labile fraction is more mobile. This study highlights the role of organo-mineral interactions in DOM cycling at the land-ocean interface, especially in organic-poor, sandy environments.

Keywords: *permeable sediments, reactive iron, redox cycling, dissolved organic matter, subterranean estuary.*

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ESTIMATION OF GROUNDWATER DISCHARGE AND NUTRIENT LOADS TO PUCK BAY USING COUPLED HYDROLOGICAL MODELS

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ABSTRACT

This study focuses on the integration of surface water and groundwater models to evaluate the quantity and quality of the surface water discharge and submarine groundwater discharge (SGD) to Puck Bay (Polish Baltic coast). The main goal was to investigate how the current land use and agricultural practices may affect groundwater recharge, SGD and the associated N-NO3 fluxes. The area is characterized by a complex groundwater system with two main aquifers formed in Quaternary fluvioglacial deposits (sand and gravel) separated by moraine tills. In the framework of the WaterPUCK project (www.waterpuck.pl) an integrated modelling approach has been developed, which couples the SWAT hydrologic model, MODFLOW-NWT groundwater flow model, and MT3DMS transport model. Model simulations showed significant spatial and time variability of groundwater recharge, SGD and the associated N-NO3 loads. However, there is no simple spatial relationship between recharge and nitrate load. Patterns of seasonal changes were distinguished, with maximum values of the SGD flux in late winter/early spring and minimum values in early autumn. Seasonal changes in SGD correspond approximately to seasonal changes in groundwater recharge. During the simulated period the relative differences between monthly averaged SGD fluxes in the shallow aquifer reach 120%, while in the deep aquifer they do not exceed 31%. A similar dependence is observed in the case of N-NO3 load to the Puck Bay, which is strongly controlled by groundwater discharge variability. We will also present ongoing developments of the modelling platform, carried out in the framework of the EU Horizon project SOILPROM (grant 101156589, soilprom.eu). They include phosphorus transport model and improved description of water and nutrient movement through the deep vadose zone.

Keywords: *submarine groundwater discharge, nutrients, model coupling, Baltic Sea*

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FRESHENING OF PALEO-SALINITY IN THE CUBANGO MEGAFAN, NAMIBIA – A LARGE SCALE NATURAL ION EXCHANGE EXPERIMENT

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ABSTRACT

The people in the semi-arid north of Namibia suffer from an inadequate water supply, both in quantity and quality, exacerbated by repeated drought seasons. Geologically, the region is comprised mostly of the Cubango Megafan, a very large fluvial inland delta (54,000 km²). Both sediment and groundwater recharge stem from the Angolan Highlands in the north. The megafan contains three aquifer systems, a shallow perched system of low yield and dubious water quality and two transboundary regional aquifers. The latter are also in part saline.

An analysis of the distribution of salinities and water types in the upper regional aquifer showed that groundwater with higher salinities, of the NaCl-type, occurs mostly at the terminal (downstream) parts of the fan. Lower-salinity groundwater dominates further upstream, at first as NaHCO3-type and finally the CaHCO3-type. Analyses of drill cores revealed that the pore waters of the megafan material must have been saline initially. Since fresh groundwater recharge comes from the highlands up north, we therefore postulate that that the freshwater pushes the saline waters out (freshening), thereby creating the classical ion exchange sequence described by the water types mentioned above.

A 2D areal numerical flow and reactive transport model was set-up to emulate the observed variations in water qualities across the south-west of the megafan. Groundwater flow was modeled using available groundwater levels to approximate present-day flow conditions, despite poorly defined boundary conditions and limited, often unreliable data. Despite using time-invariant flow to reconstruct paleo-hydrogeological conditions the model produced a good fit to the spatial hydraulic head and hydrochemistry data obtained in the field. The results confirm our conceptual model of a freshening front advancing from the north and provides time-averaged recharge volume estimates needed to recreate present-day observations. These findings may offer valuable insights for future groundwater exploration in this vast system.

Keywords: *Namibia, ion exchange, freshening, paleo-salinity*

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GEOCHEMICAL BEHAVIOR OF A SUBTERRANEAN ESTUARY ON THE EAST COAST OF INDIA

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ABSTRACT

Subterranean estuaries (STE), the zone where fresh groundwater mixes with saltwater, influence the chemical fluxes to the ocean. In this mixing zone, the chemical elements carried by the groundwater undergo biogeochemical transformations before being discharged to the ocean. Therefore, the aim of the present study is to understand the biogeochemical processes at the STE of a section of the Odisha coast (east coast of India). The coast is tidally influenced and the climate is tropical with an annual rainfall of about 1550 mm. Sampling took place in the pre-monsoon (May 2024) and post-monsoon (October 2024) seasons. Seawater, groundwater and sediment porewater (down to 125 cm) in transects along the coastline in the intertidal zone were sampled. Samples were collected for the measurement of several parameters including nutrients, major and trace elements and carbon species. The surface and pore waters showed differences in salinity values between the two campaigns: during the pre-monsoon, salinities were up to 36 PSU, while after the monsoon, the salinities decreased to a maximum of 30 PSU, and values close to 2 were found in the porewaters. During the post-monsoon season, more low salinity spots were detected along the coastline, which may be due to the more pronounced hydraulic gradient after the monsoon season. Salinity values were positively correlated with beach elevation, and a seepage line indicating the presence of diffuse SGD was found at about

2 m above the sea level. This suggests that submarine groundwater discharge is an important phenomenon in the region leading to the formation of an STE. The concentration of nutrients in the different systems suggests that the STE plays a role in the transport of nutrients to the sea, with an indication of nutrient consumption, which has a positive impact on the nutrient load to coastal waters in areas of high population density. Further studies will continue to better understand the final subterranean elemental fluxes to the coastal waters of this interesting location.

Keywords: *Submarine Groundwater Discharge. Sandy Beaches. Monsoon. Nutrients.*

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GROUNDWATER AGE AND MIXING PATTERNS IN THE DEEP SUBSURFACE OF A HIGH-ENERGY BEACH

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ABSTRACT

Subterranean estuaries under high-energy conditions function as effective biogeochemical reactors, where waterbodies of varying physico-chemical properties mix and reactions modulate the solute composition of groundwater discharging to the sea. Groundwater residence times are fundamental to understanding groundwater flow and transport regimes, and thus to interpreting (bio)geochemical data. The objective of the present study is to derive groundwater residence times and mixing patterns down to 24 m in the high-energy sandy beach aquifer on Spiekeroog, a barrier island in north-western Germany. At this study site, morphological changes of the beach surface combined with winter storm surges led to spatio-temporally variable flow and transport regimes and mixing patterns. To this end, we have combined multiple environmental tracers, including electrical conductivity, apparent tritium-helium ages, temperature and dissolved silica, obtained over a period of 1.5 years from different depths and locations along a cross-shore transect extending over 200 m from the dune base to the low water line. The results of apparent groundwater ages, travel times and seawater mixing fractions allowed delineating zones where the different endmembers were prevailing. Recirculating seawater of the upper saline plume (USP), infiltrating near the high water line, was youngest with travel times of days to weeks. Near the dune base, freshwater entering the beach from the

islands interior was several years old, subsequently forming the freshwater discharge tube below the USP, and directed towards the discharge zone where decade old brackish groundwater was encountered at depths below 18 m. Dissolved silica accumulated along the flow paths with increasing residence times, and thus served as a valuable indicator for the groundwater age distribution in the deeper parts of the subterranean estuary.

Keywords: barrier island Spiekeroog, heat as a tracer, tritium-helium dating, groundwater age, high energy sandy subterranean estuary

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HKU DEPTHWISE HYDROGEOSYSTEM FOR HIGH-RESOLUTION GROUNDWATER INVESTIGATIONS AND ITS APPLICATION IN COASTAL HYDROGEOLOGY

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ABSTRACT

This presentation introduces the HKU Depthwise HydrogeoSystem (HKU-DHS), a suite of eight innovative, low-cost technologies tailored for multi-depth monitoring across diverse hydrogeological settings, including porous media, fractured rock, and karst systems. These systems address the longstanding challenge of sparse groundwater data by enabling depth-discrete measurements that reveal critical features often overlooked by conventional methods. Manufactured using locally available components and 3D printing, these systems are designed for widespread adoption in research, education, and professional practice worldwide.

In coastal hydrogeology, the system has been successfully applied in regions like the Pearl River Delta and Hong Kong in China, where it has uncovered spatial variations in CO2, CH4, DIC, radium isotopes, and other geochemical parameters, providing insights into freshwater-saline water interactions and submarine groundwater discharge. By emphasizing open-source availability and fostering global collaboration, HKU-DHS aims to transform groundwater science from a data-sparse to a data-rich field, empowering researchers and practitioners to address pressing environmental challenges such as climate adaptation, ecosystem protection, and sustainable resource management. Case studies using the HKU-DHS have demonstrated the transformative potential of high-resolution data in understanding complex groundwater systems, underscoring the importance of detailed, high-resolution sampling in driving impactful scientific discoveries.

Keywords: *Multi-depth Monitoring System, Groundwater, High-resolution Sampling, HKU Depthwise HydrogeoSystem (HKU-DHS)*

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IDENTIFICATION OF SUBMARINE GROUNDWATER DISCHARGE (SGD) AND SALINE WATER INTRUSION (SWI) IN THE COASTAL ANDHRA PRADESH, INDIA

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ABSTRACT

Groundwater resources in coastal aquifers are threatened by seawater intrusion due to natural and anthropogenic processes. As seawater intrusion is complicated, dynamic natural process and man-made activities necessitate multi-dimensional approaches along coastal regions. Hydraulic and hydrogeochemical investigations in the shoreline aquifers are required to understand the sources of submarine groundwater discharge and salinization zones. No previous systematic studies have addressed submarine groundwater discharge and salinization zones along the coastal Andhra Pradesh. A site explicit evaluation is required to identify fresh and saline water interaction. A preliminary study was conducted to investigate submarine groundwater discharge and salinization zones using groundwater dynamics, sea surface temperature, and field water quality anomalies. Inverse distance weighted interpolation technique were used for the preparation of groundwater level maps (2018-2019) above mean sea level with the help of monitoring well data. LANDSAT 8 thermal infrared sensors were used to estimate sea surface temperature (SST) to corroborate submarine groundwater discharge zones with the sea surface temperature anomalies. The annual ranges of SST were 21-39 °C (2017), 15-34 °C (2018) and 20-39 °C (2019). A detailed hydrogeochemical studies was carried out by collecting 234 water samples (139 porewater, 31 groundwater and 64 seawater samples) along ~450 km coastline to evaluate the submarine groundwater discharge and saline water intrusion zones. Hydrogeochemical parameters (i.e. EC, TDS, pH, DO, temperature and salinity) were estimated in the field for porewater sample, groundwater and seawater sample along the coastal plains. Out of four coastal district (i.e. Krishna, Guntur, Prakasam and Nellore) of Andhra Pradesh studied, three districts (i.e. Krishna, Guntur and Nellore) were prone to saline water intrusion whereas Prakasam district was susceptible for submarine groundwater discharge zones.

Keywords: Submarine groundwater discharge (SGD), Saline water intrusion (SWI), Hydrogeochemistry, groundwater dynamics, sea surface temperature.

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INFLUENCE OF TIDAL LOADING ON SUBMARINE GROUNDWATER DISCHARGE: RA ISOTOPE AND NUTRIENT VARIABILITY IN OFFSHORE GROUNDWATERS ALONG THE WEST FLORIDA SHELF

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ABSTRACT

Submarine Groundwater Discharge (SGD) fluxes may be affected by tide-driven loading efficiency. This study presents a synoptic, year-long time-series analysis of Ra isotope activity (^{223}Ra, ^{224}Ra, ^{226}Ra, and ^{228}Ra) and nutrient concentration fluctuations across three offshore submarine well transects, each situated in a distinct aquifer on the West Florida Shelf. Fluctuations were observed throughout the year for all four Ra isotopes and nutrient concentrations (SiO_2 and TDP) despite no significant seasonal changes in the precipitation regime. However, samples were collected at different tidal stages, with water column depth increments from 2 to 5 meters, depending on the transect. In the two unconfined aquifer transects, nutrient concentrations were positively correlated with the water column depth, while the semiconfined aquifer showed no response. Likewise, radium activity ratios also showed clear correlations in the unconfined aquifers when the water column depth rose. When pressure is applied at the surface of an aquifer (e.g., from atmospheric pressure or water column height), it is partially supported by the aquifer skeleton and partially transmitted to the groundwater, altering hydrogeochemical conditions. In addition, we also provide relative transit times for those groundwaters based on ^{222}Rn/^{226}Ra and ^{224}Ra/^{228}Ra, which likely indicate that the main pathway governing the discharge on those unconfined aquifers is seawater recirculation. The observed correlations between water column depth and both nutrient concentrations and Ra isotope ratios in the unconfined aquifers suggest that tidal fluctuations enhance groundwater exchange by exerting pressure on the subsurface. This mechanism likely facilitates the release

of older, nutrient-rich groundwater into the shelf environment, influencing biogeochemical cycling and marine productivity. These findings highlight the importance of loading efficiency in modulating SGD and emphasize the role of Ra isotopes as valuable indicators of groundwater-seawater interactions along continental shelves.

Keywords: *Submarine Groundwater Discharge, Ra isotopes, tidal loading, nutrients*

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OCCURRENCE OF AS, CD, CR AND PB IN A MEXICAN COASTAL AQUIFER ASSOCIATED TO AGRICULTURE ACTIVITY: IMPLICATIONS FOR RISKS TO HUMAN HEALTH

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ABSTRACT

Groundwater from the Mocorito River coastal aquifer (MORCA), located in the agricultural valley of Culiacan, Mexico, has been historically employed for both human consumption and irrigation of its overlaying agriculture fields. In order to assess the levels and distribution of As, Cd, Cr and Pb in MORCA, as well as, to determine their sources and to estimate their potential health risks, groundwater samples were collected from wells at eighteen sites during the dry and rainy seasons. In the dry season mean dissolved concentrations (µg L-1) of As, Pb, Cd and Cr were 3.19, 0.05, 0.02 and 0.15, respectively, and their total (unfiltered) concentrations were 4.10, 0.47, 0.05 and 0.52, respectively. While in the rainy season, their dissolved concentrations were 4.60, 0.03, 0.01 and 0.06, respectively and their total concentrations were 5.58, 0.25, 0.01 and 0.12, respectively. On average, concentrations of these four Potentially Toxic Elements (PTEs) were below national and international guidelines for drinking water. Concentrations of As exceeded the safe value proposed for the World Health Organization (10 µg L-1), at three sites and yielded relatively high values of both Chronic Daily Intake and Hazard Quotient. Lifetime Cancer Risk for As indicated the probability for developing this disease of 1 in 10, 000 inhabitants. Pearson's correlation and principal component analysis (PCA-Varimax) were carried out. According to these, all the PTEs concentrations were mainly derived from natural lithogenic sources. Arsenic concentrations constitute potential human health concerns for both direct consumption and its bioaccumulation in local crops. Finally, due to high As concentrations in some sites in the aquifer, the implementation of a sustainable groundwater management plan in the MORCA, that include a monitoring of PTE levels, is recommended.

Keywords: *Arsenic, Chronic daily intake, Heavy metals, Lithogenic sources, Risk quotients indices*

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PHYSICAL, CHEMICAL, AND MICROBIAL PROCESSES OF SALT WATER INTRUSION IN GROUNDWATER ON THE SOUTHERN COAST OF LAIZHOU BAY, CHINA

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ABSTRACT

The southern coast of Laizhou Bay is one of the most severely affected areas in China by salt water intrusion. This study established a groundwater monitoring profile along the southern coast of Laizhou Bay, approximately 35 km in length. Groundwater and sediment samples were collected, and physical and chemical parameters, isotope tracing, and microbial analyses were conducted. The results indicate that the primary cause of salt water intrusion on the southern coast of Laizhou Bay is the historical over-extraction of groundwater. The salt water intrusion results from the combined effects of freshwater and brine groundwater funnels, which alter the groundwater flow field, leading to the movement of saline water toward the southern freshwater zone. Groundwater salinity increases from inland to the coastal zone on the southern shore of Laizhou Bay. The salinity of the brine originates not only from ancient seawater but also from the dissolution of rock salts. The saline water is the result of the mixing of groundwater with saltwater and brine. The microbial diversity in groundwater shows a trend of decreasing first and then increasing with salinity, while the microbial diversity in sediments generally increases with increasing salinity. Microorganisms such as genus Marinobacter and family Alteromonadaceae can serve as biomarkers for seawater or ancient seawater sources. The groundwater salinization process affects biogeochemical processes such as carbon, nitrogen, and sulfur cycling. Sulfate reduction is enhanced in groundwater with high salinity.

Keywords: Saltwater intrusion; High-density electrical method; Isotope tracing; Numerical modelling; Microbial community

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Phytoplankton Dynamics in Fangar Bay: Model vs. Observation

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ABSTRACT

Primary production in coastal bays and estuaries is influenced by physical factors such as wind, tides, freshwater inputs and light. In the short term, these elements affect phytoplankton biomass and nutrient availability. In Fangar Bay, a shallow, microtidal environment in the northwestern Mediterranean, spatial and temporal variations in phytoplankton concentration have been observed, closely linked to wind patterns. Regular sea breezes and strong northwesterly gusts generate stratification or mixing of the water column, influencing phytoplankton distribution.

To analyse these processes, the ROMS model coupled to a NPZD (nutrient, phytoplankton, zooplankton, and detritus) scheme was used, with simulations compared to in situ measurements. Both observational and model results show that, with sea breezes (6 $m \cdot s^{-1}$), phytoplankton concentrate at the surface due to stratification, whereas, with northwesterly winds above 10 $m \cdot s^{-1}$, mixing of the water column homogenises nutrients and favours biomass increase in deeper layers.

In addition, freshwater plumes from drainage canals affect the spatial distribution of phytoplankton. Numerical simulations confirm the relationship between these dynamics and satellite observations, showing the correspondence between model and real data. These findings provide key information to improve ecosystem management by optimising the interaction between freshwater inputs and prevailing winds. Strategies based on natural processes could help regulate phytoplankton growth and prevent eutrophication, promoting the sustainability of the bay.

Keywords: *phytoplankton biomass, ROMS-NPZD model, freshwater plumes, Fangar Bay*

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Qualitative Approaches Unveiling the Evolution of Seawater Intrusion into Karst Aquifers of The Adriatic Coastline, SE Italy.

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ABSTRACT

Around the world, areas near islands and coastlines frequently provide substantial potential for socio-economic development, which raises the need for freshwater resources. The increased demand, strictly related to tourism and agriculture activities, raises the possibility of aquifer overexploitation. A major challenge to the sustainability of groundwater supplies in coastal locations is the problem of seawater intrusion (SWI). In karst coastal aquifers, the evolution of hydrochemistry is rapidly impacted by SWI. Qualitative data integration can be one of the premises and a key to hydrochemistry evolution or seawater intrusion research under complex geological and hydrogeological conditions. This contribution focuses on a coastal strip along the Adriatic coast of south eastern Italy, positioned between two distinct groundwater systems. A total of 73 sampling sites were systematically monitored over a four-year period (2007–2010) to investigate the temporal evolution of the hydro-geochemical parameters within the region. This work aims at conducting a comprehensive analysis of SWI dynamics, evaluating historical, current, and projected future scenarios to better understand the mechanisms and impacts of SWI in the context of regional hydrogeological processes. To understand the past scenario for the seawater intrusion spatial mapping for single parameters and chemical indices, these were overlaid to create a seawater intrusion map (SWIM), coupled with a graphical plot and salinity profiles along the study area. The results show a strong correlation between total dissolved solids (TDS) and chlorine ion (Cl^-) concentration. Meanwhile, the SWI pattern from spatial mapping over the study area shows diffusion transport reflected by an increase in brackish water facies area and a decrease in fresh and saline facies, respectively, over the monitoring period.

Keywords: *Karst Aquifer, Seawater intrusion, water quality, hydrochemistry, spatiotemporal evolutions.*

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QUANTIFYING LONG-TERM SEAWATER CIRCULATION FLUXES IN COASTAL AQUIFERS: INSIGHTS FROM MULTI-ELEMENT ANALYSIS AND FIELD APPLICATIONS

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ABSTRACT

Quantifying solute fluxes through Submarine Groundwater Discharge (SGD) into the ocean is challenging due to the complex groundwater flow mechanisms in coastal aquifers and subterranean estuaries. These mechanisms operate across diverse temporal and spatial scales, from wave- and tide-driven circulation to seasonal variations and density-driven circulation that spans thousands of years. This study, based on a comprehensive dataset from coastal aquifers and new analyses of major elements (Ca, Mg, Na, K, and Sr) in subterranean estuaries, demonstrates that these elements are predominantly influenced by longer-term seawater circulation. Using a multi-element Monte Carlo ocean budget, we quantified the long-term seawater circulation flux at approximately 1,000 km^3/year. Additionally, we developed a method to quantify local long-term circulating seawater fluxes in the field, employing an array of piezometers and seepage meters. A case study from Indian River Bay, Delaware, identified the long-term seawater component as contributing about 10% of the total circulating seawater discharge, based on major element concentrations.

Keywords: *Ocean chemistry, Major element budget, datasets, long-term seawater circulation in aquifers*

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RADIOCARBON AGE DATING OF COASTAL SEAWATER INTRUDING BENEATH A LARGE FRESHWATER LENS

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ABSTRACT

The results of age-dating and quality evolution of intruding Coastal North Sea (CNS) water are presented and discussed, based on 18 monitoring wells in 2 transects, reaching about 9 km inland from the North Sea. There, reclaimed Lake Haarlemmermeer at 5 m below sea level (BSL) is forming a great sink attracting this seawater, which is flowing at 80-180 m BSL underneath a deep, broad, fresh dune water lens.

For each sample of intruded CNS a chemical mass balance (CMB) has been drawn up, with a new Excel based code (R+SWi). The radiocarbon dating method is fully linked to this CMB. It yields ages between 0.37 and 6 ka, distributed in 2 main age zones. Old CNS (3-6 ka) intruded during a period of coastal progradation. Young CNS (<2 ka) slowly intruded during a period of coastal erosion (100-1000 AD), followed by slightly accelerated intrusion due to drainage of peat areas as of 1525 AD. Reclamation of Lake Haarlemmermeer and dune groundwater extraction after 1850 AD strongly accelerated the intrusion rate.

Sensitivity analysis revealed that the ^{14}C age determination is most sensitive to the assumed ^{14}C activity (age) of reactive organic matter and carbonate minerals in the submarine Holocene deposits under the seafloor.

INTRODUCTION

^{14}C age dating of saline groundwater in coastal aquifers has received relatively little attention (Yechieli et al. (2001). The main reasons are: (i) in many cases, the expected intrusion distance and travel time are short (<50 years) making ^{14}C not fit as age-tracer, (ii) ^{14}C-age dating is complex (Plummer & Glynn 2013), and (iii) monitoring networks often do not target the saline parts of the aquifer system, hence suitable observation wells tend to be limited in number.

This study is focusing on an ideal area for ^{14}C age dating (Fig.1). A dense network of multi-level observation wells with short (1-2 m) well screens is located from 0.04 to 9 km inland, at depths ranging from sea level to 84-183 m below sea level (BSL); see Fig.2 for northern transect.

MATERIALS AND METHODS

Intruded North Sea water was sampled twice from 18 piezometers along 2 transects in December 2019 and March 2022. Samples for ICP-MS multi-scan analysis of cations, PO_4, SiO_2 and (ultra)trace elements were filtrated in the field over 0.45 µm and acidified by HNO_3. Samples for analysis of Cl, Br, SO_4, NO_3, F, alkalinity, NH_4 and TOC were not filtrated but analyzed within 24 hours in the lab. The high salinity of each sample (on average 30,000 mg/L) necessitated a 10-100 fold dilution step, except for total alkalinity, NH_4 and DOC.

The following isotopes were analyzed: ^{2}H, ^{3}H,^{18}O,^{13}C and ^{14}C.

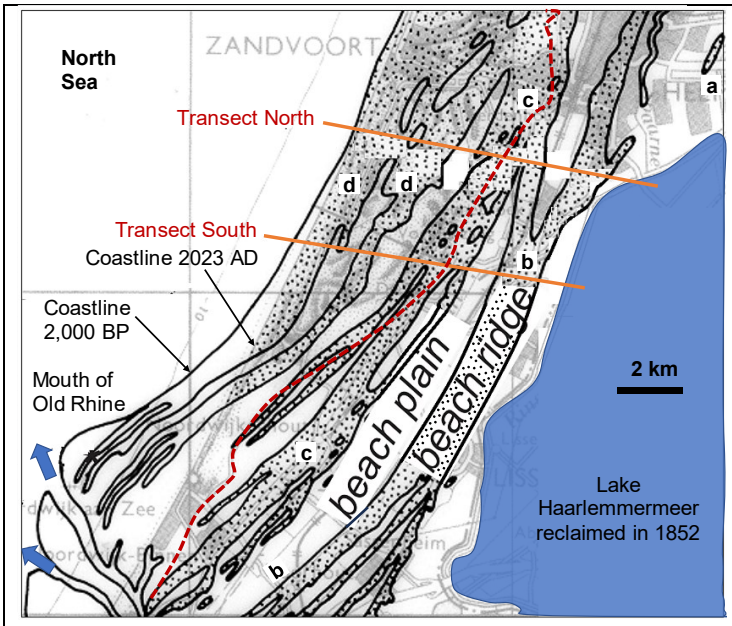

FIG. 1: Palaeogeographical map showing approximate position of coastline, mouth of Old Rhine River, beach plains and beach ridges, reclaimed Lake and both transects. Based on data in e.g. Vos et al. (2020). Marine erosion especially in the period 0-1,200 AD removed the more seaward deposits.

a – d = formation time of beach ridges (ka BC): a = 3-3.85, b = 2.3-2.75, c = 1.5-1.85, d = 1-1.5.

Red dashed line = landward limit of younger dunes overlying the beach ridges and plains.

THE ^{14}C METHOD

The mass balance code R+SWI.xlsx (Stuyfzand et al. in prep) was used to identify and quantify the reactions of the input (coastal seawater) with the porous medium. Summation of input and the reacted amounts generates the measured output (sampled groundwater). This code specifically addresses Salt Water Intrusion and ^{14}C age dating. It needs the composition of input, output and, if relevant, admixed ambient groundwater, including ^{13}C and ^{14}C if dating required. It utilizes Excel's Solver routine as calibration method, and offers the option to adjust the concentration of main constituents within narrow bounds to cover uncertainties (which in salt water are relatively high with impact on the accuracy of the mass balance).

COASTAL SEAWATER AND THE ADMIXING OF FRESH DUNE GROUNDWATER

Coastal North Sea water (CNS) along the Dutch coast is a mixture of (open) ocean water and river water from the Rhine, Meuse and Scheldt. The estimated high age of intruded CNS water justifies to take pre-industrial fluvial water compositions. The fraction of the fluvial mix in CNS then becomes 0.1518 (assumed constant on the study site).

The ^{14}C activity of the North Sea and Atlantic Ocean shows a structural depletion relative to the coeval atmosphere, leading to an average age set-back of 508 years. The age set-back for the combined fluvial inputs is probably 2 ka (Stuyfzand et al 2025). This reduces the ^{14}C activity of CNS water from 100 to 91.68 pmC.

Our intruded seawater samples show very little admixing (generally 0-14%) of fresh, deep dune groundwater (evidenced by Cl in Fig.2). Cl and ^{18}O were used to correct the samples for this admixing, which is due to vertical dispersion across the fresh/salt interface. This dispersion was enhanced by upward movement of this interface during overexploitation (1902-1957) and subsequent downward movement when basin recharge with Rhine River water replaced the extraction of deep dune groundwater (as of 1957).

RESULTS OF RADIOCARBON AGE DATING

All samples of CNS infiltrate are practically without tritium (^{3}H < 0.03 TU), indicating that they do not contain a measurable fraction of subrecent (<70 years old) CNS or dune water due to e.g., leaky risers. Fig.3 shows the ^{14}C-age of infiltrated CNS along the northern transect, while Fig.4 displays the age distribution at 80-180 m BSL in top view for both transects.

Relatively low ages (0.37-1.9 ka) are only found along the northern transect, in zone a (Fig.4). All other wells show ages between 3 and 6 ka, most of which in zone 'b' (3–5 ka) and the remainder in zone 'c' (5–6 ka). This age pattern is explained as follows. The bulk of sampled

CNS intruded in the period 3,000 – 1,000 BC in an open coastal sea environment driven by vertical and lateral density differences with less saline groundwater under and inland. The intrusion happened in front of beach barriers that, in the period 3,000 – 1,000 BC, successively expanded seaward (Fig.1). This CNS infiltrate was probably mixed by the dynamics arising from density driven flow, and by subsequent dispersion and diffusion within the aquifers during (semi)stagnant conditions for several millennia.

Zone 'a' has a remarkable shape with a finger pointing inland (Fig.4), towards the focus area of dune groundwater extraction in the period 1853-1980. However, other factors may play a role as well, such as the uncertain permeability distribution below the coastal seafloor.

Sensitivity analysis revealed that the ^{14}C age determination is most sensitive to the assumed ^{14}C activity (age) of reactive organic matter and carbonate minerals in the entire Holocene sequence under the seafloor. Variations in other parameters ($^{13}C_{SOM}$, $^{14}C_{CNS}$ and $^{14}C_{UPPER\ SEAFLOOR}$) have a minor impact. ^{13}C and ^{14}C data of Holocene deposits were taken from Van der Valk 1992.

The observed age distribution is confirmed by SEAWAT modelling of the northern transect including changes in coastal and inland boundary conditions as of 1500 BC (Post et al. 2025).

PRACTICAL CONCLUSIONS

Chemical mass balancing and paleohydrology are indispensable in ^{14}C age dating. The age distribution within a coastal aquifer helps to indicate the most vulnerable intrusion zones. Knowledge of the hydrogeological structure below the seafloor is often lacking but crucial.

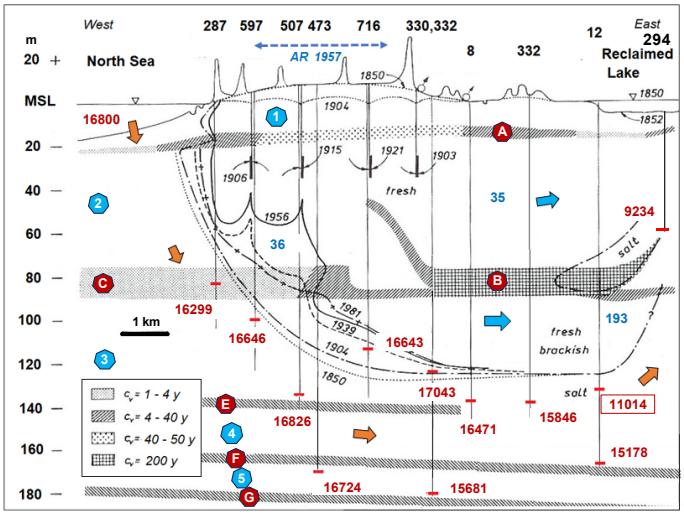

FIG. 2. Schematic of transect North, showing the position of sampled piezometers (red cross line) with their Cl concentration in red (mg/L), aquifers (1-5), aquitards (A-G), fresh-salt interface (8400 mg Cl/L) in period 1850-1981, water table and important hydrological changes. Cl within dune water lens in blue.

1850 = background situation prior to reclamation of lake in 1852 and start of groundwater extraction in 1853. 1904-1913 = before large scale addition of deep wells in period 1903-1925. 1956 = year before start of artificial recharge in northern area (AR).

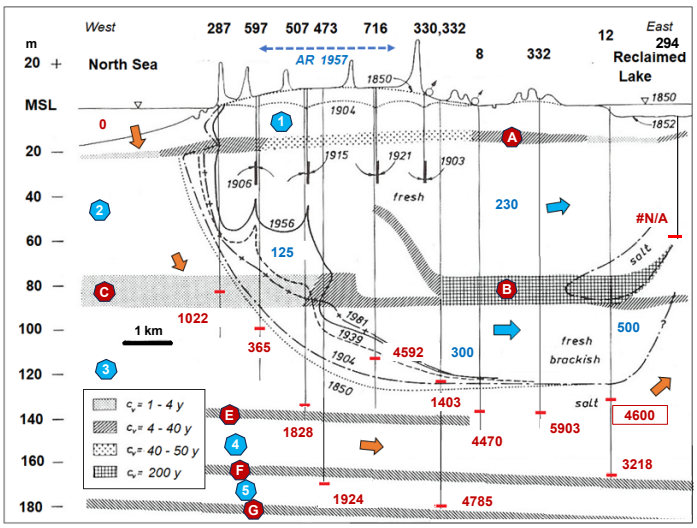

FIG. 3. Northern transect with the ^{14}C model age (years) of the intruded North Sea water in red. Numbers in blue = approximate age of dune groundwater. 1 – 5 = aquifers, A – G = aquitards. The framed red number indicates substantial admixing of fresh dune groundwater (ca. 35%). c_V = hydraulic vertical resistance. Calendar age = ^{14}C age + 72 year.

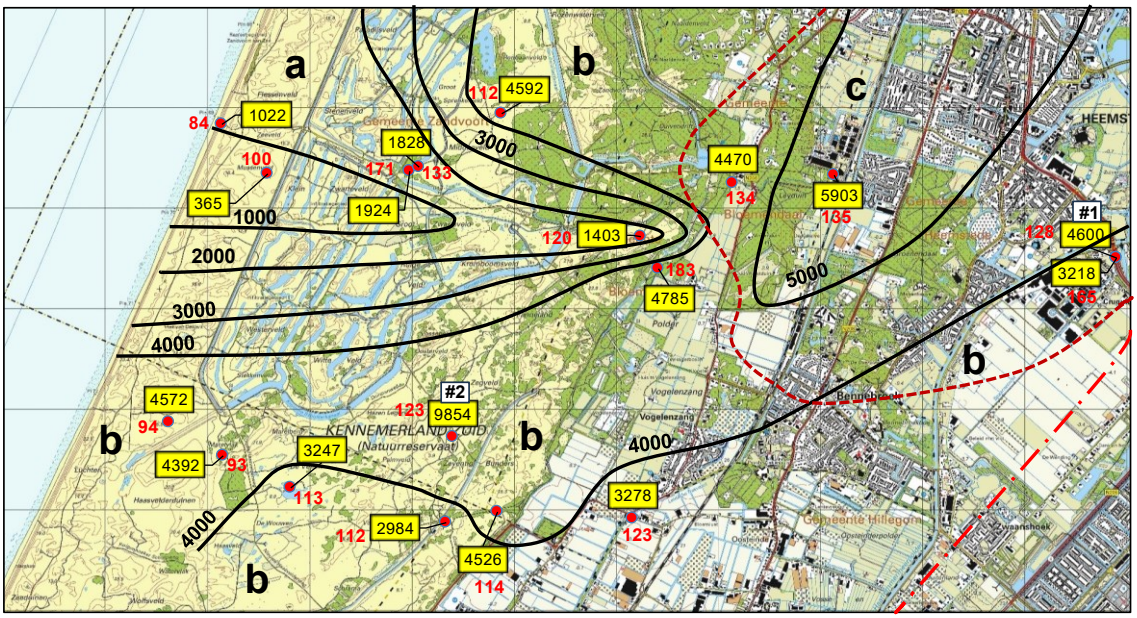

FIG. 4. Carbon-14 model age (year) of infiltrated North Sea water (in yellow rectangle) in planar view on the aquifer at 80-180 m BSL. Zones: a = <2 ka; b = 3–5 ka; c = 5–6 ka. The dark red dashed line delimits the presence of aquitard B (glaciolimnic clay) on top of aquitard C (fluvial clay loam). The red dot stripe line marks the approximate position of the North Sea intrusion front (defined as the 10,000 mg Cl/L line). #1 = corrected for 35% admixed dune groundwater; #2 = as #1 but considered an anomaly; red numbers = well screen depth in m BSL.

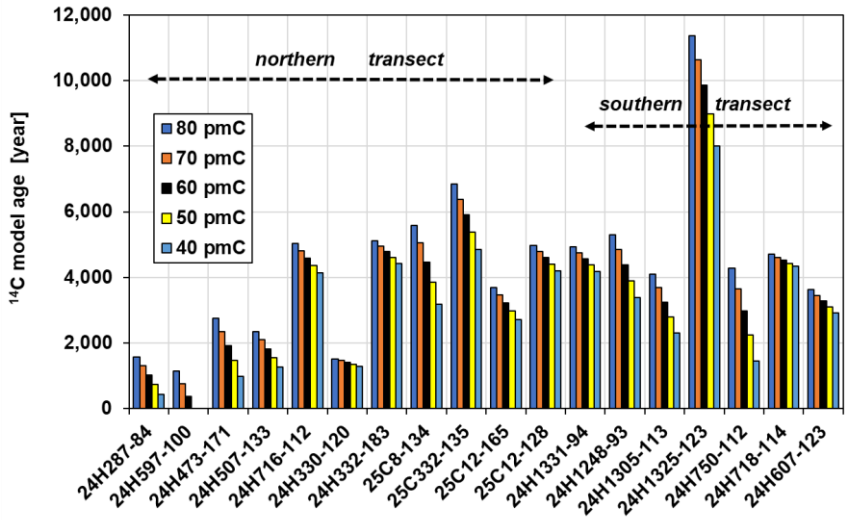

FIG. 5. Spectrum of ^{14}C model ages of intruded coastal North Sea water in all 18 samples, based on variation of average ^{14}C activity (40-80 pmC) of the combined Holocene sedimentary units.

REFERENCES

Plummer P.D. & P. Glynn 2013. Radiocarbon dating in groundwater systems. Ch.4 in IAEA book "Isotope methods for dating old groundwater", IAEA Vienna, 33-89.

Post V.E.A., P.J. Stuyfzand & P.R. Nienhuis 2025. Multi-millennia reactive transport modelling to elucidate seawater intrusion dynamics in the Amsterdam water supply dune area. This volume.

Yechieli Y. O. Sivan, B. Lazar, A. Vengosh, D. Ronen and B. Herut 2001. Radiocarbon in seawater intruding into the Israeli Mediterranean coastal aquifer. Radiocarbon 43(2B), 773–781.

Van der Valk L. 1992. Mid- and late-Holocene coastal evolution in the beach-barrier area of the Western Netherlands. Ph.D. Thesis Inst. of Earth Sci., Free Univ. Amsterdam, 235p.

Vos, P., M. van der Meulen, H. Weerts & J. Bazelmans 2020. Atlas of the Holocene Netherlands, landscape and habitation since the last ice age, Amsterdam (Amsterdam University Press)

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RARE EARTH ELEMENT PATTERNS AS TRACERS OF GEOCHEMICAL PROCESSES IN SUBTERRANEAN ESTUARIES

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ABSTRACT

Rare earth elements (REEs) are a group of 15 metals, ranging from lanthanum (La) to lutetium (Lu). Due to their characteristics, the patterns of REEs have been extensively used as tracers in oceanic processes including particle removal, redox changes, and the origin of particles or water masses. Recent studies have shown that submarine groundwater discharge (SGD) may contribute, depending on the characteristics of the area, with comparable or even greater amounts of REEs than those from regional rivers or sedimentary diffusive fluxes. To this end, the processes controlling the behaviour – and therefore the fluxes – of REEs in subterranean estuaries (STE) need to be further explored.

An integrated study of continental groundwater discharge was conducted in a large coastal inlet surrounded by a crystalline drainage basin (Ría de Vigo, NW Iberian Peninsula) during July 2023 (dry period) and March 2024 (wet period). Samples were collected at local subterranean estuaries (8), wells (7) and rivers (2), as well as in surface and deep waters of the Ría de Vigo (where a slight gadolinium (Gd) anomaly was detected due to domestic effluents from the WWTPs). Concentrations of total REEs (ΣREEs) were higher in the wells and rivers compared to STE and ría waters. Normalized patterns of REEs were distinctive for each well and river and were in agreement in both sampling campaigns – although higher total concentrations were determined in the wet period – indicating that their distribution is controlled by the lithological setting. Rare earth element patterns at the STE varied at the two sampling dates and did not followed a continuum with respect to the end-members (groundwater and ría waters); instead, the decrease in REEs concentrations at the STE and the appearance of a sharp positive anomaly of the particle-unreactive anthropogenic Gd suggests that STE may act as a sink of dissolved REEs in this area.

Keywords: *Rare earth elements, subterranean estuary, geochemical processes, gadolinium anomaly*

Acknowledgements: This research was funded by the projects INTEGROUNDS, (TED2021-130020B-C21/ AEI/10.13039/501100011033/ European Union NextGenerationEU/PRTR) and UNDERGROUND (Galician Marine Science Program, part of the Complementary Science Plans of the Ministry of Science, Innovation, and Universities, included in the Recovery, Transformation, and Resilience Plan (PRTR-C17.I1), funded through the Xunta de Galicia with Next Generation EU funds and the European Maritime, Fisheries, and Aquaculture Fund of the European Union).

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REDOX-SENSITIVE TRACE METAL MOBILITY IN THE DEEP SUBSURFACE OF A HIGH-ENERGY BEACH

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ABSTRACT

Intertidal sandy high-energy beach subterranean estuaries (STE) represent complex and dynamic biogeochemical reactors. The aim of our study was to assess trace metal mobility, with a special focus on Co, along redox and salinity gradients in the deep STE of a high-energy beach on Spiekeroog Island (Germany). Groundwater down to 24 m was sampled from permanent wells and by additional direct push sampling to obtain a high resolution cross-sectional view on the deep STE biogeochemistry between 2022 and 2024. Sediments were collected during the well installation in 2022. Co behavior revealed a specific mobilization horizon, which was predominantly related to zones of incipient Mn reduction. Fe reducing conditions resulted in Co removal to the solid phase, possibly due to accompanying slight sulfate reduction and the formation of Co-rich Fe sulfides or CoS. Solid phase analyses indicated that the potential for metal oxide and Co mobilization was highest in a former tidal flat sediment layer, which is currently covered by ~5 meters of beach sands and underlain by Pleistocene glacio-fluvial deposits. Co mobilization and removal behavior observed in the field could be reproduced in a laboratory incubation experiment illustrating high release and removal rates of Co along a redox gradient of oxic to Fe/potentially slightly SO_4 reducing conditions in comparison to the redox-

related reactivity of U, Mo, and Re. With regard to coastal element budgets, high-energy beach STEs may favour Co mobilization due to high electron acceptor supply resulting in less reducing conditions and spatially extended intermediate redox levels. Furthermore, discharge of elements like Co, Mn, and Fe may be enhanced by advective groundwater flow in contrast to diffusion-dominated systems where the exfiltration is more likely to be limited by reoxidation processes.

Keywords: *subterranean estuary, cobalt, uranium, rhenium, molybdenum*

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AI-QUIFER – DETERMINING OFFSHORE GROUNDWATER OCCURRENCES BY THE APPLICATION OF ARTIFICIAL INTELLIGENCE

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In numerous coastal regions the salt/fresh water interface is moving landward. However, it may also be located 10s of kilometres seaward on the ocean shelf, indicating the presence of offshore freshened groundwater resources. The genesis of these offshore freshened groundwater (OFG) resources most probably dates back to previous glacial periods when sea levels were substantially lower, facilitating the deposition of freshwater in the land and now marine sediments (Fig. 1). While some of these offshore brackish lenses are disconnected from present-day land systems, others continue to be replenished by land-based aquifers, generating SGD.

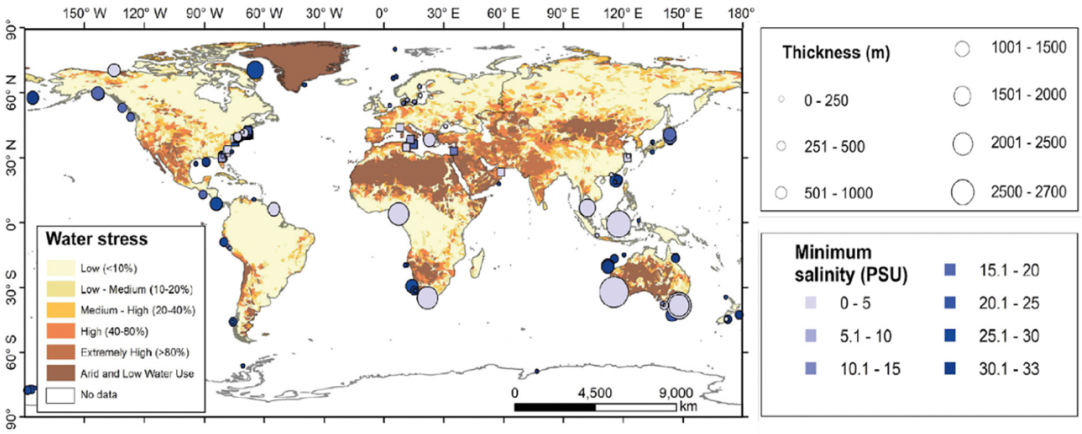

Fig. 1: Global Map of water stress [12]; together with estimated OFG thickness and minimum salinity [2]. Square symbols denote sites where OFG thickness could not be detected.

OFG bodies depend on long-term processes that are driven from within the catchments that recharge the hydraulically transmissive sedimentary bodies along the global coastlines. There are

certain prerequisites that are necessary to facilitate the formation and preservation of freshwater in (nowadays) offshore aquifers. These are (i) the hydrogeological composition of the feeding terrestrial catchments, (ii) permeable shelf sediments hosting the OFG and particularly important (iii) either a fine-grained sediment cover, acting as an impermeable layer and protecting freshwater from seawater infiltration or (iv) effective hydraulic gradients between groundwater tables on land, hydraulically connected to the OFG bodies and the sea level. Climatic factors in conjunction with the catchment topography, in particular slope and drainage patterns, control the volume and pressure of freshwater transported towards the coast, which allowed flushing of shelf sediments during sea level low stands and can now contribute to a continuous recharge of the onshore-connected OFG bodies.

OFG research faces two main challenges: (1) there is very limited data on the extent of global OFG bodies and most of this data data is present as point source data rather than areal information. (2) the majority of past hydrogeological studies have not taken into account the onshore-offshore connectivity of aquifers. There are only a few places along the Earth's approximately 350 000 km length of coast, where systematic studies of offshore freshened groundwater based on 2D marine geophysical data and amphibious hydrogeological models have been investigated [1, 2]. Expensive geophysical exploration techniques, in particular marine electromagnetics, are useful for the identification and characterisation (eg. volume, salinity gradients and coastal connectivity, [3]) of OFG but are only feasible where OFG occurrence is likely or has already been established. The AI-quifer project aims to bridge this knowledge gap by applying data-driven ML techniques to account for the complex underlying mechanisms of OFG emplacement and preservation. In line with recent developments in terrestrial data-driven groundwater modelling [4-7], we apply globally available geospatial datasets of various disciplines (e.g. physical geography, geology, hydrogeology, climate) to train KI-based algorithms to derive probability maps of the location of the coastal fresh/saltwater interface.

The initial phase of the project focused on the generation of a suitable training dataset, which will be augmented by hydrogeological modelling. Therefore, hydrogeologic cross sections perpendicular to the coastline are derived from borehole data and geologic maps for the coastal regions of New Jersey and Martha's Vineyard, Massachusetts. These profiles span approximately 160 km, extending from the groundwater divide on land to offshore areas where the seafloor reaches 50 meters depth (Fig. 2). The profile sections are combined with offshore geophysical observations to quantitatively and qualitatively simulate an onshore-offshore groundwater system, applying numerical flow model (FeFlow). Transient runs were performed over the last interglacial period, starting ca. 120,000 years ago, when sea level and climatological conditions were supposed to resemble those of today. Boundary conditions and groundwater recharge as

driving force have been defined based on long-term climatological and sea-level fluctuation data series [8].

Although these models are constructed and parameterized with considerable uncertainties, the results are reasonable and align with the current situation, thereby demonstrating their reliability.

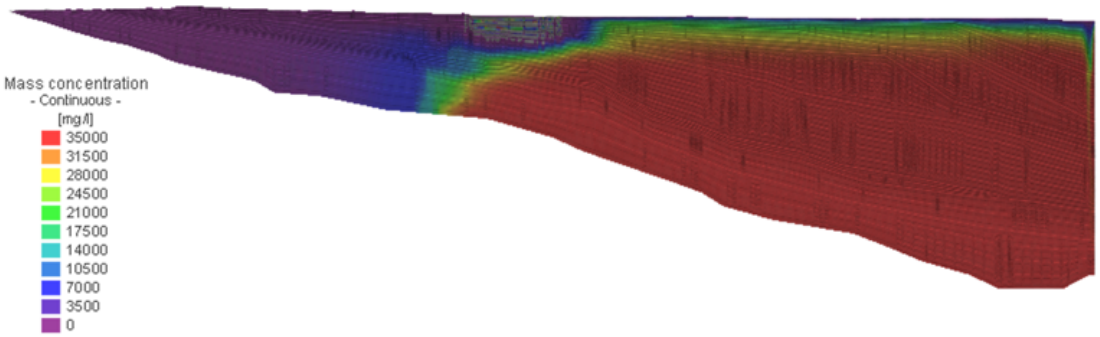

Fig. 2. Simulation results of the transient model reveal the mass concentration (mg/L) at the state following the last ice age, approximately 10,000 years ago. The results indicate that, after the last glacial maximum, freshening occurred due to groundwater recharge, which extends to depths of over 200 meters.

Sensitivity analyses as for the influence of parameter shifting (e.g. hydraulic conductivities) indicate temporal variabilities in the development of the OFG lens. Therefore, the models also shed light on the behaviour and influence of hydraulic conditions on the development of OFG due to changing boundary conditions (transmission from glacial to interglacial). With the completion of the data mobilization, ML optimization will commence. For validation purposes we focus our initial modelling efforts on the US East Coast, in particular the well-studied coast of New Jersey [9]. Eventually, the fine-tuned ML method will be applied to gain insights and guide active research into the largely unknown OFG systems of New Zealand [3, 10, 11]. The work presented here will highlight the knowledge gain from the initial data mobilization phase of the AI-quifer project.

References

[1] J. Bear, A. H. D. Cheng, S. Sorek, D. Ouazar, and I. Herrera, Eds., *Seawater intrusion in coastal aquifers: Concepts, methods and practices*. Netherlands: Springer Science & Business Media, 1999.

[2] A. Micallef, M. Person, C. Berndt, C. Bertoni, D. Cohen, B. Dugan, et al., "Offshore freshened groundwater in continental margins," *Reviews of Geophysics*, vol. 58, e2020RG000706, 2021.

[3] Z. Faghih, A. Haroon, M. Jegen, R. Gehrmann, K. Schwalenberg, A. Micallef, J. Dettmer, C. Berndt, J. J. Mountjoy, and B. A. Weymer, "Characterizing Offshore Freshened Groundwater Salinity Patterns Using Trans-Dimensional Bayesian Inversion of Controlled Source

Electromagnetic Data: A Case Study From the Canterbury Bight, New Zealand," *Water Resources Research*, vol. 60, no. 3, e2023WR035714, 2024.

[4] M. J. Asher, B. F. W. Croke, A. J. Jakeman, and L. J. M. Peeters, "A review of surrogate models and their application to groundwater modeling," *Water Resour. Res.*, vol. 51, pp. 5957–5973, 2015.

[5] G. Kopsiaftis, E. Protopapadakis, A. Voulodimos, N. Doulamis, and A. Mantoglou, "Gaussian Process Regression Tuned by Bayesian Optimization for Seawater Intrusion Prediction," *Computational Intelligence and Neuroscience*, vol. 2019, pp. 1–12, 2019.

[6] E. A. Hussein, C. Thron, M. Ghaziasgar, A. Bagula, and M. Vaccari, "Groundwater Prediction Using Machine-Learning Tools," *Algorithms*, vol. 13, pp. 300, 2020.

[7] M. E. Gerlach, K. C. Rains, E. J. Guerrón-Orejuela, W. J. Kleindl, J. Downs, S. M. Landry, and M. C. Rains, "Using Remote Sensing and Machine Learning to Locate Groundwater Discharge to Salmon-Bearing Streams," *Remote Sensing*, vol. 14, pp. 63, 2021.

[8] http://www.sealevels.org

[9] C. Gustafson, K. Key, and R. L. Evans, "Aquifer systems extending far offshore on the U.S. Atlantic margin," *Sci Rep*, vol. 9, pp. 8709, 2019.

[10] L. K. Morgan and J. J. Mountjoy, "Likelihood of offshore freshened groundwater in New Zealand," *Hydrogeol J*, vol. 30, pp. 2013–2026, 2022

[11] A. Micallef, M. Person, A. Haroon, B. A. Weymer, M. Jegen, K. Schwalenberg, Z. Faghih, S. Duan, D. Cohen, J. J. Mountjoy, S. Woelz, C. W. Gable, T. Averes, and A. Kumar Tiwari, "3D characterisation and quantification of an offshore freshened groundwater system in the Canterbury Bight," *Nature Communications*, vol. 11, Art. No. 1372, 2020.

[12] R. W. Hofste, S. Kuzma, S. Walker, E. H. Sutanudjaja, M. F. Bierkens, M. J. Kuijper, et al., "Aqueduct 3.0: Updated decision-relevant global water risk indicators," World Resources Institute, Washington D.C., 2019.

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BRIDGING LAND-SEA TO INVESTIGATE SALTWATER INTRUSION AND SUBMARINE GROUNDWATER DISCHARGE (GRANADA, SE SPAIN): THE META PROJECT

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ABSTRACT

A set of coordinated techniques has been applied in the study of the coast of Granada (South-East Spain) aiming for the identification and characterization of saltwater intrusion and submarine groundwater discharge simultaneously. Through the study of a range of coastal aquifer types and with the combination of methods developed from the sea and in land, it has been possible to provide a full picture of the processes taking place along a region where freshwater is essential for society.

The methods in land included in addition to the geological research, the monitoring of the water table and the salinity changes in groundwater, the use of transient electromagnetic, electrical resistivity tomography and chargeability, and gravimetry techniques and the groundwater modelling as integration tool. For the study in the sea, radon was used as tracer of groundwater discharge, together with measurements of temperature and salinity in the bottom of the sea combined with high resolution seismic to characterize the sediments under the sea. The study area included a range of settings from thick sedimentary aquifers with several recharge sources to limited size and highly salinized aquifers, and carbonate systems affected by karstification.

The combined interpretation of results showed different cases along the coast despite all the coastal aquifers are very proximal to each other. High resolution seismic profiles reveal the heterogeneous character of the geological structure offshore and show the presence of coarse sedimentary units that possibly favours the groundwater discharge, even at long distances from the coast. The methods in land showed a high degree of variability of the geometry of the freshwater-saltwater interface due to geological factors and the variable aquifer recharge. The ongoing research of META project will contribute to determine the characteristics and factors affecting to groundwater discharge in this region.

Keywords: *Saltwater intrusion monitoring, geophysics, radon, SGD, combined methods*

META Team: Ángela Blanco-Coronas, Cecilia Morales, Gemma Ercilla, María Luisa Calvache, Manuel López-Chicano, Marta García, Christian Montoro, Víctor Mora, Víctor Tendero-Salmerón, Antonio Pulido-Bosch, José Benavente Herrera, Lourdes González-Castillo, Francisco Martínez Moreno, Francisco Lamas, Asier Madarieta, María Teresa Pedrosa González, Rhaissa de Souza, Denys Grombacher and Holly Michael.

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CHARACTERISATION OF SUBMARINE GROUNDWATER DISCHARGE IN THE GOZO MEAN SEA LEVEL AQUIFER SYSTEM

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ABSTRACT

Coastal groundwater discharge (CGD) is an important element of the natural water balance in small carbonate islands. Numerical models developed for the mean sea level aquifer systems in Gozo highlight that CGD could account for up to 50% of the mean annual recharge. In spite of this, studies on CGD remain limited.

To study the occurrence of CGD and the relative prevalence of diffuse and point coastal discharges in Gozo, thermographic surveys were undertaken during the periods of peak temperature difference between discharging groundwater and the receiving marine waters. The thermographic surveys were complemented by a survey of submerged marine caves undertaken under the LIFE BAHAR[1] project which led to the identification of specific sites of concentrated CGD.

Three sites with a marked temperature anomaly located along the South-Western coast of Gozo were selected by the Energy and Water Agency (EWA) and surveys were undertaken with the aim of outlining their main hydrogeological characteristics by a team of hydrogeologists and divers.

Probes were installed at the discharge points continuously measuring Electrical Conductivity, Temperature and Pressure to enable an assessment of the variation in these parameters during the year. EC and Temperature are indicators of the level of mixing of discharging groundwater with marine waters, whilst Pressure is an indicator of wave action and the enhanced ingress of marine water. Additionally, samples of the outflowing groundwater were collected from all three sites using robust syringes and analysis for chemical parameters were undertaken.

From a hydrogeological perspective, all the discharge points are located along fault-planes where submerged caves have developed. Data analysis indicate different mixing functions depending on the season and influence of marine waters. Invariably, however, all three discharges are limited quantitatively and do not justify commercial exploitation.

Keywords: *Coastal Groundwater Discharge, Submerged Marine Cave, Groundwater Balance, Thermographic Survey*

[1] The LIFE Bahar (LIFE12 NAT/MT/000845) Project was co-financed under the EU LIFE Programme

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IDENTIFYING GROUNDWATER DISCHARGE TOWARDS THE MAR MENOR LAGOON (SE SPAIN) COMBINING GEOPHYSICAL AND ENVIRONMENTAL TRACER METHODS

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ABSTRACT

Groundwater discharge is a crucial process for relevant hydrological and ecological processes in coastal environments, contributing to coastal stability, lagoon resilience, geochemical mass balances, or nutrient cycling. However, growing urban and agricultural development induce severe groundwater pollution and contributes to the degradation of coastal ecosystems. This is the case of the Campo de Cartagena aquifer – Mar Menor lagoon system (Murcia, Spain), where the lagoon has experienced severe eutrophication events linked to nutrient inputs through surface and groundwater flows. Surface water inputs are well known and consist of one permanent stream and sporadic runoff derived from heavy rainfall. The existence of permanent submarine diffuse groundwater discharge (SGD) is hypothesized since long ago. This work studies the hydrogeological conditions for the existence of SGD to the Mar Menor in different seasons, using a combination of electrical resistivity tomography (ERT) and environmental tracers (Cl^-, ^{18}O, ^{2}H). To perform the work, four land-sea transects were studied in two field surveys carried out in April and November 2023. ERT data were generated using an amphibious electrode arrangement perpendicular to the coast, and tracer data of shallow groundwater in emerged and submerged sediments were obtained using push-point piezometers. ERT showed the existence of a huge volume of fresh water under the Mar Menor bottom, penetrating as far as 80 m from the shore. The hydraulic gradient favoured diffuse SGD across the bottom. Tracer mass balances confirmed the existence of SGD at least up to 35 m from the shoreline. The shape and size of the fresh water mass remained stable during the study and are expected to maintain along years if the piezometric levels near the coast does not decrease significantly. This work is part of projects funded by the Spanish Ministry of Science and Research, the Séneca Foundation and the European Union.

Keywords: Mar Menor, submarine groundwater discharge, electrical resistivity tomography, environmental isotopes

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INTEGRATED ASSESSMENT OF CONTINENTAL GROUNDWATER DISCHARGE IN COASTAL CRYSTALLINE BASINS

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ABSTRACT

Crystalline coastal basins are predominantly composed of hard, low-porosity rocks such as granites and gneisses. As such, they are often considered of low groundwater storage capacity and, therefore, irrelevant in terms of continental groundwater discharge to the coast. In these systems, groundwater storage capacity and movement largely depend on the extent of basement rock fracturing, weathering, and regolith thickness, creating complex and heterogeneous flow paths as well as diffusive discharges difficult to observe at the shore. An integrated study of continental groundwater discharge was conducted in a coastal inlet surrounded by a crystalline drainage basin (Ría de Vigo, NW Iberian Peninsula) during July 2023 (dry period) and March 2024 (wet period). For this, a multitracer (^{222}Rn, ^{226}Ra, stable isotopes of water, thermal imagery) and multianalyte study of embayment's surface waters was complemented with a synoptic survey of local subterranean estuaries (8), wells (7) and rivers (2). A large enrichment in ^{222}Rn (up to 1250 Bq m^{-3}) was observed in the inner flanks of the embayment (San Simón and Baiona bays), attributable to continental groundwater discharge. These are tidally modulated, peaking during low tide, but also by the complex circulation patterns within the embayment. The water isotopic signature confirmed the presence of continental groundwater within the embayment and in the sampled subterranean estuaries, where discharge is observable through thermal imagery. Continental groundwater discharge is a significant portion of total freshwater input into the system; however, its composition drastically changes as it passes through local subterranean estuaries. These, predominantly anoxic in contraposition to the local oxic groundwaters, modulate the transfer of land-derived solutes such as nutrients, organic matter, metals or rare earth elements, which affects the local microbial community structure and composition. Results emphasize the need for interdisciplinary approaches to quantify and monitor these hidden yet impactful groundwater flows in crystalline coasts.

Keywords: *Submarine groundwater discharge, coastal crystalline basin, subterranean estuary, seepage face, coastal management*

Acknowledgements: This research was funded by the projects INTEGROUNDS, (TED2021-130020B-C21/ AEI/10.13039/501100011033/ European Union NextGenerationEU/PRTR) and UNDERGROUND (Galician Marine Science Program, part of the Complementary Science Plans of the Ministry of Science, Innovation, and Universities, included in the Recovery, Transformation, and Resilience Plan (PRTR-C17.I1), funded through the Xunta de Galicia with Next Generation EU funds and the European Maritime, Fisheries, and Aquaculture Fund of the European Union).

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NEW DISCOVERY OF OFFSHORE FRESHENED GROUNDWATER OFF THE COAST OF SOUTH-EAST SPAIN

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ABSTRACT

Fresh groundwater has been detected for the first time in submarine sediments off the Motril-Salobreña aquifer in the southern coast of Spain, at 1-2 km from the shoreline in the subaqueous portion of a deltaic system. The freshwater has been identified by direct measurements of electrical conductivity after extracting pore water from sediment cores collected during the SANIMED oceanographic survey in 2024. The freshwater has been detected at several locations in the shelf off the Guadalfeo River delta indicating that the submarine freshwater occurrence is pervasive off the coastal aquifer.

The correlation between sampling locations and high-resolution sub-bottom acoustic profiles acquired in the study area reveals that freshwater is detected at two stratigraphic levels. The shallower occurrence is related to stratified acoustic facies which are overlain by laterally discontinuous chaotic sheets. Since these confining sediment sheets are not continuous, submarine groundwater discharge is likely to occur where the confining unit abuts against widespread stratified facies. The deeper occurrence is related to deposits bounded by a major erosional unconformity, sealed by low-angle, low-amplitude shelf deposits. Such occurrences are tentatively assigned to the late Holocene highstand and to the Last Glacial Maximum intervals.

Two hypotheses can be proposed to explain the occurrence of submarine freshwater in the Guadalfeo deltaic system: I) submarine groundwater discharge from the coastal aquifer, which receives significant recharge from river infiltration and its irrigation systems that distribute water over most of the surface of the aquifer; II) relict freshwater trapped in the shelf during previous lowstand conditions. This discovery has important implications for regional water management, as this is an area frequently affected by droughts.

Keywords: *Offshore freshened groundwater, seismic methods, SGD*

SANIMED SCIENTIFIC TEAM*: Bárcenas, P., Cabrera, C., Cerrillo-Escoriza, J., Durán, R., López-Quirós, A., Luján, M., Mendes, I., Pérez-Asensio, J.N., Portnov, A., Quintana, R., Rosales, A., Sánchez, M.J., Sánchez Guillamón, O., Verweirder, L.

Salt Water Intrusion Congress (SWIM 2025)

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OFFSHORE FRESHENED GROUNDWATER IN THE LEVANT BASIN: DIFFERENT MODES OF ACTIVE LAND-SEA CONNECTEDNESS DICTATE DIFFERENT HYDROLOGIC FUNCTIONING

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ABSTRACT

We explore the modes of onshore-offshore connection of confined aquifers in the Levant Basin, Eastern Mediterranean Sea, where large regional Karst aquifers extend into the continental shelf and feed historically documented submarine springs. Recently, an active Offshore Freshened Groundwater (OFG) system has been discovered in the southern part of the Levant Basin, near Israel. This system features a confined aquifer from the Cretaceous that is exposed to the sea along a submarine canyon, forming a hydrogeologic land-to-sea connection, which transports terrestrial water offshore. This has been documented by submarine groundwater discharge of freshened groundwater far (5 km) and deep (400 m) offshore Israel. In this study, we analyze the mode of onshore-offshore connection of the same confined aquifer in the northern Levant basin, offshore Lebanon. Here, the confined aquifer is connected to the sea via a submarine fault that cuts through the confining layer rather than exposure by an erosive canyon. We present simulations of the two different modes of active OFG, i.e., through canyon or faults, and highlight the differences in their hydrologic functioning, which have an impact on the potential for pumping-induced saltwater intrusion into the confined aquifer and responses to sea-level changes. The comparison between two adjacent systems in the Levant Basin, occurring in the same geologic unit, provides a unique opportunity to better understand and isolate the importance of specific hydrogeologic configurations in controlling the dynamics of active OFG. In addition, this talk will present and discuss differences that the canyon and fault connection modes induce in the lateral (alongshore) flow and salt transport in the confined aquifer. This 3D analysis is an important contribution to our overall understanding of active OFG, as studies of onshore-offshore aquifers traditionally focus on the cross-shore dimension (including the two mentioned above).

Keywords: *Offshore Freshened Groundwater, Confined Aquifers, Marine Hydrogeology*

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SOCIO-ECONOMIC PERSPECTIVES ON OFFSHORE FRESHENED GROUNDWATER: INSIGHTS FROM OFF-SOURCE COST ACTION

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ABSTRACT

Coastal aquifers, situated at the interface of oceanic and hydrologic systems, provide vital freshwater resources for over one billion people. However, these systems are increasingly stressed due to overexploitation, urbanization, and climate change, necessitating innovative solutions to address freshwater scarcity. Offshore freshened groundwater (OFG) refers to water stored in the sediments pores and rock fractures beneath the seafloor that has a salinity lower than that of seawater. It represents a promising yet untapped resource, but its technological, economic, environmental, and socio-political feasibility remains uncertain. This talk presents insights from the OFF-SOURCE COST Action, a multidisciplinary initiative aimed at evaluating the presence and volumes of OFG on European margins and beyond, and more in general, at addressing its sustainability as a resource for water-stressed coastal regions. Key outcomes from OFF-SOURCE to date include the development of new databases cataloguing OFG occurrences and relevant infrastructure across EU member countries, alongside technical reports and cost-effectiveness analyses that provide a foundation for assessing the viability of OFG utilization. These efforts contribute to a more comprehensive understanding of OFG distribution, accessibility, and potential pathways for protection and sustainable use. By drawing on outcomes from OFF-SOURCE activities, this presentation will highlight the evolving discourse on OFG, outline knowledge gaps, and discuss pathways for future research and collaboration. The talk will also introduce the OFF-SOURCE network and its objectives, inviting participants to contribute to ongoing efforts in shaping the future of offshore groundwater research and management.

Keywords: *offshore freshened groundwater, coastal aquifers*

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12 YEARS OF MONITORING CONTROLLED ARTIFICIAL RECHARGE AND DRAINAGE (CARD) IN ZEELAND, THE NETHERLANDS; INSIGHTS AND SIGNIFICANCE TO INCREASE FRESHWATER AVAILABILITY FOR IRRIGATION

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ABSTRACT

In 2013, a controlled artificial recharge and drainage (CARD) system was installed in Zeeland, southwestern Netherlands. The CARD system aims at increasing a freshwater lens and freshwater supply for irrigation in an area where both surface water and groundwater are predominantly saline and there is no external supply of freshwater for irrigation. Pauw et al. (2015) published the results of the first year of monitoring after implementation of the CARD system, as well as a model to predict how the development of the freshwater lens would continue in the following 10 years. Between 2013 and 2025, monitoring of the CARD system continued, first focusing on the increase of the freshwater lens and since 2023 also on saltwater upconing below two horizontal wells, which are used to extract fresh groundwater for irrigation.

12 years of monitoring the CARD system have given valuable information on the dynamics of the freshwater lens. The model results of Pauw et al. (2015) clearly show an overestimation of the growth of the lens. Drilling and geophysical logging data collected in 2022 indicate more low-permeable layers than were implemented in the model, which could explain the observed limited growth of the lens. These layers also limit the speed at which saline groundwater migrates to the horizontal wells. Our understanding of the geological context and the spatial distribution of these low-permeable layers should be improved to better quantify the influence of these layers on freshening, salinization, and sustainable pumping rates. Future work should also focus on water quality and filtration requirements of artificial recharge water, as well as assessing clogging risks of the tile drains, to better assess the potential of CARD systems to increase freshwater supply in the region.

Pauw, P.S., van Baaren, E.S., Visser, M., de Louw, P.G.B., and Oude Essink, G.H.P. (2015). Increasing a freshwater lens below a creek ridge using a controlled artificial recharge and drainage system: a case study in the Netherlands. *Hydrogeology Journal*, *23*(7), 1415–1430. https://doi.org/10.1007/s10040-015-1264-z

Keywords: *artificial recharge, freshwater lens, monitoring*

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A New Multiscale and Multisensory Approach for Coastal Groundwater Discharge – the SUBGEO Project

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ABSTRACT

The characterization and monitoring of groundwater resources play a crucial role in the sustainable development and management of coastal areas. This is a fundamental aspect considering the climate changes occurring in areas particularly exposed to coastal erosion, groundwater salinization, flooding and other hazards in low-lying coastal zones. Moreover, coastal freshwater reservoirs can represent a fundamental resource to address water shortages.

The hydro-geological potential and economic factors linked to the groundwater and to submarine groundwater are the starting point of the two-year Italian Research Project of National Relevance (PRIN-2022) SUBGEO (funded by the European Union-NextGeneration EU, Mission 4, Component 2, INVESTMENT 1.1, CUP H53D23011270001) where the University of Bari (UNIBA) and the two Institutes (IMAA and IRPI) of the National Research Council are involved. The project is focused on the submarine groundwater discharge analysis with an innovative and integrated geophysical approach based on the use of electric and electromagnetic methods for the twofold targets of coastal underground freshwater reservoir non-invasive characterization and to gain useful tools for the optimal and sustainable management of the coastal areas and resources.

Here we present the first project results which consist in the output of geophysical investigation

strategy tuning phase and in investigation strategy application in three different test areas located in Puglia region and Pianosa Island.

As regard as the tuning phase, it has been focused on the definition of the best acquisition procedures to follow and to check the sensitivity of the strategy for different subsurface conditions. All these activities have been performed by developing small-scale laboratory experiments, numerical simulations and field tests.

Keywords: *Electrical resistivity, Electromagnetic methods, Coastal Aquifer, Subsurface Characterization.*

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ALL THINGS FLOWING AT THE COAST – A COMMUNITY EFFORT PROPOSAL

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ABSTRACT

Coastal environments are characterized by pronounced hydrological, physical and chemical gradients where terrestrial freshwater cycles meet the saltwater systems of the ocean. Research at this interface is inherently multidisciplinary, engaging marine chemists, biologists, geophysicists, hydrogeologists, and sedimentologists, among others. This diversity of perspectives has led to a proliferation of conceptual models and terminologies for describing coastal flow phenomena, particularly in the context of saltwater intrusion and submarine groundwater discharge.

For instance, the mixing zone of saltwater and freshwater is in hydrogeology often termed 'coastal aquifer', in geochemistry 'subterranean estuary' and in biology sometimes 'anchialine' habitat. Similarly, the extent of the 'coastal aquifer' is ambiguous – does it only encompass the mixing areas or does it reach inland up to the watershed? Another example is the difference between pore water exchange and submarine groundwater discharge that is ambiguous in some instances. These issues have been the subject of ongoing debate for decades, but this initiative could be an opportunity to tackle this discussion in a structured effort.

Here, we propose a comprehensive, community-driven initiative to synthesize and standardize definitions of coastal hydrological features. Our approach entails aggregating diverse datasets and conceptual frameworks in questionnaires spread to the diverse coastal research community. We will distil the information from the responses, extract features and definitions which we will then discuss in a structured way with the community. Ultimately, we will publish the product showcasing the variety of community knowledge as a community effort. We invite the conference participants to join the discussion during our poster session, shape the process and fill in the first questionnaires. Eventually, this discussion will help us to produce exchange for more compatible research between the different disciplines involved in the complex system of the coast.

Keywords: *coastal hydrology; definitions; interdisciplinary; knowledge collection*

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An Integrative Approach to Submarine Groundwater Discharge and Seawater Intrusion: Insights from the Odisha Coast, India

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ABSTRACT

Submarine Groundwater Discharge (SGD) and Seawater Intrusion (SWI) are opposing yet interconnected processes along the land-sea continuum that shape coastal groundwater dynamics. This study identifies SGD and SWI zones along the water-stressed Odisha coast using a multi-proxy approach and quantifies SGD and associated chemical fluxes through seepage meter measurements. A total of 340 samples (85 per season: 30 porewater, 30 seawater, and 25 groundwater) were collected across ~145 km of coastline during two pre- and two post-monsoon seasons. Elevated groundwater electrical conductivity (>3000 µS/cm) indicated three probable SWI sites, while low porewater salinity (<32 ppt in pre-monsoon, <25 ppt in post-monsoon) suggested four SGD zones. These findings were validated by hydraulic gradients (positive >10 m near SGD, negative <0 m near SWI) and anomalous sea surface temperature patterns. Hydro-geochemical analysis and stable isotopic signatures further confirmed the identified sites. SGD fluxes, measured via Lee-type seepage meters, ranged from 2940.91–4247.97 $m^3 \cdot m^{-2} \cdot y^{-1}$ in post-monsoon (Dec 2022) and up to 1503.13 $m^3 \cdot m^{-2} \cdot y^{-1}$ in pre-monsoon (May 2023), among the highest global seepage rates. Nutrient fluxes varied from 1308.14–12863.81 $mmol \cdot m^{-2} \cdot y^{-1}$ (total carbon), 154.3–849.9 $mmol \cdot m^{-2} \cdot y^{-1}$ (dissolved silica), 48.35–261.54 $mmol \cdot m^{-2} \cdot y^{-1}$ (total nitrogen), 57.04–203.65 $mmol \cdot m^{-2} \cdot y^{-1}$ (nitrate), and 0.85–9.12 $mmol \cdot m^{-2} \cdot y^{-1}$ (phosphate). Heavy metal fluxes followed the order B > Sr > Li > Ba > Al > As > Fe > Cu > Co > Ni > Mo > Be > Mn. Despite high seepage rates, relatively low chemical fluxes suggest dilution, limited contaminant sources, adsorption, or biogeochemical attenuation. This study provides the first SGD flux estimates from Odisha's coastal plains, emphasizing the need for further research on subterranean estuarine processes to refine our understanding of fresh-saline interactions and material transport mechanisms.

Keywords: *Submarine Groundwater Discharge, Seawater Intrusion, Coastal groundwater dynamics, Subterranean Estuary, Chemical Fluxes*

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ASSESING THE IMPACT OF AQUIFER HETEROGENEITY ON COASTAL GROUNWATER FLOW AND SALT DISTRIBUTION UNDER TIDAL FORCING

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ABSTRACT

This research investigates the effects of transient sea levels and aquifer heterogeneity on groundwater flow and solute transport in coastal aquifers through simulations. Using FEFLOW, a finite-element groundwater flow and solute transport model, we conducted 2D simulations, a 200 [m] length over 20 [m] depth simulation, in a Monte Carlo work frame to analyze groundwater flow and salt transport under tidal sea-level fluctuations and changing heterogeneity properties. We used object-based modeling, as well as geostatistical realizations utilizing the sequential indicator simulation (SISIM) algorithm through the Stanford Geostatistical Modeling Software (SGeMS) program. Our preliminary results reveal transient responses in groundwater flow paths to tidal changes, showing areas of preferred flow, along with an increase in the size of the saltwater transition zone, compared to equivalent homogeneous models. In addition, we see a decrease in overall groundwater circulation volumes based on heterogeneity at the tidal zone boundary facies distribution. By comparing heterogeneous and homogeneous models, we assess the effects of different lithological connectivity measures on flow patterns, volumes and solute transport, such as an increase in the fresh saline intertidal zone volume in heterogeneous simulations compared to homogeneous ones, with the greatest difference being between high connectivity steady state and transient simulations. The results provide insight into how heterogeneity affects circulation volumes and salinity distribution, offering information for future coastal aquifer management.

Keywords: (*simulation, heterogeneity, tide*)

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ASSESSING NEARSHORE SUBMARINE GROUNDWATER DISCHARGE DYNAMICS IN CONTRASTING GEOLOGICAL SETTINGS USING AMPHIBIOUS ELECTRICAL RESISTIVITY TOMOGRAPHY

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ABSTRACT

Submarine groundwater discharge (SGD) is a critical yet complex hydrological process influencing coastal water quality, nutrient fluxes, and ecosystem dynamics. Its quantification is challenging due to the multiple mechanisms driving groundwater flow, including hydraulic gradients, wave action, tidal forces, and the geological heterogeneity of coastal aquifers. This study employs Amphibious Electrical Resistivity Tomography (AERT) to investigate the spatial and temporal variability of SGD in the nearshore zone of two distinct coastal settings on the microtidal Mediterranean coast.

AERT integrates terrestrial and marine geophysical techniques to bridge the observational gap at the land-sea transition zone, enabling high-resolution imaging of subsurface salinity variations. To validate resistivity data, we

conducted complementary field measurements, including porewater sampling, manual piezometers, and seepage meters, to characterize groundwater flow and solute fluxes. Our results reveal significant differences in nearshore SGD dynamics between the two geological settings. In the karstic environment, high resistivity values indicate well-defined freshwater discharge pathways controlled by fractures and conduits, leading to rapid salinity fluctuations in marine sediments. In contrast, the detrital aquifer exhibits more diffuse discharge patterns, with slower and more gradual salinity variations. Temporal resistivity changes align with minor sea-level oscillations, suggesting that even under microtidal conditions, pressure-induced shifts can modulate groundwater discharge rates.

These findings highlight the effectiveness of AERT as a tool for monitoring SGD in the nearshore zone of different coastal environments. Integrating geophysical, hydrogeological, and geochemical approaches provides insights into small-scale and short-term variations in freshwater-seawater interactions, improving the quantification of SGD, assessing its ecological and hydrological implications, and contributing to a better understanding of submarine groundwater discharge processes.

Keywords: *SGD, Mediterranean Sea, Electrical resistivity tomography, Coastal groundwater*

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Assessment of Aquifer Salinity Variations in the La Pletera Salt Marsh Area (NE of Catalunya) by Means of ERT

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ABSTRACT

This study was carried out in the La Pletera salt marsh area (NE of Catalunya), situated in the north of the Ter River mouth. This area presents a coastal lagoon system associated with the shallowest aquifer levels of the Ter River fluviodeltaic system (10-20 m thick). Which are composed of prograding alluvial deposits, replaced by coastal deposits (marshes, dunes, and beaches) in the areas closest to the shoreline. The salinity regimes of these lagoons fluctuate significantly according to the volume of freshwater inputs from surface and groundwater sources, the presence of underlying sediment with low permeability and the climate conditions.

The aim of this study is to determine the variation in aquifer salinity, comparing the dry and wet periods of the year, as well as considering the aquifer-lagoon interactions. Fifteen Electrical Resistivity Tomography (ERT) campaigns were conducted periodically from June 2022 to November 2024, combined with continuous measurements of electrical conductivity (EC), temperature, and water levels of the main lagoons and superficial piezometers, located next to the lagoons. Additionally, during each campaign, potentiometric measurements were taken from nearby wells, to determine the water table evolution of the Ter River fluviodeltaic aquifer.

The study period coincides with a severe drought episode, during which precipitation was 30% below the average, leading to reduced freshwater recharge to the aquifers. Potentiometric data show a constant decline in the water table levels of the aquifers, decreasing by 0.3 to 1.5 m during the study period. Meanwhile, the continuous EC measurements and the ERT profiles reveal a progressive inland advance of seawater and the leaching of hypersaline water from the lagoons to the aquifer.

This study has been realized within the framework of the collaborative international Project consortium TREASURE (PCI2024-153436) and the AquiPondSys grant (PID2023-147186OB-I00), funded by MCIN/AEI/10.13039/501100011033.

Keywords: *coastal lagoon system, saline intrusion, fluviodeltaic aquifer and Electrical Resistivity Tomography (ERT).*

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BARITE IN FRESHWATER SEDIMENTS OF THE BALTIC SEA CRYSTALLISES IN A DIFFUSIVE SALINISATION GRADIENT

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ABSTRACT

Barium plays a significant role in low-temperature geochemistry due to its connection with major biogeochemical cycles, such as carbon and sulfur. Barite, a common authigenic mineral in marine sediments, is a valuable proxy due to its low solubility and long-term stability. It is widely studied as an indicator of oceanic paleo-productivity but also forms in environments with steep gradients of dissolved barium and sulfate, such as hydrothermal vents, cold seeps, and during diagenesis in sediments. The focus of this research is on diagenetic barite crystallized in the freshwater sediments of the Baltic Sea, particularly in the Gotland Basin, where barite nodules are found in glacial varved clays beneath brackish Holocene muds. These barites formed after the Baltic Sea's post-glacial connection with the Atlantic during the Yoldia stage. Sulfate for barite precipitation originated from downward diffusion, while dissolved barium originated from ionic exchange between brackish water and the glacial clays. The sulfur isotope signatures of barite, marcasite, and pyrite reveal significant microbial sulfate reduction and suggest the porewater sulfur reservoir was initially closed to sulfate. The study also shows that sulfur isotopes in these diagenetic barites display a downward gradient at the boundary between brackish Yoldia sediments and Baltic Ice Lake clays, suggesting isotope discrimination during solid phase formation. Additionally, changes in barite surface texture, micro-morphology, Sr composition, and isotopic signatures (Ba, S, O) indicate variations in supersaturation, fluid composition, and crystal growth rates, supporting the idea of a paleo-salinization gradient and highlighting the modification of paleo-porewater components through diffusional processes.

Keywords: *stable isotopes (H, O, S, Ba); porewater gradients; mineral textures; Baltic Sea*

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CLIMATE CHANGE IMPACTS TO COASTAL AQUIFER SALINIZATION BY RIVER BOUNDARY CONDITION: RIVER NERETVA DELTA

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CLIMATE CHANGE IMPACTS: THE EFFECTS OF SEA-LEVEL RISE, OVER-ABSTRACTION AND EXTREME EVENTS ON COASTAL SYSTEMS

Introduction

Understanding saltwater intrusion (SWI) in coastal systems is crucial for water resources management and environmental sustainability worldwide. Climate change effects are shown to be main threat leading to intensification of saltwater intrusion (SWI) into coastal aquifer systems. For purpose of this work we consider Neretva river delta as a relevant site influenced by the SWI which is visible via decreased agricultural production. Our methodological approach relies on in-situ monitoring, harmonic analyses, analytical solution and laboratory experiments thus offering a comprehensive way to demonstrate the nature of the river Neretva salinity regime, external forces controlling the salinity and the consequences on the climate change scenarios with emphasis to local aquifer salinization.

Site description and problem formulation

River Neretva delta is located in the south-eastern part of the Republic Croatia, facing the Adriatic Sea and being set up in between karstic hills to the north, south and south-east. In the past the area was a marshland mostly covered by the Adriatic Sea either local lakes. After the implementation of the melioration infrastructure in 1960s, about 4200 ha of this area have been improved and preferred agricultural preconditions have been reached. Since its operation, melioration controls the groundwater level along the study area and keeps it 1.50-2.50 m below the mean sea level thus emphasizing the coastal aquifer system hereby is faced to significant active (SWI) [1].

From hydrological point of view, two main factors determine river Neretva hydrological regime, respectively, precipitation along the catchment area and the operating mode of the Mostar hydropower plant upstream in Bosnia and Herzegovina. During the dry season, usually from May to November, discharge ranges between 80 and 250 m^3/s with very occasional exceedance of 250 m^3/s depending on the Mostar hydro power plant operation. Rain season discovers dominantly natural regime of the Neretva river with discharge values going up to 1850 m^3/s [2]. Since Neretva riverbed in its length of app 25 km is settled beneath the mean sea level, significant water column stratification of the SWI parameters (temperature (T) and electrical conductivity (EC)) characterizes the dry period.

The mixed diurnal - semi-diurnal tide of the Adriatic Sea contributes to harmonic SWI character independently of the river Neretva hydrological regime. By the inspection of the long term sea level oscillations it has been found four main tidal constituents — O1, K1 diurnal constituents and M2 and S2 semi diurnal constituents are responsible for over 95% of the observed sea level fluctuations [3].

Up to date, our findings identified two main pathways of active SWI resulting in the salinization of the groundwater along the Neretva delta coastal aquifer especially during dry season whose duration ranges from six till nine months per year depending on local hydrological, climatological and oceanographic conditions [2]. Unless constant pathway of SWI, present independently of the rain either dry season occurrence, occurs through the two kilometers long coastal embankment, Neretva riverbed has been identified as a SWI corridor feeding the aquifer with the saltwater during dry season. The reason of the discrepancies in salinity boundary conditions is found in the disbalance between natural fresh water discharge upstream and Adriatic Sea level present during rain season thus leading to saltwater cline diminishing and refreshing of the Neretva river water column.

To improve the knowledge of the river Neretva salinity transience for the purpose of salinity boundary condition definition, a detailed analyses have been performed for the dry period, mostly being focused to influence of freshwater discharge and tidal oscillations to Neretva water column salinity regime and consequently SWI into the coastal aquifer system with a potential to be implemented in the climate change influence analyses and mitigation measures setting up.

Methodology

To examine how T, EC and salinity (S) vary vertically within the river Neretva water column, periodic profiling has been carried out between 2019 and 2023 using a SEBA KLL-Q-2 multiparameter probe six times per year. The latter has been performed during the dry season at two profiles respectively, Komin and Opuzen, located 9 and 12 kilometers upstream from the mouth of the Neretva River. The instrument measures water depths with a range of 0 to 500 meters, T from −5 °C to 50 °C and EC within the range of 0–200 mS /cm.

Apart from the intermittent monitoring, continuous monitoring programme has been set up and implemented at Metković profile, 22 km upstream from the river's mouth. At this location, two sensors have been installed to observe for T and EC at fixed depths, −0.37 m and −5.40 m (HVRS71) respectively. The upper layer probe is MANTA 2 +40, operates in a range of 0–100 mS /cm for EC and 0–50 °C for T with provided accuracies of ±1% of for the EC and ±0.1 °C for T. The bottom TruBlue CTD 585 probe enables the insight to groundwater level, T and EC time series with accuracy of ±0.05% for water level, ±1% or 0.02 mS/cm for EC over 0.005–100 mS/cm interval and ±0.2 °C for T within the operating range 0–50 °C. Continuous Adriatic Sea level is observed at the coastal tide gauge station equipped with a THALIMEDES OTT encoder with operating range of ±19.999 m, resolution of 0.001 m and accuracy of ±0.002 m. Same technical equipment is used to observe Neretva river surface elevation at stations Opuzen and Metković.

To assess Neretva river discharge, measurements of the surface water level from THALIMEDES OTT gauge, the geometry of the river bed and the velocity data from three horizontal ADCPs at the Metković Bridge have been integrated. Sampling frequency of all abovementioned monitoring infrastructure has been adjusted and corresponds to time scale of 1 h.

In this study several approaches — Discrete Fourier Transform (DFT) with t_tide harmonic analysis [4], coherence and the Welch method —were used to investigate the tidal influences to the Neretva water column salinity and potential relationships in between the Neretva river system variables. DFT, enhanced by the widely used t_tide, extracted the most significant tidal constituents, including M2, S2, K1 and O1, and provided reliable amplitude and phase definition. These constituents were analyzed to understand tidal propagation along the river Neretva riverbed.

Coherence analysis [5] has been applied to quantify and interpret the strength and time lags of the interactions between the different signals. In particular, magnitude squared coherence was used to measure the frequency-dependent correlation and phase shifts between the sea level and the water levels in Opuzen and Metković. This approach allowed the identification of time lags between certain frequencies (constituents) and provided valuable insights into the coupling mechanisms controlling freshwater inflow, tidal forcing and salinity.

These methods were integrated to analyze sea level data and Neretva surface levels at Opuzen and Metković for tidal dynamics. They were also used to identify the influence of sea level changes and discharge to the EC in the upper and lower water column layer.

To assess the salinity along the Neretva estuary, one-dimensional (1D) analytical model based on the advection – diffusion equation has been used with the integration of tidal oscillations and estuarine geometry [6]. The model relies on several input parameters derived from field measurements and empirical estimates, including river discharge Q, tidal excursion E (derived from tidal amplitude and tidal velocity), the model parameter dispersion coefficient D (derived from measured salinity profiles, estuarine geometry and discharge) and estuarine geometry (cross-section A0 and convergence length a). Model calibration has been performed by the derivation of the analytical model parameters from in situ observed data so the model represents a tool for predicting future scenarios and potential variabilities in the salinity regime.

After the definition of the driving forces controlling river Neretva salinity regime we configure a 2D experimental sand box to mimic the influence of river Neretva boundary condition to SWI into the coastal aquifer system. Different scenarios of boundary conditions have been taken into consideration and analysed to demonstrate SWI sensibility and its influence to groundwater salinization. As climate change indicators we consider scenarios with increase of the mean sea level and river surface elevation.

Results

Water column profiles at Opuzen and Komin show a pronounced salinity stratification. The salt–freshwater interface (SFI) is typically found between −1.9 and −6.25 m below the mean sea level at Opuzen, and between −1.95 and −6.5 m at Komin. Profiling results also show the increase in river discharge tends to force the SFI to a more downward position, with the exception of higher mean sea level occurrence. The SFI transition zone shows very thin transition zone with on average width of 0.5 m and is dominantly controlled by tidal forcing.

During the dry season, the coherence values in between observed sea level and Neretva surface elevation at stations Opuzen and Metković for both semidiurnal and diurnal tidal constituents takes values above 0.98, leading to the fact the water level oscillations observed upstream are significantly controlled by tides. Time lag between sea level and Opuzen water level equals 10 minutes while the time lag for Metković water level relative to sea level equals 15 minutes. Strong coherence at both tidal constituents indicates efficient transmission of tidal energy, extending the effects of sea level oscillations upstream to Opuzen and Metković. Both spectrogram and t_tide analysis show tidal amplitudes increase upstream, emphasizing the increasing role of tidal forcing in shaping the river's flow regime during dry period. For the semidiurnal tidal constituent, coherence values in between sea level and EC at the top layer of the river at Metković station range from 0.75 to 0.95, indicating significant tidal influence to salinity regime. The

time lag equals 3 to 4 hours, suggesting that changes in salinity occur slowly in response to sea level oscillations. The diurnal constituent has a coherence of less than 0.6, indicating less significant influence on salinity in the surface layer. At the bottom, the coherence with sea level semidiurnal frequency is found between 0.67 and 0.87 with the time lag is 0.5 and 1 hour.

The coherence analysis at the Metković station shows strong influence of the river discharge on the salinity in the surface layer. The coherence between discharge and electrical conductivity (EC) at the surface is found between 0.75 and 0.98, with a short time lag of 0.3 to 1 hour, indicating freshwater rapidly reduces saltwater intrusion.

1D model to assess the salinity along the river Neretva upstream shows the salinity is influenced by several factors, including river discharge, tidal motion, sea level fluctuations and the geometry of the estuary. Model demonstrates increased sea level increases the salinity while the discharge increase reduces the salt intrusion due to the flushing effects.

Once the transience of river Neretva salinity has been captured, 2D experiments have been conducted in the laboratory flume. For homogeneous aquifer case, the increase in the mean sea level as a climate change scenario has been modeled with clear emphasis on the influence of the boundary conditions as found along the Neretva river to SWI into the aquifer system. With the increase of hydraulic gradients, model shows clear SWI intensification via: i) elongation of the seawater cline, ii) increase in cline wedge height and iii) domination of the advection driven SWI component.

Discussion and conclusions

This study enables the conclusion salinity in River Neretva estuary is governed by multiple interacting factors, including river discharge, tidal forcing, sea level oscillations and the geometry of the estuary. The dry season is pointed out as critical period when freshwater discharge decreases as a consequence of evident climate change effects. The latter leads to increasing trend in water column salinity of the Neretva river. Although the interplay in the driving forces controlling the salinity regime, our results enable the definition of the intensity of separate driving force contribution. Hereby, the mean sea level shows to be a dominant factor defining the Neretva salinity during the dry period. Intermittent discharge changes induced by hydropower plant operation upstream are shown to lead to temporally local and significant changes of the salinity. Latest, tidal oscillations lead to minor changes in the SFI depth. Unlike local salinity features derived from the in-situ observations, analytical 1D model, based on advection – diffusion mechanisms integrate all abovementioned influences — sea level oscillations, discharge, tidal forcing and estuarine geometry to represent river water column salinity and project future climate change scenarios under varying boundary conditions. The latter has been supported experimentally ensuring the relevance of obtained results via the determination of the SWI intensification under the climate changes impact through reduced discharge values and increase of the mean sea level.

Keywords: *Neretva river, coastal system, salinity, tides, discharge*

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References

1. Badaruddin, S., Werner A.D., Morgan L.K., (2017). Characteristics of active seawater intrusion. Journal of Hydrology 551. https://doi.org/10.1016/j.jhydrol.2017.04.031.
2. Lovrinović I., Bergamasco A., Srzić V., Cavallina C., Holjević D., Donnici S., Erceg J., Zaggia L., Tosi L., (2021). Groundwater Monitoring Systems to Understand Sea Water Intrusion Dynamics in the Mediterranean: The Neretva Valley and the Southern Venice Coastal Aquifers Case Studies. Water 13(4). https://doi.org/10.3390/w13040561.
3. Srzić, V., Lovrinović, I., Racetin, I., Pletikosić, F., (2020). Hydrogeological characterization of coastal aquifer on the basis of observed sea level and groundwater level fluctuations: Neretva Valley Aquifer, Croatia. Water 12(2). https://doi.org/10.3390/w12020348.
4. Pawlowicz, R., Beardsley, B., Lentz, S., (2002): Classical tidal harmonic analysis including error estimates in MATLAB using T TIDE, Computers & Geosciences 28(8). https://doi.org/10.1016/S0098-3004(02)00013-4.
5. Lovrinović, I., Srzić, V., Aljinović, I., (2023). Characterization of seawater intrusion dynamics under the influence of hydro-meteorological conditions, tidal oscillations and melioration system operative regimes to groundwater in Neretva valley coastal aquifer system, Journal of Hydrology: Regional Studies 46 https://doi.org/10.1016/j.ejrh.2023.101363.
6. Xu, Y., Hoitink, A.J.F., Kästner K., Zhang W., (2019). Analytical model captures intratidal variation in salinity in a convergent, well-mixed estuary. Hydrology and Earth System Sciences. 23(10). https://doi.org/10.5194/hess-2019-256

Salt Water Intrusion Congress (SWIM 2025)

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COASTAL AND OFFSHORE GROUNDWATER INVESTIGATIONS FOR PRINCE EDWARD ISLAND, CANADA

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ABSTRACT

Prince Edward Island (PEI) is the only Canadian province 100% dependent on groundwater for both irrigation and drinking water. Groundwater resources on PEI, which also sustain surface water ecosystems, have faced compounding stresses in recent years due to water demands and nitrate contamination from the extensive agricultural industry. There is also increasing concern regarding the impacts of droughts and saltwater intrusion due to climate change. Freshened Offshore Aquifers (FOAs) may represent a new freshwater resource for PEI, and for similar island settings worldwide.

SOURCE is an exploratory study of freshened submarine groundwater resources offshore of PEI in the Gulf of St. Lawrence. Here, the growth and collapse of the Laurentide Ice Sheet led to the formation of extensive networks of paleo-channels and lakes, superimposed on fractured continental sandstones. A 9-week research expedition onboard the RV Maria S Merian was conducted in the fall of 2021 to collect geophysical data, conduct sediment coring, and undertake bathymetric mapping. Data from this expedition are being interpreted in a numerical model (HydroGeoSphere) of 3D variable-density groundwater flow and salt transport to assess

the evolution of freshened groundwater in the Gulf of St. Lawrence and to investigate the hydrogeologic controls.

Concurrent onshore (coastal) hydrogeological investigations are being conducted on PEI to elucidate onshore-offshore aquifer connections and regional aquifer dynamics. A developed island-wide groundwater elevation map and numerical groundwater model reveal how regional hydrogeological systems influence the island groundwater dynamics, water budget, and connections to offshore aquifers. Coastal drone-based thermal mapping and sampling has been conducted at low tide to provide insight into submarine groundwater discharge patterns and mechanisms and associated nutrient loading. Understanding onshore and offshore groundwater dynamics and their connections will help ensure that the implementation of recent groundwater legislation for this vulnerable island province is grounded in hydrogeologic science.

Keywords: *offshore aquifer, submarine hydrogeology, subsea groundwater, coastal groundwater, island hydrogeology*

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COMPARING THE EFFECTS OF SEA- AND RAINWATER ON THE RELEASE OF DISSOLVED ORGANIC MATTER AND NUTRIENTS FROM BEACH WRACK

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ABSTRACT

Subterranean estuaries (STE) underneath high-energy beaches are dynamic interfaces for the exchange of dissolved organic matter (DOM) and nutrients between marine and terrestrial environments. Beach wrack deposited during tides and waves and leached during tidal inundation, wave swash and precipitation contributes DOM and nutrients to STEs. Wrack is often considered a nuisance in recreational beach use, but its removal could deprive the organic-poor ecosystem of an important energy source. The complex interplay of environmental factors influencing the release of DOM and nutrients from beach wrack remains poorly understood, making it difficult to assess its role in sustaining the beach bioreactor.

To address this knowledge gap, we conducted a comprehensive beach wrack leaching experiment. We collected wrack typically found along the North Sea shoreline like bladder wrack (*Fucus* sp.), jellyfish (*Aurelia* sp.) and terrestrial plant and peat debris. Inundation by tides or precipitation was simulated by submerging wrack subsamples in artificial sea- and rainwater with conductivities typical for the North Sea coast. In addition, we simulated solar weathering by irradiating wrack subsamples with UVA light and subsequently leached the wrack subsamples with artificial seawater. Leaching media were then analyzed for dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) concentrations. DOM was desalted and analyzed using ultra-high-resolution mass spectrometry, yielding thousands of molecular formulae for each wrack sample and treatment type.

Our results showed substantial releases of DOC and TDN from *Fucus* sp., and high TDN concentrations from *Aurelia* sp. wrack in artificial seawater incubations. In wrack-derived DOM, we unveiled a predominance of molecular formulae characteristic of biochemical building blocks like sugars, amino acids, and vitamins. This suggests that the DOM leached from beach wrack could provide a valuable source of energy and nutrients for microbial communities in these systems. Notably, our findings also included high abundances of aromatic and humic-like DOM in macroalgal beach wrack, which could complicate the interpretation of marine and terrestrial source-sink molecular proxies. DOM and nutrients released from beach wrack were type- and treatment specific. We recommend the inclusion of wrack-derived inputs into reactive transport models and posit that wrack and consumer species composition at beach STEs could be tightly linked.

Keywords: dissolved organic matter, sandy beach, subterranean estuary, wrack, nutrients

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COMPTABILITY BETWEEN HARBOUR INFRASTRUCTURES AND STRATEGIC AQUIFERS FOR THE DRINKING WATER SUPPLY IN BARCELONA. CATALONIA.

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ABSTRACT

The Master Plan for the expansion of the Port of Barcelona includes, in terms of a potential impact on the strategic aquifers of the Llobregat Delta, two important actions: dredging of the breakwater to increase the berthing depth and expanding the quays to gain ground from the sea. In 1999, the Department of Land Engineering of the School of Civil Engineering of the UPC assessed these impacts and determined that they could be summarised as a possible increase in the piezometric levels of the surface aquifer and a possible increase in the conductivity of the water in the deep aquifer. This analysis was used for the construction period 2000-2010.

To quantify the follow works in the harbour, and more specifically concerned about the possible increase in conductivity of the deep aquifer, the CUADLL has been carrying out a study commissioned by the Port of Barcelona with the contribution of CSIC-IDAEA, through numerical modelling with different approaches, from the most local to the regional level, taking into account all the aquifers of the Low Valley and Llobregat delta. The results of the modelling quantify a small, compatible and acceptable impact. An environmental monitoring plan has also been designed based on a control network to detect, as far as possible, variations indicative of the possible impacts of the works that will be carried out during this decade.

Keywords: *infrastructures, impact, modeling*

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DEVELOPING AN INTEGRATED CONCEPTUAL MODEL OF SALINIZATION PROCESSES FOR SOUTHWESTERN COASTAL BANGLADESH

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ABSTRACT

Salinization of water resources and soils is a critical global issue, particularly in low-lying coastal regions, where around 600 million people reside – a number expected to surpass 1 billion by 2050. Globally, salinization impacts hundreds of millions of people, particularly in riverine deltas which are especially vulnerable. High salinity of soil and water has been a major environmental concern for the coastal communities in Southwest Bangladesh. However, this problem is being intensified due to reduced river discharge, land subsidence, land-use changes, groundwater pumping as well as climate change impacts such as increased coastal storm surges and inundation during intensified cyclone events. Salinization of surface water, groundwater, and soils threatens agricultural productivity and freshwater availability, and livelihoods, making salinization a key driver of migration and underscoring the need for effective adaptation strategies.

This study aims to integrate existing conceptual models of salinization processes in the coastal aquifers of southwestern coastal Bangladesh, providing an initial framework for developing numerical models that incorporate the uncertainties and challenges of these complex systems. Previous research show that areas receiving reduced river discharge, especially during dry season, and affected by upstream irrigation water withdrawals, are significantly impacted by salinization. This streamflow reduction, along with seasonality changes, accelerates the process on a large scale in these vulnerable areas.

Locally, salinization of shallow aquifers is exacerbated by episodic tropical cyclones and associated storm surges, which leads to direct infiltration of saltwater contributing to increase salinity, particularly in polder areas. Deep aquifer host predominantly freshwater, with only minor influences from connate water trapped during historical transgression events. This suggests that shallow aquifers are highly vulnerable, while the deep aquifer system keeps important freshwater reserves. Those insights are critical for developing sustainable water management strategies in response to changing hydrological and climatic conditions, as well as increasing freshwater demands.

Keywords: *Conceptual model, Salinization, Water resources, Bangladesh*

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DYNAMIC DRIVERS OF MARSH MIGRATION IN THE COASTAL CRITICAL ZONE: UNTANGLING TEMPORAL AND SPATIAL VARIABILITY

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ABSTRACT

Along the Delmarva Peninsula, USA, salt marshes are rapidly migrating into freshwater uplands, such as forests and agricultural land, resulting in widespread vegetation mortality and shifts in groundwater levels and salinity dynamics. The extent and persistence of saltwater intrusion (SWI) in coastal wetlands are shaped by the interplay between vertical and lateral salinization, as well as freshwater events. To disentangle these simultaneous processes, we instrumented transects at six field sites along the Peninsula, each equipped with shallow wells, soil moisture sensors, and redox probes, capturing space-for-time changes. Through three years of high-resolution data collection, our findings reveal that vertical salinization is episodic, driven by storm surges that primarily affect shallow soils, with recovery time dictated by soil type and the magnitude of salinization. In contrast, lateral salinization progresses gradually, controlled by shallow hydraulic gradients and exacerbated by droughts, which lower upland groundwater heads on intermediate timescales, or by sea-level rise over longer periods. Freshwater events act as both buffers and drivers of change, flushing salinity following salinization events, but also lowering redox potentials in shallow soils, which may cause anoxia and subsequent vegetation stress. These dynamic interactions underscore the complexity of the coastal critical zone, where hydrology, geomorphology, biogeochemistry, and ecology interact to create feedbacks that may accelerate or slow coastal change. Our study highlights that some coastal wetland transitions may occur more rapidly than previously thought when considering only sea-level rise or storm surges alone. By capturing multi-scale hydrological drivers, we provide new insights into SWI processes and marsh migration, offering a more comprehensive understanding of coastal wetland transition in response to climate change.

Keywords: *Sea Level Rise, Storm Surge, Saltmarsh, Saltwater Intrusion, Marsh Migration*

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TITLE

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ABSTRACT

In coastal regions, surface water supplies are frequently limited, and groundwater is essential to handling the intricate problem of water supply. Groundwater resource management is being negatively impacted by urbanization and climate change in a number of ways, and as the population grows, so does the amount of wastewater produced.

Furthermore, salinity issues and heavy urbanization are common in coastal areas. Seawater migrates inland and rises toward the wells as a result of the extensive groundwater extraction from coastal aquifers, which also lowers freshwater outflow to the sea and causes seawater intrusion

The municipalities of Malgrat, Palafolls and Blanes (Barcelona province, NE Spain) are located over sedimentary detrital formations of deltaic origin that form the mouth of the Tordera River and has an historical dependence of groundwater resources for water supplying. Moreover, the current monitoring network is not able to provide details about the water mixing processes due to technical con-straints (limited number of piezometers with limited depth). Electrical resistivity tomography (ERT) has proven to be effective in providing the comprehensive subsurface data needed for improving groundwater modelling. The connections between the salinity of groundwater and the electrical resistivity of the bedrock and alluvial sediments demonstrate the advantages of geophysical approaches over other, more expensive subsurface research strategies. Our study's findings demonstrate that ERT in conjunction with implicit modelling methods can yield data that is highly useful for determining aquifer geometry in the Tordera's delta (NE of Spain) and describing the saltwater intrusion of the shallow alluvial aquifer.

Keywords: *Electrical Resistivity Tomography, Geophysics, Salt Water intrusion, Modelling.*

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EVALUATION OF MANAGED AQUIFER RECHARGE TO PREVENT SEAWATER INSTRUSION USING "INTERFACE-EGG"

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ABSTRACT

This study evaluates the effectiveness of Managed Aquifer Recharge (MAR) in preventing seawater intrusion near rivers in Gimpo, South Korea. MAR is a technique used to enhance groundwater storage by artificially recharging aquifers through infiltration or injection methods. It plays a crucial role in mitigating groundwater depletion, improving water quality, and preventing seawater intrusion in coastal areas.

To assess the impact of MAR on seawater intrusion, a field experiment was conducted using an injection well and three observation wells located 5m, 10m, and 15m away. Long-term monitoring was carried out to measure groundwater level changes, electrical conductivity profiles, and freshwater-saltwater interface movement. The study employed the "Interface-Egg" method, which tracks the position of the interface using buoyancy-driven neutral density devices.

The results showed that after MAR implementation, groundwater levels increased by 0.8 to 1.2 meters at all observation wells. The most significant seawater intrusion mitigation was observed at wells closest to the injection site, demonstrating the localized impact of MAR. Additionally, the effect persisted for several days after the injection ceased, indicating potential long-term benefits. However, variations in response time and duration were noted due to differences in geological conditions, highlighting the need for site-specific assessments.

This study confirms the effectiveness of MAR in controlling seawater intrusion and demonstrates the application of the "Interface-Egg" method in monitoring interface dynamics. The findings suggest that MAR can be a viable solution for sustainable groundwater management in coastal regions. Continuous monitoring is essential to assess the long-term effectiveness and potential environmental impacts of MAR systems.

Keywords: *managed aquifer recharge, seawater intrusion, interface-egg, coastal aquifer management*

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FloaTEM SURVEY OF THE VERTICAL STRUCTURE OF GROUNDWATER-SEAWATER MIXING AT THE HANKO SGD SITE, FINLAND

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ABSTRACT

The submarine groundwater discharge (SGD) site in Hanko on the southern coast of Finland has been previously studied for its geological structure and Rn-based groundwater discharge estimates (Virtasalo *et al.*, 2019), for the impacts of focused groundwater flow from seafloor pockmarks on the heterogeneity of seabed biogeochemical processes and microbial community structure (Purkamo *et al.*, 2022), and for the behavior of Li, S and Sr isotopes in the subterranean estuary (Ikonen *et al.*, 2022). Here, we report results of a FloaTEM survey to characterize the vertical structure of the seawater-groundwater mixing.

FloaTEM is a floating time-domain electromagnetic profiling instrument that measures continuously while towed by a small boat. Our survey was run on October 13, 2023, along shore-parallel survey lines over known pockmark locations. The FloaTEM system used had a 4x4 m transmitter coil and a receiver coil at an 8 m offset. The survey speed was 5–6 km/h. Resistivity of the brackish sea water was *ca*. 1.2 Ωm. Water depth was recorded using an echosounder and applied as a constraint for the top layer thickness in data inversion. The data was processed in Aarhus Workbench and a preliminary inversion was made by using a 1D laterally constrained inversion (LCI) scheme. The data was inverted with a smooth layer model type consisting of 15 layers with depth layer boundaries from 1–80 m.

The survey results showed downward increasing resistivity values (1–100 Ωm) in organic-rich muddy sediments below the seafloor. The resistivity values were higher (>10 Ωm) beneath the pockmarks, indicating funneled upward groundwater flow.

References:

Ikonen J. *et al.* 2022, *Applied Geochemistry* 147, 105471. [link]
Purkamo L. *et al.* 2022, *Geochimica et Cosmochimica Acta* 334, 14–44. [link]
Virtasalo JJ. *et al.* 2019, *Solid Earth* 10, 405–423. [link]

Keywords: *Coastal aquifer; Submarine groundwater discharge; Electromagnetic profiling; Baltic Sea; Finland*

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FRESH SUBMARINE GROUNDWATER DISCHARGE IN BELGIUM: AN OVERVIEW

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ABSTRACT

Coastal groundwater is very complex and dynamic as fresh- and saline water are in direct contact with one another. A unique approach is needed in order to investigate the beach and near-coast as the conditions are different from on land and marine studies, the seawater inundates the intertidal zone driven by tidal cycles but the water layers remains relatively thin. This imposes logistical difficulties for exploration techniques, which is one of the reasons why this transition zone is often neglected and poorly investigated.

Geophysical tools are very useful in obtaining an image of the salinity distribution. To investigate large areas, airborne electromagnetic induction methods (AEM) are often chosen which allow to cover large areas very quickly, however, these can lack the needed resolution. Which is why a ground-based approach is sometimes better, by using for example land electrical resistivity tomography (ERT) or marine continuous resistivity profiling (CRP). The latter – as the name suggests – allows for profiling while towing a floating cable. This can lead to several kilometres of data in a just a single day.

Investigation of fresh submarine groundwater discharge (FSGD) has never been done in the Belgian coastal area. Over the last few years, we were able to map the saltwater distribution in an extensive part of the Belgian coastal zone. By extending resistivity measurements on land (ERT) with marine data (CRP), discharge could be observed in the intertidal zone and further offshore. The final map shows a large spatial variability in the FSGD footprint, of which the drivers are yet to be fully understood. The thickness of the dunes belt (the recharge zone), which borders the sandy beach, definitely plays a role. Locations where it is widest shall need more investigation.

Keywords: *Geophysics, electrical resistivity tomography, continuous resistivity profiling, fresh submarine groundwater discharge.*

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GEOPHYSICAL INVESTIGATION OF SUBMARINE GROUNDWATER DISCHARGE (SGD) AT KÖNIGSHAFEN (SYLT)

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ABSTRACT

Submarine Groundwater Discharge (SGD) are investigated worldwide on different scales, because of their significant influence on the sea. . The DFG funded project “Königshafen Submarine Groundwater Discharge Network” (KiSNet) follows an interdisciplinary approach to optimize the combination of methods used. However, here we focus on geophysical investigations to locate SDG spots in the Königshafen bay. Geoelectric (ERT), seismic, electromagnetic (EMI), ground penetration radar (GPR) and nuclear magnetic resonance measurements (NMR) took place between 2019 – 2022. As the electrical resistivity differs between freshwater and saltwater, ERT and EMI are capable to locate groundwater discharge. While EMI covers easily larger areas, delivering 2D el. resistivity maps with an investigation depth confined to about 5m, vertical resistivity sections by ERT can image SGD’s in greater depth (up to 20m in this case). GPR profiles were also recorded along the ERT lines for a fast cross validation. Although GPR can practically not penetrate saltwater saturated sediments, it can if freshwater is present, i. e. at SGD spots. Another obstacle or ERT and EMI is that clay cannot be distinguish from saltwater because of its similar el. resistivity. Hence, NMR soundings were performed at locations with a high clay probability, because the NMR signal decays so fast in the presence of clay that it cannot be detected. So in case NMR shows zero decay time in a certain depth range and ERT images show a low resistivity, it is most likely caused by clay.

The results show that geophysics can locate SGD’s with a high probability. It is recommended to start with EMI to obtain lateral resistivity maps, followed by ERT to image possible SGD’s

locations in greater depth. Additionally, a cross validations with GPR can be made to distinguish between near surface artefacts and SGD's. If necessary NMR soundings can be added to the survey if clay formations have to be identified.

Keywords: *Geophysics, SGD, ERT, EM*

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GROUNDWATER MODELING TO ASSESS THE POTENTIAL IMPACT OF A PORT ENLARGEMENT OVER A COASTAL WETLAND (SOUTH OF SPAIN)

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ABSTRACT

The Charca de Suárez is a 15 ha wetland located a few hundred meters from the sea on the south coast of Spain. It is a Protected Nature Reserve with ecological interest due to its high biodiversity and its role as a refuge for permanent and migrant species, some of which are in danger of extinction. The wetland depends hydrologically on the surface water from excess irrigation and water from nearby rivers and groundwater. The wetland is surrounded by undeveloped, industrial and residential areas. The port of Motril, located 500 m from the eastern border of the Charca de Suarez wetland, has been proposed to be expanded by an increase of 60% in dock capacity. The port of Motril has an extension of 91 ha and provides services for commercial, fishing and marina uses. This expansion would involve digging inland to increase the number of boats that could be docked. The engineering activity would involve the modification of the hydrogeological conditions of the region by decreasing the water table and favoring the encroachment of the saline wedge; however, it is unclear whether this would affect the Charca de Suarez wetland. For this purpose, a groundwater model with density-driven flow was developed using SEAWAT to assess the impacts on the groundwater heads and salinity distribution within the aquifer. In addition, potential solutions for compensating these effects have been proposed by implementing different recharge methods like injection wells, recharge along trenches or increasing the surficial inputs to the wetlands.

Keywords: *wetlands, port, saltwater intrusion, groundwater modeling.*

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GROUNDWATER TEMPERATURE IN COASTAL AQUIFERS: SURFICIAL HEAT SOURCES AND GEOTHERMAL HEATING

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ABSTRACT

Temperature distribution in coastal aquifers is the consequence of different thermal sources, including groundwater recharge, seawater infiltration, atmospheric temperature, and geothermal heating. While previous studies have investigated the seasonal changes in temperature in the first upper meters of the aquifer (Li et al, 2006; Vandenbohede and Lebbe, 2011), and the impact of geothermal warming on the increase in groundwater temperature with depth (Parsons, 1970), there is still a lack of comprehensive information on the distribution of temperature in coastal aquifers considering all the possible thermal sources.

To fill this research gap, this study focused on the Motril-Salobreña aquifer (Spain) and proposed a generic theoretical model of temperature distribution. The model took into account temperature sources from both the surface (recharge, air temperature, and seawater infiltration) and the bottom of the aquifer (geothermal heating). The model was adapted to reproduce the real conditions with the calibration of hydraulic properties and other relevant parameters. The temperature data of three wells located at distances of 285 m, 300 m, and 700 m from the coastline were used to validate the model.

The model results revealed that the distribution of temperature was closely related to the position of the freshwater-saltwater interface (FSI). The flow patterns established in coastal aquifers due to variable density forced groundwater heated in the base of the aquifer to ascend, generating a thermal plume along the FSI. This created a thermal barrier, which differentiated the temperature of the saltwater domain from the freshwater domain. The models also showed that the position of the toe of the FSI was dependent on the geothermal gradient because of its influence on water density. Aquifers with higher heating would exhibit a different thermal profile, which could affect the position of the FSI and have implications for the temperature distribution of the aquifer.

Keywords: *geothermal heating, ascending thermal plume, numerical modelling*

REFERENCES

Li, L.; Horn, D.P.; Baird, A.J. Tide-induced variations in surface temperature and water-table depth in the intertidal zone of a sandy beach. J. Coast. Res. 2006, 22, 1370–1381

Vandenbohede, A.; Lebbe, L. Heat transport in a coastal groundwater flow system near De Panne, Belgium. Hydrogeol. J. 2011, 19, 1225–1238.

Parsons, M.L. Groundwater thermal regime in a glacial complex. Water Resour. Res. 1970, 6, 1701–2172.

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HIGH RESOLUTION MODELLING OF HYDRODYNAMICS FOR MANAGING COASTAL BAY IN FANGAR BAY CASE

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ABSTRACT

This work investigates the hydrodynamic response of a semi-open bay with micro-tidal dynamics, is located in the Ebro Delta (NW Mediterranean Sea) Fangar Bay, in order to solve the problems affecting mussel farms, such as the impact of freshwater discharges from multiple planting areas containing potential pollutants or nutrients on aquaculture areas, causing change of salinity field the decline in production and the limited water renewal that causes anoxia within the bay. Using the TELEMAC 3D model, we preliminarily included the internal and external forces affecting the bay's hydrodynamics (i.e, meteorological forcing, river fluxes, regional hydrodynamics provided by CMEMS products). The model achieved a relatively high-resolution grid (20 m) and completed the preliminary verification of temperature and salinity in the profile, as well as water residence study in the summer period, analyse the local flushing time for the bay mouth, aquatic area and the top of the bay. Also, by modifying the flow of these drainage channels, increasing the arrival of freshwater to solver problem of water renewal. In addition, explored the impact of these increases in freshwater flows on the salinity profiles and fields of the bay in particularly on aquatic areas. Results demonstrate feasibility of altering freshwater discharge and contribution to reducing residence time.

Keywords: Hydrodynamic; Aquaculture; Freshwater; Residence Time

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HYDROGEOLOGICAL MODELLING OF THE RED RIVER AND MEKONG DELTAS

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ABSTRACT

Arsenic contamination of groundwater is observed throughout South and Southeast Asia, affecting the low and flat floodplains of rivers draining the Himalayas. This geogenic contamination exposes over 100 million people to arsenic through their drinking water, posing a major health hazard.

Two such affected areas are the Red River and Mekong deltas in Vietnam, where growing population and climate change combine with natural arsenic occurrence to form highly unpredictable spatial and temporal patterns of groundwater contamination.

In the context of the DeltAs project, which aims to quantify the temporal and spatial variation of Arsenic in deltaic environments, we develop detailed 3D geological and hydrogeological models of the Red River and Mekong deltas. Each forms a complex coastal aquifer system that is non-negligibly affected by its neighbouring sea. Saline water intrudes both underground, in freshwater aquifers, and overground as a result of subsidence. Tidal and wave action significantly shapes the sedimentation of the delta mouth. Estuarine sediments, different in their composition from landward alluvial depositions, influence the distribution of groundwater arsenic. The hydrogeological modelling of these deltas thus require careful integration of the land-ocean transition zone.

We present here the current state of both the Red River and Mekong deltas hydrogeological models. They are developed using MODFLOW, with a prior geological model constructed using ArchPy, an open-source method and Python module for modelling heterogeneous Quaternary environments. ArchPy allows stochastic modelling, a semi-automated workflow and a flexible, all-in-one framework. The land-ocean transition zone is represented with an equivalent freshwater head boundary at this stage of model development, in order to ensure reasonable computing times for inversion calibration.

Keywords: *modelling, case-study, Vietnam, delta, groundwater*

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IMPACT OF SEA LEVEL RISE ON SHALLOW GROUNDWATER IN SOUTHERN BALTIC COAST (POLAND) BASED ON 1D NUMERICAL MODEL

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ABSTRACT

Shallow coastal aquifers are vulnerable hydrosystems controlled by many factors, related to climate, seawater-freshwater interactions and human activity. That is especially true for freshwater lenses situated in sandbars, which are recharged only by rainfall and snowmelt infiltration. Rising sea level poses increasing risk of salinization for such groundwater resources. IPCC report forecasts that global sea level rise will reach from 29–59 cm (RCP 2.6) to 61–110 cm (RCP 8.5) until 2100, comparing to 1986–2005. Baltic Sea region is additionally affected by glacial isostatic adjustment, which results in Fennoscandia uplift and subsidence of southern Baltic coast. Therefore, sea level is determined by an interplay between global sea level rise and land movement, which strongly depend on local factors. Main goal of our work was to forecast groundwater table level until 2100 for two sandbars, Vistula Spit and Hel Spit located in southern Baltic Sea coast (Poland). For this purpose, one-dimensional numerical models of two representative unsaturated zone profiles were developed using HYDRUS-1D, calibrated with groundwater level measurements. Weather data and sea level rise predicted for moderate and high emissions scenarios (RCP 4.5 and 8.5), were implemented to the simulations. To include possible land use change, three variants of vegetation cover (pine forest, grass, bare soil) were included. The results show the largest water table rise for 8.5 RCP scenario, 75–122 cm for Vistula Spit and 69–102 cm for Hel Spit. For 4.5 RCP the average groundwater elevation is expected to increase 54–96 cm in Vistula Spit, and 53–74 cm in Hel Spit. In that case, water table is equal or only slightly higher than the sea level, which leads to significant decrease or complete salinization of shallow aquifers, especially during low recharge periods.

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Keywords: *coastal aquifers, saltwater intrusion, sea level rise, climate change, HYDRUS-1D*

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INCREASING USE OF DESALINATION ALONG THE COAST OF SOUTHERN CALIFORNIA, USA

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ABSTRACT

Desalination of both seawater and brackish groundwater has been increasing along the coast of southern California, USA. Since 1999, three facilities have been planned, opened, or expanded in order to improve the reliability of supplying municipal water. Since about 1945, most municipal water used in southern California has been imported from sources many hundreds of kilometres away—either from Owens Valley, northern California, or the Colorado River. In the past 20 years, however, these sources have become less reliable because of environmental restrictions and climate variability. In order to continue to ensure an adequate supply of municipal water for the huge population of southern California, water agencies have instituted a variety of measures including conservation, in lieu water trades, new reservoirs, enhanced recharge, and expanded use of desalination. These three desalination facilities illustrate the range of technical options that are being pursued.

Keywords: *(desalination, coastal, groundwater, seawater)*

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LIFE REMAR PROJECT, TREATED WASTEWATER RENATURALIZATION USING SOIL-AQUIFER TREATMENT WITH REACTIVE BARRIERS

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ABSTRACT

The Spanish Mediterranean coast has faced a dramatic increase in water demand driven mainly by the rapid expansion of agriculture and tourism, leading to groundwater overexploitation and seawater intrusion. Climate change exacerbates this situation. The LIFE REMAR project (LIFE20 ENV/ES/000284) addresses this issue through Managed Aquifer Recharge (MAR), using treated wastewater from the Cambrils Wastewater Treatment Plant (WWTP) to replenish the Plioquaternari Detrital Aquifer of Camp de Tarragona, mitigating aquifer depletion and improving water quality.

The project employs Soil-Aquifer Treatment (SAT), incorporating reactive barriers in infiltration basins to enhance contaminant removal, including nitrogen, contaminants of emerging concern, microplastics, pathogens, and antibiotic resistance genes, among others. The pilot system consists of two 400 m² basins and is designed to recharge up to 400 m³/day of treated wastewater. Groundwater conditions and water quality are continuously monitored using piezometers equipped with *Aquatroll-500* probes and CTD-Diver sensors, measuring electrical conductivity, pH, temperature and nitrate levels, among others. Periodic water sampling is also carried out.

Results demonstrate a significant reduction in nitrogen and *Escherichia coli* concentrations as water infiltrates through the unsaturated zone and flows through the aquifer, highlighting the system's effectiveness in improving groundwater quality.

LIFE REMAR provides a sustainable solution to groundwater overexploitation in coastal areas. By expanding water resources through a nature-based technology, it presents a replicable model for the Mediterranean and other water-stressed regions, contributing to water security, ecosystem resilience, and the advancement of sustainable aquifer management strategies.

Acknowledgments

The LIFE REMAR project (LIFE20 ENV/ES/000284) has received funds from the European Union.

Keywords: *(maximum 5 keywords)*

Coastal Aquifer

Seawater intrusion

Treated Wastewater Renaturalization

Managed Aquifer Recharge

Water Quality

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LINKS BETWEEN LAND COVER AND THE CHEMICAL CHARACTERISTICS OF GROUNDWATER IN A TIDAL CRYSTALLINE COASTAL ENVIRONMENT

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ABSTRACT

Continental groundwater represents a significant local source of nutrients and pollutants into coastal waters, affecting ecosystem functioning. Two rivers, 7 wells and 8 subterranean estuaries (STEs) located in the Ría de Vigo (NW Spain) were sampled in July 2023 and March 2024. Concentrations of dissolved oxygen, inorganic nutrients, and dissolved organic matter (DOM), optical indices of DOM and trace metals, together with the diversity and abundance of prokaryotes were measured. Land cover characterization around the sampling sites was undertaken using the SIOSE Land Use Information System. The 15 most representative uncorrelated land cover classes were selected, and a principal component analysis was performed to identify coherent clusters of samples. Two principal components (PC) explaining 27.7 % and 18.0 % of the variance were obtained. The first PC (PC1) was related to a gradient from highly anthropized to moderately artificialized areas dominated by natural cover classes. Land cover classes associated with agriculture activities positively correlated with the second principal component (PC2). The chemical composition and DOM optical indices of groundwater drawn from wells and rivers were closely associated with the land cover characteristics of the sampling area. Nitrate concentration, the ratios FDOMm/a325, FDOMc/a340 and a254/a365 and Cr, Cu, Zn, As, Cd and Pb concentrations, positively correlated with artificialized land cover whereas a254/DOC was related to forest-dominated areas. None of the chemical variables correlated with the PC2. By contrast, the relationship between the chemical variables and land cover in STEs was less clear; only silicate was positively correlated with PC1 and dissolved oxygen, Cu and As with PC2. These results highlight the uniqueness of STEs as reactive interfaces mediating the transfer of groundwater-borne solutes to the coast, relatively independent on the uses of the surrounding landscape. STEs, therefore, control the magnitude of land-derived solute

transport via continental groundwater discharge to the coast.

Keywords: *(maximum 5 keywords)*

Land cover, Subterranean estuaries, Groundwater, chemical composition.

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MANAGEMENT OF COASTAL AQUIFERS AND RELATED ECOSYSTEMS IN HEAVY PUMPED AREAS DURING AQUIFER DEWATERING OPERATIONS

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ABSTRACT

In many European countries with a temperate climate like Belgium, the large-scale infrastructure projects with deep foundations or long trajectories often require prolonged dewatering periods to manage groundwater levels during construction works. Dewatering involves the removal of groundwater to create dry and stable conditions for excavation and building. While some of these projects contribute to climate goals, it also necessitates a thorough evaluation of its environmental impacts, particularly concerning salinity distribution and the adverse impact on biodiversity. Therefore, the implementation of targeted mitigation strategies is essential to ensure that the project's benefits are realized in an environmentally responsible manner.

Managing saltwater displacement during dewatering operations in the coastal aquifers is crucial due to the potential environmental risks involved. To manage and mitigate salinity issues, the following strategies have been applied: first, implementing controlled extraction practices, where the excavation is subdivided into dewatering phases to prevent overexploitation and maintain natural balance between freshwater and saline water as possible. Second, applying artificial recharge near the dewatering location by re-introducing the pumped groundwater back into aquifers through infiltration basins, ditches or injection wells to reduce the zone of influence and maintain a sustainable level.

Monitoring and modeling are implemented during the dewatering operation by utilizing advanced tools and models to monitor the zone of influence, salinity distribution and predict future changes, aiding in proactive management decisions. In the context of dewatering operations, SEAWAT can be employed to predict how groundwater extraction might influence the movement of saline water and contaminants. By modeling different dewatering scenarios, it is possible to identify strategies that minimize the risk of contaminant displacement and salinity intrusion. For instance, adjusting pumping rates, configuring extraction wells or introducing hydraulic barrier based on the model simulations can help control the direction and extent of groundwater flow, thereby mitigating potential adverse effects not only by mitigating the risks associated with salinity changes and contaminant displacement but also to control the impact on the fauna and flora and avoid the risks of prolonged drought.

Keywords: *Coastal aquifers, Dewatering, Biodiversity, Management, Modelling.*

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MICROBIAL CONTRIBUTIONS TO THE FATE OF ORGANIC CONTAMINANTS IN SUBTERRANEAN ESTUARIES: A CASE STUDY IN MARSEILLE

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ABSTRACT

Subterranean estuaries (STE) are a continuum from the land to the sea where groundwater interacts with seawater. This biogeochemically dynamic environment shape the fate of nutrients and chemical contaminants before their delivery into coastal waters. These environments, often overlooked, particularly under urbanized beaches, are increasingly exposed to anthropogenic pollutants. In particular, pharmaceuticals and personal care products (PPCPs) raise concerns due to their persistence and potential ecotoxicological impacts. On the other hand, environmental gradients and coalescence of evolutionary divergent microbiomes puts forward STE as a hot spot of microbial diversity, with a higher probability of encountering microbes able to modulate chemical contaminations.

This study aims to characterize microbial community dynamics and their potential for PPCP degradation in a subterranean estuary of a highly urbanized Mediterranean beach in Marseille, France. By coupling *in situ* field sampling with controlled laboratory experiments, we assess the influence of salinity gradients, redox conditions, nutrients and PPCPs on microbial diversity. Using flow cytometry, quantitative PCR and metabarcoding, distribution and taxonomic diversity of heterotrophic prokaryotes and fungi are evaluated to locate the microbiological reaction field and its environmental drivers. In parallel, microcosm experiments are performed to evaluate biodegradation potential of STE communities for different PPCPs (two antibiotics (azithromycin, erythromycin), an antidepressant (fluoxetine) and a beta-blocker (sotalol), or one UV filter (octocrylene)).

Preliminary results highlighted a wide salinity gradient under this beach, ranging from 0.7 to more than 38 $g.L^{-1}$ at the end of the dry season as well as during winter. This salinity gradient seemed to structure microbial assemblages with microbial hotspots at intermediate salinity (between 8 and 10 $g.L^{-1}$). First results on laboratory experiments show significant stimulation of underground community growth in the presence of octocrylene at a concentration representative of values observed in summer bathing areas, and in just one day.

Keywords: *(maximum 5 keywords)(separated by comma ",")*

Subterranean estuary, microbial ecotoxicology, UV filters, pharmaceuticals, biodegradation

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MINERALOGY AND MULTI-ISOTOPE GEOCHEMISTRY OF A HIGH-ENERGY SUBTERRANEAN ESTUARY IN THE TEMPERATE CLIMATE ZONE

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ABSTRACT

Subterranean estuaries (STE) serve as critical interfaces between terrestrial water and element cycles and the marine coastal environment. They are characterized by steep biogeochemical gradients that influence processes such as the transport and transformation of carbon, sulfur, and metal compounds. Besides oxygen and nitrate, sulfate availability often plays a key role in carbon mineralization. Interactions with mineral phases within the aquifer contribute to the hydrochemical properties of solutions existing in the sediment, with minerals acting as elemental sources or sinks during biogeochemical cycling. Within the research group DynaDeep, it is aimed to investigate processes within a STE built of permeable sands located in the southern part of the North Sea in the temperate climate zone. The dynamic beach system in the north of Spiekeroog Island offers a unique setting to study interactions between fresh and saltwater under present and future environmental conditions. Vertical observations of sediments, and seasonal changes of pore water composition are made possible through boreholes and multi-level wells. This study presents findings from multi-isotope (COSH) analyses of water, dissolved carbon species, sulfate, and iron sulfides, alongside hydrochemical gradients and sedimentary mineral phase analyses. Water isotope ratios reveal freshwater mixing, while carbon isotope signatures in dissolved inorganic carbon highlight sources such as organic matter degradation and carbonate corrosion. Sulfate and iron sulfide isotopes indicate formation of reduced phases from microbial sulfate reduction, with evidence of sulfide oxidation near the surface or contributions from non-marine sulfate at lower salinity. Microscopic and phase analyses identify iron sulfides of in-situ formations, and calcite, apatite, and barite in the sediments, primarily of in-situ or detrital origin. Dolomite, another potential alkalinity source, is identified as detrital.

Keywords:

Subterranean estuary, submarine groundwater discharge, stable isotopes, sediments, mineralogy

Salt Water Intrusion Congress (SWIM 2025)

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MULTI-APPROACH STUDY TO CHARACTERIZE SALTWATER INTRUSION DYNAMICS AFFECTING A WELLFIELD IN A CONTEXT OF GROUNDWATER-RIVER EXCHANGE

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ABSTRACT

The Marana Golo wellfield supply drinking water from the Golo alluvial aquifer to over 23,000 people south of Bastia (Corsica, France).

Wells in the catchment area tap the aquifer at shallow depths, 5 km far from the Mediterranean coastline. This productive aquifer is largely sustained by the Golo river. Annual production volumes average 2.6 million m3.

In Automn 2017, under drought conditions, a conductivity peak of up to 900 µS/cm was measured in the eastern part of the wellfield by one of the autonomous and remote controlled geophysical monitoring tools (SMD@pattented by imaGeau presented at SWIM2018). This phenomenon could be a precursor of saltwater intrusion progressing near the wellfield.

In this context, the acquisition of multi-disciplinary & multi-scale (both temporal and spatial) data on

- the aquifer (geophysical prospecting by ERT; Well logging),
- the groundwater (multi-depth electrical conductivity via automation and long-term monitoring SMD, real time water level),
- the Golo river (topology, real time level, electrical conductivity campaigns from the mouth to the wellfield)

have enabled the construction and calibration of a hydrogeological density model taking into account the interaction between surface water and groundwater.

The simulations generated by the hydrogeological model allow us to determine the origin of high chloride content episodes in the wellfield. The results show that salinity peaks in groundwater, and notably the 2017 event, are due to chlorides originating from the Golo river through marine inflows and tide propagation; groundwater-river exchange being enhanced by pumping.

The simulations also allow the definition of a threshold level for the Golo river (-6 cm NGF at the front of the wellfield) for which saltwater would reach the meander located in the middle of the wellfield if the river mouth is open (climate change simulation to 2070). This would impact

groundwater over the wellfield with salinity levels exceeding 4g/l.

Keywords: groundwater-river exchange**,** multi-disciplinary & multi-scale (both temporal and spatial) approach, long-term monitoring, hydrogeological density model

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ON THE INTERACTION BETWEEN SGD AND SWI PROCESSES AND RESEARCHERS

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ABSTRACT

Submarine Groundwater Discharge (SGD) and Seawater Intrusion (SWI) are complementary processes. SWI occurs regardless of whether any groundwater discharges into the sea, but can become severe in the absence of SGD. As a result, SWI scientists view SGD as their “boundary condition”. They are primarily interested in SGD to gain understanding into inland processes. SGD is important as a source of nutrients and elements that are scarce in the ocean, so that SGD may be a limiting factor for some of them. Therefore, SGD scientist are primarily interested in SWI and inland processes as a way to identify which elements may enter the sea through SGD and to quantify their fluxes. These interests are complementary and strong collaboration should be expected this two groups. That this collaboration is not as rich as it should can be attributed to different causes, but probably the most important are their different backgrounds, scientific methods, and probably different perceptions. SWI scientists are hydrogeologists, familiar with the slow laminar flow of aquifers, which use chemistry as a way to understand groundwater flow, but rarely to study biological processes, limited by the slow transport and thus where biochemical activity is equally slow. SGD is studied by a broad range of scientists, but usually more familiar with ocean processes, where flow is turbulent, where chemistry is strongly linked to biological activity, and where most life is highly mobile. These differences have also promoted very different working methods. The objective of this presentation is to promote a debate between SGD and SWI scientists to acknowledge differences, so as to find common grounds for collaboration

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OPEN ACCESS TOOLS: TOWARDS A BETTER MANAGEMENT OF THE UNDERGROUND RESOURCES

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ABSTRACT

Building a groundwater model is often essential to make accurate predictions about the evolution of groundwater resources. To this aim, a wide variety of data can be used, such as groundwater levels, geophysical measurements or pumping tests. However, integrating these data into a consistent groundwater modelling workflow is known to be difficult.

In the last decade, open science has become widely accepted in geosciences with the emergence of many software, datasets and methodologies that are freely accessible and facilitate the development of more holistic approaches that better integrate different types of data. Within this philosophy, we have developed a set of geostatistical tools and modelling approaches to simplify the complex task of (hydro)-geological modelling and spatial predictions.

First, we have a python library called ***GEONE*** which includes a large panel of geostatistical functions (random fields, indicator simulations, multiple point statistics). Second, around ***GEONE***, we have ***ArchPy***, a python module that allows the fast generation of hierarchical geological stochastic models that respect both geological concepts (stratigraphic relations, lithofacies, etc.) and geological data (geological maps, boreholes, cross-section). ***ArchPy*** is flexible and can be simply coupled with other open access software such as geophysical and groundwater forward. Notably, there is the *archpy2modflow* submodule which allows to easily create a MODFLOW model directly from an ***Archpy*** model. It also integrates options for automatic simple upscaling of ***Archpy*** models, reducing the computational burden of hydrogeological modelling while preserving latent complex geology. This is even more critical for coastal aquifers, where seawater need to be considered, making the computation of groundwater heads difficult and computationally expensive. Finally, we have developed a web-interface, *ArchPyOnline*, that allows to generate a geological model on demand via an open access website. All of these tools facilitate the emergence of coupled and holistic workflows that allow better management of underground resources.

Keywords: open science, geological modelling, integrated approaches, uncertainty quantification

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REACTIVE-TRANSPORT MODELING OF CARBONATE SPECIES IN SEAWATER-INFLICTED COASTAL AQUIFERS: IMPLICATIONS FOR AQUIFER HYDRO-GEOCHEMISTRY AND CO_2 SEQUESTRATION

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ABSTRACT

Coastal aquifers are dynamic hotspots of complex hydro-geochemical interactions between fresh groundwater and saline seawater. Understanding the reactive transport of major solute species (eg. Ca^{2+}, CO_3^{2-}) is critical to advance our understanding of the carbonate system in saline aquifers which fundamentally impacts carbon cycling. This study employs a commercially available FEFLOW package to simulate the reactive transport of dissolved Ca^{2+} and CO_3^{2-} species in a saline aquifer, incorporating both density-driven hydrodynamic mixing and geochemical reactions. Originally developed to investigate CO_2 injection in saline aquifers as a climate change mitigation technique, this modeling framework provides insights into how the CO_2 influx in dissolved form affects the geochemical system, especially carbonate equilibrium. A steady-state conservative mixing model was first developed using hydraulic head and solute concentration (TDS, Ca^{2+}, CO_3^{2-}) boundary and initial conditions. Transient reactive transport simulations were then performed to evaluate the geochemical evolution of Ca^{2+} and CO_3^{2-} species, focusing on their enrichment or depletion in the model domain. The model dynamically solves the reaction-transport equation, coupling advective-diffusive transport with precipitation-dissolution kinetics based on carbonate saturation state. Preliminary results indicate that mixing-induced geochemical reactions significantly alter the spatial distribution of dissolved Ca^{2+} and CO_3^{2-} concentrations with time (in years) within the model domain. The findings from the present study highlight the importance of considering reactive transport processes in saline aquifer models to better assess the impact of CO_2 injections on water-rock interactions. This study will potentially provide deeper insights into the evolution of water chemistry in coastal aquifers with implications for carbon sequestration and long-term CO_2 storage in coastal regions.

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SAND TANK EXPERIMENTS IN COASTAL HYDROGEOLOGY – HOW TO DO THEM AND HOW TO DO THEM BETTER

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ABSTRACT

Sand tank experiments in coastal hydrogeology have been widely applied for over 100 years now. They help to visualise and explore variable-density groundwater flow processes, which are typically not directly visible in nature. Laboratory experiments may vary in size, complexity and materials. Three major fields of application for sand tank experiments in coastal hydrogeology may be distinguished: 1) Visualisation and investigation of naturally occurring phenomena and processes: e.g. the influence of subsurface heterogeneities, transport processes within and above the saltwater wedge, impacts by seawater over-wash, as well as tides and resulting recirculation cells. 2) Exploration of human impacts and geo-engineering strategies, e.g. subsurface physical and hydraulic barriers: an overview and bibliometric analysis including a review of mitigation strategies was presented by Kassem et. al (2024). 3) Benchmarking for the validation of numerical variable-density codes: a numerical benchmark of a freshwater lens, including a review, was presented by Stoeckl and Graf (2016). Practical information on planning, conducting and evaluating variable-density sand tank experiments has been summarizes by Stoeckl and Houben (2023). Several prerequisites are essential for the successful outcome of a laboratory experiment, e.g. precalculations of runtimes and materials, scales and (visual) data recording. Aspects like tank constructions, porous media, liquids and tracer dyes also have to be accounted for. The collection of hints and tips may guide novices, as well as experienced researchers, and possibly prevent them from repeating errors that have been encountered during a long history of experimental work conducted.

Keywords: sand tank experiments, variable-density flow and transport, laboratory studies, hints and tips

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SEA-GROUNDWATER RELATION IN LEGENDS OF MESOPOTAMIA GODS (~3500 YEARS BP) – A LESSON FROM FAR AWAY HISTORY?

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EXTENDED ABSTRACT

The researchers of the SWIM community have been studying the interrelation between groundwater and the sea for many years. It seems that people have asked themselves somewhat similar questions many years ago, as found in the cuneiform texts in the Mesopotamia area (Iraq of today and nearby areas, Fig. 1). The ancient cultures included kingdoms of Akkadian and Sumerian speaking cultures, including the well-known kingdoms and empires of Babylonia and Assyria, as well as other societies, that lived in this area from around 5000 years BP till ~2000 years BP. Among the texts produced by these societies, are the famous epic of Gilgamesh and the code of Hammurabi (Fig. 2).

Among the many gods in their culture, two gods appear in the Babylonian Creation Myth (dated to ca. 1000 BCE) as the first two primordial divine elements. These were the god of the subterranean freshwaters Abzu (who lives in the underground and is therefore considered as the god of groundwater although it may include the water of the big rivers, which are mainly surface water), and the goddess of the Sea (Tiamat). The mating between these two primordial gods yielded offspring which were important in the Mesopotamian culture, mythology, and theology, but of no specific hydrological significance. An exception to this is the Sumerian god Enki (called Ea in Akkadian), a god born a few generations after the initial mating of Abzu and Tiamat, who, within an intergenerational combat, killed his forefather Abzu, and since then resided in the subterranean freshwaters called Abzu as well (Apsu in Akkadian). Enki's son, born to him in the Abzu subterranean waters is the god Marduk, who according to the myth created the world, mostly from the body of the slain Tiamat. Thus, the primordial mating of the sea and the freshwaters resulted in creation.

There are a few older mythological narratives that feature the groundwater god Enki dispersing his sperm in the ground and by that creating the flow of the rivers of Mesopotamia. In addition, the goddess of the sea is sometimes portrayed as a cosmic womb creating offspring.

The god Enki is also depicted in art, for instance in cylinder seals. It is interesting to note that in some of these depictions, the direction of the flow can be seen according to the movement of the fish (Fig. 3), showing flow from the rivers toward groundwater which will define it in modern terms as a losing river.

It is difficult to know from these mythological texts how much the ancient people knew about hydrogeology. They definitely knew about the difference between surface water and groundwater, the latter responsible for springs discharging at different locations. There are textual and iconographical descriptions of water coming from holes or caves (possibly toward the rivers?) and these probably refer to groundwater flowing to the river. The ancient people regarded the water in the underground as highly pure water. They considered the canes (common reed) at the vicinity of the rivers as stemming from the pure waters of the groundwater. There were many wells in the ancient towns that indicate some knowledge about groundwater. But, there is no information about whether they knew about the effect of mixing between the two water sources on the salinity of groundwater and springs. This is especially interesting since some of the largest communities lived in the southern part of Iraq (near Basra) where marshes and swamps are found near the coast, an environment where mixing is known to occur. In this area, the two big rivers (Tigris and Euphrates) flow to the sea and mix with seawater of the Persian Gulf.

The extent of knowledge of ancient people from similar periods of time about hydrogeology has been questioned before also regarding many archeological sites in Israel (e.g. Yechieli et al., 2021). In some sites it seems that people knew enough about groundwater in order to reach it by digging wells, while in other sites it appears that they did not know, and either missed groundwater even after deep digging or found groundwater by chance. This is not unreasonable when considering the fact that even today, with our modern knowledge and technology, we sometime miss and do not manage to reach producible groundwater.

It is interesting to note that there was another god during that time, which was more important for the ancient people away from the delta in the south and this is the god of rain, Ba'al or Hadad. This god is more important in Syria and other places farther away from the southern Mesopotamian area, since the south is much drier than the northern area (precipitation of ~100 mm/year in the south versus ~1000mm/year in the high mountains in the north). The people who wrote the mythologies of the gods of groundwater and the sea lived in the south and therefore were less interested in the god of rain.

References

Yechieli, Y., Reich, R., Galili, E., Tsuk, T., Dahari, U., Avni, G., Sivan, D. (2021). Hydrogeology in archeological perspective: what did people in ancient times know about hydrogeology? The Many Facets of Israel's Hydrogeology, ed. by U. Kafri & Y. Yechieli, Springer, pp. 417-443.

More information about gods in Mesopotamia see website:
https://oracc.museum.upenn.edu/amgg/sitemap/

Keywords: groundwater, sea-aquifer relation, Mesopotamia gods, history, archeology.

Figure 1. Map of the Mesopotamia region, located mostly in the area of modern Iraq. Ancient Mesopotamian is the area around the Tigris and Euphrates rivers, in Iraq and its surrounding. Note the location of Babylon near Baghdad and the location of Assur and Nineveh in the northern part (near Mosul). Also note the area in the south, near Basra, where the delta of the two major rivers reach the Persian Gulf.

Figure 2. Left: Cuneiform tablet containing the Epic of Gilgamesh, specifically the story of the great flood (Nineveh, 7th century BCE). Right: The Code of Hammurabi is a Babylonian legal text, composed c. 1755–1750 BC.

Figure 3: God of groundwater, Enki (Cylinder seal, ca. 2300 BCE). The flow of fish toward him through his arms indicates that the direction of flow is from the river toward groundwater.

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Seasonal oscillations and saltwater intrusions in the Roussillon aquifer

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ABSTRACT

With 80% of the world's population living in coastal areas, aquifers in direct contact with the sea are widely exploited and are experiencing rising temperatures, sea levels and droughts, making them vulnerable to saltwater intrusion. The Roussillon plain is a region in the south of France, bordering the Mediterranean Sea, which has suffered severe drought in recent years, from an average rainfall of 600 mm per year to a total of 250 mm for 2023, affecting both surface and groundwater. The main activities in the region are tourism and agriculture, which require water especially in spring and summer for crop irrigation and drinking water. In summer, when surface water levels are at their lowest, the region's water supply depends heavily on groundwater. The plain is covered by sediments deposited during the Pliocene and Quaternary, which form aquifers with favorable transmissivities for groundwater exploitation, extending several kilometers under the sea shore. Intensive pumping in recent years has lowered the groundwater level, making it more vulnerable to saltwater intrusion. We show that the seasonality of pumping has a strong effect on groundwater levels, and that the seasonal oscillations of the groundwater level increase the risk of possible seawater intrusion. Our work therefore focuses on building a transient land-sea Modflow model that matches the observed oscillations and helps to manage the Roussillon aquifer by anticipating possible saltwater intrusions. The heterogeneity of the aquifer, with alternating sand and clay layers, is an important factor in this aquifer and must be carefully considered when attempting to model saltwater intrusion. We show that high-permeability layers are the main pathway for intrusion during low-water periods, and that low-permeability layers that become salt-contaminated by dispersion are salt reservoirs, making the intrusion more difficult to reverse.

Keywords: *Coastal aquifer, modelling, saltwater intrusion*

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SMALL-SCALE VARIABILITY OF MICROBIAL COMMUNITIES AND THEIR FUNCTIONAL POTENTIAL IN A MEDITERRANEAN BEACH AQUIFER

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ABSTRACT

Coastal aquifers are dynamic interfaces where groundwater interacts with seawater environments through submarine groundwater discharge (SGD). This process transports dissolved compounds and essential elements that influence the productivity of coastal areas and biogeochemical cycles occurring in them. Microbial communities residing in these underground habitats play an essential role in modifying the chemical characteristics of groundwater, ultimately influencing the composition of SGD and its effects into the ocean. Despite this, the contribution of microorganisms in controlling groundwater composition and nutrient fluxes has been largely overlooked, as research on SGD has been driven by other disciplines, often disregarding the microbiological aspects. Recent studies have shown that microbial communities from coastal aquifers can be very heterogeneous at small spatial scales, but few investigations have considered this small-scale variability in porewater microbiota located next to groundwater discharge sites. In this study, we aimed at exploring the small-scale spatial patterns of microbial communities inhabiting a karst beach aquifer discharging in the Mediterranean Sea. We investigated changes in prokaryotic abundance, activity and the

abundance of different functional genes involved in nitrogen transformations along two transects perpendicular to the coast, and linked them to variations in nutrient concentrations and other physicochemical characteristics. Our initial findings reveal highly heterogeneous porewater microbial communities along the studied transects, which vary depending on salinity and other factors. Among them, we identify abundant small-sized populations of ultramicrobacteria, which could alter important biogeochemical processes and are the focus of ongoing research. Additionally, next generation sequencing and functional gene tracking are being used to understand how their metabolic activity modulates nutrient fluxes associated with SGD. Gaining a deeper understanding of coastal groundwater microbial populations will provide valuable insights into the drivers of SGD to the ocean.

Keywords: submarine groundwater discharge, microbial communities, biogeochemical processes, ultramicrobacteria, nitrogen transformations

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SUBMARINE GROUNDWATER DISCHARGE AS A SOURCE OF NUTRIENTS TO LA VENTANA BAY, MEXICO, FROM A COASTAL AQUIFER INFLUENCED BY AGRICULTURAL ACTIVITY.

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ABSTRACT

Nutrients, particularly nitrogen and phosphorus, are widely used in agricultural activities worldwide, but the excess of these elements can significantly impact marine ecosystems. La Ventana Bay is a coastal zone surrounded by agriculture and other anthropogenic activities (formerly a mining area). It also has the presence of important geological faults, which cause hydrothermal activity on the beach and groundwater of the valley.

This study evaluated nitrogenous nutrients ($N\text{-}NO_2^-$, $N\text{-}NO_3^-$, and $N\text{-}NH_4^+$) and phosphate contamination levels in groundwater (Los Planes aquifer) and seawater (La Ventana Bay). The objective was to confirm possible nutrient sources and determine their transport through groundwater towards the bay.

Field sampling was conducted in three climatic seasons. Dissolved concentrations of the N and P chemical species were analyzed in marine water and groundwater samples.

Results indicate that during the dry, and cool rainy seasons, a higher nutrient input was observed in the north of the bay, where the submarine groundwater discharge (SGD) was identified. This confirms the importance of the SGD as a pollutant source for the bay and suggests that nutrient transport from agricultural sources is seasonally variable, with potential implications for coastal ecosystem dynamics.

This study highlights groundwater as a key transport pathway of nutrients from agricultural areas to coastal ecosystems, emphasizing the need for monitoring strategies to mitigate eutrophication risks.

Keywords: Submarine Groundwater Discharge, coastal aquifer, nutrient contamination.

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THE INPUTS OF SOLUTES THROUGH SGD OVER A TIDAL CYCLE IN A COASTAL SYSTEM

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ABSTRACT

A study of the influence of continental groundwater discharge during a tidal cycle (semidiurnal mesotidal) in a large coastal inlet surrounded by a crystalline drainage basin (Ría de Vigo, NW Iberian Peninsula) during two contrasting climatic and oceanographic periods in July 2023 (dry period) and March 2024 (wet period) has been carried out. In order to monitor this, three Time Series stations were located through the system under study: the first and the second ones in the inner ría (Cobres) and outer ría (Baiona), were increased subterranean waters discharge were already detected, and the third one in the middle ría (Toralla), where the contribution of the continental groundwater discharge was low according to previous studies. ^{222}Rn and ^{226}Ra activity was measured in seawater as tracers of the subterranean waters in order to characterize its temporal variation in different sectors of the Ría over a tidal cycle. Moreover, geochemical parameters *e.g.* trace metals and several chemical elements, organic matter, optical properties of the DOM, nutrients, stable isotopes and rare earth elements were analysed. Variations in the salinity values were correlated with changes in the sea level due to the semidiurnal regime as well as ^{222}Rn activity and redox sensitive metals as Fe and Mn. Lower salinity levels occurring during low tide and increased ^{222}Rn activity, mainly during the wet period, correlates with higher values of the geochemical parameters, *e.g*. DOM, Fe and Mn. This fact emphasizes the importance and the contribution of the groundwater waters into the Ría seawater, and the needing of these high frequency studies on a temporal scale.

Keywords: *Submarine groundwater discharge, metals, DOM, tidal cycle*

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THE RELEVANCE OF METAL INPUTS INTO MAR MENOR COASTAL LAGOON (SPAIN) THROUGH SUBMARINE GROUNDWATER DISCHARGE

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ABSTRACT

Mar Menor is one of the largest hypersaline (38-51 ppt) coastal lagoons along the Mediterranean coast. The relatively long residence time (months) of water within the lagoon, combined with potential metal inputs from its economic activities (agriculture, tourism, fishing and the historical mining activity) may lead to high concentrations. Although there are previous studies about the presence of metals in Mar Menor sediments or lagoon waters, there is little

information on inputs of metals supplied by submarine groundwater discharges (SGD) which is recognize as a potential relevant source of metals. In the present study, samples from groundwater (wells and piezometers) streams and lagoon water were collected during two different contrasting hydrologic seasons (July and November 2021), in order to elucidate both the magnitude of SGD-driven inputs and the spatial and temporal distribution of these metals in the lagoon. Metals studied included Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Cd and Pb. The results demonstrated higher levels of Fe, Mn and As in groundwater than the concentrations in streams and lagoon water and higher levels of Cr, Cu, Cd and Pb in streams. Furthermore, the metal concentrations were higher in the North and Southeast areas of Mar Menor which could be associated with the agriculture activity at the North and the Cartagena-La Unión mining district located at the Southeast. In terms of fluxes, the predominant pathway transporting Mn, Fe, Co, Ni, Zn and As into the lagoon was through SGD (higher levels for Mn and Fe), nevertheless, Cr, Cu and Pb the had a main flux from the streams. The work done in this research allows a broader picture of all the possible aquatic pathways of metals to the Mar Menor waters, taking into account the relevance of SGD as a conveyor of them.

Keywords: Metal pathways, Submarine Groundwater Discharge, coastal lagoon, anthropogenic activities

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TRACING THE SOURCE OF MINERALIZATION AND GROUNDWATER RECHARGE IN A SEMI-ARID COASTAL REGION IN MOROCCO.

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ABSTRACT

In arid and semi-arid zones, water resources are faced with several problems, especially the extensive drawdown of the water table and the continuous degradation of quality. Stable isotopes, specifically oxygen-18 (18O) and deuterium (2H), are used in this study to identify the origin of water masses and the history of their movement at the surface and underground. Isotopic tracing also make it possible to understand the groundwater recharge mechanism, to determine the origin of water mineralization and to estimate their recharge attitude. The isotopic values in δ18O and δ2H of Cenomano-Turonian waters are respectively between - 6.3 and 0.5‰ with an average of - 5.2‰ and between - 39.2 and 2.2‰ with an average of - 29 ‰. The majority of points are closed to GMWL and the LMWL. This reflects that the recharge of the Cenomano-Turonian aquifer is ensured by precipitation of Atlantic origin. The 18O vs. EC diagram concentrations show that the groundwater mineralization is governed by dissolution phenomenon. The lack of correlation between 18O and chloride levels indicates that the mineralization is acquired by dissolution of the minerals. This is also confirmed by the hydrogeochemical approach, which suggests that water mineralization is not mainly linked to evaporation or seawater intrusion, but essentially comes from the dissolution of minerals, following water-rock contact. The recharge altitude varies between 400 and 1400 masl. Some points have altitudes far exceeding the maximum altitude of the study area (about 800 masl). This reflects that the recharge zone of these points is outside the study area. The mixing ratios deduced from the mass balance of stable isotopes shows that surface water contributes between 32.16 and 70.42% to the Cenomano-Turonian aquifer recharge. The study provides valuable information on the water isotopes that could be used by policymakers and water managers for more informed decisions about how to allocate and use this precious resource.

Keywords: *Water mineralization, Seawater intrusion, Groundwater recharge, Water managers, Stable isotopes.*

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UNDERSTANDING HYDROGEOLOGICAL CONTROLS ON SEAFLOOR OLIVINE WEATHERING FOR ATMOSPHERIC CARBON DIOXIDE REMOVAL

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ABSTRACT

Coastal hydrogeology plays a fundamental role in shaping biogeochemical processes at the land-ocean interface and the seafloor, influencing carbon dynamics and climate mitigation strategies. One carbon dioxide removal (CDR) approach is coastal enhanced weathering through olivine dissolution. Olivine weathering in coastal zones, where freshwater and saltwater converge, may accelerate dissolution due to enhanced geochemical gradients, dynamic groundwater flow, and temperature variations. Sea surface temperature (SST) is a critical factor in mineral dissolution rates, yet its role in coastal sediment weathering processes remains underexplored. Additionally, most prior studies focus on olivine dissolution in the water column, whereas this study explores weathering after the mineral powder settles on the seafloor.

To address this, we employ a 2D reactive transport modeling approach of the coastal aquifer using FEFLOW coupled with piChem to investigate how submarine groundwater discharge (SGD), porewater flow, sediment permeability, tidal pumping, and SST control olivine weathering rates in coastal sediments. The results confirm that warmer SST enhances weathering efficiency, making temperature a key driver of olivine dissolution. High permeability and high tidal pumping further amplifies dissolution rates by facilitating reactive transport, while slow groundwater flow within sediments limits dissolution compared to the water column due to localized saturation effects. These findings emphasize that seafloor permeability, temperature, and tidal dynamics are key hydrogeological controls on olivine dissolution in coastal environments. Accounting for the interplay between slow groundwater flow and enhanced reactive transport mechanisms is essential for optimizing coastal enhanced weathering as a viable CDR strategy.

Keywords: *Submarine Groundwater Discharge, carbon dioxide removal (CDR), Reactive transport modelling*

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UNDERSTANDING THE HYDROGEOLOGICAL INTERACTION BETWEEN RAILWAY AND PORT INFRASTRUCTURES IN TERMS OF THEIR EFFECTS ON SEA WATER INTRUSION IN AN URBAN COASTAL AQUIFER

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ABSTRACT

Currently, around 40% of the global population resides in coastal cities, and this percentage is expected to rise in the coming years. In this context of growing urban concentration in maritime areas, coastal aquifers serve as crucial water reserves, particularly in arid and semi-arid regions, and become even more essential during droughts. These aquifers face multiple human and climatic pressures that influence both the quantity and quality of their water resources. Among human-induced changes, the expansion of underground infrastructure—such as rail tunnels—stands out due to its significant hydrogeological effects. Many of these constructions are positioned between retaining walls and/or include drainage systems that disrupt the natural groundwater flow, leading to a reduction in available water. Additionally, the construction of inner docks causes the coastline to shift inland. The combined impact of these alterations can accelerate saline intrusion into coastal aquifers, making it crucial to assess their consequences.

This research analyses the cumulative effects—both in quantity and quality—of railway tunnels and an inner dock on the primary aquifer of the Llobregat Delta (Spain) from 1966 to 2024. The total impact, the specific influence of each infrastructure, and their interactions are examined. First, the conceptual and geological model of the aquifer was revised, followed by the development and calibration of a three-dimensional variable-density groundwater flow and chloride transport model using MODFLOW 6. The discretization of the model has been designed to accurately represent the tunnels, their retaining walls, and the geological formations in the area.

The study consists of three sets of simulations. The first includes two scenarios: one depicting the current state with infrastructure in place and another simulating a hypothetical situation without these structures. The second set of simulations assesses the incremental impact of each infrastructure by progressively adding them at their respective times of construction over the historical period. The third set involves independent simulations for each infrastructure element to quantify their individual effects and evaluate non-linear relationships in their cumulative impact. In all cases, differences were analysed in mass balance, chloride concentration maps,

and piezometric levels between scenarios. Initial findings suggest that the inner dock, constructed in an area with unfavourable geological conditions, has had the most significant impact. Additionally, the impact of tunnels and retaining walls associated with rail lines appears to be strongly dependent of the presence of the port.

This study provides a methodological framework for assessing similar impacts in other coastal aquifers while underscoring the importance of geological understanding, the adoption of best construction practices, and the strategic planning of infrastructure to safeguard water resources in urban coastal areas.

Keywords: Coastal aquifer, Sea water intrusion, Underground infrastructure, Railway tunnels, Inner dock

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