MARSoluT
Managed Aquifer Recharge ITN

The MARSoluT project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement no 814066.

MARSoluT

Managed Aquifer Recharge Solutions Training Network

A Horizon 2020 MSCA ITN

Deliverable Title	MARSoluT International Conference
Author(s) [1]	A. Wefer-Roehl, K.E. Roehl, C. Schüth (TUDa)
Deliverable No.	D6.3
Work Package	WP6 Knowledge Transfer and Dissemination
Version	1.1
Version Date	29.12.2022
Dissemination Level [2]	PU
Status [3]	Final
File name	MARSoluT_D6-3_Conference_v11.pdf

[1] TUDa: TU Darmstadt, Germany.
[2] PU: Public, RE: restricted to a group specified by the consortium, CO: Confidential, only for members of the consortium; Commission services always included
[3] Draft, Revised, Final

Contents

1 Goal and scope

Managed Aquifer Recharge (MAR) – storing water in aquifers during times of excess – is a key strategy to enrich groundwater resources in water scarce regions by providing intermediate storage, addressing the typical mismatch between water demand and availability. MARSoluT - Managed Aquifer Recharge Solutions Training Network - is a four-year Marie Skłodowska-Curie Actions (MSCA) Innovative Training Network (ITN) funded by the European Commission. MARSoluT tackles specific technical challenges in the operation of Managed Aquifer Recharge (MAR) sites on a scientific basis. Specifically these are chemical, biological, and hydraulic processes governing water infiltration rates, hydrogeochemical processes affecting water quality issues, monitoring and modelling techniques, and the implications of these processes and techniques on the technical design of real-life MAR projects.

At the same time, MARSoluT trains a number (12) of Early Stage Researchers (ESRs) to become experts in the application of MAR in the frame of an Integrated Water Resources Management. We envisage these ESRs to become highly qualified multipliers for the effective promotion and implementation of MAR concepts in Europe and worldwide. The MARSoluT project consists of a network of 18 institutions, of which 8 come from academia and 10 from the non-academic sector, including SMEs but also large companies from the water sector, indicating the high potential of the research results for commercial, full-scale application.

Specific goals of the 2-days international MARSoluT conference towards the end of the funding period of the project were to present recent research results and project achievements to an international scientific audience and to discuss latest developments in the field of MAR with international experts. Four major themes were selected for being addressed in the conference:

- Chemical, biological and hydraulic processes resulting in clogging and reduction of infiltration rates,
- Hydrogeochemical processes affecting the water quality, with special focus on micro-pollutants,
- Performance monitoring and modelling, including reactive transport models to predict the fate of pathogens and emerging pollutants, and
- Implications of the processes mentioned above on the technical design of MAR projects in the frame of regional flow models and water management plans.

The MARSoluT research fellows were supposed to have an active role in developing themes, inviting speakers, and to coordinate this event. The conference was addressing specifically young scientists to participate. In the conference, all research fellows of the project were expected to give a presentation on their project results. In addition, invited speakers and speakers from the project consortium partners were supposed to give presentations related to the major themes of the conference from a broader perspective. A panel discussion covering aspects of "global applicability, bottlenecks, and proactive legislation" of MAR implementation was planned to conclude the indoor part of the conference, to be followed by a field trip to the Lower Llobregat decantation and infiltration basins near Barcelona.

This project deliverable is a formal report of the conference.

2 Conference

2.1 Basic data

Dates: 19. - 20. October 2022

Location: Hybrid event

- Universitat Politècnica de Catalunya (UPC), A3 building, North Campus of UPC, C. Jordi Girona, 1-3, Barcelona, Spain
- Online via Google Meet

Convenors:

- Prof. Christoph Schüth, Institute of Applied Geology, Technical University of Darmstadt, Darmstadt, Germany
- Prof. Xavier Sanchez-Vila and Prof. Daniel Fernàndez-Garcia, Department of Civil and Environmental Engineering, Universitat Politècnica de Catalunya. Barcelona, Spain

2.2 Participants

A total of 48 people have registered to attend the conference in person, and 31 persons registered for online participation. The audience included members of the MARSoluT Consortium including Partner Organisations, researchers from the partner MAR Interreg project DEEPWATER-CE, representatives from other universities or water companies such as Amphos 21 and Cetaqua, and interested individuals from different countries. Particularly, the organisers wish to thank external experts of the MARSoluT project, Dr. Joseph Guttman from Mekorot, Israel, and Prof. Martin Reinhard from Stanford University, USA, for their participation and valuable contribution.

2.3 Program

The conference was advertised on the MARSoluT website and disseminated by the project network. A registration form was developed for registering as in person or online participant. The suggestion by research fellow Marcel Horovitz (LNEC, Portugal) of giving the conference the short-name "MAR Con ‘22" was gladly accepted.

The program of MAR Con '22 was divided into four main themes, to collect research results, practical experience, and innovative ideas related to the following aspects of Managed Aquifer Recharge (MAR) activities, which were also the titles of the four main sessions of the conference:

- **Sustaining Rates –** Chemical, biological and hydraulic processes resulting in clogging and reduction of infiltration rates.
- **Improving Quality –** Hydrogeochemical processes affecting the water quality, with special focus on micropollutants.
- **Proving Performance –** Performance monitoring and modelling, including reactive transport models to predict the fate of pathogens and emerging pollutants.
- **Optimizing Design –** Implications of the processes mentioned above on the technical design of MAR projects in the frame of regional flow models and water management plans.

3 Conference contents, abstracts of presentations

3.1 Session 1: Sustaining Rates

On the relevance of site exploration as prerequisite for successful MAR site planning and operation

Rebecca Sultana[1,2], Ulrike Werban[1], Marco Pohle[1], Rudy Rossetto[3], Thomas Vienken[1,4]

[1] Helmholtz Centre for Environmental Research (UFZ), Leipzig, Germany

[2] Technical University of Munich (TUM), Campus Straubing, Straubing, Germany

[3] Scuola Superiore di Studi Universitari e di Perfezionamento Sant'anna (SSSA), Italy

[4] Weihenstephan-Triesdorf University of Applied Sciences, TUM Campus Straubing, Straubing, Germany

Managed aquifer recharge (MAR) is an effective technique where water is injected artificially through unsaturated zone for sustainable management of groundwater. Aquifer replenishment can be achieved using various MAR techniques and river bank filtration (RBF) is the most popular MAR technique applied in Europe. In this method, surface water is exchanged with groundwater by pumping wells which are installed at rivers bank. Management and operation of RBF sites requires knowledge about the influence of river bed subsurface structure on surface water (SW) and groundwater (GW) interactions. However, determination of variable river bed properties with conventional approaches lead to understanding based on few measured points. As a result, full complexity of river bed structure often cannot be reflected in modelling studies due to limited data.

In this research, to overcome the data driven restrictions faced in modelling studies, multidisciplinary approach was applied to characterize Cornia river bed which is located at Suvereto MAR site in Italy. The site characterization include surface geophysics, direct push sensing and direct push soil sample collection. The results demonstrated the variation of river bed in both lateral and vertical direction. Moreover, it also revealed that fine confining layer is present in the river bed which may inhibit river water infiltration.

Understanding and predicting clogging behaviour to enhance and maintain infiltration capacity of MAR infrastructure

Maria Chiara Lippera[1,2], Ulrike Werban[1], Rudy Rossetto[2], Thomas Vienken[1,4]

[1] Helmholtz Centre for Environmental Research (UFZ), Leipzig, Germany

[2] Technical University of Munich (TUM), Campus Straubing, Straubing, Germany

[3] Scuola Superiore di Studi Universitari e di Perfezionamento Sant'anna (SSSA), Italy

[4] Weihenstephan-Triesdorf University of Applied Sciences, TUM Campus Straubing, Straubing, Germany

Managed Aquifer Recharge (MAR) techniques are a viable adaptation measure to declining water levels due to climate change and groundwater overexploitation. However, physical clogging is a long-lasting problem affecting the infiltration efficiency of MAR sites. Fine materials, such as silt and clay particles, are transported during water recharge and deposited into the sediment matrix. This physical process leads to a decline in infiltration rates over time. Maintenance costs can be high to restore the original infiltration rates, and in extreme cases, the site is abandoned.

Our research aims to provide a methodology for MAR operators to assess the risk of physical clogging during the planning phase of the MAR site. This can be achieved by developing routines for site characterisation in combination with numerical modelling. First, a semi-empirical model to determine the vertical distribution of fines over depth was calibrated by reviewing multiple column experiments in the literature and performing additional experiments. The geometric ratio of the fines-porous media size diameters proved to be a good predictor for internal and superficial clogging formation. These findings allowed the modelling of variations in soil permeability over depth, given the physical and hydraulic properties of the sediments at the site.

The routines for site characterisation and the model for clogging were tested at the infiltration basin in Suvereto (Italy). Obtaining the clogging factors in the field and using the developed model, estimations on the clogging

time and depth of the damage can be computed for varying hydraulic loadings. Our methodology allows MAR practitioners to explore different design and management actions to maintain high infiltration capacity and reduce future operation and maintenance (O&M) costs. This assists the decision-making process towards optimal choices during the MAR site's planning phase.

Fig. 1: Maria Chiara Lippera giving her presentation on clogging behaviour at MAR facilities.

Making MAR systems work: Different approaches to maintaining infiltration and abstraction rates

Niels Hartog
KWR Water Research Institute, Netherlands

Managed Aquifer Recharge (MAR) techniques may prove critical to sustainably maintain or restore groundwater systems and are a valuable for increasing water availability in water stressed areas by subsurface infiltration and storage, to overcome periods of drought, and to stabilize or even reverse salinization of coastal aquifers. However, to fulfilling this promise of MAR requires understanding and operational predictability and reliability in sustaining the designed infiltration and abstraction capacities. Depending on the local hydrogeological and MAR application conditions the risks and opportunities for sustaining rates vary of which this talk aims to provide a useful overview. Examples to be discussed will include the prevent air entrapment clogging in infiltration basins, the use of subsurface iron removal to prevent iron hydroxide clogging and a recent innovation to create expanded diameter wells (EDGW). Overall, it is illustrated that improving understanding and application of drilling, well-construction, development and regeneration techniques strongly contribute to sustaining infiltration and abstraction rates for MAR in practice.

3.2 Session 2: Improving Quality

Experimental studies of the sorption and remediation of selected emerging organic contaminants

Edinsson Muñoz-Vega, Stephan Schulz, Christoph Schüth
Technical University of Darmstadt (TUDa), Darmstadt, Germany

Contamination of water bodies with pharmaceutical active compounds (PhACs) increased over the last decades. Potential pathways of PhACs to groundwater include systems such as managed aquifer recharge with treated wastewater or bank filtration of PhACs-loaded surface waters. To assess the transport processes and remediation of PhACs in the environment, this work includes two sections. First, we focus on biological processes, specifically in the role of soil biofilms on hydraulic conductivity reduction and on the fate of PhACs in the subsurface, using column experiments with a natural organic soil. Second, we focus in remediation, studying the effect of ambient pH in the sorption of PhACs onto biochar, powder activated carbon and colloidal activated carbon using batch experiments.

Large-scale sand tank experiments to assess water quality changes during soil aquifer treatment

Marcel Horovitz[1,2], Edinsson Muñoz-Vega[2], Teresa Leitão[1], Christoph Schüth[2], Stephan Schulz[2]
[1] Laboratório Nacional de Engenharia Civil (LNEC), Lisbon, Portugal
[2] Technical University of Darmstadt (TUDa), Darmstadt, Germany

Managed aquifer recharge (MAR) via infiltration basins is an important part of the integrated water resource management (IWRM) toolbox. However, soil aquifer treatment (SAT)-MAR also poses the risk of contaminating the aquifer, by infiltrating secondary treated wastewater effluent, which may still contain high concentrations of e.g., nutrients (N and P) and emerging organic compounds (EOCs), e.g., pharmaceuticals.

To bridge the gap between widely used laboratory column experiments and in-situ field experiments, we designed and conducted a large-scale sand tank experiments to give insights into the mixing processes of infiltrating secondary treated wastewater and a continuously flowing groundwater. Preliminary results on the influence of operational regimes and lessons learned for follow-up experiments will be presented.

Reactive Transport Modelling in a Double Source MAR Site

German Rudnik[1,2], Daniel Kurtzman[1], Avinoam Rabinovich[2], Yoram Katz[3], Guy Gasser[4]
[1] Agricultural Research Organization (ARO), Bet Dagan, Israel
[2] Tel Aviv University (TAU, Tel Aviv, Israel
[3] Mekorot Israel National Water Company, Tel Aviv, Israel
[4] Water Authority, Tel Aviv, Israel

Seawater Desalination and Managed Aquifer Recharge (MAR) are important practices which are implemented in various regions in the world to tackle issues of water scarcity. In Menashe Streams MAR site, located at the sandy dunes next to Caesarea and overlying the Israeli Coastal Aquifer, annual mean of ~2.2 Mm^3 of desalinated seawater (DSW) is recharged at one of the infiltration ponds since the year 2015. This is in addition to the annual mean of ~10 Mm^3 rainfall runoff which is diverted from and adjacent (more impervious) catchment since the 1960s'. Lack of Mg^{2+} in tap water in Israel since the beginning of the "desalination era" is a public health concern, thus possible enrichment of the recharge DSW is of interest. We use stable water isotope deuterium, as a conservative tracer of the DSW, and follow the spreading and mixing of the recharged DSW in the aquifer. Observations show that DSW which arrives to the aquifer with ~3 mgL^{-1} [Mg^{2+}] is enriched by up to 300% of this value before reaching nearby production well, regardless of mixing with ambient groundwater. Furthermore, ongoing effort of a construction of a 3D site-scale reactive transport model is presented.

Renaturalization of reclaimed water through enhanced soil aquifer treatment with reactive barriers

Cristina Valhondo[1], Lurdes Martínez-Landa[2], Jesús Carrera[1], Jingjing Wang[3], Stafano Amalfitano[4], Silvia Diaz-Cruz[1]

[1] Instituto de Diagnóstico Ambiental y Estudios del Agua (IDAEA-CSIC), Barcelona, Spain

[2] Universitat Politecnica de Catalunya (UPC), Barcelona, Spain

[3] Tongji University, Shanghai, China

[4] Istituto di ricerca sulle acque (IRSA-CNR), Rom, Italy

Soil Aquifer Treatment (SAT) is a Managed Aquifer Recharge (MAR) technique that improves the quality of reclaimed water by inducing its infiltration through the vadose zone to recharge the underlying aquifers. However, its implementation is hindered by fears of polluting aquifers, which leads to strict quality requirements for the source water. These requirements may make SAT economically unfeasible. To address these concerns, we have designed and tested reactive barriers aiming to renaturalize the recharged water by boosting the processes involved in improving its quality; sorption and biodegradation. The goal of the barriers is to (1) provide a range of sorption sites to favour the retention of chemical contaminants and pathogens; (2) favour the development of a sequence of redox states to promote the degradation of the most recalcitrant organic contaminants; and (3) promote the growth of plants both as a source of organic carbon and sorption sites, and to reduce clogging. The tested barriers have been proven very effective enhancing the removal of emerging contaminants (e.g. ultraviolet filters, pharmaceuticals), although the design should be reviewed with the aim of improving the retention of pathogens beyond traditional SAT systems.

Precipitation of Fe(III) oxyhydroxides in porous media and its influence in solute breakthrough

Rodrigo Pérez Illanes[1], Edinsson Muñoz Vega[2], Stephan Schulz[2], Christoph Schüth[2], Daniel Fernàndez-Garcia[1]

[1] Universitat Politecnica de Catalunya (UPC), Barcelona, Spain

[2] Technical University of Darmstadt (TUDa), Darmstadt, Germany

Iron is one of the most common elements on earth, with a determinant role in chemically and biologically controlled processes in the environment. Experimental studies on the precipitation of Fe(III) have shown the complexity of this process, with a strong dependence on factors like pH and temperature, and the intermediate transition through colloidal stages until precipitation. However, most of these analyses have been performed in controlled batch setups, whereas the interaction between precipitation and hydrodynamic dispersion has received little attention in literature. This work presents the results from an experimental study of the Fe(III) precipitation process on a two-dimensional, homogeneous porous flow-through system. Precipitation is induced by transverse mixing of two agent solutions continuously injected through contiguous inlet ports: iron nitrate with acidic pH and sodium hydroxide at basic pH.

The objective of this study is to characterize the influence of the precipitation process in solute breakthrough measured at the system outlet, with attention to changes in the properties of the porous medium induced by precipitation. For these purposes, two different magnitudes of inflow iron concentration are employed, in the range of relevance for environmental applications. Breakthrough measurements consider sampling during the injection and cleaning phases of the experiments. Evidence of precipitation is observable in breakthrough curves, especially during the cleaning phase where an abrupt increase in iron concentration confirms the release of the precipitation product. Experiments are complemented with reactive transport modelling, with discussions on the challenges imposed by the intrinsic characteristics of this chemical system and the precipitation process. Transverse hydrodynamic dispersion induce a non-uniform distribution of pH, which favours precipitation of Fe(III) oxyhydroxides in the mixing-zone between the two agent solutions. In the experiment with higher iron concentration, fast precipitation induced clogging of the porous medium, influencing groundwater flow.

Engineering of managed aquifer recharge systems to optimize biotransformation of trace organic chemicals

Uwe Hübner[1], Christian Wurzbacher[1], Damian E. Helbling[2], Jörg E. Drewes[1]

[1] Technische Universität München (TUM), München, Germany

[2] School of Civil and Environmental Engineering, Cornell University, Ithaca, New York 14853, USA

Biological treatment is considered inefficient for the removal of trace organic chemicals (TOrCs), because many of these substances persist conventional activated sludge systems. However, many studies showed high potential of biological system for an efficient removal of TOrCs, especially in managed aquifer recharge systems. This presentation discusses major parameters affecting the biotransformation of TOrCs in MAR systems and outlines solutions to improve biotransformation of TOrCs through i) optimization of environmental conditions for microbial TOrCs degradation, ii) biostimulation of degrader activity, and iii) bioinoculation of specific TOrC degraders. Enhanced biotransformation of many TOrCs has been observed under oxic and carbon-limited conditions. The concept of sequential managed aquifer recharge technology (SMART) has been proposed to enhance removal of TOrCs. SMART combines two infiltration systems with an intermediate aeration to provide fully oxic and carbon-limited conditions in the second infiltration. Enhanced biotransformation of several substances under controlled oxic and carbon-limited conditions provided by SMART has been validated at different scales (from lab- to field-scale) utilizing different source waters. While such concepts to optimize environmental conditions for TOrCs biotransformation have been tested at different scale, bioinoculation and biostimulation approaches have so far only been tested to remove contaminants in biologically active sand filters or for the remediation of contaminated groundwater. The applicability of these concepts to MAR systems with a mix of TOrCs at low initial concentrations needs further research.

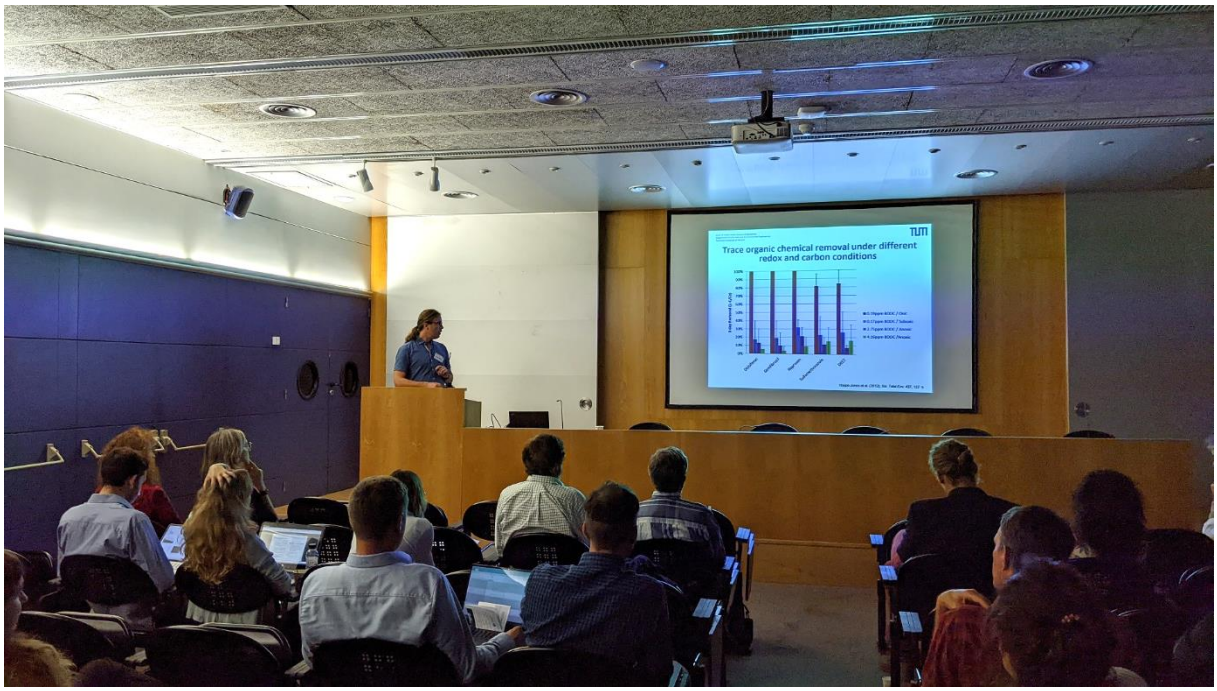

Fig. 2: Uwe Hübner giving his presentation on engineering of managed aquifer recharge systems to optimize biotransformation of trace organic chemicals.

3.3 Session 3: Proving Performance

MAR Modelling: Hydrogeochemistry and Fate of Contaminants

Vera Behle, Paula Rodríguez-Escales, Xavi Sanchez-Vila
Universitat Politecnica de Catalunya (UPC), Barcelona, Spain

Managed Aquifer Recharge (MAR) is a technology to deal with water stress and water scarcity worldwide. Depending on the origin and degree of prior treatment, the water inflow in MAR facilities contains measurable concentrations of Emerging Organic Compounds (EOCs). Understanding the processes that influence the fate of EOCs in the aquifer is therefore a key point for evaluating and predicting contaminant plumes and risk assessment. Such fate is clearly linked to the presence of biofilms that develop mainly in the first centimetres of the aquifer. Yet, the link between microorganisms, the development of biofilm and the fate of contaminants is not well understood. The degradation of pollutants in groundwater is dominated by redox reactions mediated by microorganisms. Since these reactions and thus the reduction rates are carbon limited, sedimentary organic matter (SOM) plays an important role. The present work addresses about hydrolysis of SOM and the release of dissolved organic carbon into the system and its implementation in conceptual and numerical modelling. The results are compared with data from column experiments.

Hydroinformatics and monitoring for investigating groundwater quality changes in managed aquifer recharge

Esteban Caligaris[1], Stefanie Schmidt[2], Christoph Schüth[2], Rudy Rossetto[1]
[1] Scuola Superiore di Studi Universitari e di Perfezionamento Sant'anna (SSSA), Italy
[2] Technical University of Darmstadt (TUDa), Darmstadt, Germany

While there have been significant advances in the understanding of drought in the surface water domain, little knowledge is available for groundwater and the interactions with surface water. In particular, few studies have been run to understand the changes in groundwater quality, especially since the early onset of a hydrological drought period. This contribution presents information on the groundwater hydrochemical and hydrodynamics changes occurring in an aquifer following the onset of an early dry season in Spring 2021 and developed in a hydrological drought period lasted until December 2021 in the alluvial plain of the Cornia River in coastal Tuscany (Italy).

The Cornia plain hosts a Holocene coastal aquifer constituted, in the investigated area, mainly by gravel in silty matrix. We monitored groundwater chemical quality and hydrodynamics in a series of multi-depth piezometers in a recharge area covering three different depths from the soil surface (i.e., 8 m, 12 m, and 18 m) in the vicinity of a Managed Aquifer Recharge (MAR) scheme. We monitored this network of piezometers and the relations with the Cornia River surface water for nine months from April 2021 (when the max groundwater head was recorded) until December 2021 (when the drought period ended).

Nine sampling campaigns were performed in this period, covering the early end of the annual MAR operation period in May 2021, and monitoring every fifteen days in the initial phase of the dry season. The last effective rainfall occurred on 11 May 2021. A total of 138 water samples were collected. The concentrations of the main ions in the water samples were determined using an Ion Chromatography (IC) instrument. The concentrations of trace elements were determined using an Inductively Coupled Plasma Mass Spectrometer (ICP). The concentration of Boron in water was determined using a Microwave Plasma Atomic Emission Spectrometer (MP-AES). Physico-chemical parameters were measured in the field with a multiparametric probe. This resulted on the measurement of the spatiotemporal variation of 49 different parameters at each of the study point.

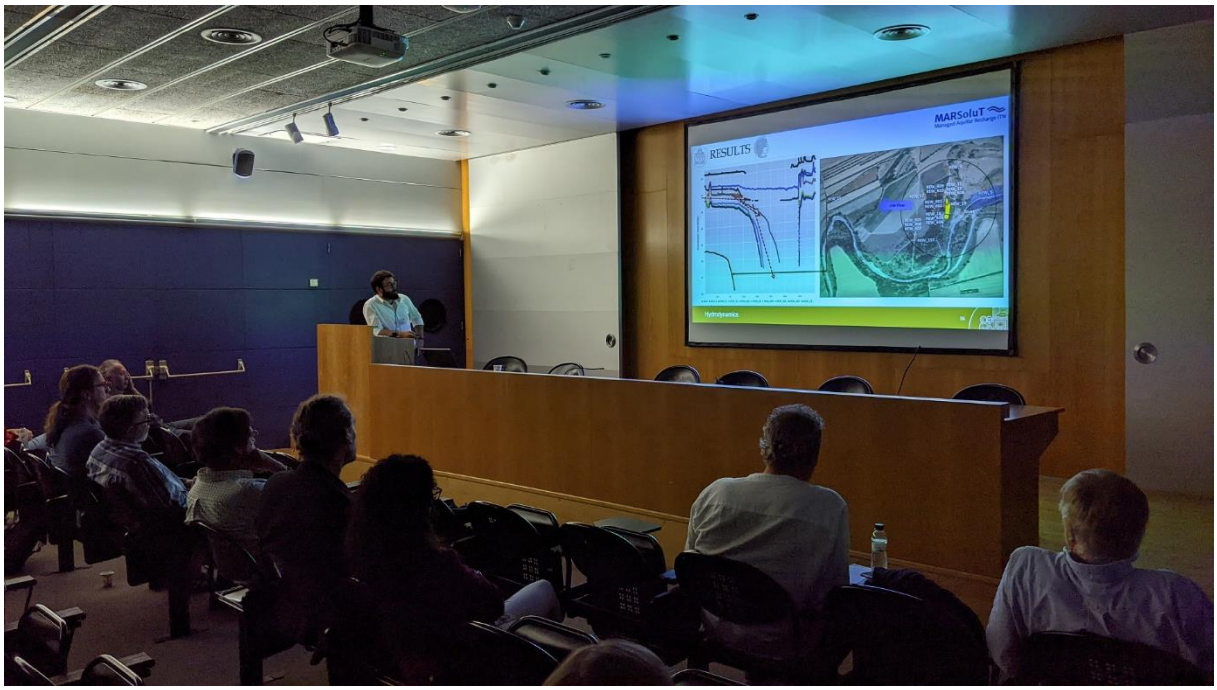

Fig. 3: Esteban Caligaris presenting monitoring results from the Val di Cornia case study site in Tuscany, Italy.

Participatory modelling in MAR

Angeliki Vlassopoulou[1], George Tentes[2], Andreas Kallioras[1]

[1] National Technical University of Athens (NTUA), Athens, Greece

[2] Green2Sustain (G2S), Athens, Greece

Public participation is a key factor for the implementation of the Water Framework Directive. The aim of this project is to promote stakeholder involvement in water resources modelling of MAR sites through participatory approach. A stakeholder analysis took place to identify the main stakeholders in Argolis area, Greece. Focus groups of 6-10 people is the method of participation that was chosen for this case study. Two participatory meetings had been organised with the representatives of the Farmer's Unions (Local Land Improvement Agencies) and the Regional Unit of Argolida (Peloponnese District). The topics that were discussed were related to the energy cost, the water canals that exist in the area, the need for application of MAR and the water supply. Moreover, information was shared between the participants concerning the current water quantities available for MAR and the state of the irrigation networks in the area. Problems and solutions were discussed between the members of the focus group and research results were shared from the NTUA organisers.

Hydrological Aspects of the Shafdan (SAT) Plant

Ido Negev

Mekorot Israel National Water Company, Tel Aviv, Israel

The Shafdan sewage treatment plant has treated and recycled all the sewage produced in the Dan area since 1977 (about 2.5 million residents from Tel Aviv and from neighbouring municipalities). About 140 million of cubic meters (MCM) of secondary level effluents from the treatment plant are recharged every year to the aquifer for a complementary Soil Aquifer Treatment (SAT), and about 130-165 MCM are recovered and supplied to irrigation in the Negev area. The recovered effluents are of very high-quality and are qualified for unrestricted irrigation. The aquifer also serves as a seasonal and multi-annual operative reservoir. Overall, about 110 hectares of recharge ponds enable the stable and robust irrigation of about 40,000 hectares in the Negev.

The management of the SAT plant includes hydrological aspects related to the recharge process, water quality, and the management of the water in the aquifer. During the last decade intensive studies conducted by Mekorot employees and partners have led to significant advancements in these fields.

Hydrological management of the aquifer requires maintenance of proper water balance and proper water levels in order to prevent effluent leakage to the regional aquifer on one hand, and to prevent sea-water intrusion on the other. The operative principles developed for the Shafdan plant to achieve these goals (and other) are detailed in Kafri and Yechieli (eds.), 2021, The Many Facets of Israel's Hydrogeology, pp. 246-258.

Water quality aspects include mainly manganese reductive dissolution, and the risks of contamination by bacteriologic and organic pollutants. The SAT process has proved to be very efficient in the removal of all types of bacterial and virus contaminants, as well as the vast majority of the known micro-pollutant except carbamazepine (CBZ). In two different studies we developed new tools to use CBZ and water isotopes as tracers for the spreading of the effluent in the Shafdan basins. The development of the MnM® technology for the removal of Mn at the well head, together with operational changes of the wells, has helped to manage the Mn challenge.

Recharge aspects include the challenge of coping with increasing effluent production on one hand and the reduction of infiltration capacity on the other. In a series of studies and urgent operational changes, we managed to increase the infiltration capacity of the plant from 116 to ~145 MCM (25%) in only two years. These changes included managing the cultivation tools and cultivation regimes, optimizing the flooding regime, changing the water quality of the effluent, and development of an automated system (SATix®) for monitoring and controlling the recharge processes. The current study is focused on the rehabilitation of low-capacity recharge ponds by replacing the top soil layer only.

The extensive activities performed in the last decade have proved of great importance to the SAT treatment of the Shafdan plant, given the importance of maintaining and increasing its capacity as much as possible.

3.4 Session 4: Proving Performance

Advanced technical and conceptual solutions in managed aquifer recharge

José David Henao Casas[1, 2], Enrique Fernández Escalante[1], Francisco Ayuga[1]

[1] Empresa de Transformacion Agraria S.A. (TRAGSA), Madrid, Spain

[2] Universidad Politécnica de Madrid (UPM), Madrid, Spain

Managed Aquifer Recharge (MAR) is a term that refers to a set of technologies that aim to recharge aquifers intentionally to dispose of stored water volumes in the future and to recover environmental assets. In recent years, four major gaps related to MAR have been identified: (i) lack of examples showing successful adaptation to climate change (CC) through MAR systems; (ii) insufficient interoperability in the exchange of environmental monitoring data and the lack of common terminology in the realm of MAR; (iii) the need for more regulations that prevent negligence in MAR operations that undermine the confidence and perception of these set of technologies and potentially result in damage to the environment and human health; (iv) there is room to improve MAR systems' performance through design adjustments, particularly with regard to infiltration rates and clogging.

In the framework of the MARSoluT project, several technical and conceptual solutions have been proposed to address the identified gaps and improve MAR system performance. They include: (i) framing Los Arenales MAR systems as a low-regret measure against the impact of climate change, increasing the confidence in MAR and providing solutions to adapt for CC in the rural context; (ii) a MAR ontology and draft standard that facilitates environmental data exchange and MAR system operation and interconnection; (iii) the Monitored and Intentional Recharge (MIR) conceptual model, which lists and elaborates on the most important aspects to

consider while drafting MAR guide and regulatory documents; and (iv) a detailed study showing that trees in infiltration basins can considerably increase infiltration rates, providing low-cost and nature-based solutions (NBS) for MAR. These technical and conceptual solutions will help to improve MAR from different perspectives and advance the current state-of-the-art.

Hydrogeological and geochemical modelling of a sea-water intrusion barrier in an island/coastal groundwater body

Francesco Demichele, Manuel Sapiano
Energy and Water Agency (EWA), Luqa, Malta

The Mean Sea Level Aquifer (MSLA) of the island of Malta is a freshwater lens system sustained in a carbonate formation, floating on seawater in the bedrock. Given the specific hydrogeological and climatic conditions, the water table today reaches its maximum elevation at around 3 m amsl at the centre of the 316 km^2 island, with a maximum thickness of freshwater lens being about 90 m. Seawater intrusion occurs as an unavoidable effect of groundwater abstraction and the situation is further exacerbated during the dry summer period when water demands are higher.

The status of fresh groundwater in the MSLA is assessed through vertical profiles of salinity along the water column of Deep Monitor Boreholes (DMBs) which penetrate partly or entirely through the brackish-water transition zone that separates freshwater from the underlying higher density seawater in freshwater lens systems. Salinity profiles were measured using a multiparametric probe (SEBA HYDROMETRIE KLL-Q-2 with MPS-D8 probe) lowered from the water table till the bottom of the DMBs measuring electrical conductivity (as a proxy for salinity), temperature, pressure and pH in three DMBs on a weekly basis over one year during the wet seasons. Furthermore, groundwater level hydrographs are measured through CTD divers.

The collection of historical and current monitoring data available for the Malta MSLA allowed to generate a groundwater flow numerical model of this groundwater body. By implementing several scenarios based on the feasibility of MAR schemes in Malta, the optimum MAR network system for improving the groundwater qualitative and quantitative status was identified. The MAR network system shall be composed of an infiltration gallery located in the middle of the MSLA for diffused infiltration while a localized hydraulic mound created from an injection boreholes array would halt seawater intrusion in Malta South-East.

The monitoring of salinity profiles over time in the DMBs allowed the detection of typical patterns of fresh/sea-water interface fluctuations according to the occurrence of external driving forces like precipitation and/or local abstraction. The profiles were correlated with aquifer characteristics such as, fractures and orientation of strata in the DMBs which were determined through high resolution images captured with an optical televiewer probe (MOUNT SOPRIS QL40-OBI-2G).

Analysis undertaken on Temperature-Depth (TD) profiles measured over a period of two days in 17 DMBs outlined a baseline condition related to the status of groundwater salinization. Using the heat as a tracer of vulnerable areas to saltwater intrusion, TD maps of the MSLA highlighted warm zones within the groundwater body impacted by salinization mechanisms.

The outcomes of this study illustrate the value of DMBs in establishing an effective monitoring framework for island groundwater bodies status. The sought optimization of the MSLA monitoring network is achieved through analysis undertaken on groundwater level hydrographs, salinity profiles, and temperature-depth maps.

Opportunities to improve aquifer status using MAR through River Basin Management Plans in the Algarve, Portugal

Kathleen Standen[1], Jose Paulo Monteiro[1], Luis Costa[1], Rui Hugman[2]

[1] Universidade do Algarve (UAlg), Faro, Portugal

[2] Flinders University, Adelaide, Australia

The Algarve region, Portugal suffers from extreme water scarcity, with existing water resources unable to meet the demand, particularly in drought years. Climate change will result in greater demands at a time when less water is available. Conventional water resources such as new dams or strategic transfers now need to be supplemented with alternative water resources, such as Managed Aquifer Recharge (MAR), treated wastewater reuse for non-potable uses, and desalination.

A regional assessment was undertaken considering ephemeral river flow from rivers that are not already dammed upstream as the main water source for MAR. We matched water availability to the potential aquifers for MAR, and the potential beneficiaries of the MAR project. A total of 12 MAR options were identified using 11 water sources. If all these schemes were implemented, additional recharge of 25.5 Mm^3/yr could be achieved. This is more than 10% of the current annual water use in the Algarve (237 Mm^3/yr), with 15.7 Mm^3/yr to support the public irrigation perimeters of the Algarve, and almost 10 Mm^3/yr to support attainment of the Water Framework Directive groundwater objectives and/or to develop a strategic groundwater resource to be used during drought periods.

The costs for MAR were compared to the costs for other supply and demand measures being considered for the Algarve using unit costs from operating MAR facilities. The unit costs for MAR are likely to be lower than leakage reduction measures, rehabilitation of irrigation networks and other efficiency measures, and for the proposed desalination plant. Costs for MAR are similar to, or lower than, those for the first tranche of wastewater for reuse schemes. In summary, whilst further investigation of these potential MAR schemes is required, it appears that they could form a significant part of the water resources of the Algarve, with lower costs, fewer environmental impacts, and lower energy use than many of the water supply measures currently being considered.

The experience of Acacia Water in the design and implementation

Daniela Benedicto van Dalen, Beatriz de la Loma Gonzalez, Tine te Winkel

Acaciawater, Gouda, The Netherlands

Texel is one of the Islands located in the Wadden Sea under UNESCO's world heritage predicate, hosting nature, residential areas, a large tourism sector and a commercial farming community. It faces several challenges when it comes to freshwater availability, the first one being its dependency on the mainland for drinking water since both shallow and deep groundwater are brackish, while agriculture is meant to be mainly rain fed.

Successes obtained in other projects on the Dutch coastal zone, associated with the forecasted unfavourable climate change impacts, have helped increase interest on ASR (aquifer storage and recovery) systems, its social acceptance and economic feasibility to increase fresh-water availability in the Texel and perhaps make it fresh water sufficient in the future. Several stakeholders have congregated around the idea of developing, managing, owning and maintaining two (2) ASR pilot systems in the northern part of the island for the purpose of building on/ maintain and share an underground freshwater bubble for irrigation purposes. The idea is to collect drained rainwater with suitable quality in ditches, transport it to the infiltration gallery and then inject in the subsurface – or discard in case EC is too high.

Assessment of the existing aquifer conditions and knowledge of Texel's hydrogeology has been upgraded by site investigations such as pumping tests and geophysical survey, as well as a desk study including a 2D groundwater flow model to identify the aquifer's technical viability: identification of the best storage possibilities and transmissivity conditions is essential to allow proper recovery.

The direct benefit of ASR on Texel Is the avoidance of drought damage to the crops and in a later stage also salt damage. The system needs to be economically viable, cover the water demand and have suitable quality to be considered a success. Based on estimations in current and future conditions under climate change a water demand of 80-100 mm per year/ha has been calculated, while the average benefits are between 1.100 and 2.750 dollars/ha/year.

The most suitable hydrogeological conditions were found in the deeper aquifer, around 13-19 meters below surface, with hydraulic conductivity K ~ 40 m/d. Due to the limited thickness of the aquifer, the most feasible solution became a horizontal directional drilled well of 300 meter length. The ASR has been successfully implemented, is being tested currently and will be fully operational during the winter 2022-2023.

Fig. 4: Daniela Benedicto van Dalen presenting the development and implementation of an ASR system on the island of Texel.

3.5 Panel discussion: Global applicability, bottlenecks and proactive legislation

The panel (Fig. 5) consisted of Enrique Fernández Escalante (Tragsa, Spain), Joseph Guttman (Mekorot, Israel), Niels Hartog (KWR, The Netherlands), Uwe Hübner (TU Munich, Germany), Joao Paulo Lobo Ferreira (LNEC, Portugal), Ido Negev (Mekorot, Israel), Martin Reinhard (Stanford University, USA), Rudy Rossetto (SSSA, Italy), Manuel Sapiano (EWA, Malta), Cristina Valhondo (CNRS, France), and Daniela Benedicto van Dalen (Acaciawater, The Netherlands), and was chaired by Christoph Schüth, MARSoluT project coordinator (TU Darmstadt, Germany).

The discussion started with a brief overview by Christoph Schüth on the knowledge gained from the MARSoluT predecessor project MARSOL and the resulting open questions, and how these challenges were tackled by MARSoluT. In the following, the participants of the panel addressed the absolute necessity of MAR being included into integrated water resources management approaches specifically

in light of the pressures upcoming from climate change, and the need to openly address and resolve the various and still existing obstacles regarding a more widespread application and implementation of MAR schemes. Parameters addressed in the discussions were, inter alia:

- Minimum water quality requirements for water reuse
- Improvement of water injection techniques into an aquifer
- Policy options
- MAR regulations in Europe in the frame of the WFD and GWD
- MAR regulations outside Europe

Further, the panel members from institutions/companies who actually already apply MAR were asked what they require from the scientists. The answers focused on an improved and easier understandable communication to politicians, end-users, and stakeholders, and to extend technological knowledge also to the developing countries. Marketing MAR is another big issue; an example was given where a government minister drank "*new water*" from a wastewater treatment plant applying reverse osmosis as the final treatment, to give people an example on the quality of the reclaimed water. It was also recommended to look at the energy consumption of water supply. Again, the importance of communication about MAR was emphasized, using the example of the drought in Europe in summer 2022. People were asking for more dams, which is not a solution in such a situation since no rain also means no water in the reservoir. A strong example for this are the currently empty surface water reservoirs in California. Storing water in the geological underground is a more natural way of water storage than storing it in open water reservoirs. Since people only talk about what they see, it is our task to make the invisible more visible. In addition, MAR should be brought into the media, into education and courses, and to technicians etc.. Actual stakeholders might have a greater influence to demand MAR implementation.

Fig. 5: Impression from the panel discussion.

However, it was pointed out that the issue of water quality is the *"elephant in the room"*. Hence, the definition of good groundwater status under the Water Framework and Groundwater Directives was discussed, giving due consideration to the definition of such status based on the needs of receptors (agricultural irrigation, drinking water or ecosystems). The application of water infiltration techniques, which do not result in the degradation of status (hence not affecting the needs of receptors) but resulting in limited changes in specific chemical parameters was discussed, and the need for a comprehensive interpretation of the prevent and limit objectives of the Groundwater Directive identified - in particular in view of recent decisions by the European Court of Justice. This could be based on a risk-management approach, i.e. defining the risk and limit the water input as to not to exceed the then set standards. Risk assessment is an important issue here. Although the quality of the infiltrated water has to be regulated to some extent, more focus should be given to the processes in the subsurface that can improve water quality making it fit for the intended end-use.

It was decided to try to organize a meeting in Brussels at the end of the project to present the water-policy-related findings of the two projects, MARSOL and MARSoluT, to relevant EU representatives.

Since climate change will bring more droughts and floods the design of MAR schemes has to be improved. Guidelines and handbooks will be useful here. The trend will go to develop further the concept of so-called *"Sponge Cities"*.

It was emphasized that - similar to other technology fields - successful model case studies are needed, as had been the approach of the previous MARSOL demonstration project, in order to promote MAR towards policy makers and regulators and to encourage others to implement MAR as well. *"Leading by example"* is one of the key aspects of introducing a technology to the public and building confidence in its performance.

Concerning the research done in the MARSoluT project, as presented at the conference, it was pointed out that the project's research fellows are the future of MAR through building up an extensive knowledge base and networks, and it was suggested to utilize this by, for instance, founding innovative start-ups.

3.6 Field Site Visit

In the afternoon the decantation and infiltration ponds of Molins de Rei in the Lower Llobregat area were visited (Fig. 6). Explanation were given by Vinyet Solà from the *Comunitat d'Usuaris d'Aigües de la Vall Baixa de Delta del Llobregat* (CUADLL, Community of Water Users of the Low Valley of Delta del Llobregat). The MAR site is part of an Interreg Sudoe program project named *"Aquifer"*.

The objectives of *the Community of Water Users of the Low Valley of Delta del Llobregat* are to ensure the quantitative and qualitative improvement of the groundwater of the aquifer, directly manage the common interests of water use and its policing and, if necessary, resolve issues or disputes between users, within the framework of their competences. An important goal of the presented project is not only to test innovative practices for the conservation, monitoring and integrated management of aquifers that help when making decisions about the management of groundwater resources, but also to improve technology transfer to local actors, new synergies to create and develop common tools related to water scarcity and environmental threats.

Fig. 6: Field site visit (top left: Vinyet Solà giving explanation on the MAR site; top right: infiltration basin; bottom left: valve connecting decantation and infiltration ponds, equipped with a flowmeter; bottom right: Llobregat river).

Both the quantity and the quality of the water are taken into account by considering the management of the recharge, the monitoring networks and, in particular, hydrological modelling. In total, three water clusters linked to a network of actors and start-ups in the water sector are involved, and a decision support tool is used to disseminate good practice through the creation of a permanent and free website for all water stakeholders.

In the Molins de Rei MAR site, water from the Llobregat river is diverted, first into a decantation basin and then in two infiltration basins for Aquifer Storage and Recovery - ASR (Fig. 6). In addition, a pipeline with treated wastewater serves to replenish the aquifer and thus also act as a barrier against possible seawater intrusion. Fig. 7 gives an overview of the environmental adaptation of a section of the river Llobregat at Molins de Rei and the implementation of a recharge system to the aquifer. Some operability data are list in Fig. 8.

Website CUADLL: https://www.cuadll.org

Website Aquifer project: https://interreg-sudoe.eu/gbr/projects/the-approved-projects/226-innovative-instruments-for-the-integrated-management-of-groundwater-in-a-context-of-increasing-scarcity-of-water-resources

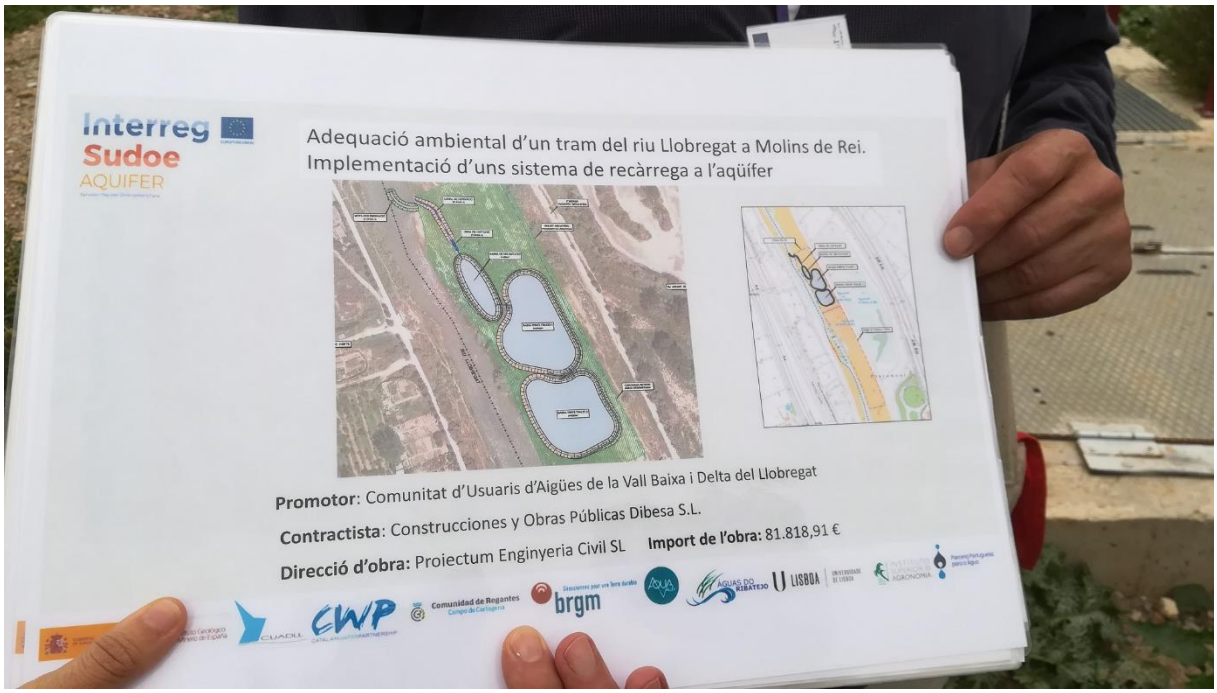

Fig. 7: Overview on the MAR site design, given by Vinyet Solà.

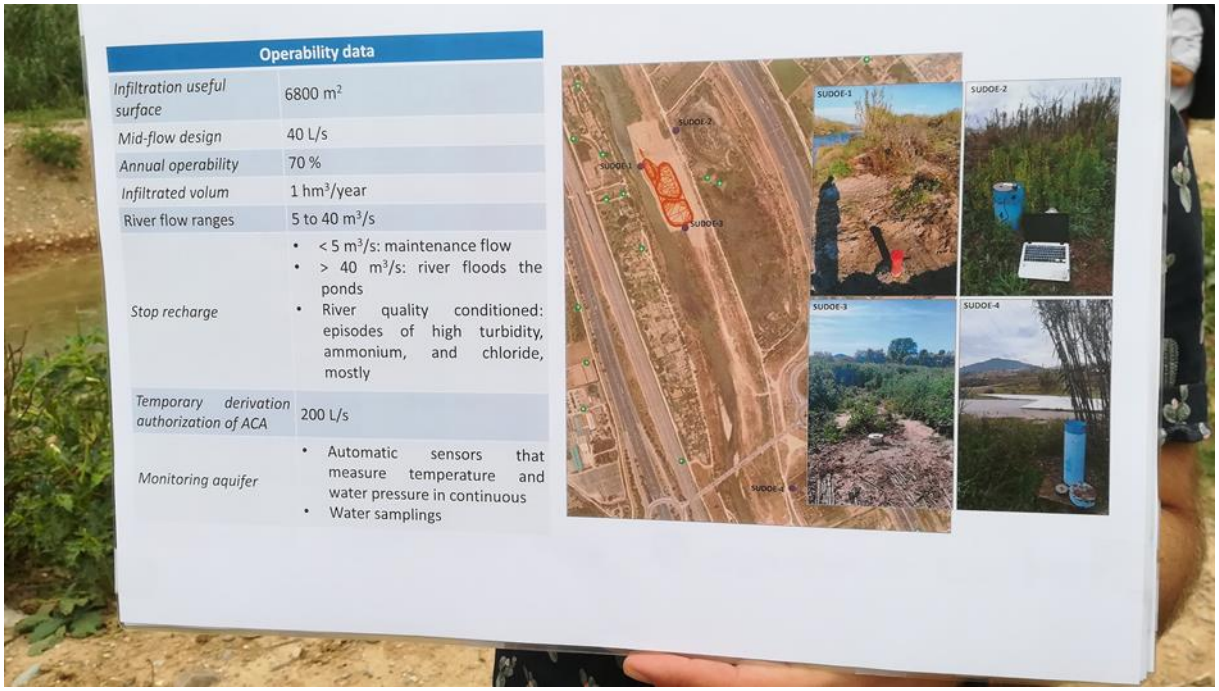

Fig. 8: Overview on the Operability data of the MAR site, given by Vinyet Solà.

4 Summary and conclusions

We see the MAR Con '22 "Managed Aquifer Recharge Solutions - International Conference on Current Research Results" in Barcelona, 19.-20. October 2022, as a great success and a good show-case for the research ongoing on European level in the field of MAR. In total 78 persons registered for participation in the conference which provided excellent opportunities for international networking. The hybrid nature of the event (allowing also online participation) allowed a larger audience to attend, for instance for interested persons from e.g. South America, students with a low budget, or attendees from companies who have rather limited time and prefer to avoid the travel. While the program was mainly composed of contributions by MARSoluT members, particularly the research fellows, it was emphasized by some participants that the invited speakers had been chosen very well and made a good complement to the specific sessions and the panel discussion.

The panel discussion emphasized the absolute necessity of MAR being incorporated into integrated water resources management and regulations in the frame of the WFD and GWD. Therefore it is essential to increase communication to politicians, end-users, and stakeholders, and MAR should also be brought into the media, education, courses, to technicians etc. It was also emphasized that successful model case studies need to be brought into the foreground, in order to promote MAR towards policy makers and regulators and to encourage the more widespread use of MAR approaches in water management, as one of the major tools to mitigate adverse climate change effects in the water sector. *"Leading by example"* is one of the key aspects of introducing a technology to the public and building confidence in its performance. Water quality concerns remain an obstacle, therefore it is suggested to focus discussion on a *"fit for purpose"* approach, i.e. applying different quality-governing measures for, e.g., agricultural purpose, golf courses, or drinking water production.

Fig. 9: Group picture of conference participants on UPC Campus.

Annex 1: Conference program

MARSoluT
Managed Aquifer Recharge ITN

MAR Con ´22 - Barcelona

Managed Aquifer Recharge Solutions
International Conference on Current Research Results
Barcelona, 19.-20. October 2022


The overall objective of MAR Con '22 is to collect research results, practical experience, and innovative ideas related to the following aspects of Managed Aquifer Recharge (MAR) activities:

- Chemical, biological and hydraulic processes resulting in clogging and reduction of infiltration rates,
- Hydrogeochemical processes affecting the water quality, with special focus on micropollutants,
- Performance monitoring and modelling, including reactive transport models to predict the fate of pathogens and emerging pollutants, and
- Implications of the processes mentioned above on the technical design of MAR projects in the frame of regional flow models and water management plans.

Venue: Universitat Politècnica de Catalunya, Master's and Multipurpose Classroom, A3 building, North Campus of UPC, C. Jordi Girona, 1-3, Barcelona, Spain

Participation in the conference is free, and may be in person or online. For registration and an updated program please visit www.marsolut-itn.eu.

MSCA MAR SoluT TECHNISCHE UNIVERSITÄT DARMSTADT UPC UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

The MARSoluT project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement no 814066. Photo credits: The LIFE REWAT infiltration basin in Suvereto, Italy, by Esteban Caligaris, SSSA.

MAR Con '22 - Conference Program

Managed Aquifer Recharge Solutions

International Conference on Current Research Results, Barcelona, Spain

Wednesday October 19th

9:00 Check in / registration / welcome

9:30 Welcome words by Christoph Schüth (TUDa) and Xavier Sánchez-Vila (UPC)

Session 1: Sustaining Rates Chair: Ulrike Werban

9:45 Sultana, R., Werban, U., Pohle, M., Rossetto, R. & Vienken, T. (UFZ, Germany, & SSSA, Italy): *On the relevance of site exploration as prerequisite for successful MAR site planning and operation*

Lippera, M.C., Werban U., Rossetto, R. & Vienken, T. (UFZ, Germany, & SSSA, Italy): *Understanding and predicting clogging behaviour to enhance and maintain infiltration capacity of MAR infrastructure*

Hartog, N. (KWR Water Research Institute, Netherlands): *Making MAR systems work: Different approaches to maintaining infiltration and abstraction rates*

Summary and outlook - *Spotlight on quantity*

11:00 Coffee break

Session 2: Improving Quality Chair: Christoph Schüth

11:30 Muñoz Vega, E. & Schüth, C. (TUDa, Germany): *Experimental studies of the sorption and remediation of selected emerging organic contaminants*

Horovitz, M., Muñoz Vega, E., Leitão, T.E., Schüth, C. & Schulz, S. (LNEC, Portugal, & TUDa, Germany): *Large-scale sand tank experiments to assess water quality changes during soil aquifer treatment*

Rudnik, G., Rabinovich, A., Katz, Y. & Kurtzman, D. (ARO, TAU, & Mekorot, Israel): *Reactive transport modelling in a double source MAR site*

Valhondo, C. (CNRS, France*): Renaturalization of reclaimed water through enhanced soil aquifer treatment with reactive barriers*

13:00 Lunch break

14:30 Pérez Illanes, R., Muñoz Vega, E., Schulz, S., Schüth, C. & Fernàndez-Garcia, D. (UPC, Spain, & TUDa, Germany): *Precipitation of Fe(III) oxyhydroxides in porous media and its influence in solute breakthrough*

Hübner, U. (TUM, Germany): *Engineering of managed aquifer recharge systems to optimize biotransformation of trace organic chemicals*

Summary and outlook - *Spotlight on the chemistry*

15:30 Coffee break

Session 3: Proving Performance Chair: Rudy Rossetto

16:00 Behle, V.R., Rodríguez-Escales, P. & Sanchez-Vila, X. (UPC, Spain): *MAR modelling: hydrogeochemistry and fate of contaminants*

Caligaris, E.R. & Rossetto, R. (SSSA, Italy): *Hydroinformatics and monitoring for investigating groundwater quality changes in managed aquifer recharge*

Vlassopoulou, A., Tentes, G. & Kallioras, A. (NTUA, & G2S, Greece): *Participatory modelling in MAR*

Negev, I. (Mekorot, Israel): *The Shafdan Experience*

Summary and outlook - *Spotlight on techniques and tools*

17:30 End of day 1

Thursday October 20th

Session 4: Optimizing Design Chair: Enrique Fernández Escalante

9:00 Henao Casas, J.D., Fernández Escalante, E. & Ayuga, F. (Tragsa & UPM, Spain): *Advanced technical and conceptual solutions in managed aquifer recharge*

Demichele, F. & Sapiano, M. (EWA, Malta): *Hydrogeological and geochemical modelling of a sea-water intrusion barrier in an island/coastal groundwater body*

Standen, K., Monteiro, J.P., Costa, L. & Hugman, R. (UAlg, Portugal, & Flinders University, Australia): *Opportunities to improve aquifer status using MAR through River Basin Management Plans in the Algarve, Portugal*

Benedicto van Dalen, D. (Acaciawater, Netherlands): *The experience of Acacia Water in the design and implementation of ASR systems - the case of a farming cooperative in Texel, the Netherlands*

Summary and outlook - *Spotlight on scenarios*

10:30 Coffee Break

Session 5: Global applicability, bottlenecks and proactive legislation

11:00 Panel – experts statements and audience discussion
Final remarks and closing of the conference

13:00 Lunch break

Field site visit

14:00 *MAR activities in the Llobregat Lower Valley – an overview*

Tour for those who registered for the site visit. Exact meeting point and time for departure of the bus will be announced at the conference. Return planned for 18:00 h at the same place.

The conference is organised for the EU MSCA MARSoluT Innovative Training Network (ITN) by Technical University of Darmstadt (TUDa), Darmstadt, Germany, and Universitat Politècnica de Catalunya (UPC), Barcelona, Spain. Registration on www.marsolut-itn.eu.