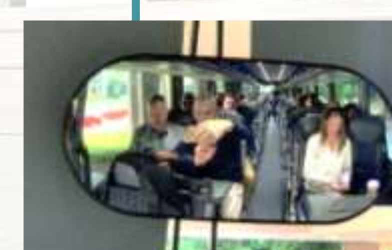
P-ISMAR 11

11ST INTERNATIONAL SYMPOSIUM ON MANAGED AQUIFER RECHARGE, ISMAR-11, POSTERS. LONG BEACH, CALIFORNIA, USA



11º SIMPOSIO INTERNACIONAL DE GESTIÓN DE LA RECARGA DE ACUÍFEROS, ISMAR-11, PÓSTERES. LONG BEACH, USA

EDITOR: ENRIQUE FERNÁNDEZ ESCALANTE, IAH-MAR, MARSOLut-TRAGSA GROUP

P-ISMAR 11. POSTERS OF THE 11st INTERNATIONAL SYMPOSIUM ON MANAGED AQUIFER RECHARGE, LONG BEACH, CALIFORNIA, USA

INTRODUCTION

From 2022 April 11st to 15th has taken place in Long Beach, Hilton Hotel, the 11th International Symposium on Managed Aquifer Recharge (ISMAR 11), hosted by GRA and co-hosted by AHS and OCWD; under the auspices of the International Association of Hydrogeologists (IAH), UNESCO and ASCE, among others, under the title*:* ***"Managed aquifer recharge: A key to sustainability".***

The symposium counted on 350 delegates from 27 countries, and had 26 technical sessions, 123 oral presentations, 10 posters, 2 keynote presentations, side events, three first day short courses, two technical field trips, one after-conference course, and plenty of knowledge. Detailed info is provided at http://ismar11.net

Poster´s authors were specifically requested by the organizers. Some of the posters are digital photos, taken by the editor, always with permission. All of them have been gathered in this collection called P-ISMAR 11.

Both, the classification and the editing tasks were carried out by an IAH-MAR Commission editor with the assistance of the ISMAR 11´s organizers.

You can hereby enjoy the publication resulting from this cooperation, which consists of 7 posters and allows us to share some information that, otherwise, could have been lost.

Further information on this event can be found at:

http://recharge.iah.org/ismar

http://ismar11.net

POSTERS DEL 11º SIMPOSIO INTERNACIONAL DE GESTIÓN DE LA RECARGA DE ACUÍFEROS ISMAR-11, LONG BEACH, CALIFORNIA, USA.

INTRODUCCIÓN

Entre los días 11 y 15 de abril de 2022 tuvo lugar en Long Beach, hotel Hilton, la 11ª edición del congreso: *International Symposium on Managed Aquifer Recharge* (ISMAR 11), promovida por AHS y OCWD, bajo los auspicios de la Asociación Internacional de Hidrogeólogos (IAH), UNESCO y la asociación de ingenieros civiles de Estados Unidos (ASCE), entre otros, bajo el lema: ***"MAR: una llave para la sostenibilidad".***

El simposio reunió a 350 asistentes de 27 países y contó con 26 sesiones técnicas, 123 presentaciones orales, 8 posters, 2 ponencias clave, tres minicursos de primer día, dos viajes de campo, un curso post-congreso y mucha recarga de conocimiento. Información detallada puede ser consultada en http://ismar11.net.

Los autores de los posters fueron contactados por los organizadores. Algunos posters son presentados como foto digital, tomadas por el editor, siempre con permiso de los autores. Todos ellos has sido agrupados en la presente publicación titulada P-ISMAR 11.

Tanto la recopilación como la edición han sido realizadas por un editor y co-coordinador de la Comisión IAH-MAR, con el apoyo de los organizadores.

El resultado es la presente publicación, que consta de 7 pósters, bien de fotografías originales o bien de los ficheros digitales facilitados por los autores, que permiten compartir una información que, de otro modo, se habría perdido.

Información adicional sobre este evento se encuentra en:

http://recharge.iah.org/ISMAR

http://ismar10.net

CLEAR CREEK ASSOCIATES

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HOSTED BY GRA AND CO-HOSTED BY AHS AND OCWD

Groundwater Resources Association of California

ARIZONA HYDROLOGICAL SOCIETY

ORANGE COUNTY WATER DISTRICT
SINCE 1933

P-ISMAR 11

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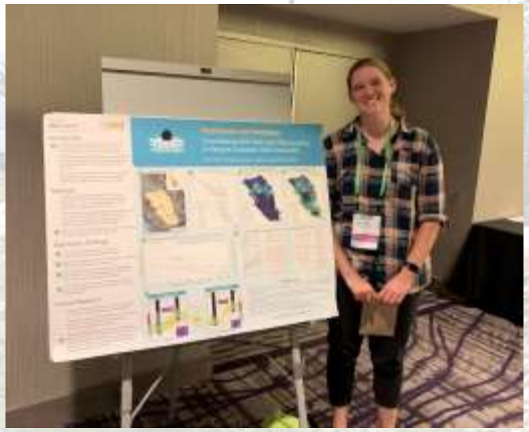
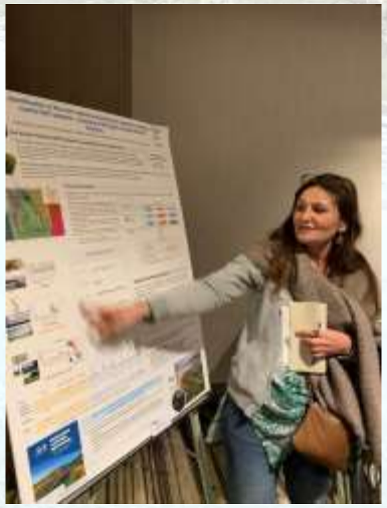




MAR to Mitigate Intensive Aquifer Exploitation

Insights From Los Arenales Aquifer (Spain)

PRESENTER:
Jose D. Henao Casas

BACKGROUND

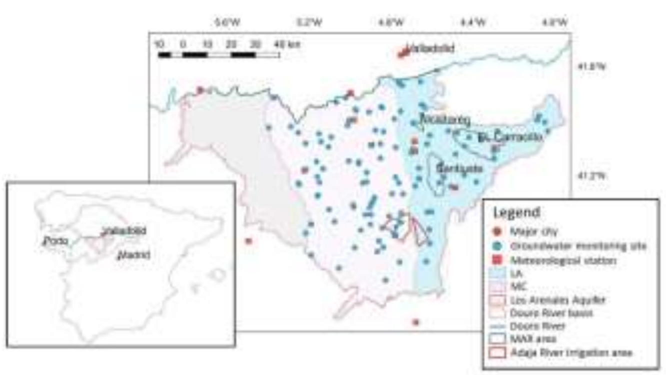
Los Arenales Aquifer has been intensively exploited for agricultural irrigation since the second half of the 20th century (up to -1.1 m/year)

OBJECTIVE

Evaluate if managed aquifer recharge (MAR) has helped palliate groundwater stress in Los Arenales Aquifer

METHODS

Compared groundwater level evolution between two water management regions within Los Arenales Aquifer: Los Arenales (**LA**) (implemented MAR in 2002) and Medina del Campo (**MC**) (No MAR before 2020)

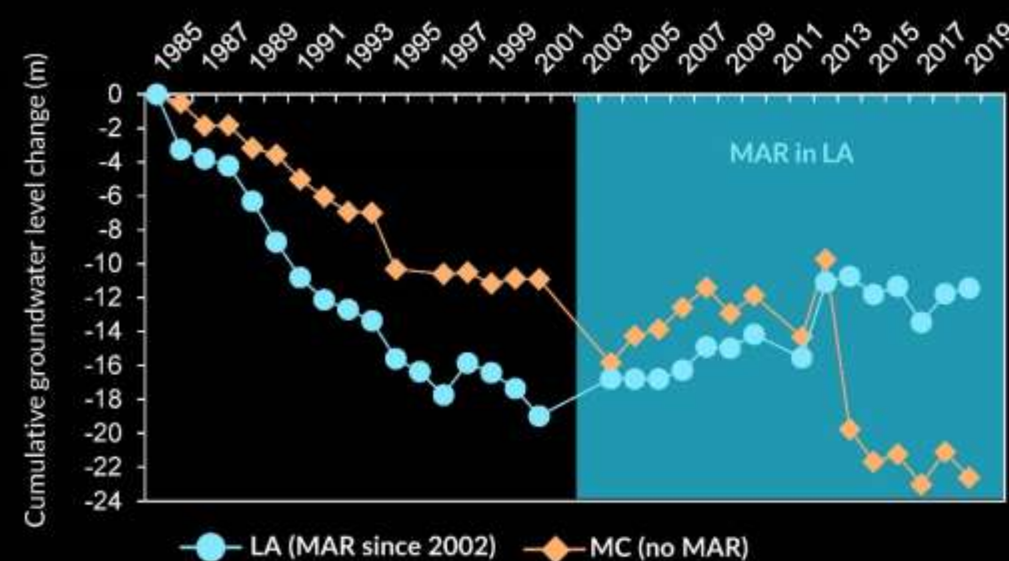


Analysis of **groundwater level trends** and variables that could explain the observed changes in groundwater levels: **MAR**, **groundwater abstractions**, **land use**, **cropping patterns**, and **water governance dynamics**

MAR in LA: three major areas (Santiuste, El Carracillo and Alcazarén)

- Main water source: winter river surpluses
- 21 infiltration basins
- ~50 km of infiltration channels
- Six artificial wetlands (improve water quality)

MAR contributes **replenishing stressed aquifers** thanks to **additional recharge** and **water governance dynamics**



MAR in LA

Supplies more than 10% of irrigation demands

MAR irrigation communities

- Cooperate to control water demand
- Ease innovation to cope with dry years, avoiding groundwater overdraft

RESULTS

From 1985 to 2001, ~100% of statistically significant **groundwater level trends** decrease in LA and MC. From 2012 to 2020, ~75% of the trends in LA are increasing, while ~75% of the trends in MC are decreasing

MAR provides at least 10% of irrigation demands in LA. Annual **groundwater abstractions** in LA are below recharge + returns since at least 2009, reflecting more control on water demand. No relevant changes in **land use** or **cropping patterns** were found

Water governance dynamics:

Two irrigation communities (gather farmers exploiting a common water source) created in **LA** to benefit from MAR. These communities foster:

- Direct communication with the local water authorities
- Negotiation of water rights (abstractions)
- Information transfer

The lack of irrigation communities in **MC** results in:

- Farmers acting on their own
- More illegal abstractions
- Less influence of the local water authority to introduce innovation, transfer knowledge, and control demand (Giordano et al., 2021)

Jose David Henao Casas (Tragsa, UPM)
Enrique Fernández Escalante (Tragsa)
Francisco Ayuga (UPM)

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MARSoluT Managed Aquifer Recharge ITN

GrupoTragsa www.tragsa.es

MARSoluT Managed Aquifer Recharge ITN www.marsolut-itn.eu

Monitored and Intentional Recharge (MIR). Methodological approach and guidelines

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Henao Casas, José David[1,2]
Calero Gil, Rodrigo[1]

INTRODUCTION

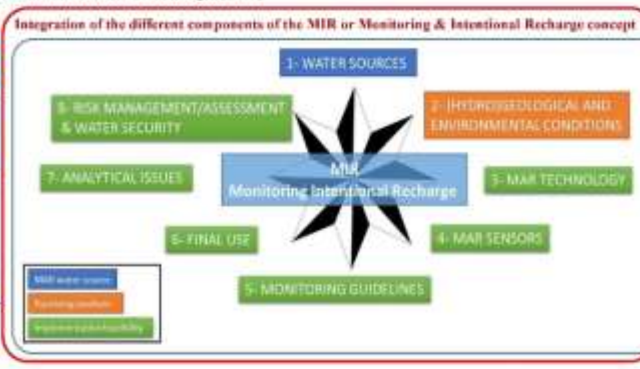
The main international guidelines on Managed Aquifer Recharge (MAR) and reuse have been studied and discussed.

The advances obtained from each analysis prove to be key for the design of specific regulations or guidelines for a given country, including general rules of broad use, integrated within the Monitored and Intentional Recharge (MIR) concept.

SETTINGS

All these factors have been grouped into a single and integrative concept, which has been termed by the authors as MIR or Monitored and Intentional Recharge (Fernandez et al., 2022, in press). The main factors to be taken into account during the development of any MAR guidelines document, have been grouped into eight families:

Integration of the different components of the MIR or Monitoring & Intentional Recharge concept



1. WATER SOURCES
2. (HYDRO)GEOLOGICAL AND ENVIRONMENTAL CONDITIONS
3. MAR TECHNOLOGY
4. SENSORIC FOR MAR
5. MONITORING GUIDELINES
6. END USE
7. ANALYTICAL ASPECTS
8. RISK ASSESSMENT

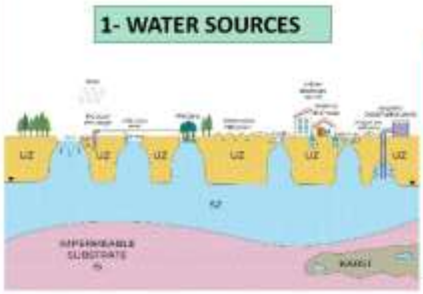
BACKGROUND

Most of the published MAR Guidelines have been gathered and studied to address the Monitored and Intentional Recharge (MIR) concept and implementation methodology

Etc…

RESULTS

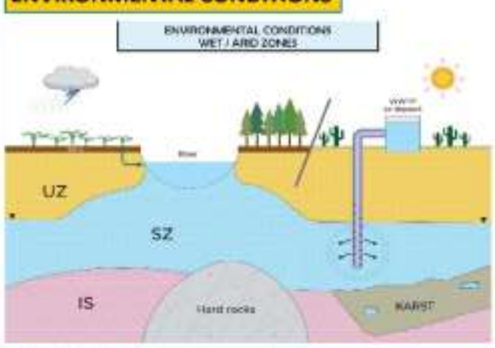
1- WATER SOURCES



Different water sources for MAR have been detected and organized under an integrative perspective

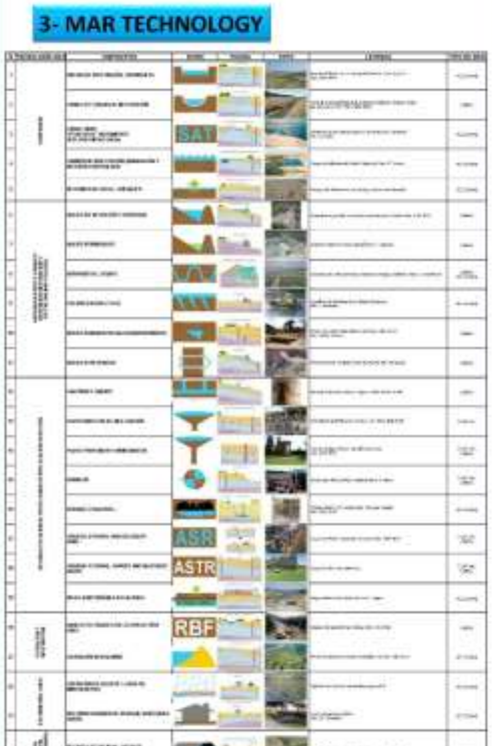
2- (HYDRO)GEOLOGICAL AND ENVIRONMENTAL CONDITIONS

ENVIRONMENTAL CONDITIONS WET / ARID ZONES



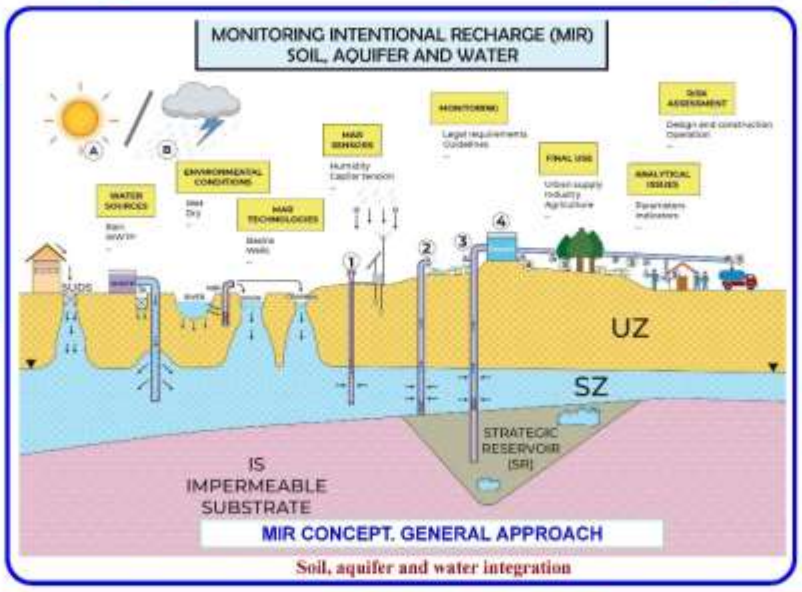
A first definition of the receiving medium characteristics is mandatory for MAR guidelines drafting applying the MIR recommendations

3- MAR TECHNOLOGY



The MIR concept relies on the 25 MAR typologies inventory assessed by DINAMAR, 2011 and MARSOL, 2016

MONITORING INTENTIONAL RECHARGE (MIR) SOIL, AQUIFER AND WATER

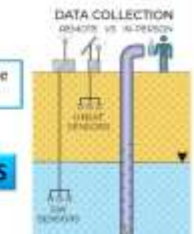


MIR CONCEPT. GENERAL APPROACH

Soil, aquifer and water integration

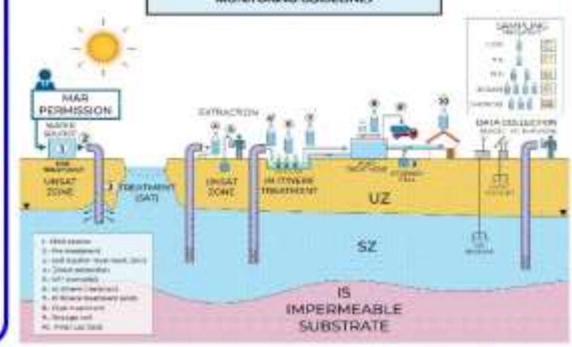
4- MAR SENSORS

A vast amount of sensor used for MAR have been included in an ontological table

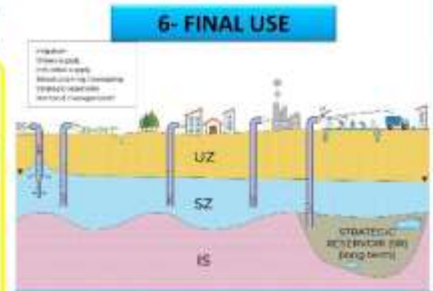


5- MONITORING GUIDELINES

The monitoring scheme includes most of the components of the MIR concept and the posible sampling points to be defined into each MAR guidelines document



6- FINAL USE



The uses of recharged water are multiple
The figure 6 specifies the most common ones

7- ANALYTICAL ISSUES

The main parameters regulated in international guidelines have been included in a compilation table. Sampling frequency must be defined too

8- RISK MANAGEMENT/ASSESSMENT & WATER SECURITY

Several lines of action related to risk and impact assessment, risk management and water safety are differentiated. Two major blocks have been proposed: design and construction and operation; assessing their technical and non-technical limitations

CONCLUSIONS

Eight differentiated blocks included in the methodological approach a recommendations to pursue "Monitored and Intentional Recharge" (MIR) applications

MIR is a guideline for guidelines documents

- **The study that precedes any MAR project must be quite complete, comprehensive and often expensive in relation to the price of the subsequent work.**
- **The final product should function properly and be framed within the framework of sustainable development and under minimum environmental impact standards.**
- **Monitoring intentional recharge is a basis for the MAR guidelines applied to specific environmental conditions and, generally, attaining each country´s regulations**
- **The MIR concept proposes the set of blocks and lines of action to stablish the framework for future MAR implementations within a certain technical guarantee of success.**

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GrupoTragsa

MAR to improve water security and rural development using drainage water sources, Arabayona demo-site, Salamanca, Spain.

[1-2]Fernández Escalante, Enrique*
[1] Paredes Núñez, José Miguel

[1]Tragsa Group, Madrid, Spain [2]Technical University of Madrid (UPM), Spain

INTRODUCTION

The Arabayona irrigation sector is located 30 km to t northeast of the city of Salamanca, Spain, and occupies a r area of 3,349 ha. The perimeter can be considered as rectangular strip, measuring approximately 12 km by 5 ki with altimetry oscillating between 887 masl and 830 masl the pumping station.

The irrigation area occupies an old wetlands system, what entails flooding and drainage problems. desiccated since the 80[th]s, for rural development and enhancement of the economic activity in a depressed area.

There is a neighbor aquifer with MAR possibilities and a semiconfined aquifer layer about 100 m depth with vertical drainage possibilities.

Arabayona, Salamanca, Sp

★ Overflooded areas

-DISTURBING PRESENCE OF WATER IN AGRICULTURAL AREAS
-AGRICULTURE PROBLEMS (FLOOD, DRAINAGE DIFFICULTIES)

>>SUBVERTICAL AND VERTICAL DRAINAGE SOLUTIONS

PHASES FOR A NEW MAR SYSTEM IMPLEMENTATION

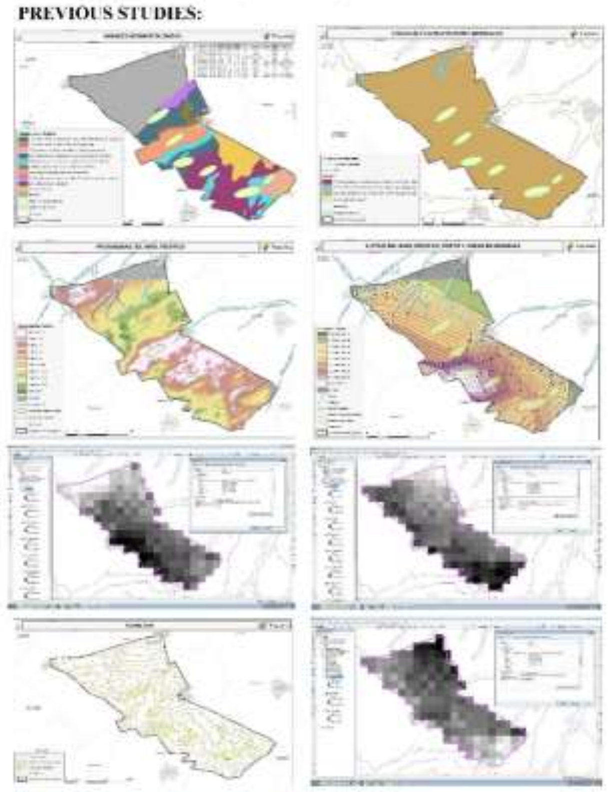
1. Study of the legal framework and foreseeable administrative setbacks.
2. Study of the degree of implementation of the technology in the area and the presence of experts and technical background.
3. Cost/benefit analysis.
4. GIS preparation and homogenization of available data.
5. Study of environmental conditions: hydrology, climatology, relief, including micro-topography.
6. Initial characterization of the aquifer. Background information. Available useful information. Lithologies and their distribution.
7. Review of existing borehole data.
8. Inventory of water points.
9. Geophysical prospecting campaigns for the three-dimensional reconstruction of the aquifer.
10. Three-dimensional reconstruction of the receiving environment > Elaboration of thickness cartographies of the aquifer and the unsaturated zone.
11. Elaboration of cartographies of water points, geology, hydrogeology (study of piezometry referred to a given period and elaboration of a hydrogeological cartography using UNESCO standards) and main hydraulic parameters, such as transmissivity/permeability and storage coefficient.
12. Determination of the presence of impermeable surface outcrops and their mapping.
13. In situ permeability tests.
14. Elaboration of a "MAR map" at local scale.
15. Studies of the possibilities of applying MAR technologies in the study area. First approximation stage.
16. Drilling of research boreholes, construction of piezometers and instrumentation of the most relevant ones.
17. Design of a monitoring and follow-up network for the elaboration of updated hydrogeological cartography.
18. Elaboration of hydrogeological models of flow and quality as tools for decision making. Modeling of aquifer functioning and its response to artificial recharge by simulating several different assumptions.
19. Water quality maps and localization of contamination sources.
20. Hydrochemistry and quality studies in the (un)saturated zone. It may be convenient, at the discretion of the technician, to add a study of the Unsaturated Zone (UZ), both in terms of capillary stresses and unsaturated hydraulic parameters.
21. Study of the quality of the water and its evolution after the interaction processes.
22. Proposed location of devices and selection of their typology. First approach.
23. Study of environmental impact and risks. Design of environmental indicators.
24. Specific design of recharge devices at preliminary design level. E.g. Well-well system for managed aquifer recharge and vertical drainage.
25. Second stage of refinement. Design of structures at project level.
26. Construction / Implementation.
27. Elaboration of a follow-up and control plan, with various programs on water safety, monitoring, toxicology...

Fernández-Escalante, 2022.

METHODOLOGY

In order to avoid the excessive water-related problems due to the surface and underground puddling, causing root asphyxia, loss of harvest, difficulties to work, etc. (sub)vertical drainage and MAR possibilities were studied.

PREVIOUS STUDIES:



DRAINAGE AND WATER DIVERSION WORKS:

Recharge rate differs depending on the water flow regime to the drains (permanent or variable) and also vary according to the time of year (maximum water demand by the crops, rainy or dry season, etc.), so that the recharge by deep percolation due to rain, irrigation, drainage and possible combinations of these phenomena are responsible for the elevation of the water table and determine the best drainage criteria to be applied. It is especially based on the definition of the optimum depth of the water table and its permanence along the time. Both are the main factors to be selected for the design of the underground drainage system, according to the agro-hydrological conditions to be achieved, to control a favorable water balance in the root zone.

RESULTS

The tertiary aquifer for the drainage area is composed of sandstones, conglomerates, silts, and muds of poor hydraulic characteristics, being the receiving medium of the same nature, but having higher hydraulic conductivity and storage coefficients.

Once studied the plot drainage needs as well as the design of the main and secondary sewers to facilitate the evacuation of the excess water utilizing both, natural and artificial drainage networks in the area, MAR is contributing to rural development as a component of the local IWRM system.

It includes an infiltration canal at the end of the irrigation network with a double function: to increase the water security and to reuse a volume of (ground)water that, otherwise, would abandon the system or will remain to flood the soils and affecting negatively the agricultural activity. The MAR canal recharges a neighbor part of the aquifer with a capacity to store and reuse the previously nuisance volume of water, with a flow rate between 2 and 5 l/s depending on the period.

Studies about deep recharge possibilities using abandoned boreholes (phreatic level about 100 m deep) willing to be reused are being conducted. The initial calculation of the recharge average by bottom-up percolation for each borehole provides a figure of about 5 L/s per borehole. This activity has been stopped due to qualitative reasons (nitrates concentration exceeding 50 ppm), therefore, only surface MAR is taking place combining drained, runoff, and rain waters.

A technical solution to solve this situation is ongoing, and probably the deep recharge in Arabayona will be an imminent reality.

MAR to reduce the disturbing presence of water in agricultural areas with drainage problems affecting food production

CONCLUSIONS

MAR has become a complementary technology to store a fraction of "nuisance" subsurface water surpluses into the aquifer. It covers a double objective, on the one hand, it has become a component of the integrated management or water resources in the area, and on the other, it is a water security element to increase the agricultural activity production.

The most remarkable fact has been the reuse of the water collected through drains for a MAR canal constructed reusing a previous stream (currently dried), to recharge a different area of the aquifer with appropriate characteristics for MAR. Implementation has been conducted by JCyL by means of Tragsa.

-Natural situation and MAR as a complementary technology for aquifer storage using a fraction of "nuisance" surface water
-Food production is resulting increased
-Nitrates impact
MAR success indicator: balance surface water-GW storage
Drainage areas with MAR present high nitrates concentration
Food production is increased.
Water security and MAR requires guidelines which redaction might be based on the Monitored and Intentional Recharge "MIR" concept.

Location: https://www.google.es/maps/@41.0291384,-5.3322185,657m/data=!3m1!1e3

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Repurpose and Recharge

Coordinating MAR and Land Repurposing to Reduce Domestic Well Vulnerability

Yara Pasner, Giorgos Kourakos, Graham Fogg & Helen Dahlke

Introduction

1 In California's Tulare Lake Basin (TLB), rural domestic wells are at risk of failure[1] and contamination[2] from surrounding agriculture

Agricultural managed aquifer recharge[3] (Ag-MAR) and land repurposing[4] have potential to improve groundwater quality and reduce groundwater overdraft

Gap exists in previous research on how Ag-MAR and repurposing projects can be coordinated regionally to improve domestic well reliability

Methods

Existing integrated water model (C2VSim) developed by California Department of Water Resources is used to simulate historic baseline conditions (Water Years 1974-2015)

From baseline, agricultural fields were idled evenly across the TLB, and in variably sized buffers around rural communities; model outputs were used to simulate domestic well failures[5]

2 Baseline C2VSim model accuracy was investigated before simulating Ag-MAR scenarios[6]

Preliminary Findings

3 C2VSim head residuals are too large to differentiate between modeled scenarios

4 Baseline simulation does not sufficiently reproduce historically observed well failures

5 Repurposing land near vulnerable communities prevents more simulated domestic well failures than idling land in a distributed fashion

6 Simulated buffer zones in TLB larger than 1km had diminishing return on regional groundwater replenishment

Future Research

Ability for land repurposing to prevent domestic well failure will be compared with Ag-MAR

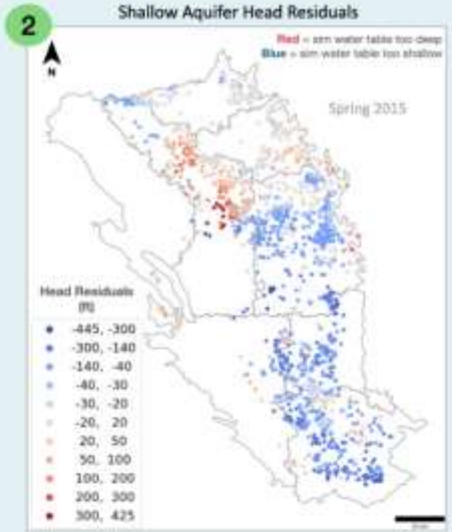
Regional non-point source pollution model[7] can be applied to assess water quality impacts of simulated management scenarios

7 Vertical head gradients can be used to improve parameterization of C2VSim with focus on vertical anisotropy (K_h/K_v)[8] which is key to modeling interactions between recharge, deep agricultural pumping, and the water table

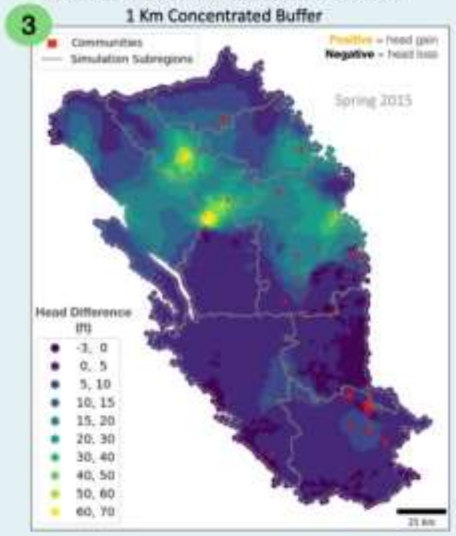
1 Tulare Lake Basin, California

Map by USGS California Water Science Center, 2018

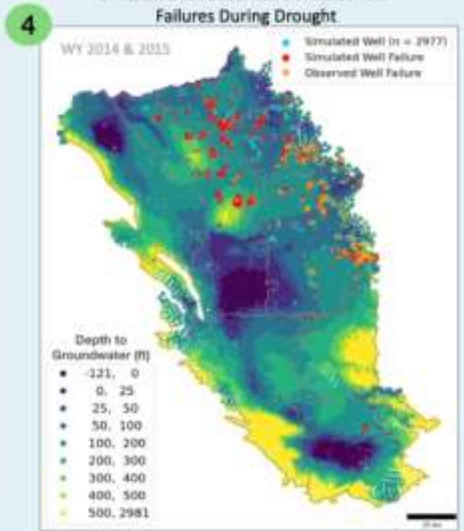
2 Shallow Aquifer Head Residuals



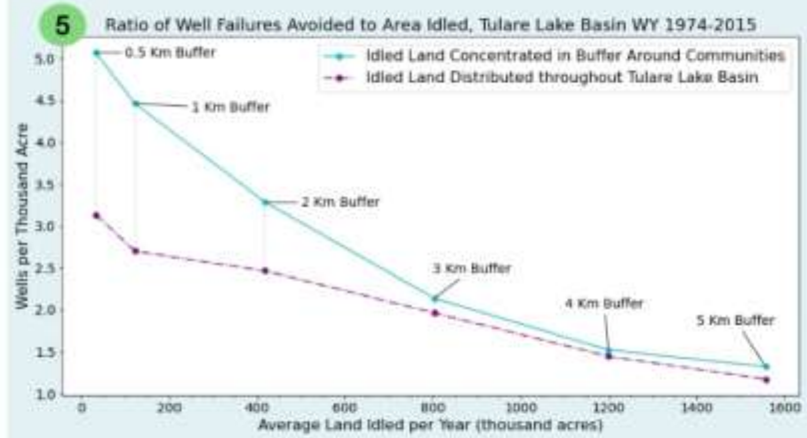
3 Simulated Head Difference Between Baseline & 1 Km Concentrated Buffer



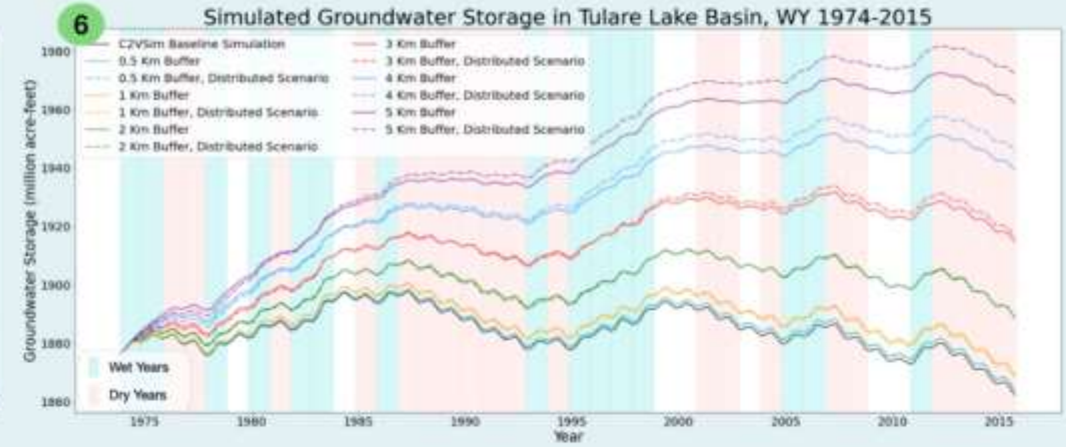
4 Simulated vs. Observed Domestic Well Failures During Drought



5 Ratio of Well Failures Avoided to Area Idled, Tulare Lake Basin WY 1974-2015



6 Simulated Groundwater Storage in Tulare Lake Basin, WY 1974-2015



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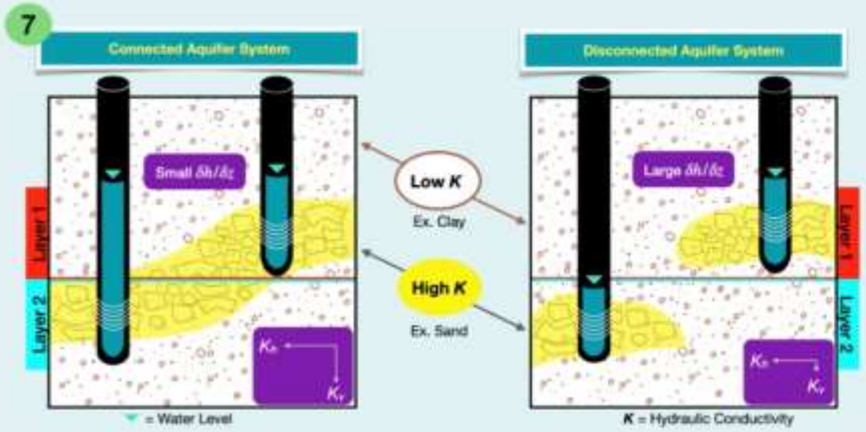

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[5] Community locations and well screen information taken from Marwaha *et al.* 2021

[6] Water level data used to compute groundwater head residuals was pulled from Levy *et al.* 2021, and included imputed values

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Identification of the main natural and anthropic variations affecting coastal SAT systems – example of the Agon-Coutainville SAT (France)

Guillemoto Q, Devau N, Picot-Colbeaux G, Valdes D, Mathurin F, Pettenati M, Neyens D, Mouchel J-M, Kloppmann W.

Soil Aquifer Treatment (SAT) scheme for preservation of the coastal areas

How impacted are groundwater flow velocities and efficiency of SAT ?

- Soil Aquifer treatment (SAT) system in coastal area using Secondary Treated Wastewater (STWW)

Part of the full-scale operational WWTP sustainably integrated within the municipal wastewater treatment line since 14 years along the English Channel coast. The STWW discharge of ~1600m³/day is infiltrated alternatively into three natural reed bed areas of 35000 m² before reaching the sand dune aquifer. The direct discharge of STWW to the sea is avoided to guaranty the sustainability of the shellfish production and preserve the touristic economy along the coast (Picot-Colbeaux et al., 2021).

- SAT system integrated with the hydrosystem where groundwater flows may be subject to variations depending on climate, tides, STWW

Integrated into the hydrosystem in which groundwater flows may be subject to variations caused by meteorological events and tides, but also by human activities such as STWW discharges from WWTP. The natural and anthropic activities could influence groundwater flow velocities and hence the efficiency of the SAT system.

Operators:

Time series analysis

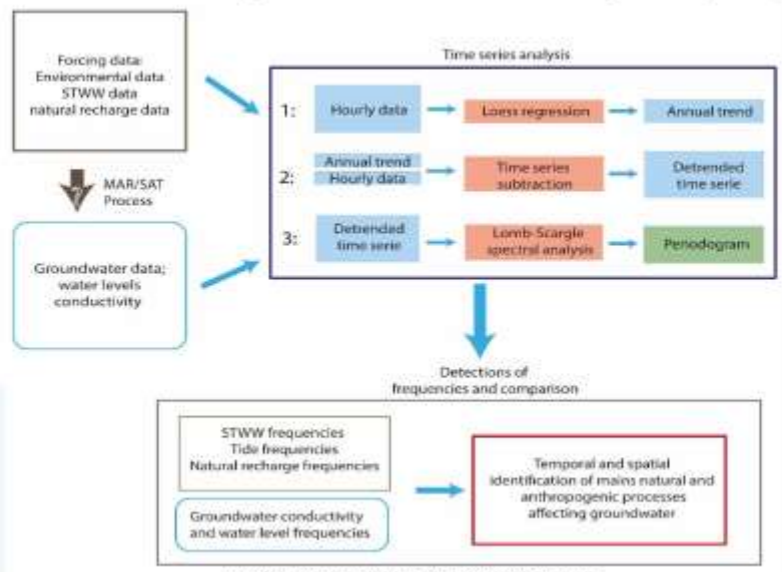
Detection of the common frequencies between observed groundwater level and forcing data (Tides, Climate, STWW)

To identify major natural and anthropogenic forcing factors driving this SAT system, time series analyses were carried out on environmental data such as sea tides, natural recharge estimated by Potential Evapo-Transpiration (PET) and rainfall records, STWW flow discharge in the three infiltrations pounds.

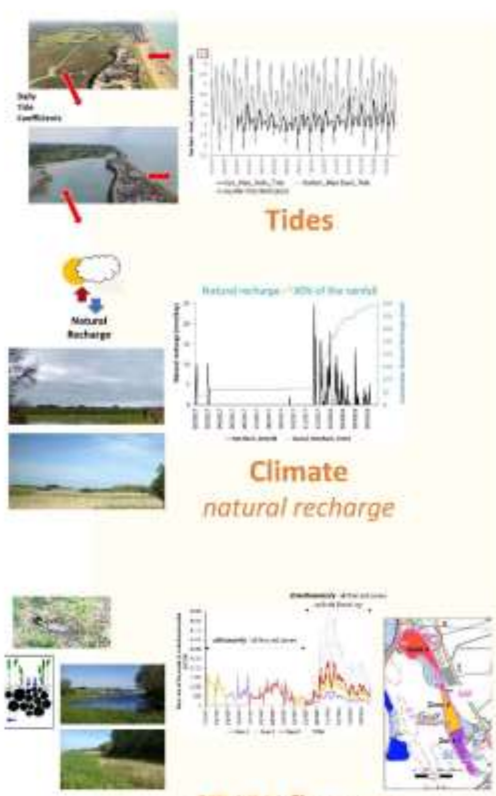
The same analyses were carried out on groundwater level and electrical conductivity monitored in several observation wells.

Then, these results were compared/correlated to give evidence of the impact of each factor in this SAT system.

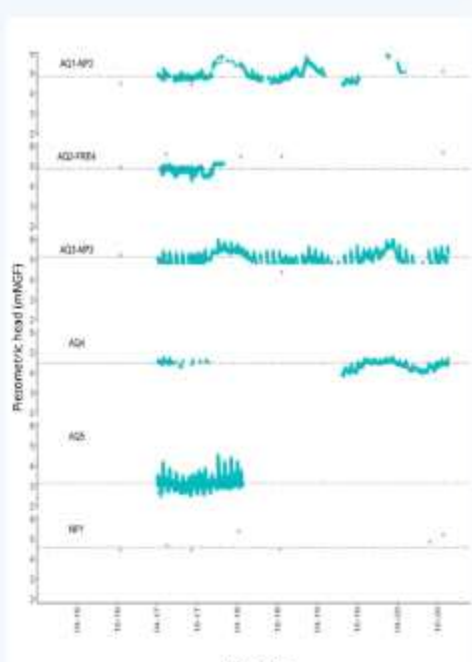
- trend calculation : Loess regression
- frequency analysis : Lombs-Scargle (Lomb, N.R., 1976)



Methodology applied on the time serie analysis



Groundwater level

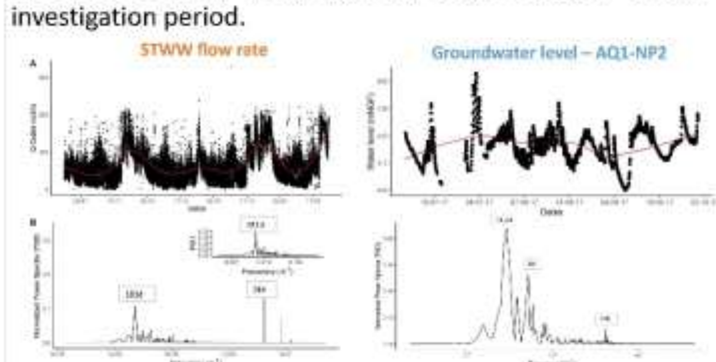


Time scales	Tides	STWW discharges	Climate	AQ1-NP2	AQ2-FRE4	AQ3-NP3	AQ4	AQ5	NP1-PZ1
Annual - biannual	-	365d , 181d	365d	365d, 181d	-	365d	Few data	Few data	Few data
Monthly	14.8d	-	-	14.8d	-	14.8d	14.8d	14.8d	Few data
Daily	12.25h	24h	-	24h (summer)	24h	-	-	12.4h	Few data

Summary table of the variations period identified on groundwater level data

Results of the time series analysis

Results provide quantifications calculated from the Power Spectrum Density (Periodogram, Lombs-Scargle) within the investigation period.



Spatial identification and quantification of the effect of tide, STWW and climate to the groundwater levels.

SAT system influenced by:

- **Locally by Tides** = mainly **14.8d and 12.25h period variations**
- **All by Climate (Natural recharge)** = **annual variation**
- **Locally by STWW flows = daily and annual variations** relationship between STWW flow and climate during winter periods showing that a large part of parasitic water was drained through sewer system

SAT Conceptual model for further application to a groundwater modelling tool

The results obtained by time series analysis are a support to :

- **Understand main processes affecting groundwater flow** at the scale of an operational SAT plant
- **Help to define the conceptual model** for a further groundwater modeling tool
- Variations observed and quantified **potentially jeopardizing** the **efficiency of the SAT** (vadose zone thickness, groundwater flows, solute residence time and geochemical processes)

Water JPI supported by the European project EVIBAN

References:
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Picot-Colbeaux et al., 2021. Picot-Colbeaux, G., Mathurin, F., Pettenati, M., Malacher, F., Guillemoto, Q., Bollwen, M., Devau, N., Gonzalez, M., Allain, D., Neyens, D., Lartigaut, C., Dufour, E., Sypole, A., Degras, O., Neuilly, F., 2021. Sustainable Managed Aquifer Recharge (MAR) – Soil Aquifer Treatment system to protect coastal ecosystem in Agon-Coutainville (Normandy), France, in: Zheng, Y., Ross, A., Villholth, K., Dillon, P. (Eds.), Exemplary Case Studies of Sustainable and Economic Managed Aquifer Recharge., UNESCO-IAH-GRIPP Publication. A UNESCO-IAH-GRIPP Publication.

Technical University of Munich

Feasibility of Managed Aquifer Recharge on Grand Bahama Island

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Introduction

Groundwater is the main drinking water supply for the approximately 50,000 residents of Grand Bahama Island (GB). Due to a storm surge during Hurricane Dorian in 2019, groundwater resources were significantly contaminated with saltwater and have not fully recovered to date. As a result of the contamination, more than 30% of GB households were supplied with brackish water until the end of 2021, when a desalination unit was installed. Another result of the hurricane was the death of most of pine trees that cover the interior of the island.
The potential for MAR was evaluated in terms of sustainable water supply as well as mitigation of saltwater intrusion, despite limited data availability.

Methods

1. Is there water demand (quantity/location)? — NO → Extend study area or stop
   - Determination by using information on pumping volumes and salinity from the water supplier
2. Do suitable aquifers for MAR exist? — NO → Extend study area or stop
   - Literature review on the water resources of GB
3. Are there water sources for MAR available (and which types)? — NO → Extend study area or stop
   - Literature review on the water resources of GB
4. Selection of suitable MAR types
   - Development of decision trees dependent on water source; choice of the most promising option

5. Risk assessment → mitigation possible? — NO → Extend study area or stop
   - Qualitative risk assessment after Imig [1] and Swierc [2], identification of possible risk treatments
6. Selection of most suitable location(s)
   - Suitability mapping in QGIS with the identified criteria for risk treatment

Detailed investigations | Extend study area or stop

Results

1. Water Demand

Water supply from wellfields with equally spaced shallow pumping wells

- Replacement of 11,000 m^3/day of saline water supply from Wellfield 6 (treated with reverse osmosis (RO))
- Mitigation of saltwater intrusion especially in Wellfield 6

Map of main wellfield clusters on Grand Bahamas (map: Google [3])

2. Suitable Aquifers

The entire island consists of a karstified carbonate bank within which freshwater lenses (FWLs) float on top of saline groundwater

- Good infiltration and storage capacity of all FWLs
- Recovery and low distance to water table might be problematic for MAR

3. Water Sources

Rainwater	Wastewater	Desalinated Water
1600 mm/yr (average 2012 – 2020), thereof around 75% evapotranspiration and 25% recharge [4, 5]	Decentralized treatment in septic tanks with soakaways, already recharging the aquifers	Portable reverse osmosis (RO) unit with 11,000 m³/day capacity

4. Suitable MAR Types

Rainwater | Wastewater | Desalinated Water

Rural Areas (Wellfield 6)
- Afforestation
- Increasing permeability by removing the silt layer from hurricane Dorian

Urban Areas (Freeport)
- Permeable paving
- Rainwater harvesting from roofs (soakaways, drain trenches, infiltration galleries, geocellular systems)

5. Risk Assessment

Remaining high risks despite risk treatment:

- Lack of funding (Economical/ social risk)
- No regulatory requirements for MAR (Legislative risk)
- Public acceptance of MAR (Economical/ social risk)

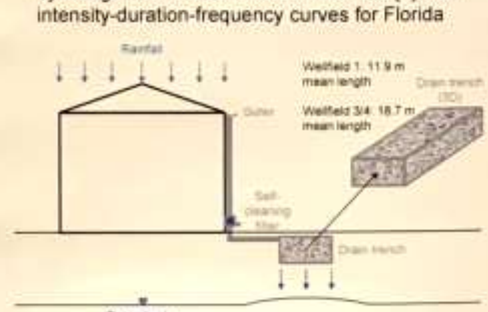
6. Suitability Mapping

- More than 3 m distance to water table
- MAR directly within wellfields
- MAR only in elevated areas where high storm surge is unlikely (includes Wellfields 1 and 3/4)

Suitability map for Wellfields 1, 3 and 4 (map: Google [3])

Conceptual Design

- Rainwater harvesting with drain trench (1m deep, 2 m wide)
- Average supply if installed to all buildings in Wellfields 1, 3 and 4: 1200 m^3/day (losses and current recharge considered
- Drain trench length calculated for average roof sizes in Wellfield 1 (W1) and Wellfield 3/4 (W 3/4) by using German Guideline DWA-A 138 [6] with intensity-duration-frequency curves for Florida



Conclusions

The only available water source for new MAR systems is rainwater, 75% of which is currently lost to evapotranspiration.
Rooftop rainwater for MAR is a sustainable, complementary option to desalinated water supply. It could replace 10.5% of RO water if used on all buildings in Wellfields 1, 3 and 4, in addition to reducing flood risk. Assessment of flow paths and remaining runoff potential from streets (locally existing storm drains) could allow for expansion of MAR supply.
MAR is not appropriate for mitigating the severe saltwater intrusion in Wellfield 6.

Technical University of Munich
TUM School of Engineering and Design
Chair of Hydrogeology

References

A 3D numerical groundwater flow model to assess the feasibility of managed aquifer recharge in the Tamne River Basin of Ghana

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Introduction

In Northern Ghana, groundwater serves as the main source of water supply for domestic and agricultural purposes. However, there are reported cases of declining water levels mainly due to increasing population pressure on the existing water sources and the global climatic changes. The area is a semi-arid region where instances of flooding have occurred every rainy season, but no water for use during the season mainly due to poor groundwater resources planning. This has affected the livelihoods of the farmers, especially during dry-season irrigation farming.

It is against this background this project seeks to assess the feasibility of managed aquifer recharge (MAR) through groundwater modeling by simulating injection and abstraction scenarios using the available flooding water that is registered during every season.

Study area

The study area was carried out in the Tamne River Basin of Northeastern Ghana, which falls within the White Volta River Basin. It is underlain mostly by the Tamnean Plutonic Suite rocks consisting of granites. The mode of groundwater occurrence is through secondary porosity, arising from the fracturing and weathering of the underlying rocks.

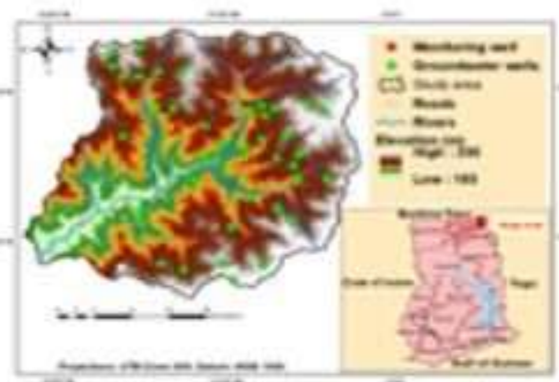

Fig.1 Study area

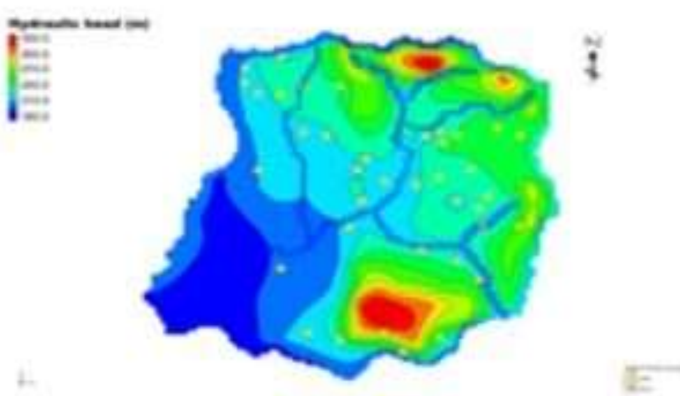

Fig.3 Steady-state simulation

MAR Scenarios

Scenarios	Description	Injection rate during the 4months/8-months period (m^3/day)	Number of injection wells	Volume of water abstracted(m^3/day
1	Baseline Scenario	NA	NA	6591.4
2	MAR injection	325	35	6591.4
3	MAR Abstraction	NA	35	12559.6
4	MAR abstraction increased by 50 %	NA	35	18829.34

Methods

A 3D numerical groundwater flow model was set up using a cell-centered finite difference USGS MODFLOW- 2000 incorporated in the GMS Software. The MODFLOW model was used to simulate groundwater flow under steady-state and later under transient conditions. A general head boundary was imposed in the model with the following input parameters:

Hydraulic conductivity = 0.12 m/day - 15 m/day
Specific storage = 0.00002 - 0.000025 1/L
Specific yield = 0.02 - 0.03
Precipitation = 0.00005 – 0.000065 m/day
Abstraction = 15.01 m/day

Results

A steady-steady state model was calibrated by using 35 hydraulic head measurements of groundwater wells. The correlation between the simulated and measured field groundwater heads (Fig 2) shows a significant correlation with R^2 = 0.86, and a root mean square weighted residual of 6.91 m at a 95% confidence interval The correlation between

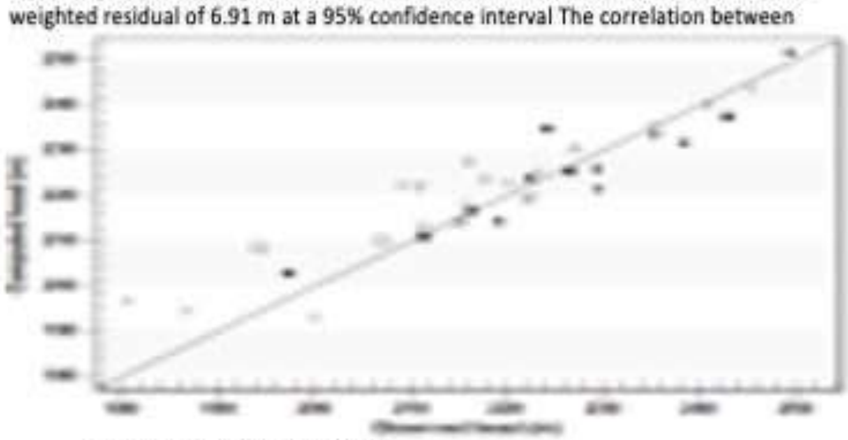

Fig.2 Observed head vs Computed head

The spatial hydraulic head distribution of the steady-state model (Fig 3) ranges between 180 m and 330 m. The highest hydraulic heads are found in the northern and south-eastern parts of the study area.

Figure 4 shows the hydraulic head changes in the different scenarios. The injection scenario shows that the groundwater levels rise by 1.05 m on average. This shows that MAR is feasible in augmenting the water levels in the area

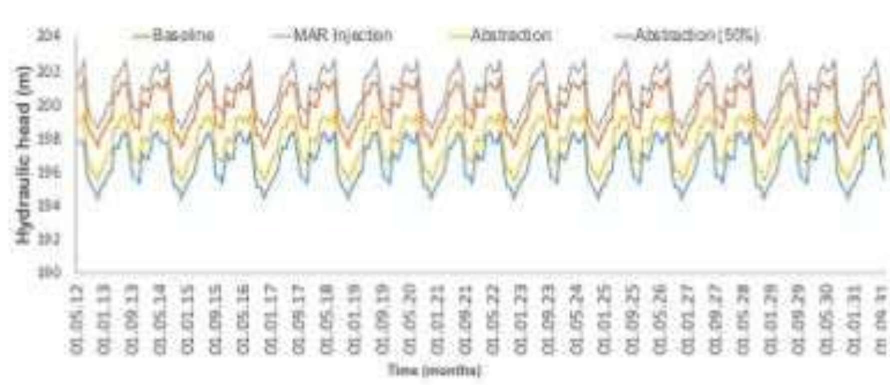

Fig.4 Hydraulic head changes of the different MAR Scenarios

Conclusions

- The total volume of water injected at the end of the 4-months every year is 1.3×10^6 m^3.
- This shows a resultant increase in aquifer storage and groundwater levels and proves that MAR is feasible in the Tamne River basin.
- The volume of water that can be abstracted at the end of the 8- months period is 1.48×10^6 m^3.
- This volume of water would be sufficient for the region during the prolonged dry season months, in which there is water scarcity.

Acknowledgements

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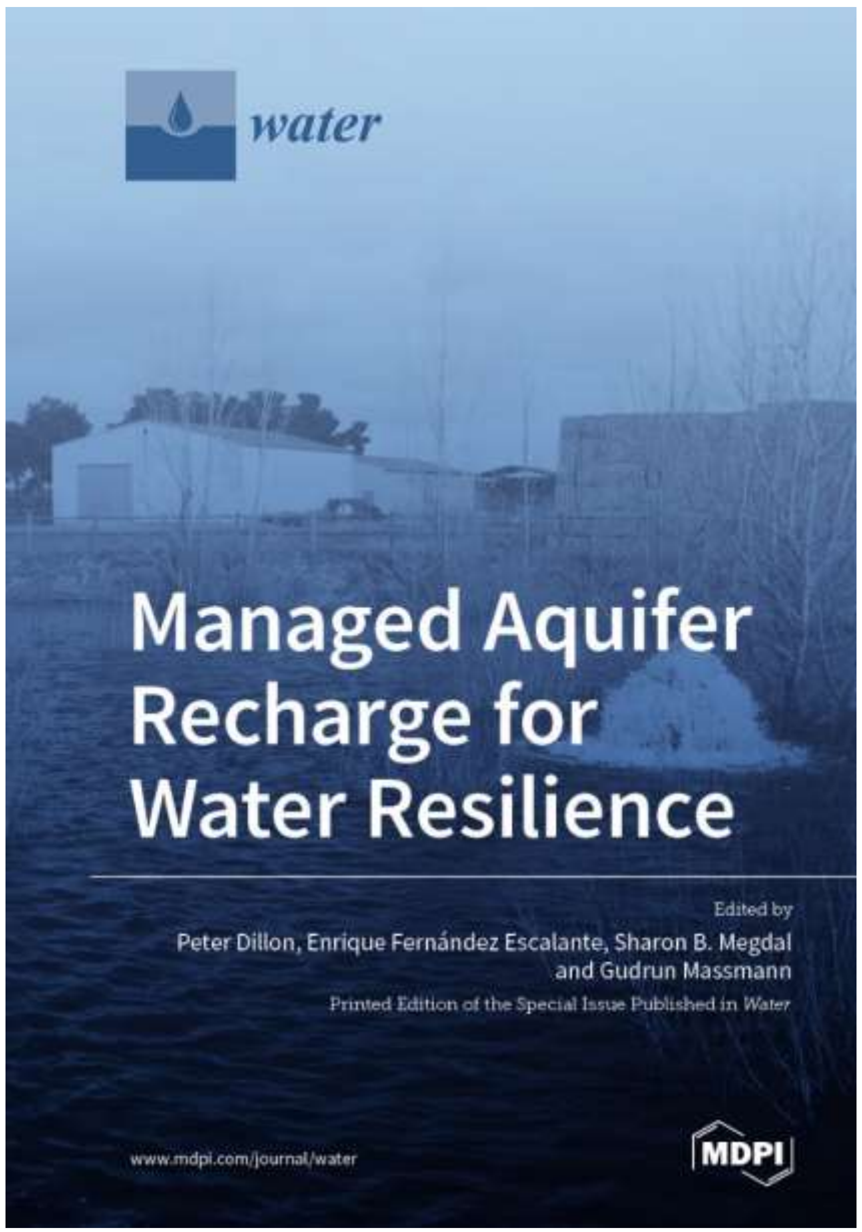

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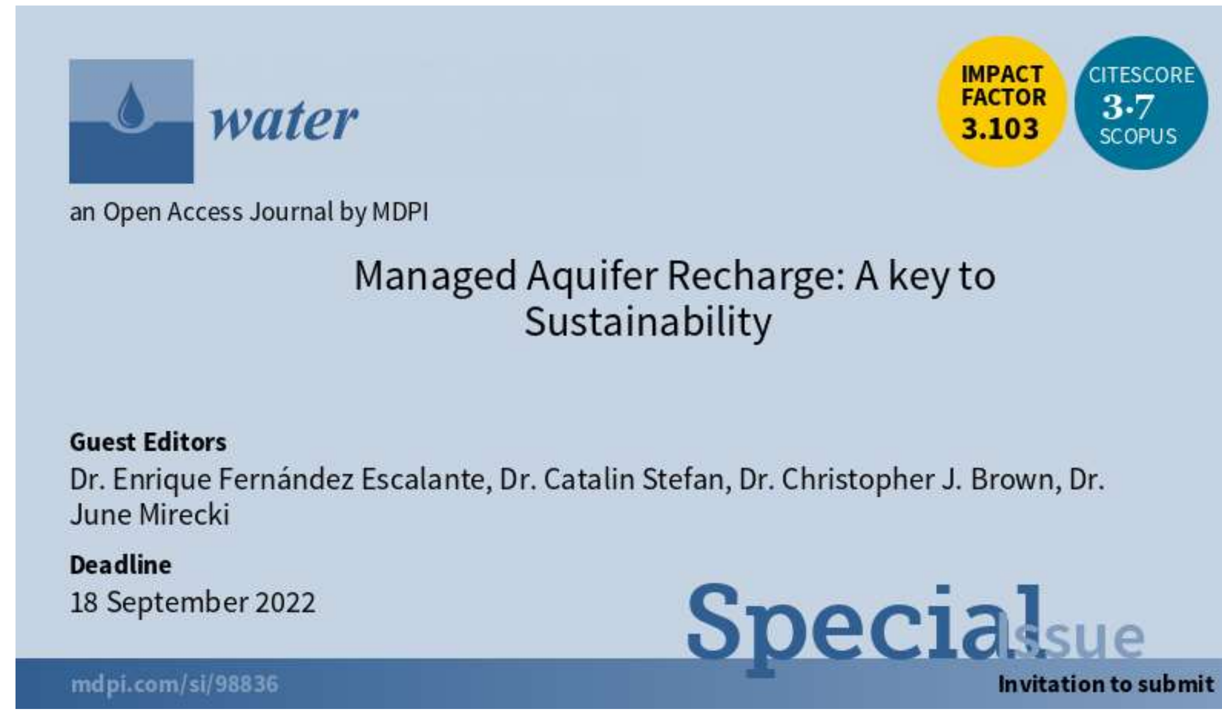

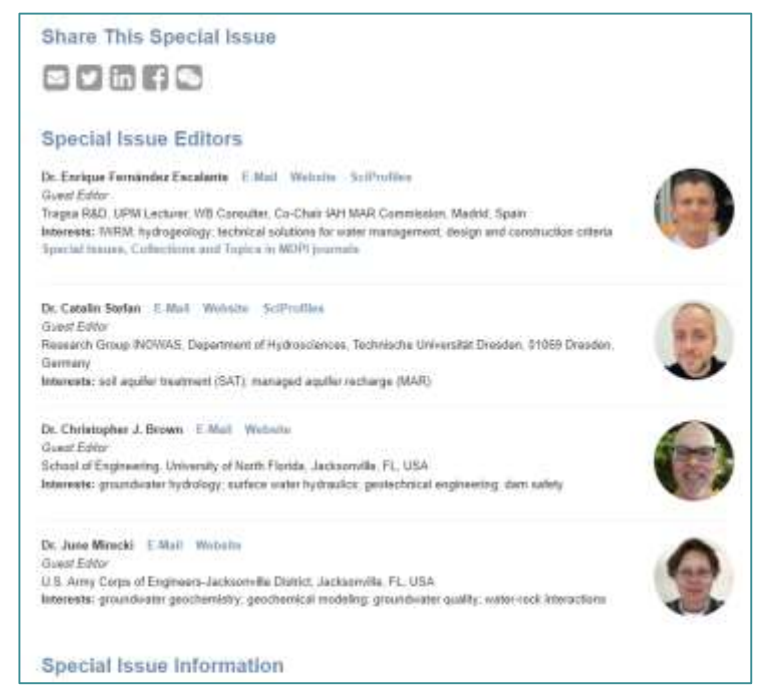

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