WORKSHOP PROCEEDINGS

A whole day on MAR
Managed aquifer recharge as a real climate change adaptation mechanism. Examples and indicators from five countries

Workshop organised as side event within the EIP Water Innovation Conference 2019 "Accelerating action to tackle water pollution and enhance EU preparedness to water-related climate change impacts".

Location
Palacio de Congresos de Zaragoza
Plaza Lucas Miret Rodriguez, 1, 50018 Zaragoza, Spain

Date
11 December 2019, 09:00 – 13:00

Executive summary

The present workshop was organised as part of the EU Water Innovation Conference 2019 (EUWIC) by the Commission on Managed Aquifer Recharge of the International Association of Hydrogeologists (IAH-MAR Commission), in collaboration with the Commission on Groundwater and Climate Change (CGCC) and the EU-funded MARSoluT project.

Managed aquifer recharge (MAR) has been considered for a long time as an important solution to combat the adverse effects of climate change. All around the world, MAR is used in combination with other Integrated Water Resources Management (IWRM) measures to reduce the adverse impacts of climate change as an adaptation and even mitigation strategy to face up climate change challenges. The aim of this side event organised within the EIP Water Innovation Conference in Zaragoza, Spain, is to support this statement on the basis of real sites, indicators and cases located all around the world.

Planning and feasibility assessment of MAR

An important role in safeguarding the success of MAR is the correct planning and execution of the project. Not seldom, GIS-based tools are employed for assessing a wide variety of issues such as, for example, the selection of suitable sites, aquifers or watersheds for MAR implementation (example from Chile, p. 15), or the pre-assessment of aquifers' vulnerability to seawater intrusion in Portugal (p. 17). Used properly, these tools become very useful in supporting the decision making process while their use can be incorporated at any stage of the project.

Technical and nature-inspired solutions for climate change mitigation

Several climate change effects were discussed during the meeting, starting from the increase of mean temperature, decrease of annual precipitations, intensification of extreme events or sea level rise. Practical MAR projects (i.e. from Spain, Italy, Portugal, Malta, etc.) are presented (p. 7 and p. 19) in direct response to these challenges demonstrating that MAR is not just a simple technique but a multi-purpose tool, a mix of nature-based solutions and engineered technologies able to provide several functions at the same time while being both efficient and effective in climate change mitigation. While the main geographical focus of the workshop is in Europe, best-practice examples from Africa are also presented, where cost-effective sand river aquifer systems are successfully implemented for agricultural development (p. 9).

Monitoring of MAR schemes

A very important aspect emphasized during the workshop regarding the evidence that MAR is a safe, sustainable solution for water resources management is the monitoring component. Sometimes overseen, monitoring of MAR plays a crucial role in assuring compliance with the regulations. An flagship example from Italy brings the perspective of a "controlled recharge" of the aquifers by making use of ICT tools and adequate decision support systems. The observation and control of the system can be thus realized in real time according to a set of criteria and thresholds. Within the recent EU-funded research project SMART-Control, the real-time monitoring of MAR schemes in several countries of Europe and South America is amended by web-based real-time numerical modelling, opening thus new perspectives in monitoring of MAR processes and their associated risks (p. 11).

Regulatory frameworks for MAR in Europe

The Water Framework Directive (2000/60/EC) and a small set of additional guiding documents are the basis for MAR regulation in Europe. Nevertheless, the need for specific MAR guidelines has become stringent over the past years, especially in the context of the extreme climate conditions impacting water resources in Europe. A proposal for the first EU-wide guidance document on MAR is therefore discussed, together with the road map and associated challenges in its achievement (p. 21).

Stakeholder engagement for decision making

The success of MAR cannot be guaranteed without the support and engagement of local stakeholders. The specific barriers and the opportunities for policy uptake are exemplified with a case study from Spain aiming at the co-development of adaptation strategies to reduce the drought risks and improve the aquifer status. Workshops and interviews are used for identification and ranking of solutions, as well as to assess the measures' effectiveness perception by key stakeholders (p. 22).

Training and capacity development

Last but not least, the workshop addresses the role of capacity development for MAR uptake within the wider context of groundwater-dependent ecosystem services. A joint academic programme (GroundwatCH) is presented as example of successful international cooperation on groundwater and climate change among European universities and research institutions (p. 13).

Report compiled by Catalin Stefan and Enrique Fernández Escalante
(Co-Chairs of the IAH Commission on Managed Aquifer Recharge).

Online publication: January 2020

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Topics

Why managed aquifer recharge is a successful tool to climate change adverse effects adaptation? International examples and indicators

ENRIQUE FERNÁNDEZ ESCALANTE and JON SAN SEBASTIÁN SAUTO (Tragsa Group, Spain)

Figure 1. Dr. Enrique Fernández Escalante (Tragsa Group, Spain) provided evidence on why managed aquifer recharge can be considered a successful adaptation tool for climate change effects

The first presentation of the day was entitled "Why managed aquifer recharge is a successful tool to climate change adverse effects adaptation? International examples and indicators". The talk was given by Dr. Enrique Fernández Escalante and co-authored by Dr. Jon San Sebastián Sauto, both from Tragsa Group, Spain. The lecture was anchored in the climate change reality, expressed especially in the increasing number and intensity or dry periods. As consequence of this, in the Mediterranean region, the decline of available water resources is expected to increase up to 50% until 2100. In this context, several solutions based on the managed recharge of aquifers are proposed to address and reduce the impact caused by the climate change. In order to assess the effects and efficiency of these solutions, a series of indicators have been designed and adopted. For quantification purposes, the indicators are expressed in forms of volumes, lengths, percentages, degrees, euro etc.

The presentation continued with a listing of the four effects of climate change and the description of corresponding solutions and indicators. For the increase of mean temperatures, successful examples from Spain and worldwide were provided on underground storage (UAE), positive evolution of regional groundwater levels (Los Arenales aquifer, Spain), reduction of subsurface temperatures and increase in soil moisture (Los Arenales, Spain), as well as important savings in energy consumption due to application of managed aquifer recharge (El Carracillo, Spain). The solutions proposed against the increase of extreme precipitation events included: infiltration of reclaimed water for aquifer recharge with emphasis on circular economy (Graz, Austria), punctual water infiltration in Madrid, Spain, targeted infiltration as flood protection measure in Balsa del Campo, Valencia, Spain, water storage outside the riverbank in Pisa, Italy and Ica River, Peru, aquifer recharge in conjunction with sustainable urban drainage systems in Adelaide, Australia, and directed infiltration through the use of communication pathways in Segovia, Spain. Further on, the author demonstrated how MAR can be used also as response to extreme phenomena, giving examples from different countries: ecosystem restoration and regeneration in Phoenix, Arizona, surplus infiltration / detention and retention in Las Palmas, Spain and Zarzis, Tunisia, detraction of the peak flow of an overflood (Sierra Espadán, Castellón, Spain), and storage solutions in subalvee (examples from dykes in Alicante, Spain and sand dams in Kenia). In terms of sea water level rise, the examples included positive hydraulic barriers from Barcelona, Spain and from Malta, where reclaimed waters from the Sur treatment plant are infiltrated for the reduction of marine water intrusion. In all the examples presented, the author provided clear indicators of success for the different MAR solutions, such as, for example, changes in groundwater volume storage (i.e. intentional increase in water reserves), reduction in energy costs (i.e. percentage cost of kg of CO_2 emissions), percentage of total runoff water changes. or seepage rates for specific receiving media.

Figure 2. Examples of application of managed aquifer recharge for mitigation of extreme precipitation events

In conclusion and based in the examples provided, the authors demonstrated that MAR is a multipurpose and effective measure of adaptation to climate change. The positive impact of MAR can be quantified by a large set of indicators, making MAR also economically sustainable as most solutions provided are passive systems. The use of these concepts are therefore expected to increase in the Mediterranean region, area heavily impacted by the effects of climate change.

Download the presentation (PDF, 2.23 MB): https://bit.ly/2rNqFYZ.

Groundwater assessment in sand rivers in adaptation to climate variability and water scarcity: opportunities and challenges in semi-arid Africa

TIBOR STIGTER (Institute for Water Education – IHE, Delft, the Netherlands)

The present talk by Dr. Tibor Stigter is dedicated to nature-based water storage in dry rivers of warm semi-arid regions in Africa, frequently considered of low potential for agricultural development due to limited access to water. The project A4Labs (https://a4labs.un-ihe.org/) addresses this issue by assessing the sand river potential to strengthen the water – energy – crop – market nexus for individual farmer. The approach proposed involves a type of alluvial aquifer formed in thick sand beds of wide ephemeral rivers deposited from pronounced upstream catchment weathering and erosion (Figure 3).

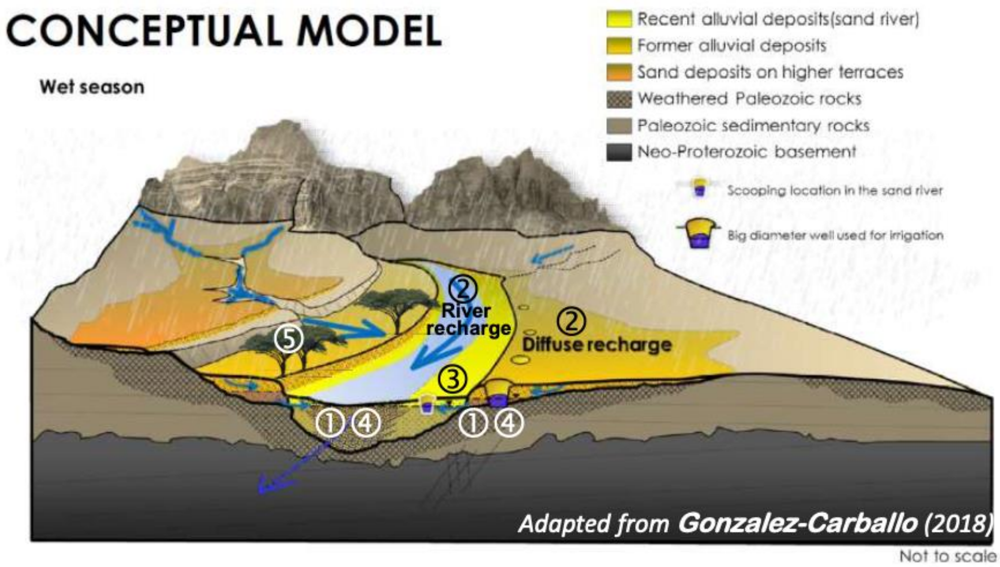

Figure 3. Conceptual model of a sand river aquifer system

The solution requires the study of the sand river aquifer characteristics at different scales, including: hydrogeology and connectivity with margins, recharge/discharge mechanisms, abstraction location/rates, hydrochemistry and water quality, competition with other users (Figure 4). These investigations are exemplified by investigations from different case studies in Africa.

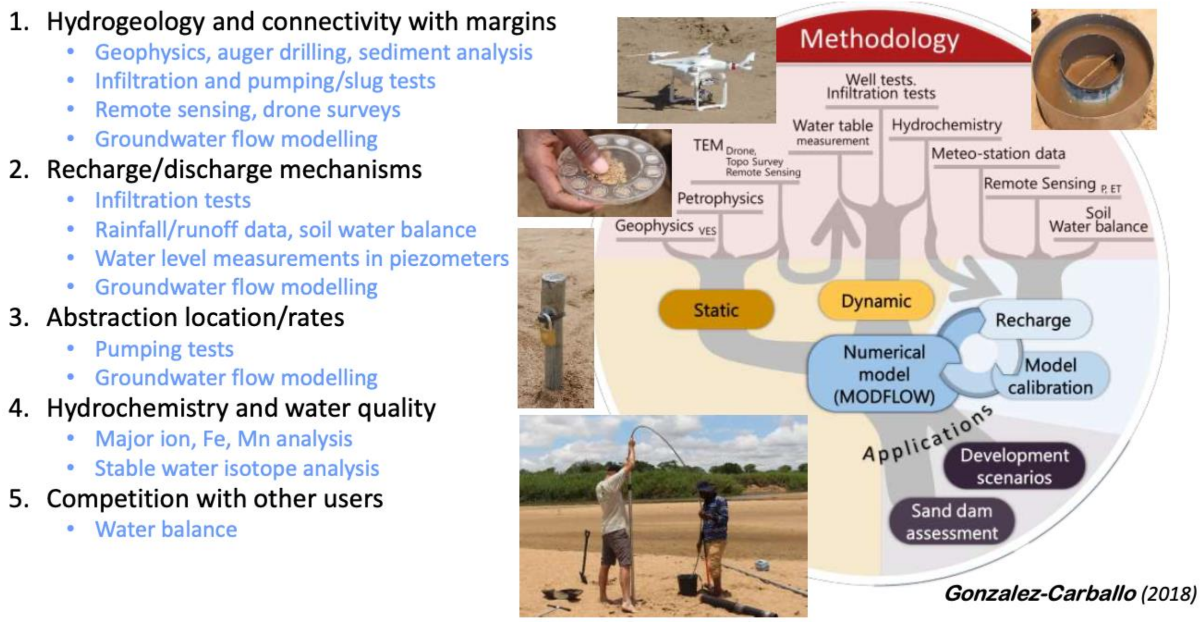

Figure 4. Sand river aquifer research methodology proposed by the A4Labs project (https://a4labs.un-ihe.org)

The conclusions extracted from the project include the following lessons learned:

- The dominant mechanism of sand river recharge is runoff infiltration, a very fast process, which guarantees rapid replenishment of depleted storage;
- The dominant mechanism of sand river discharge is evaporation;
- Groundwater flow below the riverbed is slow and further hampered by rock sills, creating independent compartments;
- Good abstraction practices in time (start of dry season) and space (inside river bed) minimizes evaporation losses and the risk of salinization;
- In the largest sand river systems evaporation is less important than lateral discharge towards the river and base flow;
- Connectivity with the margins is often limited by hardrock or very fine sediments, but may locally be relevant (e.g. paleo-channels, requires further study);
- Downward leakage of sand river water can be relevant in fractured bedrock;
- The impact on riparian vegetation and downstream users requires further study, but runoff can be reduced if exploitation of a sand river is intensified.

Download the presentation (PDF, 2.25 MB): https://bit.ly/35zYw67.

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SMART-Control: Web-based real-time monitoring and modeling of managed aquifer recharge applications

CATALIN STEFAN and JANA GLASS
(Research Group INOWAS, Technische Universität Dresden, Germany)

Figure 5. Dr. Catalin Stefan, head of Research Group INOWAS at Technische Universität Dresden, Germany, introduced the development and application of a web-based real-time monitoring and modelling approach at six managed aquifer sites in Europe and South America

In his lecture, Catalin briefly presented six examples of managed aquifer recharge sites from Germany, France, Cyprus and Brazil. The schemes presented are at different stages of development, from very small research units (Dresden, Germany), to pilot systems (Brazil), up to medium-size scheme in Cyprus and full-scale municipal infiltration systems in Hyeres, France and Berlin, Germany. The schemes have different objectives, from adaptation and mitigation of extreme climatic events, reduction of surface runoff during heavy rainfalls, soil-aquifer-treatment (SAT) to increase water availability for irrigation, prevent saltwater intrusion in coastal aquifers, and increases capacity of municipal water works and sustain urban ecosystems. The presentation focused on the monitoring of these MAR schemes: in some cases laborious and at low resolution (monthly manual sampling and laboratory analysis), in others based on sensors but only for a limited number of parameters.

The project SMART-Control introduces a new approach in the monitoring of managed aquifer recharge schemes: data is collected in situ by a range of sensors and monitoring probes and sent in real time to a dedicated web-server. From here, the values are transmitted via FTP to the INOWAS platform, a free web-based platform for planning, management and optimization of managed aquifer recharge applications (www.inowas.com). The platform includes simulation tools of various degree of complexity, from simply empirical and analytical tool to numerical tools and optimization algorithms. In the new SMART-Control project, a new set of tools are developed: a tool for initial risk assessment of MAR schemes, an advanced monitoring tool, a real-time simulation tool based on

MODFLOW and sensor data, and a scenarios management tool for prognosis and forecasts. In his presentation, Catalin introduced the main principles behind the real-time monitoring tool and described the features and workflow of the MODFLOW-based numerical modelling tool. Currently under development, the real-time, web-based groundwater modelling tool will expand the functionality of the existing modelling platform by interconnecting the sensor data with the web-based groundwater models. This will provide for real-time numerical simulations of the impact of MAR on local and regional groundwater systems and will enable different groups of stakeholders to collaborate on development and assessment of MAR solutions.

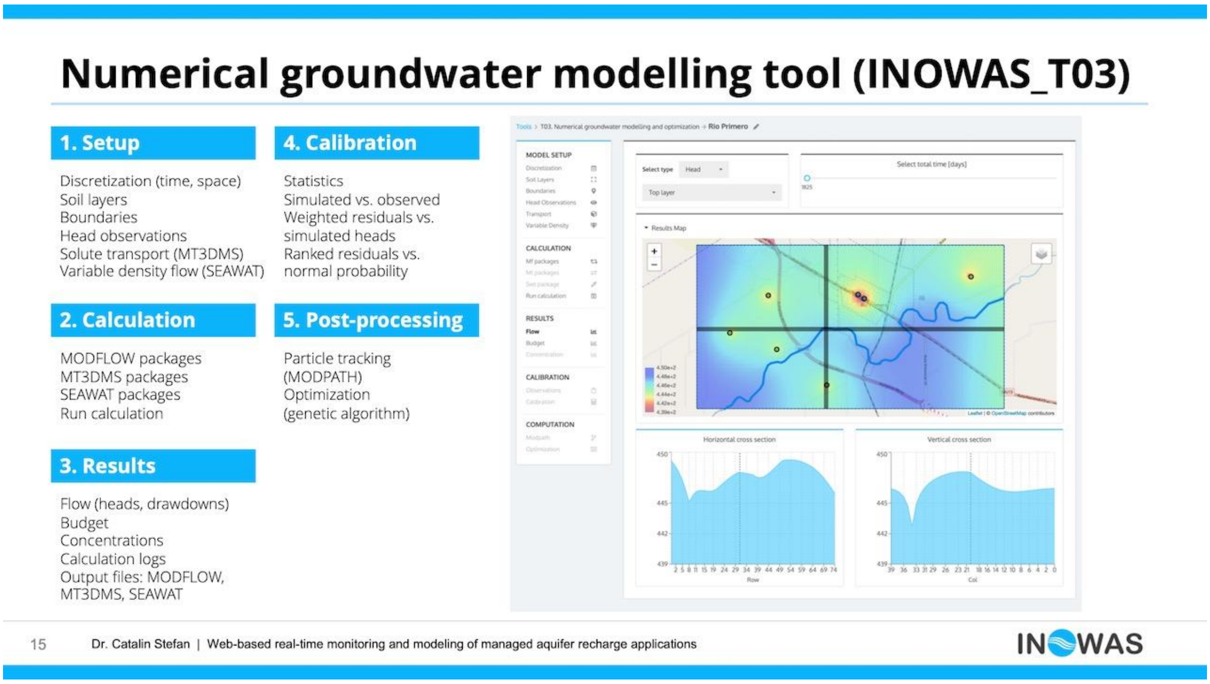

Figure 6. The main components of the web-based numerical groundwater modelling tool developed by the INOWAS group

The SMART-Control project is funded for two years under the Joint Water Programming Initiative (Water JPI) and includes a consortium of universities, research institutions, SMEs and water service operators. For more info, visit the project website at www.smart-control.inowas.com.

Download the presentation (PDF, 12.23 MB): https://bit.ly/38T3ltu.

Joint Master Programme “Groundwater and Global Change – Impacts and Adaptation” (GroundwatCH)

TIBOR STIGTER (Institute for Water Education – IHE, Delft, the Netherlands) and Catalin Stefan (INOWAS, Technische Universität Dresden, Germany)

Figure 7. Graduation ceremony of the 3rd edition of the Joint Master Programme “Groundwater and Global Change. Impacts and adaptation”. Delft, October 2019

The presentation focused on the Joint Master Programme “Groundwater and Global Change. Impacts and adaptation” (abbr.: GroundwatCH). This is a collaborative Master Course implemented by three European institutions: Téchnico Lisboa (Portugal), IHE Delft Institute of Water Education (the Netherlands) and Technische Universität Dresden (Germany). The added value is given by the technical profiles of the organising institutions: the Portuguese partner provides outstanding expertise in integrated water resources management, large experience on the implementation of the EU Water Framework Directive and they are also an excellent Groundwater Research Centre in semi-arid hydrogeology. In the Netherlands, IHE Delft excels in hydro(geo)logical research, education and capacity building across the globe while TU Dresden possesses renowned expertise in the field of climate and hydrology, safeguarded by a very well-matched combination of engineering, geo and natural sciences.

The academic calendar starts in Lisbon where the enrolled students attend a rich variety of courses in Environmental Engineering such as Hydrogeology, Hydrology, Environment and Water Resources, Groundwater Pollution and Protection, Environmental Policies and Law, to name just a few. In the second semester, the students move to the Netherlands and attend at IHE Delft courses in Water Science and Engineering: Tracer Hydrology and Flow System Analysis, Groundwater Data Collection and Interpretation, Applied Groundwater Modelling and many others. After the summer holidays, the students move again, this time to TU Dresden in Germany. Here, in the third semester, they receive a short course on statistics in R and attend courses on Climate Systems and Climate Modelling and chose from a large variety of optional modules. Additionally, they get the opportunity to engage in applied research while conducting a study project on Groundwater and Adaptation. During the fourth semester, the students have the opportunity to conduct their M.Sc. research thesis at either one of the three participating institutions in collaboration with renowned international partners from all over the world.

Upon completion of the M.Sc. study, the absolvents are able to:

a) explain in detail how groundwater systems function under different hydrogeological and climatic conditions;
b) study and describe the interactions between groundwater, climate, surface waters and land use, and their importance for water resources management;
c) use modelling tools to simulate climate and groundwater systems and managing water resources;
d) identify the consequences of global and climate change impacts for groundwater management under uncertainty;
e) set up groundwater-related adaptation solutions to deal with global change.

After three successful editions, 55 students graduated the Joint Master Programme and joined the international efforts in promoting sustainable management of groundwater resources under climate change impact.

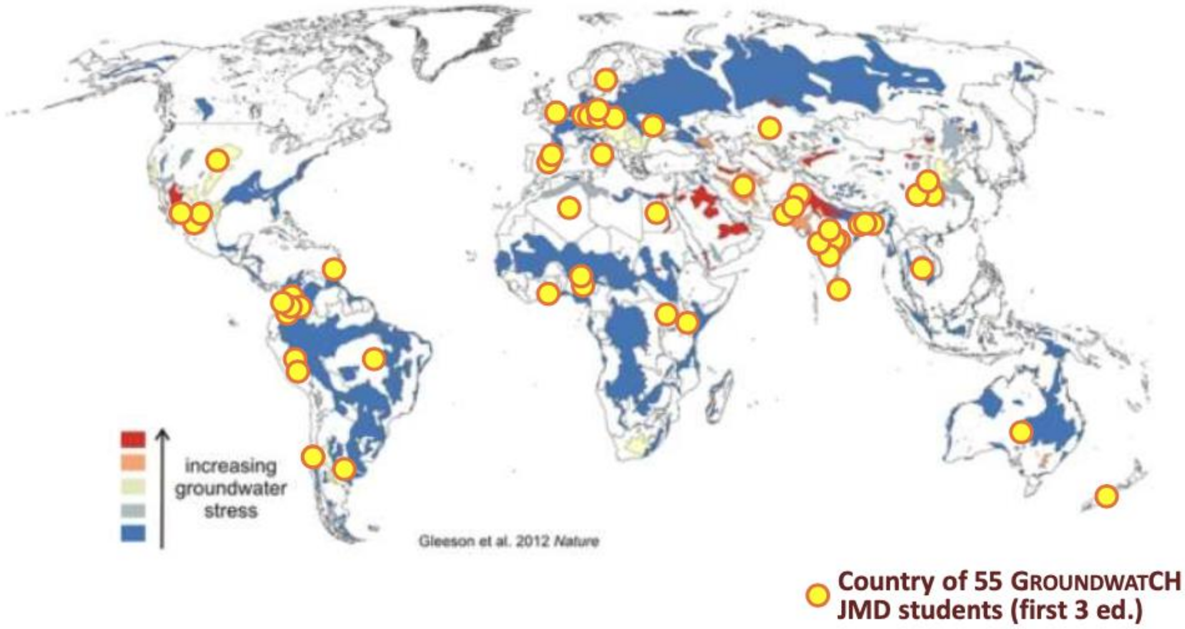

Figure 8. Distribution of GroundwatCH absolvents (background map depicts global groundwater stress)

Download the presentation (PDF, 1.05 MB): https://bit.ly/2r5nOKx.

Methodology for developing Managed Aquifer Recharge. An example of implementation in Chile

JORDI GUIMERÀ, ESTER VILANOVA and LUCIANO ACHURRA (Amphos 21, Spain)

Figure 9. Dr. Jordi Guimerà, Head of the Hydrological Services at Amphos 21, Spain, explaining the methodology for the application of managed aquifer recharge in Chile

The authors present in this interesting talk the methodology developed for MAR implementation in Chile. The main difficulty of this approach resides in the fact that Chile spans over many different climatic regions and is characterized by highly heterogeneous distribution of water resources, high demand for water, as well as high risk and exposure to natural disasters. In this context, the Chilean Water Authority launched a project to identify the most suitable regions for MAR in the country, define a project methodology and define a methodology of analysis of MAR projects.

The adopted methodology included: international literature review, selection of potential criteria (from an international and national survey of existing experiences and current and future needs), setting a quantitative ranking for selection (giving appropriate weights to a list of selection parameters, applying multi-criteria analysis (MCA) of the parameters, and MCA implementation in a GIS-based system.

The presentation continued with the introduction of each step of the process and presentation of the final result of the GIS project. As such, up to 100 potential river basins have been identified as suitable for implementation of different MAR techniques.

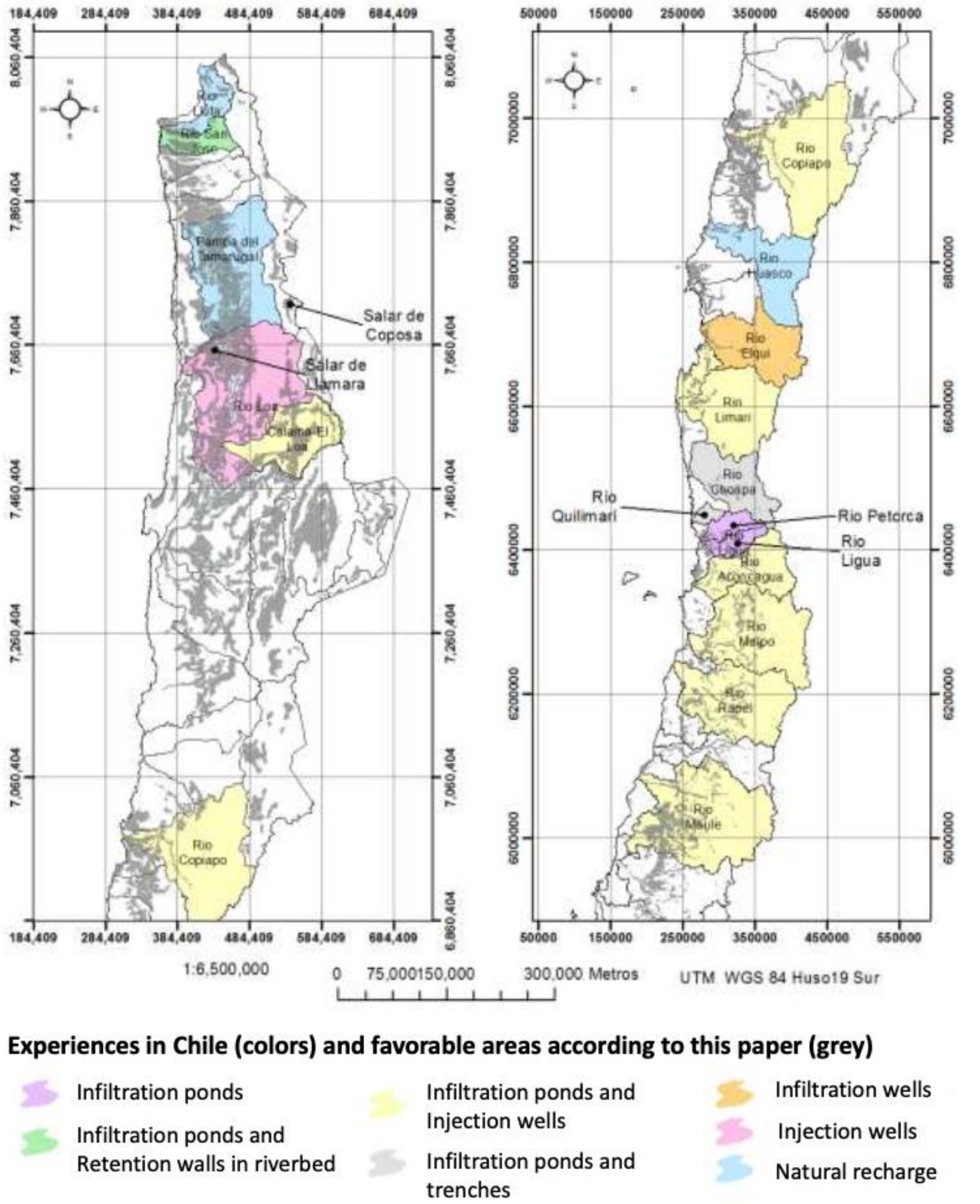

Figure 10. Watersheds in Chile according to their potential suitability for implementation of different MAR techniques

In conclusion, the results of the project revealed that the method developed represents a high value semi-quantitative tool for decision making which enhances the relative important of riverbeds, as a source and potential sites for MAR projects as a key for regulation. Nevertheless, the method does not consider the availability of water, the distance to water sources, financial constraints and social implications, so its use at local scale is rather limited but it can be enhanced by further detailed studies.

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How to control groundwater quality degradation in coastal zones using MAR optimized by GALDIT Vulnerability Assessment to Saltwater Intrusion and GABA-IFI models

JOÃO PAULO LOBO FERREIRA (Laboratório Nacional de Engenharia Civil, Portugal)

Figure 11. Prof. João Paulo Lobo Ferreira from LNEC, Portugal, introducing the GALDIT Vulnerability Assessment to Saltwater Intrusion and GABA-IFI models

The presentation started with introducing the motivation and objectives of developing prediction tools for assessing the aquifers' vulnerability to saltwater intrusion in coastal zones in different parts of Europe. The work is part of the MAR-to-MARket concept, an initiative stretching over a wide range of organisations from academia, industries, local authorities etc. A first outcome of previous works is the "White book on MAR modelling: Selected results from MARSOL project", a summary paper available on ResearchGate and www.marsol.eu, results section.

The experience accumulated by the author in previous projects (MARSOL, GABARDINE etc., and now MARSOLUT) revealed that at many MAR cases, not only big MODFLOW models are used but also 'micro-models', small but very accurate models able to represent in detail processes occurring during MAR application (i.e. small-scale clogging effects, fingering processes in different soil types etc.).

However, a major concern nowadays in Portugal (and this could be extended to the entire MENA region), as consequence of climate change, the precipitation pattern has changed noticeably over the past decade, with dry climate extending both spatially and temporally. While the average values remain mostly constant, the precipitation is mostly concentrated in shorter time periods. As consequence, the models revealed that a reduction of precipitation by 25% leads to a decrease in groundwater recharge by 75%, further exacerbating the stress on water resources available.

The solution is to store water in the subsurface during times of availability, which is the core principle behind MAR. The method feasibility was assessed in Portugal by LNEC using dedicated computer models and different climate change scenarios for the Watershed Management Plan (1971-2000). These simulation approaches also addressed challenges related to saltwater intrusion in coastal aquifers, these posing additional negative impact on groundwater systems. The numerical model simulation scales included regional scale, local scale and test site scale. For the optimization of MAR site selection, the GABA-IFI index was developed, taking into consideration the distance to the point of groundwater discharge, the depth to groundwater level and the horizontal hydraulic conductivity.

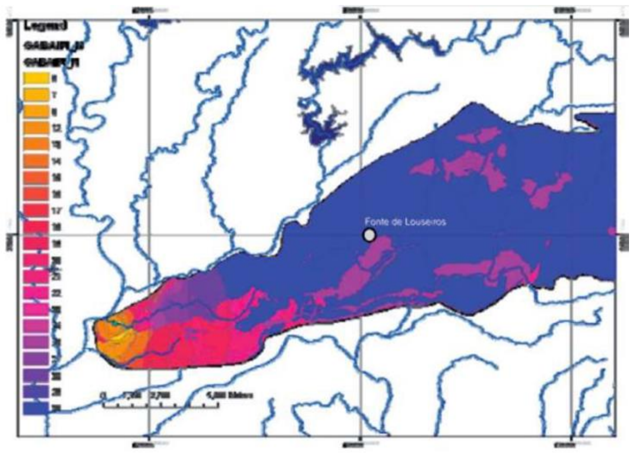

Figure 12. Application of GABA-IFI index to the aquifer system of Querença-Silves (Algarve, Portugal)

In addition to the index above, another method was developed for assessing the aquifer vulnerability to saltwater intrusion. The GALDIT index is calculated as function of groundwater occurrence, aquifer hydraulic conductivity, depth to groundwater level, distance from the shore, impact of existing status of sea water intrusion and the thickness of the aquifer.

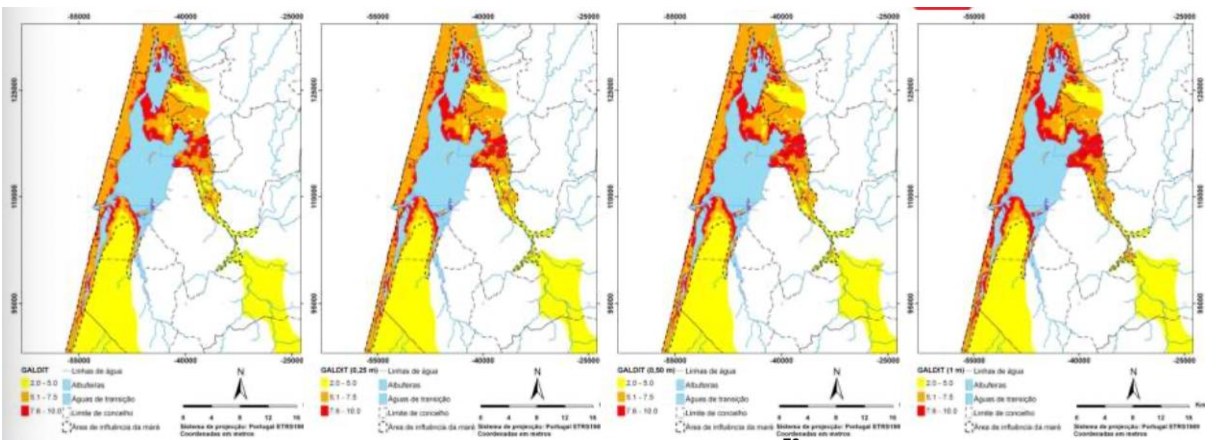

Figure 13. Application of GALDIT index for assessing the vulnerability of saltwater intrusion of an aquifer in Portugal

Download the presentation (PDF, 3.17 MB): https://bit.ly/2tYRJFo.

Sites and indicators of MAR as a successful tool to mitigate climate change effects in Spain

JON SAN SEBASTIÁN SAUTO and ENRIQUE FERNÁNDEZ ESCALANTE (Tragsa Group, Spain)

The presentation by Dr. Sebastián Sauto and Dr. Fernández Escalante from Tragsa Group brings additional evidence about MAR as successful tool to mitigate climate change effects. The talk introduces a matrix of MAR solutions in response to different climate change issues with selected examples from Spain. The efficiency of the system is assessed by specific indicators, as in Figure 14:

CC ISSUES	MAR SOLUTIONS	SITES	INDICATORS
Evaporation ↑	Underground water storage	*Canal del Guadiana (CLM)*	+48 hm³/year
	Temperature decrease	*P. de Mallorca (I. Baleares)*	-1.5-6ºC of air temperature
Evapotranspiration ↑	Soil humidity increase	*Gomezserracín (CyL)*	+15-20% soil moisture
Water demand ↑	Reclaimed water infiltration	*Alcazarén (CyL)*	+0.4 hm³
	Punctual infiltration	*Canal Isabel II (Madrid)*	+5 hm³/year
Water availability ↓	Self-purification	*Santiuste (CyL)*	+/-12-53% in water q parameters
Run-off ↓	Off-river storage	*Santiuste (CyL)*	+2.62 hm³/year out of Voltoya River
Wetlands ↓	Restoration	*Santiuste (CyL)*	-5% recharge vol. (Alkaline lake)
Hydro Electric Power ↓	Gravity flow water distribution	*El Carracillo (CyL))*	+40.7 km of canals and pipes
	E savings / Lower emissions	*El Carracillo (CyL)*	-36% E costs (-10,780 kg CO_2)
Floods ↑	Infiltration of extreme flows	*Losa del Obispo (Valencia)*	+0.05 hm³ in 14 hours
	Forested Watersheds	*Neila (CyL)*	-15-40% of diverted flood volume
Droughts ↑	Multiannual management	*Santiuste (CyL)*	Supply for 3 years with no rain
Saltwater intrusion ↑	Intrusion barrier wells	*Llobregat (Cataluña)*	30 years to regain water table

Figure 14. Indicators for the success of MAR solutions for mitigations of climate change effects at different locations in Spain

Among the examples presented, several sites are of particular importance. Using intentional recharge, the MAR system at Canal del Guadiana (Castilla-La-Mancha) is able to increase the total storage volume with about 48 supplementary hm^3 per year. On the Mallorca Island, vegetated roofs, fed by rain collection, are able to reduce the air temperature with about 1.5 to 6 °C. In Gomezserracín, Castilla y León, additional water storage in the unsaturated zone increased soil moisture by 15-20%. Further evidence is provided by Lliria, Valencia, where the karstified aquifer was used to infiltrate peak-flow from a flooding event at rates of about 1000 L/s for a period of 14 hours, significantly reducing the negative impact of the extreme flood.

Figure 15. Two best-practice MAR examples from Spain: infiltration ponds at Los Arenales aquifer (left) and deep borehole at Balsa del Campo, Lliria, Valencia (right)

In the end of the brief presentation, the authors concluded that:

- Climate change effects and their associated problems have been related to 15 successful MAR solutions in 10 sites in Spain;
- A series of indicators have been established to value the efficacy and efficiency of MAR related to climate change;
- MAR can be used as a tool that can simultaneously achieve several purposes;
- Management can help to lead MAR systems to balance different simultaneous goals (i.e. reducing filtration rate while improving water purification) or different seasonal purposes (storage vs. transportation);
- Adaptation and mitigation of climate change can be/are aims of MAR systems.

To read the full article (open access) which served as source for this presentation, visit: https://www.mdpi.com/2073-4441/11/9/1943 or download the presentation (PDF, 0.98 MB): https://bit.ly/38TwFzM.

Ensuring safe MAR to address water scarcity under the EU Water Framework Directive

MANUEL SAPIANO (Energy and Water Agency, Malta)

Figure 16. Dr. Manuel Sapiano, CEO of the Energy and Water Agency of Malta, talking about how to ensure safe implementation of MAR under the EU Water Framework Directive

The talk of Mr. Sapiano concentrated on the EU regulatory framework in regard to implementation of managed aquifer recharge. The main statements of the presentation were drawn from the MARSOL project, which delivered under the working package 17, a proposal for a regulatory framework for MAR, based on the requirements of the EU Water Acquis, and a Policy Paper to promote MAR as a safe water supply tool. In this context, the talk gave an overview on existing provisions at the EU level, such as the Water Framework Directive (Dir 2000/60/EC), the Groundwater Directive (Dir 2006/118/EC), the series of Guidance Documents of the Common Implementation Strategy (CIS) for the Water Framework Directive (especially the Guidance Document 17 “Guidance on preventing or limiting direct and indirect inputs in the context of the Groundwater directive 2006/118/EC”, Guidance Document 18 “Guidance on Groundwater Status and Trend Assessment” and Guidance Document 26 “Guidance on Risk Assessment and the use of conceptual models for groundwater”).

As way forward, a new CIS Guidance Document on aquifer recharge is proposed, anchored in the preliminary efforts in the MARSOL project. This document shall be perceived as guidance on MAR risk assessment from both a quantitative and qualitative perspective, outlining how safe MAR can contribute to the achievement of Water Framework Directive Environmental Objectives.

Download the presentation (PDF, 0.49 MB): https://bit.ly/2YZIgch.

Nature based solution on MAR and climate change alleviation

BEATRIZ MAYOR RODRÍGUEZ and ELENA LÓPEZ GUNN (iCatalist, Spain)

The presentation “Nature based solutions on MAR and climate change alleviation” introduced the main goals and preliminary results of the NAIAD project, an international project funded by the European Union under the Horizon 2020 research and innovation programme. The strategic goals of the project include:

a) Methodology assessment: biophysical, social and economic assessment at different demonstration sites;
b) Testing framework / tools at 9 demonstration sites: Integration of the knowledge and testing at real environments;
c) Policy uptake and exploitation: Identify and address specific barriers and opportunities for the uptake of nature-based solutions.

The project is currently being implemented at nine demonstration sites spread across Europe: City of Amsterdam (the Netherlands), Thames basin (United Kingdom), La Brague basin (France), Medina aquifer (Spain), City of Copenhagen (Denmark), City of Lodz (Poland), Glinsica catchment (Slovenia) and the Lower Danube (Romania).

To exemplify the project’s methodology, the case study Media aquifer was presented in more detail: despite the severe rural depopulation, the mainly agricultural area is characterized by surface and groundwater ecosystem degradation (including overexploitation of groundwater) and frequent drought risk due to climate change. The objective of the project is to co-develop adaptation strategies (including nature-based solutions) to reduce the drought risk and improve the aquifer status. To reach this goal, the project consortium together with a group of representative stakeholders developed a set of adaptation measures, including: crop changes toward drought resilience, managed aquifer recharge, introduction of innovative irrigation techniques etc.

Workshop 1 – identification and ranking of measures by stakeholders

Crop change towards drought resilient crops	9
Environmental awareness	9
Managed aquifer recharge	6
Innovative irrigation techniques	6
Soil conservation practices	5
Groundwater Users Associations	5
Waste water natural treatment and reuse	4
Tariffs and fines	4
Circular economy	4
River bank restoration	3
Reforestation	3
Small ponds for irrigation	3
Control of illegal abstractions	3
Phitoremediation	2
Flood plain restoration	2
Water transfers	1
Subsidies and compensations	1

Figure 17. Selection of adaptation measures within the NAIAD project

These effectiveness of these measures were then validated by different groups of stakeholders who perceived managed aquifer recharge (MAR) as one of the most appropriate solution for the Medina aquifer. The assessment of the impact of MAR on the groundwater system revealed no impacts on the recharge rates in the deep aquifer used for irrigation, limited impact on the shallow aquifer and 50 m corridor of riverine vegetation restoration. The main outcomes of the study concluded that in this particular case, MAR should be combined with further water management measures in order to increase its impact for drought risk or aquifer overexploitation. Nevertheless, environmental co-benefits are to be expected so MAR could have a significant contribution to the environmental recovery objective.

Download the presentation (PDF, 1.13 MB): https://bit.ly/34yeE6P.

From managed to controlled aquifer recharge: The LIFE REWAT Suvereto two-stage infiltration basin (Italy)

RUDDY ROSETTO (Scuola Superiore Sant'Anna, Pisa, Italy)

Figure 18. Dr. Ruddy Rosetto from Scuola Superiore Sant'Anna in Pisa, Italy, introducing the ICT-based monitoring concept of an induced riverbank filtration scheme in Italy

In his talk entitled "From managed to controlled aquifer recharge: the LIFE REWAT Suvereto two-stage infiltration basin (Italy)", Dr. Rudy Rossetto from Scuola Superiore Sant'Anna in Pisa, Italy, emphasized the relevance of a very important component of MAR schemes, often missed in many cases: the monitoring. The REWAT project, funded by the European Union within the Life Programme, covers this important aspect by developing a dedicated monitoring system according to the newly published Italian national regulations for permitting the set up and operation of managed aquifer recharge schemes (DM 100/2016). According to the regulations, the monitoring system must include: a discrete monthly monitoring of hydrodynamics and hydrochemistry during the design phase, an operational monitoring to evaluate the effectiveness of the scheme and to detect potential failure or deterioration, and a high-frequency or continuous first alert monitoring at the upstream recharge point to guarantee interruption of the recharge flow in case of contamination events.

In compliance with the regulations, a decision support system based on low cost sensors, remote data distribution and transmission and GIS physically-based fully distributed numerical model was developed for continuous monitoring and management of an induced riverbank filtration scheme at Serchio River well field in Italy. The architecture of the ICT infrastructure is configured for the achievement of three objectives: a) sensors, data gathering and management for operational purposes, b) sensors, data gathering and management to assess the recharge effects on groundwater, and c) data management and scheme operation (storage and transmission unit). The particularity of the system relies on the automatization of the recharge process, both quantitatively (water is allocated for recharge purposes with respect to the minimum base flow in the river) and qualitatively (only water of adequate quality is recharged, based on data gathered by the sensors).

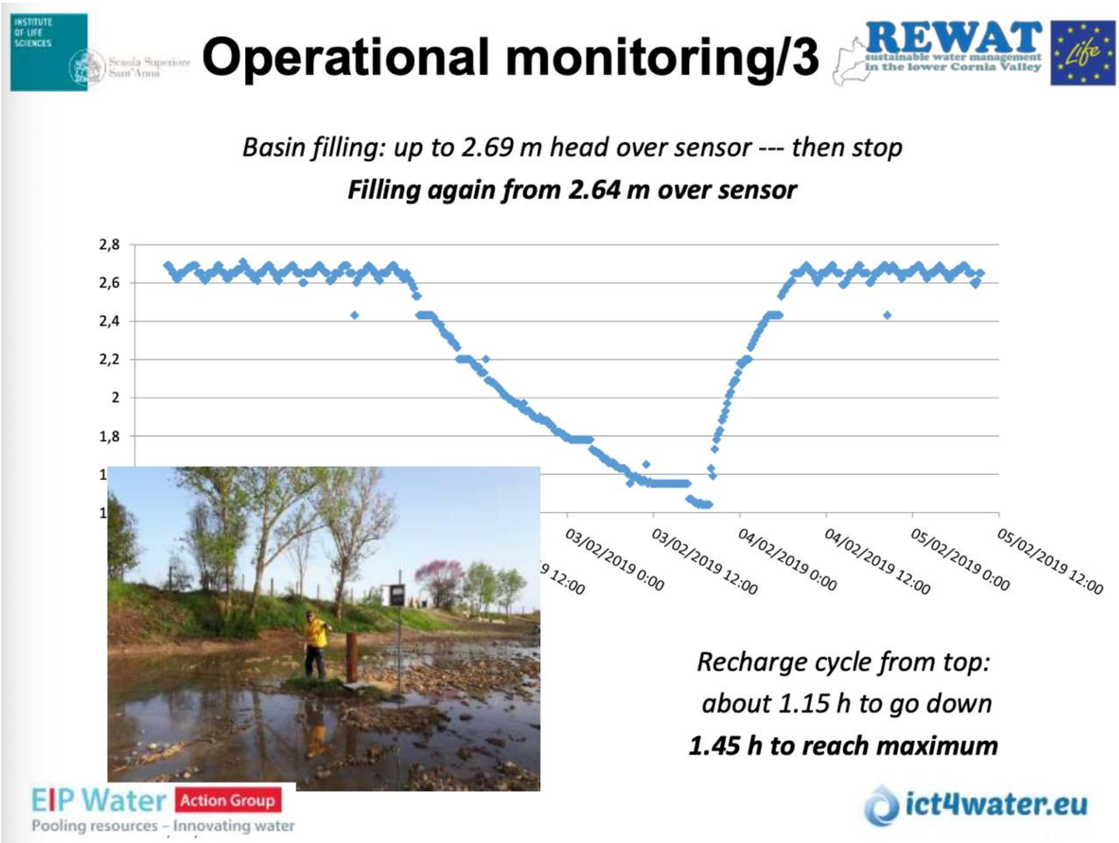

Figure 19. Example of automated operational schedule of aquifer recharge at the Serchio River well field in Italy

The project represents a flagship example in Italy and Europe for demonstrating the correct and responsible application of managed aquifer recharge with high replication potential at other sites that are not appropriately monitored.

Download the presentation (PDF, 3.23 MB): https://bit.ly/2M8AjfE.

Conclusions

The next conclusions have been compiled from both, the morning and the afternoon session, although only the first one has been summarized in this report.

One open question launched during the debate to the whole assistance was whether anybody finds any constraint against the main statement of the session (**MAR faces actively climate change adverse impacts**). Nobody acting as "the lawyer of the devil" proposed any reason to contradict this affirmation. Anyway the response brought up several open questions, such as:

- Is the regulation related to the binomial MAR-CC appropriate?;
- to what extent the economic barriers impeding SAT-MAR to succeed can be jumped over?,
- can MAR become an industrial process?...

Regarding the first question, the conjunctive response was clearly NOT and requires an urgent improvement: "the legal system does not fit for purpose". Regarding the second, the response is strongly related to the context. The third still remains being an open question.

MAR is something else…

Managed Aquifer Recharge is considered, very often, an Integrated Water Resources Management Technique, but according to the inputs from the attendants, can be considered "**something else"**, such as a mechanism of adaptation to climate change, a complex tool to combat water scarcity and drought and even an excuse to put together groups of scientists and practitioners studying how to solve urgent environmental impacts by means of an accurate risks assessment, planning and implementing practical actions with a strong scientific basis.

Barriers pendant to be jumped over

The spread of MAR experiences is still finding severe cultural and political problems, not only of economical nature. Anyway the indicators of implementation confirm that MAR is becoming more and more accepted, especially in developing countries and in arid-semiarid areas (see Dillon et al, 2019).

The preventive principle is being considered, perhaps, with a certain exaggeration in Europe, in special regarding SAT-MAR experiences. Not all the attendants agreed on this statement and some persisted in the slogan: "Not to have MAR" is better than "I have a bad MAR". The general agreement is that water authorities are, in general, conservative and the increase of the reuse and new experiences on SAT-MAR could convince them to support new implementations. This case is a vicious circle.

The biggest barrier for MAR is still cultural and political, with new agents on the stage such as pollutants, pharmaceuticals… new problems are being solved with new actions (reactive barriers…) so science related to MAR cannot stop.

Practical proposals from the attendants

The best way to protect MAR is an effective MAR, what means to gain conscience of the advantages and awareness of the economic and environmental benefits in the medium and in the long terms. Some attendants defended that the cost-benefit is equivalent to the effort paid in communication.

Regarding the statement: “Water scarcity brings MAR”, the concept is only well understood by technicians, but not by the general population and some authorities, especially at local scale (yet). Once again a proper communication becomes a first-row action, as long as technical solutions are efficient and supported by guidance documents. More effort must be paid during MARSOLut project for a wise dissemination and IAH MAR Commission must play a very important role so as to achieve this target.

The current guidelines adopted by different countries (WHO, Australian) and the imminent European Guidelines, expected for 2020, should be applicable for developing countries, but the environmental context should condition this applicability.

In general the Italian attendants expressed that wise monitoring is barely considered in the current regulations. Monitoring schemes for MAR and their know-how are missed in the regulations. It must be done during the design phase… A good monitoring is able to secure water for recharge only in case the quality standards are met. So MAR keeps being an opportunity but not a threat.

Environmental perspective

The relation of MAR with ecosystems, some attendants miss concrete studies on the effect of MAR in riverine vegetation and streams that stay dry most of the year. Also the direct infiltration in karsts requires more detailed studies. Also modeling of the distribution of flood or flash water inside big cities is becoming a usual issue. Sometimes MAR water is jumping from the river to other position of the same river, even into a different river, spending money, what entails a certain introspection to assess the convenience by means of a cost/benefit study.

The “new supply of new water” in irrigation may become an asset as MAR in irrigation is willing to improve the water quality.

The MAR water from a WWTP poured into a river justifies river bank filtration, the most extended MAR system in countries such as Germany, Italy, Hungary… although still remains the doubt about the forced classification of RBF as a pure MAR technique.

The final dilemma: to act or to get ready and wait?

The environmental circumstances will force the implementation of MAR techniques, at least in the Mediterranean countries, were indicators such as the Palmer severity index… mentions situations of extreme drought by the year 2100. So, some of the attendants mentioned the necessity of being ready with the formation of new experts in the technique´s designs and applications’, taking into account that MAR is not philosophy, but rather science. The argue was about the proactivity degree: should experts wait for MAR to be duly implemented due to climate change impacts or the pressure on governments should be higher so as to keep a preventive policy?

Within this context, according to the general feeling of the attendants, “MAR as a climate change adaptation/mitigation measure” is becoming a puzzle and each one should provide his/her chip.

Annexes

Annex 1. List of speakers (morning session)

(in the chronological order of the presentations)

	**ENRIQUE FERNANDEZ ESCALANTE** Tragsa Group, Spain *“Why managed aquifer recharge is a successful tool to climate change adverse effects adaptation? International examples and indicators”* *“Sites and indicators of MAR as a successful tool to mitigate climate change effects in Spain”*
	**TIBOR STIGTER** IHE Delft Institute for Water Education, the Netherlands *“Groundwater assessment in sand rivers in adaptation to climate variability and water scarcity: opportunities and challenges in semi-arid Africa”*
	**CATALIN STEFAN** Research Group INOWAS, Technische Universität Dresden, Germany *“SMART-Control: Web-based real-time monitoring and modeling of managed aquifer recharge applications”* *“Joint Master Programme “Groundwater and Global Change – Impacts and Adaptation” (GroundwatCH)”*
	**JORDI GUIMERÀ** Amphos 21 Consulting, Barcelona, Spain *“Methodology for developing Managed Aquifer Recharge. An example of implementation in Chile”*
	**JOÃO PAULO LOBO-FERREIRA** National Laboratory of Civil Engineering, Lisbon, Portugal *“How to control groundwater quality degradation in coastal zones using MAR optimized by GALDIT Vulnerability Assessment to Saltwater Intrusion and GABA-IFI models”*

	**MANUEL SAPIANO** The Energy & Water Agency, Malta *“Ensuring safe MAR to address water scarcity under the EU Water Framework Directive”*
	**BEATRIZ MAYOR RODRÍGUEZ** iCatalist, Spain *“Nature based solution on MAR and climate change alleviation”*
	**ELENA LÓPEZ GUNN** iCatalist. Spain *“Nature based solution on MAR and climate change alleviation”*
	**RUDY ROSSETTO** Scuola Superiore Sant’Anna, Pisa, Italy *“From managed to controlled aquifer recharge: The LIFE REWAT Suvereto two-stage infiltration basin (Italy)”*

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Annex 2. List of signing participants

Morning session.

11 December 2019, Zaragoza, Spain

Name	Institution
PAULA FERNÁNDEZ	ARAGON GOVERNMENT
Aurélien DUMONT	Consultant
Christoph Sprenger	KWB
JUSSI AHONEN	GTK
ROBERT FENZ	Ministry Environment Austria
Rodrigo Perez	UPCatalunya
Esteban Rafael Caligaris	Scuola Superiore Universitaria Sant'Anna Pisa
Marcel Horovitz	LNEC
Inés Roig	Aliantaqua
JORDI GUIMERÀ	AMPHOS 21
Sophie Trémolet	The Nature Conservancy
Catalin Stefan	TU Dresden, DE
Manuel Sapiano	Energy Water Agency
[illegible]	Energy and Water Agency
Mohácsiné S. Gabriella	Water Directorate
Daniel Fernandez Garcia	UPC Barcelona TECH
Elena Lopez Gunn	Icatalist
Lina VARON	Poitiers University/ERM
Carine PETIT	SPW DG ARNE

Name	Institution
Tenso Leitão	LNEC
Vaiklo Junglans	Humboldt University Be
DR SAM HANCOCK	Emerald Plan
FRANCESCO DEMICHELE	EWA
Rodrigo Pérez	UPC
Marcel Horovitz	LNEC
Esteban Rafael Caligaris	SSSA
Beatriz Mayor	ICATALIST
Mihacsinés Gabriella	Water Directorate
J. P. LOBO-FERREIRA	LNEC
Enrique Fdez Escalante	Tragsa

Afternoon session

Name	Institution
Christoph Schüth	TU Darmstadt
ENRIQUE CIFRES	ICOLD
Annette Wefer-Roehl	TU Darmstadt
Teresa [illegible]	LNEC
JORDI GUIMERÀ	AMPHOS 21
DR SAM HANCOCK	Emerald Planet
Endy Higgins	DG ENV
Esteban Rafael Caligaris	SSSA
Marcel Horovitz	LNEC
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RUDY ROSSETTO	SCUOLA SUP. SANT'ANNA
Christoph Sprenger	KWB
Daniel Fernandez Garcia	UPC Barcelona TECH