GOBIERNO DE ESPAÑA | MINISTERIO DE AGRICULTURA, PESCA Y ALIMENTACIÓN | MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA | MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Instituto Geológico y Minero de España

United Nations Educational, Scientific and Cultural Organization · International Hydrological Programme

ASCE AMERICAN SOCIETY OF CIVIL ENGINEERS

GrupoTragsa

ismar10

INTERNATIONAL SYMPOSIUM ON MANAGED AQUIFER RECHARGE

Madrid, 2019 May

INTERNATIONAL SYMPOSIUM ON MANAGED AQUIFER RECHARGE

MADRID / MAY 20-24, 2019

ABSTRACTS BOOK & PROGRAM 2019

THE CONFERENCE IS A CONTRIBUTION TO THE EIGHTH PHASE OF THE INTERNATIONAL HYDROLOGICAL PROGRAMME (IHP-VIII, 2014-2021)

INTERNATIONAL SYMPOSIUM ON MANAGED AQUIFER RECHARGE (ISMAR 10)

CONTENTS

INTERNATIONAL SYMPOSIUM ON MANAGED AQUIFER RECHARGE (ISMAR 10)

*MAR to solve the global water crisis**

** MAR is part of the palette of solutions to water shortage, water security, water quality decline, falling water tables and endangered groundwater dependent ecosystems. Often it is the most economic, most benign, most resilient and most socially acceptable solution, but has not been considered out of lack of awareness, inadequate knowledge of aquifers, immature perception of risk and inadequate policies for integrated water management, including linking MAR with demand management. MAR can achieve much towards solving the myriad of local water problems that collectively have been termed "the global water crisis", if it is included among the options evaluated locally. ISMAR10 strives to make transparent the effectiveness, benefits, constraints, limitations and applicability of MAR, together with its supporting scientific advances, to a wide variety of situations that have global relevance. No groundwater manager or consultant is complete without a comprehensive knowledge of MAR, and the fastest way to get up to date with international knowledge and connections is to attend ISMAR10. This premium international symposium dedicated to MAR comes along only once in three years. Spain has been a hotbed of innovation and application in this field, with the fastest national rate of growth in MAR, so Madrid is the perfect destination for water problem solvers from around the world. You are warmly invited and will be truly welcome and vocationally recharged at ISMAR10.*

Peter Dillon, Weiping Wang and Enrique Fernández-Escalante (Co-chairs of IAH Commission on Managing Aquifer Recharge)

01 WELCOME

Everyone is invited to this International Symposium on Managed Aquifer Recharge, ISMAR10, Madrid 2019 20-24 May.

ISMAR10 is held under the joint auspices of the International Association of Hydrogeologists (IAH), American Society of Civil Engineers (ASCE) and United Nations Educational, Scientific and Cultural Organisation (UNESCO) plus local organizers (Tragsa, IGME, IWRA GE).

Basic Information

Website: http://ismar10.net
Time: May 20-24, 2019
Location: Madrid, La Nave
Organizer: Tragsa Group
Co-organizers: Spanish Geological Survey, IAH, UNESCO, ASCE
Institutional Support: Ministry of Agriculture, Fisheries and Food, Miistry for the Ecological Transition, Ministry of Science, Innovation and Universities, Madrid City Council.

Contact: info@ismar10.net / Ismar10@tragsa.es

02 ORGANIZATION

Tragsa Group, with the assistance of the invited co-organizers Spanish Geological Survey (IGME), the Spanish chapter of the International Water Resources Association (IWRA) and the IAH Spanish Chapter host the International Symposium on Managed Aquifer Recharge (ISMAR10) in Madrid, 2019 May 20-24th.

03 SPONSORS, COLLABORATORS AND CLUB OF FRIENDS

Sponsors

Platinum sponsor

Silver Sponsors

Bronze Sponsors

Others

Collaborators

Collaborators

Space reserved for **Collaborators** related to the Conference topic who contribute in the event.

Club of Friends

Club of Friends involves institutions not related neither to the organization nor to the different Committees, but willing to provide some type of help, support and friendship.

Media

04 COMMITTEES

Committee of Honor:

The personalities who compose the Committee of Honor are:

- **Minister of Agriculture, Fisheries and Food, Mr. Luis Planas**
- **Minister of Science, Innovation and Universities Mr. Pedro Duque**
- **Madrid City´s Mayor, Ms. Manuela Carmena**
- **Spanish Water General Director. Mr. Manuel Meléndez**
- **IAH President. Mr. António Chambel**
- **Tragsa Group President. Mr. Jesús Casas**

Organizing Committee:

- **IAH-MAR Commission co-chairs.**

Dr. Peter Dillon
Former CSIRO Land and Water Australia
Dr. Wang Weiping
School of Resources and Environment
University of Jinan Shandong, China
Dr. Enrique Fernández-Escalante
Tragsa Group, Spain

- **UNESCO**

Dr Alice Aureli
International Hydrological Programme
UNESCO – Division of Water Sciences, Francia

- **ASCE (American Society of Civil Engineers)**

Mr. Doug Bartlett
ASCE, USA

- **The European Commission, by means of the EIP Water, also has supported ISMAR 10**

Dr. Guido Schmidt (EIP, Water)

Local Organizing Committee:

Scientific Committee :

The Sc/Tc Committee is integrated by (in alphabetical order):

Dr. Alice Aureli UNESCO-IHP France a.aureli@unesco.org	**Dr. Juan Grima Olmedo** International Water Resources Association-IGME Spain j.grima@igme.es
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Dr. José Antonio de la Orden Gómez Instituto Geológico y Minero de España (IGME). Spain ja.delaorden@igme.es	GOLD SPONSOR
Prof. José Antonio Iglesias Martín Canal de Isabel II. Spain jaiglesias@canaldeisabelii.es	ISMAR 11 ORGANIZER
Dr. José María García Asensio Tragsa International – DINA-MAR. Ecuador-Colombia jgarci36@tragsa.es	

05 CONFERENCE VENUE

LA NAVE. MADRID CITY COUNCIL´S SPACE FOR INNOVATION. La Nave is the center of inspiration, education and open innovation of Madrid City. It was built in 2015 to transform the economic and social future of the citizenship. The project is based upon two combined inspiring concepts, a virtuous circle of open innovation and the collaboration between all the Innovation Agents and the Society.

Address: 5th Cifuentes Street, 28021 Madrid, Spain
District: Los Angeles / Villaverde, Madrid South
Metro: Line 3, (Yellow color), South sector, Station: Villaverde Bajo, Cruce (Santiago Amón exit)
Train (Renfe): Puente Alcocer Station (C5 line).

06 BACKGROUND

The Tenth ISMAR edition will take place in Madrid, 20-24 May 2019, giving continuity to a series of conferences with Managed Aquifer Recharge as a first row water management technique. The Conference in being organized by Tragsa Group, with the Spanish Geological Survey (IGME) and the International Water Resources Association as invited co-organizers. These institutions have carried out most of the MAR facilities in operation in Spain, and have supported R&D projects on MAR, helping in the dissemination of this technique for decades.

The main objectives of ISMAR10 are:

1) Disseminate new knowledge on MAR
2) Provide a forum for discussion on key issues for MAR
3) Make international connections for all people involved in MAR
4) Motivate students and young researchers
5) Enhance the impact of previous ISMARs
6) Facilitate appropriate investment in MAR in Spain, Europe and globally.

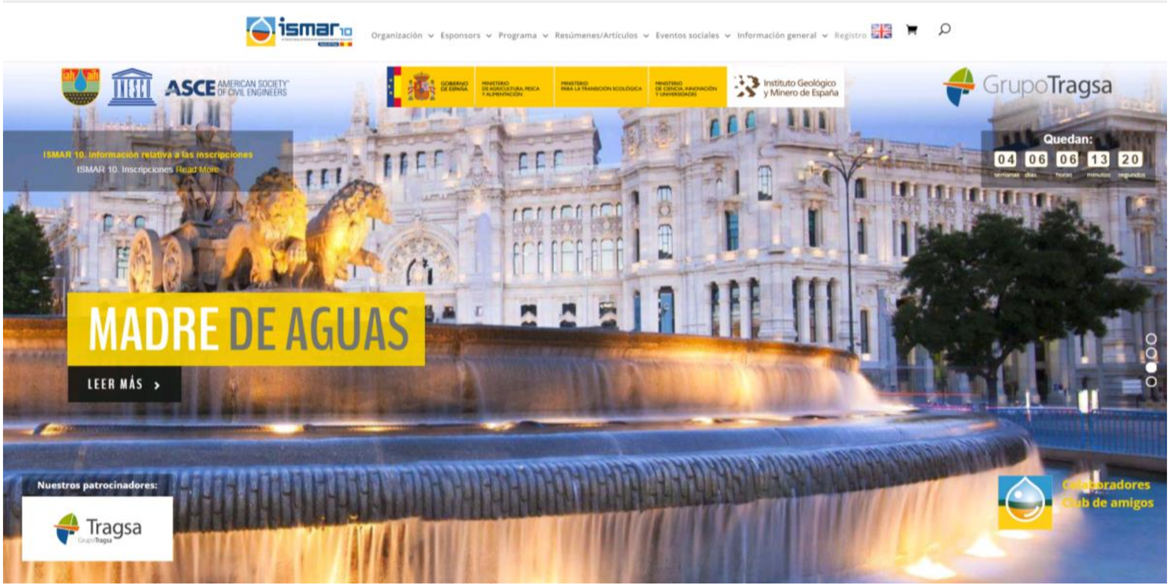
Reasons to host ISMAR10 in Europe

1) Time for ISMAR to get back to Europe
2) Increasing awareness in European decision makers
3) Initiative to get the crisis over in the EU
4) Enhance the participation from MENA region and Southamerican countries in MAR actions
5) Grouping and support Pan-European projects related to MAR
6) Involve European supporting Action Groups & Water Technological Platforms related to MAR
7) Increase the H-2020 interest on water management.

Reasons to attend ISMAR10 in Madrid

1) Spain is a pioneer country on MAR in Europe
2) Sharing the Spanish expertise on MAR
3) DINA-MAR's dissemination activities since 2008
4) Examples of MAR activities in Spain as a hot-spot technique against Climate Change
5) Experience Spanish culture and amazing hospitality
6) Excellent food and good weather

Madrid comes from the Arabic word Magerit ("mother of waters"), which was the name given to the fortress built on the banks of the Manzanares River by the Umayyad of Cordoba, Muhammed I (852-886).



Spain is a pioneer country on MAR in Europe

It is remarkable the high presence of MAR tipologies/devices in Spain.

The full inventory for the more than 30 facilities and experiences can be found at: http://www.dina-mar.es/post/2013/01/02/DINA-MAR-Publicacion-final-del-proyecto-c2a1Inminente!.aspx

There are at least 20 well documented examples distributed in the different regions, out of the 25 different MAR facilities inventoried by DINA-MAR (In DINA-MAR, 2010).

According to DINA-MAR calculations for results relating to "MAR zones" by hydrographic major basins, approximately a 16% (67,000 km^2) of the Spanish territory is suitable for MAR activities

With this potential, one of the main objectives to host an ISMAR in Spain is to get Spanish water managers to realize of the importance of deploying new facilities and experiences.

07 GENERAL INFORMATION

Website: http://ismar10.net
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Location: Madrid, La Nave
Organizer: Tragsa Group,
Co-organizers: Spanish Geological Survey, IWRA, UNESCO, IAH, ASCE
Contact: info@ismar10.com / ismar10@tragsa.es

The official language of the Conference will be English, which will be used for all printed material, presentations and discussions. There will be simultaneous Spanish-English translation during the most important events of the Symposium.

By registering for ISMAR 10 and its activities, participants understand that the Secretariat will do its best to assist everyone who wishes to attend the conference(s). A final confirmation of registration will be sent by email. In addition, participants agree to have their names, the names and the countries of their organisations included on the participants list.

ISMAR 10 will be recorded for future reference through various means, including film and photography. By agreeing to participate in ISMAR 10 2019 participants are deemed to have given their consent to be filmed and photographed, and to any subsequent reproduction, public communication and/or broadcast of the material by the ISMAR 10 organizers or any person duly licensed by it.

08 WORKSHOPS

As the tradition of ISMAR conferences, several pre- and post-seminars will be held in Madrid. They will involve members from the IAH international community and partners from 12 R&D European Projects.

1st Day Workshops and Short Courses

As the tradition of ISMAR conferences, several pre-conference seminars have been offered. Short courses require a registration fee; workshops are free for booked ISMAR 10 delegates.
Official language: English.
No simultaneous translation will be provided.
https://www.ismar10.net/en/pre-and-post-conference-seminars/

SEMINARS PROGRAM:
Monday, 2019 May 20th
Place: IGME headquarters.

MORNING PROGRAM
09:30 – 14:00 Seminars 1 to 3 and 7:

Short course nº 1

State of the Art Techniques in Characterizing, Constructing and Operating Optimum Surface Spreading Groundwater Recharge Projects

Instructors: Dr. Michael Milczarek, President GeoSystems Analysis, Inc. and Dr. Greg Woodside, Executive Director of Planning and Natural Resources (USA)

Short course nº 2

Addressing the challenges to achieve successful groundwater recharge and recovery through wells. Comprehensive coverage of investigations required for ASR projects and their operation

Instructors: Dr. D. Pyne, (ASR Systems, USA) and Dr. Russell Martin (Wallbridge Gilbert Aztec, Australia)

Workshop nº 3

MAR site suitability mapping. Utilization of spatial analysis techniques for the identification of potential MAR areas: challenges and opportunities

Instructors: Dr. José Pablo Bonilla (AyA, Costa Rica), Dr. Dan Goode (USGS, USA), Jana Sallwey (TU Dresden, Germany), Dr. Catalin Stefan (TU Dresden, Germany) and Dr. Arnaud Sterck (IGRAC, the Netherlands)

Short course nº 7

Water quality aspects of Managed Aquifer Recharge systems

Instructor: Prof. Dr. P. Stuyfzand, KWR, Watercycle Research Institute. The Netherlands

AFTERNOON-EVENING PROGRAM

14:30 – 19:00 Seminars 4 to 6 and 8:

Short course nº 4

Technical solutions to increase Managed Aquifer Recharge effectiveness. MARSOL project findings and Tragsa Group Experience regarding design and construction criteria, operation and management

Instructors: Prof. Dr. Enrique Fernández Escalante and Dr. Jon San Sebastián Sauto (Tragsa Group, Spain)

Short course nº 5

Web-based numerical modeling and optimisation of MAR applications using the free INOWAS platform

Instructors: Prof. Dr. Catalin Stefan, Jana Glass, Ralf Junghanns (TU Dresden, Germany) and Russel Martin (WGA, Australia)

Workshop nº 6

Sustainable MAR in developing countries. Developing managed aquifer recharge in Latin America

Instructors: Dr. Edmundo Claro (CSIRO, Chile); Mr Tatsuo Shubo (Fundaçã Oswaldo Cruz – Fiocruz, Brazil); Dr. Declan Page (CSIRO, Australia) and Mr. Dennis Gonzalez (CSIRO, Australia)

Short course nº 8

Modelling MAR facilities design and operations using the free and open source FREEWAT plugin

Instructors: Dr. Rudy Rossetto and Dr. Giovanna De Filippis (Institute of Life Sciences, Scuola Superiore Sant'Anna, Italy).

After the short courses will take place the **Ice braking party.**

IGME headquarters Hall, 19:30 h. Ríos Rosas 23 St, 28003 Madrid

09 KEYNOTE SPEAKERS

Lectures imparted by international experts in all facets of hydrogeology, geochemistry, microbiology, modeling, economics, water resources management and water supply and relation between MAR and the industry will open most of the sessions.

In this occasion key speakers will have a relevant recognition:

1- Dª Mª Isabel Bombal. General Director of Rural Development, Innovation and Forestry Policy Ministry of Agriculture, Fisheries and Food (MAPA).Spain
2- Dª Mª Dolores Pascual. Ebro River Basin Authority President (CHE). Ministry for the Ecological Transition (MITECO). Spain
3- Dr. Peter Dillon. IAH MAR Commission Chairman and Former CSIRO Australia. 60 years of MAR all over the world
4- Prof. Dr. Jörg E. Drewes. Expert on microbiological aspects of reclaimed water reuse. Member of the WG for the future Directive on MAR, water reuse and circular economy.Water quality aspects of MAR with reclaimed water.

10 FIELD TRIPS

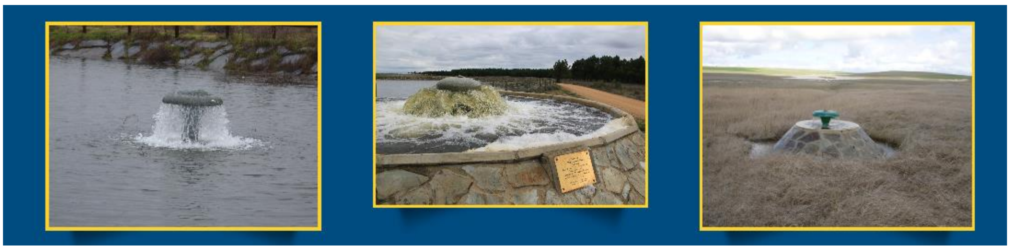
Three different excursions are envisaged in a distant closer than 180 km from the venue site. More info: https://www.ismar10.net/en/technical-tours/

Trip 1: Los Arenales aquifer facilities in Segovia province

A full day trip to visit different facilities of MAR for irrigation and environmental uses. The activity is closely linked to the agro-industry in the area, and there is a consolidated cooperation scheme between scientists and practitioners with the farmers in the irrigation communities. Facilities are managed under the river basin authorities' permission with the help of stakeholders.

There are a vast amount of dams specifically designed for MAR, infiltration ponds, canals, artificial wetlands, salt lakes restored by means of MAR, covered wells…

This is the main living lab for DINA-MAR project and the biggest MARSOL demo-site. In the way back it is feasible to visit the Roman aqueduct in Segovia province.



Trip 2: Guadiana Channel and Daimiel National Park

In the same distance but the opposite direction than the previous visit, there is a battery of 25 MAR wells and boreholes along a canal for temporal and intermittent recharge. The design is unique and is an example of quick recharge to store winter water surpluses.

At the end of this battery there are four boreholes more for environmental purposes, recharging Tablas de Daimiel National Park. The visit might be complemented with a visit to the Park before returning to Madrid.

Trip 3: ASR/ASTR/Depth Injection Boreholes in Madrid (TBC)

Managed by the Madrid Water supply company (CYII) there are three different batteries of boreholes with a specific and unique design in less than 12 km from the venue site.

Boreholes are until 500 m depth and recharge the semiconfined aquifer. These facilities could be visited in a half day trip for those attendants with time limitations.

11 SCHEDULE AT A GLANCE

Below is the planned timeline for your reference:

Milestones and Deliverables

SCHEDULE	DATES
First announcement	January 31, 2018
Second announcement. Workshop instructors call	June 15, 2018
Call for abstracts	September 10, 2018
Deadline for abstracts submission	November 25, 2018
Registration opens	December 5, 2018
Notification of abstracts acceptance	December 20, 2018
Submission of final manuscript. Deadline	March 31, 2019
Submission of final posters. Deadline	**April 15, 2019**
Third circular	April 23, 2019
Notification of final papers acceptance	April 26, 2019
ISMAR 10 Symposium	20-24 May 2019

12 PROCEEDINGS BOOK ANS ISMAR 10 SPECIAL JOURNAL

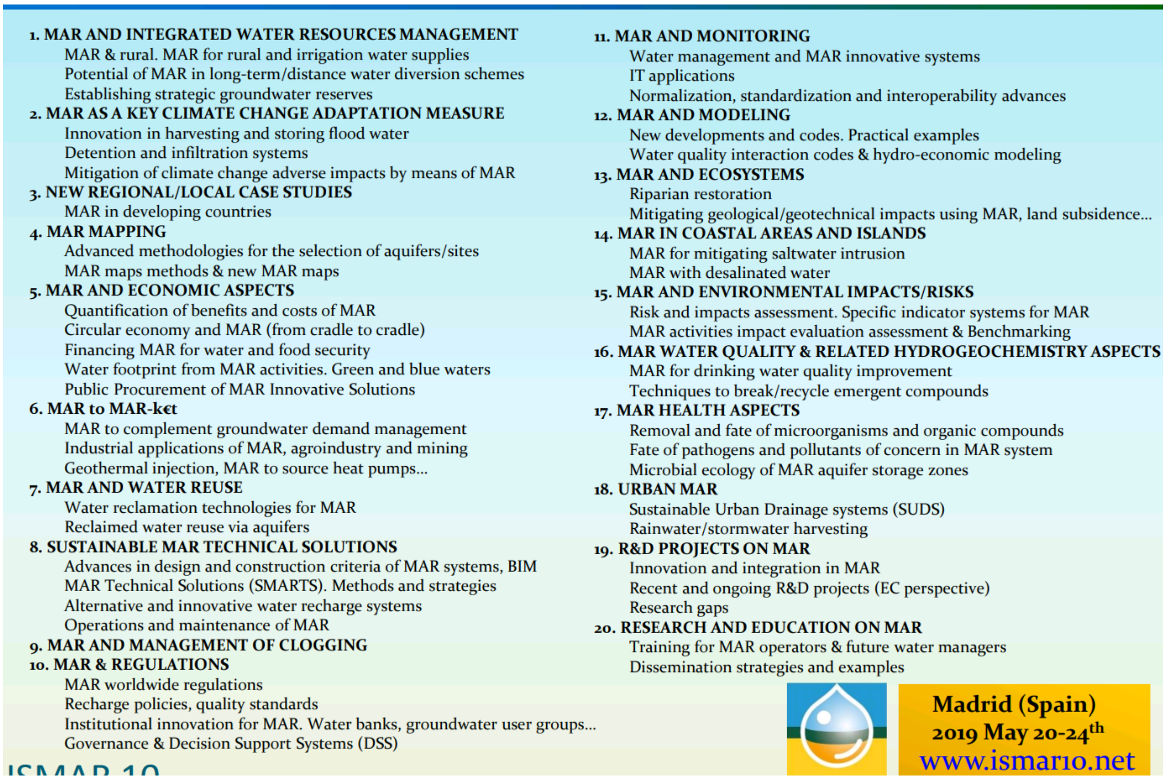
https://www.ismar10.net/en/proceedings-book/

With selected papers not reserved for journal Water: https://www.mdpi.com/journal/water/special_issues/ISAM10_2019 , organizers will mount a paper proceedings book. This is the main reason papers should be submitted prior the Symposium.

Papers selected for a Journal would set an extended abstract in the proceedings book, with a reference to the open access site. A digital version of the book will be released before 2019 December freely. Punctual information will be provided for downloading. The Editors will be Instituto Geológico y Minero de España (IGME) and Tragsa.

13 PROGRAM

Sessions and conveners



The sessions and their organizers/conveners are:

1. **MAR and Integrated Water Resources Management.**
   MAR & rural. MAR for rural and irrigation water supplies
   Potential of MAR in long-term/distance water diversion schemes
   MAR in conjunctive use of surface water and groundwater
   Establishing strategic groundwater reserves
   CONVENERS:
      Dr. Alice Aureli. UNESCO IHP. France.
      Prof. Jeff Camkin. Univ. of Western Australia-LNEC. Australia-Portugal.
2. **MAR as a key Climate Change adaptation measure.**
   Innovation in harvesting and storing flood water
   Detention and infiltration systems
   Mitigation of climate change adverse impacts by means of MAR
   CONVENERS:
      Dr. Paul Pavelic. IWMI. Laos-Australia.
      Dr. Noureddine Gaaloul. INRGREF. Tunisia-France.

3. **New Regional/local case studies.**
   MAR in developing countries
   CONVENERS:
   Dr. Yan Zheng. University of Science and Technology, Beiging, China-USA
   Dr. Carlos Gutiérrez Ojeda. Instituto Mexicano de Tecnología del Agua, Mexico
4. **MAR mapping.**
   Advanced methodologies for the selection of aquifers/sites
   MAR maps methods
   New MAR maps
   CONVENERS:
   Dr. Arnaud Sterckx. IGRAC. The Netherlands-Belgium.
   Dr. Catalin Stefan. University of Dresden. Germany.
5. ***MAR and economic aspects.***
   Quantification of benefits and costs of MAR
   Circular economy and MAR (from cradle to cradle)
   Financing MAR for water and food security
   Water footprint from MAR activities. Green and blue waters
   Public Procurement of MAR Innovative Solutions
   CONVENERS:
   Dr. Andrew Ross. Australian National University. Australia.
6. ***MAR to MAR-k€t.***
   MAR to complement groundwater demand management
   MAR and agroindustry
   MAR and Mining
   Industrial applications of MAR
   Geothermal injection, MAR to source heat pumps…
   CONVENERS:
   Dr. Jon San Sebastián Sauto. Tragsatec. Spain.
   Ph. D. Carola Rojas Vega. Autoridad Nacional del Agua. Perú.
7. **MAR and water reuse.**
   Water reclamation technologies for MAR
   Reclaimed water reuse via aquifers
   CONVENERS:
   Dr. Christoph Sprenger. Berlin Kompetenz Wasser. Germany.
   Dr. Ido Negev. Mekorot Inc. Israel.
8. **Sustainable Managed aquifer Recharge Technical Solutions.**
   Advances in design and construction criteria of MAR systems, BIM
   MAR Technical Solutions (SMARTS). Methods and strategies
   Alternative and innovative water recharge systems
   Operations and maintenance of MAR
   CONVENERS:
   Dr. David G. Pyne. ASR Systems. USA.
   Dr. Enrique Fernández Escalante. TRAGSA-IAH-MAR Comm. Spain.

9. **MAR and management of clogging.**

   CONVENERS:

   Dr. Jordan Clark. University of California, Santa Barbara. USA.

   Dr. Russell Martin. Wallbridge Gilbert Aztec, Australia.

10. ***MAR & Regulations.***

    MAR worldwide regulations

    Recharge policies, quality standards

    Institutional innovation for MAR. Water banks, groundwater user groups…

    Governance

    Decision Support Systems (DSS)

    CONVENERS:

    Dr. Manuel Sapiano. SEWCU, Malta

    Dr. Elena López Gunn, I-Catalist, Spain.

11. **MAR and monitoring.**

    Water management and MAR innovative systems

    IT applications

    Normalization, standardization and interoperability advances

    CONVENERS:

    Dr. Othman Almashaqbeh. Royal Scientific Society. Jordan.

    MSc. Eng. Bob Bower. WGA. New Zealand.

12. **MAR and modeling.**

    New developments and codes

    Practical examples

    Water quality interaction codes

    Hydro-economic modeling

    CONVENERS:

    Dr. Shakeel Ahmed. CSIR-Nat. Geophysical Res. Inst. Saphpani. India.

    Dr. Rudy Rossetto. Schola Superior Ingenieria Santa Anna, Pisa. Italy.

13. **MAR and ecosystems.**

    Riparian restoration

    Mitigating geological/geotechnical impacts using MAR, land subsidence, collapses…

    CONVENERS:

    Dr. Juan Grima Olmedo. IWRA-IGME. Spain.

    Dr. Suzana de Lima Montenegro. Pernambuco University. Brasil.

14. **MAR in coastal areas and islands.**

MAR for mitigating saltwater intrusion

MAR with desalinated water

CONVENER:

Dr. Kim Yongcheol. KIGAM. Korea.

15. **MAR and environmental impacts/risks.**

    Risk and impacts assessment

    Specific indicator systems for MAR

    MAR activities impact evaluation assessment

Benchmarking
CONVENERS:
Dr. José Antonio de la Orden Gómez. IGME. Spain.
Dr. Larry Eaton. GSI Oregon. USA.

16. **MAR water quality and related hydrogeochemistry aspects.**
MAR for drinking water quality improvement
Techniques to break/recycle emergent compounds
CONVENERS:
Dr. Pieter J. Stuyfzand. University of Delft-KWR. The Netherlands.
Dr. Teresa Leitão. LNEC. Portugal.

17. **MAR Health Aspects.**
Removal and fate of microorganisms and organic compounds
Fate of pathogens in the aquifer and fate of pollutants of concern in MAR system
Microbial ecology of MAR aquifer storage zones
CONVENERS:
Dr. Declan Page. CSIRO Land and Water. Australia.
Dr. Boris van Breukelen. Technical University of Delft. the Netherlands.

18. **Urban MAR.**
Sustainable Urban Drainage systems (SUDS)
Rainwater/stormwater harvesting
CONVENERS:
Dr. Koen Zuurbier. KWR. The Netherlands.
Dr. Sara Perales Momparler. GreenBlueManagement. Spain.

19. **R&D projects on MAR.**
Innovation and integration in MAR
Recent and ongoing R&D projects (EC perspective)
Research gaps
CONVENER:
Dr. Peter Dillon. Former CSIRO -IAH-MAR Comm. Australia.

20. **Research and education on MAR.**
Training for MAR operators
Training for future water managers
Dissemination strategies and examples
CONVENERS:
Dr. Wang Weiping. Univ. of Jinan Shandong. IAH-MAR Comm. China.
Mr. Doug Bartlett. Clear Creek Associated – American Society of Civil Engineers (ASCE). USA.

Program at a glance

Monday, 2019 May 20th	**Thursday, 2019 May 23th**
Place: IGME headquarters	Key Speaker 3
09:30 – 14:00 Workshops 1 to 3 and 7	Sessions 12 to 14 and 16 to 20
14:30 – 19:00 Workshops 4 to 6 and 8	Round Table 3
19:30 h. Ice braking party	Info on Technical tours + Post-conference field trips info

Tuesday, 2019 May 21th Opening ceremony Key Speaker 1 Sessions 1 – 6 and 15 Poster Session 1 Special sesión Adaptation Round Table 1 **Wednesday, 2019 May 22th** Key Speaker 2 Sessions 7 – 11 and arid regions Round Table 2 Flash Session 1 Poster Session 2 IAH MAR Plenary Gala Dinner	Flash Session 2 + Slot for ISMAR 11 organizers Round Table 4 Special session SAT-MAR Sessions 19 – 20 Closing Ceremony **Friday, 2019 May 24th** Technical tours 1, 2 and 3 **Post-conference tours**

Sessions

The list of presentations grouped by topics is:

Theme 1- MAR and Integrated Water Resources Management.
Theme 2- MAR as a key Climate Change adaptation measure.
Theme 3- New Regional/local case studies.
Theme 4- MAR mapping.
Theme *5- MAR and economic aspects.*
Theme *6- MAR to MAR-k€t.*
Theme 7- MAR and water reuse.
Theme 8- Sustainable Managed aquifer Recharge Technical Solutions.
Theme 9- MAR and management of clogging.
Theme *10- MAR & regulations.*
Theme 11- MAR and monitoring.
Theme 12- MAR and modeling.
Theme 13- MAR and ecosystems.
Theme 14- MAR in coastal areas and islands.
Theme 15- MAR and environmental impacts/risks.
Theme 16- MAR water quality and related hydrogeochemistry aspects.
Theme 17- MAR Health Aspects.
Theme 18- Urban MAR.
Theme 19- R&D projects on MAR.
Theme 20- Research and education on MAR.

14 PRESENTATIONS. ABSTRACTS

The whole list of abstracts submitted to ISMAR 10 is:
https://www.ismar10.net/en/list-abstracts/

nº	authors	title	organization	country	S
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155	Ting Cheh-Shyh, Tu Yung-Chang	Geophysical investigation in the high infiltration basin for groundwater recharge project in Pingtung Plain, Taiwan	National Pingtung University of Science and Technology, Taiwan	Taiwan	3
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253	Asfaw, Berhane Abrha; Kaori Sakaguchi-Söder and Christoph Schüth	Chlorine isotope fractionation during catalytic reductive dechlorination of trichloromethane ($CHCl_3$) over palladium-on-alumina in hydrogen-saturated water: implication to managed aquifer recharge as sustainable storage solution for desalinated water (MAR-DSW) in Menashe recharge basin, Israel	16
254	Maréchal, JC. ; Bouzit, M. ; Moiroux, F. ; Caballero, Y., Desprats, JF and Rinaudo JD.	Introducing economy into suitability mapping of MAR scheme	5
255	Yagual Muñoz, Omar and Hernández Domínguez, Carmen	Comparative Analysis of the Implementation of the Underground Flow Model to Two Geographically Distant Sub-Basins	11
256	Jon San Sebastián Sauto and Enrique Fernández Escalante	Effect of green biofilters and artificial wetlands to improve water quality in canals for MAR. Observations in Los Arenales Aquifer (Spain)	16
257	E. Fernández Escalante and J. San Sebastián Sauto	Clogging map for Santiuste basin MAR site, Los Arenales Aquifer, Spain. Multivariable analysis to correlate types of clogging and groundwater quality	9
258	Kamau, Rob; Jordan, James; Rea, Iain; Hanna, Jon and Youngs, Jed	Using Managed Aquifer Recharge of Surplus Mine Dewater to Protect a Sensitive Environmental Receptor in the Pilbara, Western Australia	8

Detailed Program

https://www.ismar10.net/en/detailed-program/

ANNEX 1. ISMAR 10 ABSTRACTS…


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los recursos
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>>TUESDAY 21

>>TUESDAY 21

CONFERENCES

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09.00/09.30 >	RECEPTION OF PARTICIPANTS			
	SALA 02* - RECHARGED SATur ROOM >	AUDITORY* - THIRSTY MARia ROOM >	SALA 06 - RECLAIMED MARta >	OTHER ROOMS AND DEMONSTRATION AREAS >
09.30/10.30 >		**OPENING.** Ministry of Agriculture, Fisheries and Food. Mr. Fernando Miranda Madrid City Council. D. Pedro Catalinas International Association of Hydrogeologist. Mr. Bruce Misstear UNESCO. Ms. Alice Aureli Tragsa Group. Mr. Jesús Casas.		
10.30/11.00 >		**OPENING SPEECH.** General Director of Rural Development, Innovation and Forestry Policy (MAPA) MRs. Isabel Bombal		
11.00/11.30 >	POSTERS/COFFEE BREAK / EXPOSITION AREA / DRONES DEMONSTRATION AREA			
11.30/13.30 >		**SESSION 1: MAR and Integrated WRM 160, 27, 115, 87, 168, 73 (R: 57, 163).** Chairs: Dr. Alice Aureli (France) and Prof. J. Camkin (Australia). Implementing Incentivized Managed Aquifer Recharge on a Basin Scale. Tuthill, David R., Jr, Carlson, Ronald D. (USA). Postdoctoral Research Associate at University of Arkansas, Associate Professor at University of Arkansas and Economist at USDA Economic Research Service. Dat Tran, Kent Kovacs and Steven Wallander. (USA). Dynamic water balance modelling for risk assessment and decission support on MAR potential in Botswana. Lindhe, Andreas; Rosén, Lars; Johansson, Per-Olof and Norberg, Tommy. (Botswana).	**SESSION 2: MAR as a key climate change 31, 130, 221, 116, 152, 250.** Chair: Dr. P. Pavelic. (Laos-Australia). A Conceptual Framework for Managed Aquifer Recharge as a Strategy to Mitigate Drought Effects in Irrigated Agriculture: The Role of Institutions and Conservation. Reznik, Ami and Dinar, Ariel. (USA). Potential for managed aquifer recharge to mitigate climate-change effects on fish and wildlife in the Snake River Basin, USA. Van Kirk, Rob;Contor, Bryce; Morrisett, Christina. (USA). Sites and indicators of MAR as a successful tool to mitigate Climate Change effects in Spain. San Sebastián Sauto, Jon; Fernández Escalante, Enrique; Villanueva Lago, María and Calero Gil, Rodrigo. (Spain).	**SESSION 15: MAR and Enviroment 15, 161, 22, 197, 251, 46. (SALA 05).** Chairs: Dr. J. de la Orden (Spain) & Dr. Larry Eaton (USA) Methodology for assessing Managed Aquifer Recharge project implementation in Chile. Guimerà, Jordi, Vilanova, Ester; Pilar Enguita; Adrián Lillo. (Spain). Evaluating the multi-scalar impact of widespread MAR implementation on groundwater storage: A critical review and case study of Gujarat. Alam, Mohammad Faiz; Villholth, Karen G.; Pavelic, Paul; Sikka, Alok. (India). Managed Aquifer Recharge to Support Environmental Outcomes on the Katarapko Floodplain. Martin, Young, Lush, Whittington. (Australia).


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11.30/13.30 >

SESSION 1: MAR and Integrated WRM 160, 27, 115, 87, 168, 73 (R: 57, 163).
Chairs: Dr. Alice Aureli (France) and Prof. J. Camkin (Australia).

Integrated Water Management Utilising the tools of Managed Aquifer Recharge (MAR): Developing a Catchment-Scale Groundwater Replenishment System for the Hekeao / Hinds Plains, Canterbury, New Zealand. Bob Bower; Brett Sinclair and Clare Houlbrooke. (New Zealand).

Seeking Simplicity, Reliability and Sustainability in Drinking Water Purification for Future: the River Bank Filtration Based One Step Reverse Osmosis Process: from Concept to Practice. Gang Liu*, Xu Wang, Harrie Timmer, Peter Wessels, Huijuan Liu, Pieter Stuyfzand, Jiuhui Qu, Walter van der Meer. (The Netherlands).

Riverbank filtration with siphon wells – breathing new life into an old idea. Grischek, Thomas; Bartak, Rico. (Germany).

SESSION 2: MAR as a key climate change 31, 130, 221, 116, 152, 250.
Chair: Dr. P. Pavelic. (Laos-Australia).

The role of Aquifer Storage and Recovery in securing resilient long-term water supplies in the East of England. Stanley-Jones, Hannah; Moncaster, Steve; Price, Victoria; Watson, Sally; MacDonald, Robert; Buckley, James. (England).

Regional impact of MAR in Southern Central Valley. Wendt, Doris E., Van Loon, Anne F., Scanlon, Bridget R. (England).

Application of MAR systems for sustainable water-curtain insulated greenhouse system. Eunhee Lee; Esther Shin; Yongcheol Kim and Kyoochul Ha. (South Korea).

Crucial Role of Managed Aquifer Recharge as an Adaptation Strategy for Groundwater Sustainability in the Face of Climate Change in India. Jain Ratan. (India).

SESSION 15: MAR and Enviroment 15, 161, 22, 197, 251, 46. (SALA 05).
Chairs: Dr. J. de la Orden (Spain) & Dr. Larry Eaton (USA)

Application and evaluation of an advanced aquifer storage and recovery pilot system in Recife, Brazil. Fernandes, Lucila; Conrad, Anika; Montenegro, Suzana; Paiva, Anderson; Andrade, Maria. (Brazil).

PVC-O pipes and fittings, the most environmentally friendly solution for water transportation. Almudena Blazquez and Dolores Herran. (Spain).

Water Quantity and Quality Risk Assessment of the Karst Aquifer Recharge with Multi-source Water in Yufu River of Jinan, China. Qu Shisong, Sun Xiuxiu and Wang Weiping. (China).

13.40/15.00 > POSTERS/COFFEE BREAK / EXPOSITION AREA / DRONES DEMONSTRATION AREA

15.00/15.40 >

SESSION FLASH 1: MAR AND INTEGRATED WRM 57, 163, 2, 66, 129, 48, 237, 219.
Chair: Prof. J. Camkin (Australia).

Strategic Water Storage and Recovery with Desalinated Seawater in Liwa, UAE. Kalbus, Edda; Koziorowski, Georg; Alhosani, Mohamed Husain Ahmed; Dawoud, Mohamed Abdel Hamyd. (UAE).

Managed Aquifer Recharge as a bridge between water demand and supply – cases in Chile, Vietnam and Malasya. Galvis Rodríguez, Sandra, van Baaren, Esther, Oude Essink, Gualbert, van Duijne, Hans, Ball, Sheila, Vergroesen, Toine. (The Netherlands).

Integration of Stormwater Capture at Flood Management Reservoir with Managed Aquifer Recharge, Orange County, California Greg Woodside, Adam Hutchinson. (USA).

SESSION 2B: MAR AS A KEY CLIMATE CHANGE ADAPTATION MEASURE 42, 235
Chair: Ing. C. Rojas (Perú).

MAR of Geneva: when climate change implies to reassess management perspectives. De los Cobos, Gabriel. (Schwitzerland).

Managed aquifer recharge as an integrated water resource management tool: a case study in semi-arid Sudan. Hassan Mohamed; Elamen, Mohamed and Tuinier, Elisabeth. (Sudan).

SESSION 5/6: MAR AND ECONOMIC ASPECTS / MAR to MAR-k€t 217, 175, 146, 127, 260, 261 (SALA 05)
Chair: Dr. A. Ross (Australia).

El Carracillo. An example of positive rural development and impact on the agroindustry thanks to MAR technique. Los Arenales Aquifer, Castilla y León, Spain. López Hernández, Manuel; Fernández Escalante, Enrique; San Sebastián Sauto, Jon; Villanueva Lago, María and Calero Gil, Rodrigo. (Spain).

The Costs and Benefits of Managed Aquifer Recharge Ross, Andrew. (Australia).

A Socio-Economic Impact Assessment of Managed Aquifer Recharge in the Pwales Groundwater Body, Malta. Schembri Michael, Sapiano Manuel, Zammit Stephen. (Malta).


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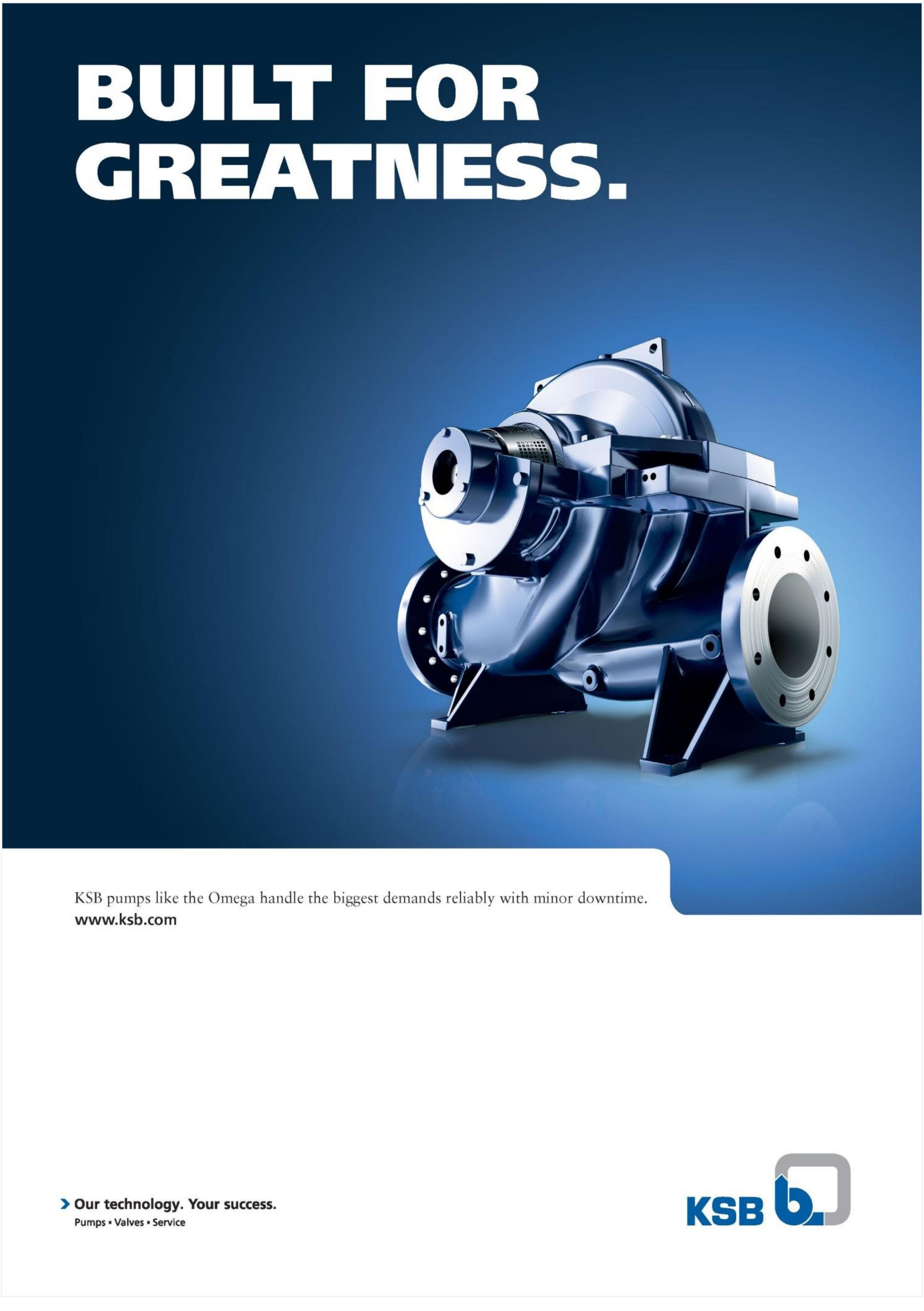
15.00/15.40 ›		**SESSION FLASH 1: MAR AND INTEGRATED WRM 57, 163, 2, 66, 129, 48, 237, 219.** Chair: Prof. J. Camkin (Australia). The Atlantis Water Resource Management Scheme – resource management is people management. Towers, Luke; Riemann, Kornelius; Weitz, Jannie; Hugman, Rui. (South Africa). Artificial recharge mechanisms via a leaky river bed – a case study in the outskirts of London, UK Karapanos, Ilias & Sage, Robert. (England). Scaling-up river water-fed Managed Aquifer Recharge in the deeply anoxic Makauri Aquifer, Gisborne (New Zealand), HARTOG; van Nieuwkerk; Hancock; Raat. (The Netherlands). Alternate Conjunctive Use and Artificial Recharge in Water Resources. Andrés Sahuquillo. (Spain). Book: MAR - a focus towards Latin America. Gutiérrez Ojeda Carlos, Escolero Fuentes Oscar A., Mendoza Cázares Edgar Y. (Mexico).		
15.40/17.40 ›	**ROUND TABLE 1: OPPORTUNITIES AND TECHNOLOGICAL CHALLENGES FOR WATER MANAGEMENT** Chair: Mr. Simón Pulido. Responsible for Hydrological Management Products and Services SUEZ. (Spain). MOLECOR TECNOLOGÍAS S.L. Mr. Agustín Moreno CATALANA DE PERFORACIONS S.A. Mr. Domènec Pintó Bascompte ALLIED WATER. Mr. Koen Zuurbier AMIBLU PIPES SPAIN S.A. Mr. Xavier Arasanz SONDEOS MARTÍNEZ S.L. Mr. Manuel Martínez PREFABRICADOS DELTA S.A. Mr. Juan Pablo Guerrero ELECTROSTEEL EUROPE S.A. Mr. Raúl Bartolomé	**SESSION 3: NEW REGIONAL CASE STUDIES 94, 192, 216, 61, 68, 124** Chair: Dr. Y. Zheng. (China). Managing Aquifer Recharge at Local Level in India: Developing a Framework for Village Groundwater Co-operatives. B. Maheshwari, P. Patil, P. Soni, Y. Dashora, P.K. Singh, J. Ward, P. Dillon, Y. Jadeja, S. Oza, M. Chhajed, R. Kookana and R. Packham. (Australia). Tunisian experience in managed aquifer recharge by hill dam water release: case of some groundwater flow systems in North of Tunisia Anis Chekirbane, Dorsaf Aloui, Insaf El Euchi, Sabrine Mejri, Samia Khadhar, Fethi Lachaal and Ammar Mlayah. (Tunisia). The MAR system in Ica, Perú. Technical and social lessons learned from a Mega-scale MAR system and improvement possibilities Navarro Benegas, Roberto; Fernández Escalante, Enrique; Guerrero Salazar, Pedro and Rojas Vega, Carola (Perú).	**SESSION 4: MAR MAPPING 132, 166, 33, 133, 223, 125** Chair: Dr. A. Sterck. (The Netherlands - Belgium). Using machine learning to incorporate potential water quality improvements for mapping MAR suitability. Galen Gorski, Andrew T. Fisher, Sarah Beganskas, Calla Schmidt, Hannah Dailey. (USA). A GIS approach to evaluating bank-filtration occurence and potential in the province of Quebec, Canada. Patenaude, Marc, Baudron, Paul, Masse-Dufresne, Janie, Pontoreau, Coralie, Dion, Gabriel. (Canada). Suitability maps for managed aquifer recharge: review and tool development. Sallwey, Jana; Schlick, Robert; Bonilla Valverde, José Pablo; Junghanns, Ralf; Vásquez López, Felipe; Stefan, Catalin. (Germany).	**SESSION 5/6: MAR AND ECONOMIC ASPECTS / MAR to MAR-k€t 217, 175, 146, 127, 260, 261 (SALA 05)** Chair: Dr. A. Ross (Australia). 150 years old IBF systems in Budapest, Hungary focusing on their sustainability and costs. Szabó, Zsóka; Mádl-Szőnyi, Judit. (Hungary). 255 TBC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SESSION 3: NEW REGIONAL CASE STUDIES 94, 192, 216, 61, 68, 124

Chair: Dr. Y. Zheng. (China).

Emergency response to drought - the City of Cape Town's groundwater abstraction and MAR scheme (South Africa). McGibbon, David; Hugman, Rui; Towers, Luke Cecil; Hartnady, Chris Hubert John; Hay, Elizabeth Rowena; Riemann, Kornelius. (South Africa).

Managed Aquifer Recharge and Aquifer Storage and Recovery in Kabul, Afghanistan. Kissane, Stephen; Tookhi, Mohammad Naim; Klein, Hugh; Matti, Boris. (Afghanistan).

Implementing an energy - neutral Aquifer Storage and Recovery (ASR) system in a complex geological context in Lebanon. Lukas Rolf, Sieger Burger and Tine de Winkel. (The Netherlands).

SESSION 4: MAR MAPPING 132, 166, 33, 133, 223, 125

Chair: Dr. A. Sterck. (The Netherlands - Belgium).

Using machine learning to Producing more interpretable maps of managed aquifer recharge suitability by visualizing sensitivity to subjective choices during mapmaking. Gorski, Galen and van der Valk, Michael. (USA).

Determining the Potential for Managed Aquifer Recharge (MAR) for the Bengal Basin, Bangladesh. Faneca Sanchez, Marta; Zahid, Anwar; Oliemans, William. (The Netherlands).

Site selection of underground dams using spatial multi-criteria evaluation in the Semi-Arid region of the State of Alagoas, Brazil. Webber, Daniel C.; Barros, Alexandre H. C.; Da Silva, Maria S.L.; Neto, Manoel B.O.; Marques, Flávio A. (Brazil).

17.40/18.10 >

POSTERS/COFFEE BREAK / EXPOSITION AREA / DRONES DEMONSTRATION AREA

18.10/19.10 >

SPECIAL SESSION 1: ADAPTATION 136, 17, 21

Chair: Dr. J. San Sebastián. (Spain).

MAR as an adaptation meassure for saline water intrusion and water scarcity in the Guanacaste Region of Costa Rica. Suárez Serrano, Andrea; Bautista-Solis, Pável; Stefan, Catalin; Alfaro, Carolina; Bonilla Valverde, José Pablo. (Costa Rica).

Groundwater Hydraulics - Computing Groundwater Into/Out Flow for Lakes. (Study Case Lake Qarun, Egypt). Dr. Mohamed Abd-El-Mooty,M.S. Rania Abd-El-Baky. (Egypt).

Correlation of the infiltration velocity with the hydraulic load of operation of the treated wastewater infiltration basin. Sánchez-Navarro, David Humberto, Navarro-Gómez, Carmen Julia, Sánchez-Navarro, Jesús Rubén, Calderón Fernández, Martha Lorena, Estrada Gutiérrez, Guadalupe Irma Graciela, Herrera-Peraza, Eduardo Florencio*. (México).

SESSION 3B: NEW REGIONAL CASE STUDIES 101, 205, 143, 238, 151

Chair: Dr. C. Gutiérrez. (Mexico).

Managed Aquifer Recharge at a Farm Level: Evaluating the Performance of Direct Well Recharge Structures P. Soni, Y. Dashora, B. Maheshwari, P.K. Singh and P. Dillon. (India).

Use of Managed Aquifer Recharge to improve Water Management in Arid and Semi-Arid Regions of Mexico Cruz A. Mary-Belle; Megdal, S.B. (USA).

Assessment of bank filtration in arid climate, case study: El-Minya, Egypt. A. Abogabal, K. Khodeif, E. Souya, M. Bakr. (Egypt).

Groundwater-based natural infrastructure: a critical piece in supporting water security and resilience Karen Villholth et al. (South Africa).

Artifical recharge proposed for the Purapurani Aquifer System, Bolivia. Rafael Cortez. (Bolivia).

SESSION 4B: MAR MAPPING 45, 108, 211, 133 (R: 86)

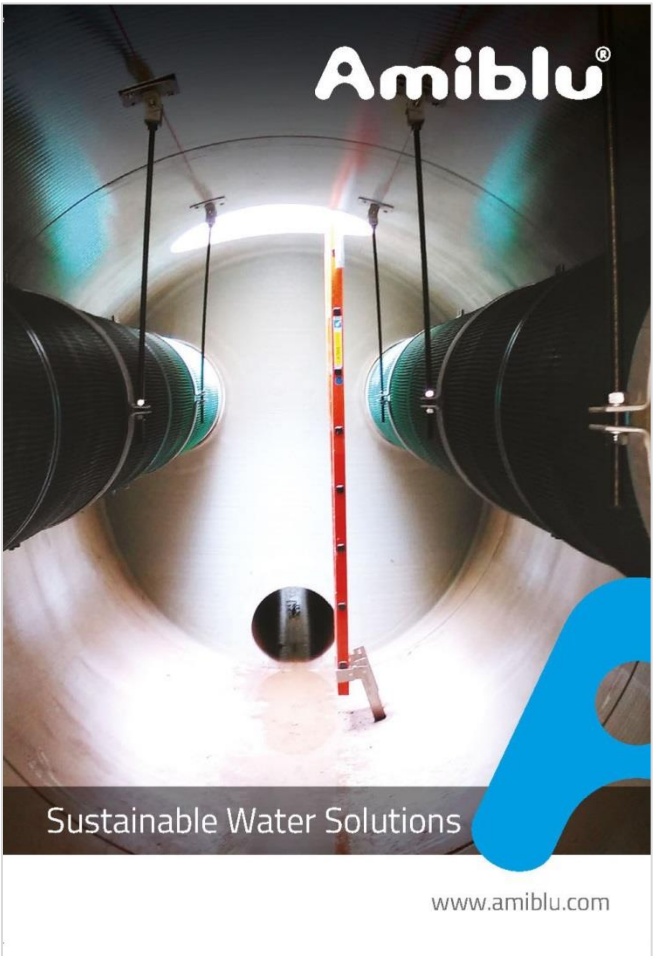
Chair: Dr. C. Stefan. (Germany).

Specific types and adaptability zoning evaluation of managed aquifer recharge for irrigation in the North China Plain. Wang Weiping, Liu Shuai, Qu Shisong. (China).

MAR suitability mapping: why and how? Lessons from a case-study in Southern France. Dupont, Fanny; Sterckx, Arnaud; Sallwey, Jana; Bonilla, Jose; Stefan, Catalin. (The Netherlands).

Evolutionary multi-objective optimization of managed aquifer recharge locations in the Central Valley (US). Brunetti, Giuseppe, Wallander, Steven, Bigelow, Daniel, Sandoval-Solis, Samuel, Dahlke, Helen. (Austria).

Producing more interpretable maps of managed aquifer recharge suitability by visualizing sensitivity to subjective choices during mapmaking. Gorski, Galen and van der Valk, Michael. (USA).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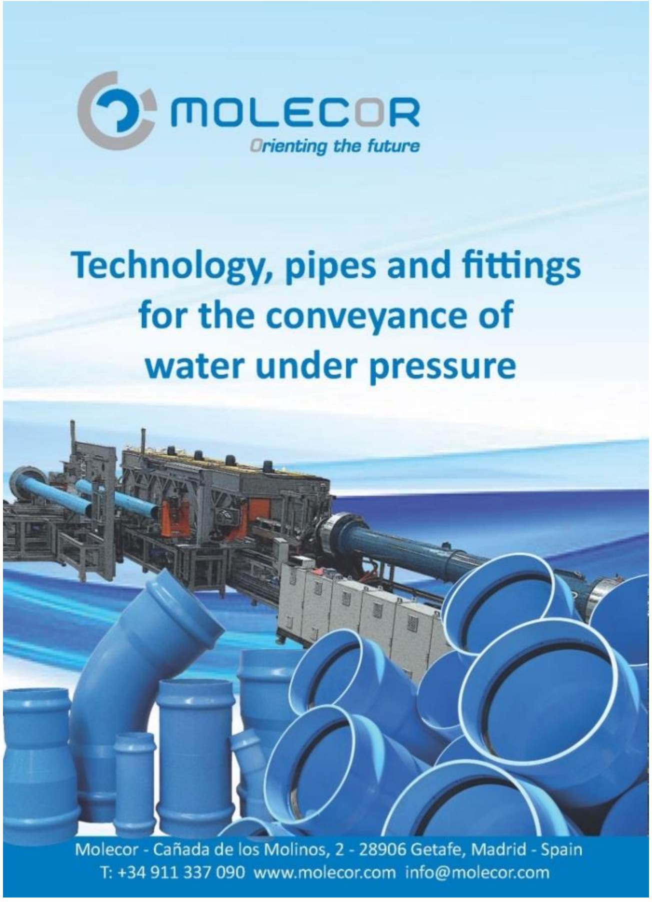
	SALA 02* - RECHARGED SATur ROOM >	AUDITORY* - THIRSTY MARia ROOM >	SALA 06 - RECLAIMED MARta >	OTHER ROOMS AND DEMONSTRATION AREAS >
09.00/09.40 >		**KEYNOTE PRESENTATION 2:** The Water in Spain. Mrs. Ma. Dolores Pascual, Ebro River Basin Authority President. (Spain).		
09.40/09.50 >		**PRESENTATION OF THE PROGRAM** Partnership for Research and Innovation in the Mediterra-nean Area (PRIMA) European Commission Tenismarers slot		**NAIAD** European Project Meeting (SALA 04)
09.50/11.10 >	**SPECIAL SESSION 2: ARID REGIONS 246, 1, 177, 89** Chair: Dr. N. Gaaloul. (Tunisia). Insights from groundwater level measurements over a managed aquifer recharge site in Central Morocco. Fakir Younes and Bouimouass Houssne. (Morroco). Crucial Role of Managed Aquifer Recharge as an Adaptation Strategy for Groundwater Sustainability in the Face of Climate Change in India. Jain Ratan Dr. (India). Flash floods – possibilities of artifical recharge, example Egypt. Troeger, Uwe, Wannous, Manal. (Gemany). Evaluation of MAR for semi-arid, cold region Nasanbayar Narantsogt. (Mongolia).	**SESSION 8: SUSTAINABLE MAR TECHNICAL SOLUTIONS 5, 222, 28, 123 (R:147)** Chairs: Dr. D. Pyne. (USA). Comprehensive Guidelines for Managed Aquifer Recharge to Be Published by ASCE/EWRI Bartlett, R. Douglas; Moore, Stephanie; Sheng, Zhuping; and McCurry, Gordon. (USA). Using environmental isotope and major ions to characteri-ze recharge and mixing properties in the aquifer system along Fen River in Taiyuan basin, northern China. Guo Chunyan, Zhang Zhaoji, Shi Jiansheng, Zhang Fenge. (China). Conjunctive Use of Aquifer Storage Recovery Wells and Desalination to Mitigate Salt Water Intrusion and Achieve Water Supply Reliability. Pyne, R. David G. (USA). Environmental impact and mitigation of intake interruptions for Basin Aquifer Transfer Recovery systems Stuyfzand. Pieter J. (The Netherlands).	**SESSION 7: MAR AND WATER REUSE 100, 164, 122, 210** Chair: Dr. C. Sprenger. (Germany). Re-engineering soil aquifer treatment (SAT) to enhance wastewater recharge flux without compromising water quality. Brooks, Josh. Weisbrod, Noam. Bar-Zeev, Edo. (Israel). Hydrogeological characteri-zation of a meso-scale managed aquifer recharge experiment focusing on the fate of nanocontaminants carried by reclaimed water (Palamós site, ACWAPUR project). Martinez-Landa, Lurdes; Valhondo, Cristina; García, Julià, and Carrera, Jesús. (Spain). Soil Aquifer Treatment in Glacial Fluvial Deposits - Analogous to Recharge in Alluvial Systems. Peter Fox. (USA). Natural-Engineered System (NES) for the Improvement of Conventional Soil Aquifer Treatment (cSAT) in Shafdan. Aharoni, Avi; Cikurel, Haim; Raanan Kiperwas, Hadas. (Israel).	**PRIMA** European Projects Presentations (SALA 05)
11.10/11.40 >	POSTERS/COFFEE BREAK / EXPOSITION AREA / DRONES DEMONSTRATION AREA			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ROUND TABLE 2. PUBLIC INSTITUTIONS AND WATER MANAGEMENT

Chair: Chairman: MRs. María Fernández. Irrigation and Rural Infrastructures Subdirector, MAPA. (Spain).

Mr Samuel Moraleda (MITECO-CHG)
Mr Ignacio Rodríguez (MITECO-CHD)
Mr Rafael Sáez ITACYL
Mr Alejandro Alonso SEIASA
MRs Belén Benito (CYII)

SESSION 8B: SUSTAINABLE MAR TECHNICAL SOLUTIONS 88, 141, 215, 173, 25

Chair: Dr. Enrique Fernández. (Spain).

Initial Results from Managed Aquifer Recharge Trials in the Hekeao/Hinds Plains, Canterbury, New Zealand. Houlbrooke, Clare, Bower, Bob, Sinclair, Brett. (New Zealand).

Flood-protection of riverbank filtration wells. Musche, Fabian; Sandhu, Cornelius; Grischek, Thomas. (Germany).

Ancient techniques of Managed Aquifer Recharge: Spanish Careos and Peruvian Amunas as an Adaptive Complex System. Breakdown, pathology and comparative analysis. Fernández Escalante, E; García Asensio, JM; Ayuga Téllez, F; Rojas Vega, C; Guerrero Salazar, P and San Sebastián Sauto, J. (Spain).

Feasibility of enhanced infiltration basins in Harris County, Texas. Sheng Zhuping; Miller Gretchen; Huang Mingyi and Lu Peirong. (USA).

Dipolic MAR "Bubble" Inside Confined Brine Formation or Floating "Lens" on Top of Unconfined Saline Aquifer. Kacimov, Anvar; Obnosov, Yurii and Al-Maktoumi, Ali. (Oman).

SESSION 7B: MAR AND WATER REUSE 113, 32, 64, 75, 82 (R: 218)

Chair: Dr. I. Negev. (Israel).

Matching agricultural water supply using industrial and domestic treated wastewater via Controlled Drainage Systems. Raat, K.J. (The Netherlands).

Large scale soil-aquifer-treatment (SAT-MAR) physical model experiments to remove rice paddy field contaminants. Leitão, T.E., Martins, T., Henriques, M.J., Lobo-Ferreira J.P., Rogeiro, J., Ilie, A.M.C. (Portugal).

Enabling the reuse of industrial wastewater to meet freshwater demands of greenhouse agriculture by using aquifer storage and recovery (ASR). Van Dooren, Teun C.G.W.; Zuurbier, Koen G.; Raat, Klaasjan J.; Hartog, Niels; Stuyfzand, Pieter J. (The Netherlands).

Infiltration of reclaimed wastewater for drinking - water production: experience of Europe's first project of this kind. Emmanuel Van Houtte, Luc Lebbe, Sayantan Samanta, Clyde Munster en Johan Verbauwhede. (Belgium).

Applications of Geochemical Tracer Experiments Near MAR Facilities to Determine Subsurface Travel Times and Hydraulic Connections to Nearby Production Wells Clark, Jordan. (USA)

SESSION 19: R&D PROJECTS ON MAR 241, 231, 10, 262, 263 (SALA 05)

Chairs: Dr. P. Dillon. (Australia).

Proposed approach to extend managed aquifer recharge facilities with reclaimed wastewater in Catalonia in a context of tighter regulations and extreme climatic events (NE Spain). Pérez-Paricio, Alfredo. (Spain).

Managed Aquifer Recharge in Italy: an overview. Rossetto, Rudy. (Italy).

Assessing travel time through dune sediments with conservative tracer tests. Guardiola-Albert, Carolina; Moreno-Merino, Luis; Kohfahl, Claus; de la Losa Román; Almudena, Ruíz Bermudo; Fernando, Martínez; Antonio, Molano-Leno, Lidia. (Spain).

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13.20/14.50 >

POSTERS/COFFEE BREAK / EXPOSITION AREA / DRONES DEMONSTRATION AREA

14.50/17.00 >

SESSION 9: MAR AND MANAGEMENT OF CLOGGING 90, 190, 20, 59, 157, 40 (R: 26, 104)

Chair: Dr. R. Martin. (Australia).

Underground Taming of Floods for Irrigation (UTFI): Global to field scale assessments. Alam, Mohammad Faiz; Pavelic, Paul; Sharma, Navneet. (India).

Biological and Physical Clogging in Infiltration Wells – The Effect of Well Diameter and Gravel Pack. Kalwa, Fritz; Binder, Martin; Händel, Falk. (Germany).

14.50/15.40 >

FLASH SESSION 2 (SESSIONS 8-11-12) 202, 239, 169, 242, 72, 58, 212, 26

Chair: Dr. O. Almashaqbeh. (Jordan).

Managed Aquifer Recharge Solutions (MARSOL). Final statements VIDEO. Ortega, R; Fernández, E; Sapiano, M; Lobo, J P.; Guttman, Y; Schütz, C.; Weffer-Roelh, A.; San Sebastián, J.; Kallioras, A. & Dietrich, P. (Spain).

Managed Aquifer Recharge Plan based on a surface water- groundwater model for the Santo Domingo creek, Baja California Sur, Mexico. Wurl, Jobst and Imaz Lamadrid, Miguel A. (México).

SESSION 10: MAR & REGULATIONS 154, 31, 193, 109, 232, 145, 183 (R: 69)

Chairs: Dr. M. Sapiano (Malta) & Dr. E. López-Gunn (Spain).

Managed aquifer recharge in Brazil: current state of the legal framework Suênio A. F. da Silva, Victor S. G. Baptista, Victor H. R. Coelho, Cristiano das N. Almeida. (Brazil).

Retrospective on 10 years of risk-based guidelines for managed aquifer recharge Dillon, Peter ; Page, Declan ; Vanderzalm, Joanne ; Martin, Russell ; Johnston, Karen ; Higginson, Simon ; Ingleton, Greg ; Naumann, Bruce ; Thomson, Yvonne ; Parsons, Stephen; Cunliffe, David ; Morris, Ryan ; Hose, Grant. (Australia).

14.50/17.00 >

SESSION 9: MAR AND MANAGEMENT OF CLOGGING 90, 190, 20, 59, 157, 40 (R: 26, 104)

Chair: Dr. R. Martin. (Australia).

Alluvial Aquifer Filtration as a Pre-treatment Option for ASR. Keller, Jason, Rice, Robert, Burt, Walter, Melady, Jason. (USA),

Laboratory Research on the Laws of Fe(III) Clogging during Urban Storm-water Groundwater Recharge. Zhang Hexuan, Du Xinqiang, Ye Xueyan. (China).

Laboratory experiments for the assessment of the impact of solar irradiance on clogging of MAR basins. Barquero; Felix; Binte, Rezwana; Mahmood, Hafsa; Muqeet, Muhammad; Stefan, Catalin. (Germany).

The Effect of Soil Tillage Equipment on Recharge Capacity of Infiltration Ponds NEGEV, IDO; Shechter Tamir; Shtrasler Lilach; Rozenbach Hadar & Livne Avri. (Israel).

14.50/15.40 >

FLASH SESSION 2 (SESSIONS 8-11-12) 202, 239, 169, 242, 72, 58, 212, 26

Chair: Dr. O. Almashaqbeh. (Jordan).

Influence of aquifer recharge structures and surface water bodies on geogenic fluoride contamination. Brindha, K., Elango, L., Kalpana, L. and Schneider, Michael. (Germany).

Numerical modeling of pumping test data at an artificial recharge site in Kuwait. Mukhopadhyay, Amitabha. (Kuwait).

Geo-electrical monitoring of soil aquifer treatment Haaken, Klaus, Weisbrod, Noam, Kemna, Andreas and Furman, Alex. (Israel).

Study on the groundwater recharge based on South to North Water Diversion Project in Hutuo River Alluvial Plain, North China. Li Ya-song. (China).

First results on the assessment of the impact of artificial recharge on the unsaturated zone: Medina del Campo groundwater body (Duero, España). Pablo Valle*, Hector Aguilera, Javier Heredia, José Antonio de la Orden, África de la Hera, Víctor del Barrio, Carlos Marcos. (Spain).

Integration of time-variable scaling factors in HYDRUS to simulate the reduction of hydraulic conductivity due to clogging during managed aquifer recharge operation. Glass, J; Šimůnek, J; Stefan, C. (Germany).

15.40/17.00 >

SESSION 11: MAR AND MONITORING 71, 121, 230, 44

Chair: MSc. B. Bower. (New Zealand).

On the mechanisms affecting and controlling SAT operation. Orgad, Ofri., Mizrachi, Guy., Furman, Alex., Weisbrod, Noam. (Israel).

Monitoring and understanding water quality changes during agricultural aquifer storage transfer and recovery: a field-study Kruisdijk, Emiel; Stuyfzand, Pieter J.; van Breukelen, Boris M. (The Netherlands).

SESSION 10: MAR & REGULATIONS 154, 31, 193, 109, 232, 145, 183 (R: 69)

Chairs: Dr. M. Sapiano (Malta) & Dr. E. López-Gunn (Spain).

Managed aquifer recharge in Brazil: current state of the legal framework Suênio A. F. da Silva, Victor S. G. Baptista, Victor H. R. Coelho, Cristiano das N. Almeida. (Brazil).

Retrospective on 10 years of risk-based guidelines for managed aquifer recharge Dillon, Peter ; Page, Declan ; Vanderzalm, Joanne ; Martin, Russell ; Johnston, Karen ; Higginson, Simon ; Ingleton, Greg ; Naumann, Bruce ; Thomson, Yvonne ; Parsons, Stephen; Cunliffe, David ; Morris, Ryan ; Hose, Grant. (Australia).

MAR Revolution in California – Policy and Regulatory Change to Increase Groundwater Recharge Statewide. Timothy K. Parker. (USA).

Scaling-up UTFI in the Watershed and Beyond: Mainstreaming in Programs and Policies of the Government. Sikka, Alok K; Alam, Mohammad Faiz; Pavelic Paul. (India).

MARSOL Policy Brief Essentials on Managed Aquifer Recharge for policy makers and water managers Schüth, Christoph; Röehl, Karl; Fernández Escalante, Enrique; Guttman, Yossy and Lobo Ferreira, João Paulo. (Germany).

Regulation of Managed Aquifer Recharge schemes under the EU's Water Framework Directive. Sapiano Manuel, Schembri Michael. (Malta).

The Legal Basis Under Idaho, USA, Law for Private Managed Aquifer Recharge and the Subsequent Rediversion and Use of Such Recharged Groundwater Foster, Kent W.; Rassier, Phillip J. (USA).

		15.40/17.00 > **SESSION 11: MAR AND MONITORING 71, 121, 230, 44** Chair: MSc. B. Bower. (New Zealand). Design and operation of the MAR infiltration scheme in Suvereto (Italy). Rossetto, Rudy; De Filippis, Giovanna; Piacentini, Simone Maria; Febo, Simone; Fabbrizzi, Benucci; Claudio, Trebino, Ennio, Brilli, Mirko, Masi, Marco, Menonna, Valentina, Pei, Alessandra, Leoni, Riccardo, Lazzaroni, Federico, Ercoli, Laura, Pellegrino, Elisa, Enrico. (Italy). MAR assessment through physical models: comparison of laboratory and field experiments. Sallwey, Jana, Barquero, Felix, Fichtner, Thomas, Stefan, Catalin (Germany).		
17.00/17.30 >	POSTERS/COFFEE BREAK / EXPOSITION AREA / DRONES DEMONSTRATION AREA			
17.30/19.00 >		**IAH MAR** Commission Plenary		
20.30 >	**ISMAR10 GALA DINNER**			

>>THURSDAY 23

>>THURSDAY 23

	SALA 02* - RECHARGED SATur ROOM >	AUDITORY* - THIRSTY MARía ROOM >	SALA 06 - RECLAIMED MARta >	OTHER ROOMS AND DEMONSTRATION AREAS >
09.00/09.40 >		**KEYNOTE PRESENTATION 3:** Prof. Dr. Jörg Drewes (PC) (Germany).		
09.40/11.00 >	**SESSION 14: MAR IN COASTAL AREAS 98, 29, 43, 228** Chair: Dr. K. Yongcheol. (South Korea). MAR on the Island of Gotland, Sweden – exploring the potential and feasibility in comparison to alternative meassures. Dahlqvist, Peter, Sjöstrand, Karin, Lindhe, Andreas, Rosén, Lars, Thorsbrink, Magdalena, Holgersson, Björn, Nisell, Jakob, Hellstrand, Eva, Persson, Lena, Bastani, Mehrdad. (Sweden).	**SESSION 12: MAR AND MODELING 120, 144, 158, 67** Chair: Dr. S. Ahmed. (India). Push-Pull test – Reactive transport modelling: A new approach to study water quality changes Kruisdijk, Emiel; Stuyfzand, Pieter J.; van Breukelen, Boris M. (The Netherlands).	**SESSION 13: MAR AND ECOSYSTEMS 198, 19, 117** Chair: Dr. J. Grima. (Spain). Conjunctive Use of Managed Aquifer Recharge to Improve Water Resources and Riparian Habitat Quality Milczarek, Michael; Keller, Jason; Lacher, Laurel. (USA).	**ROUND TABLE 3: GRIPP (SALA 04)** Chair: Dr. K. Villholth. (South Africa). **SIDE EVENT: FFGA-FENACORE (SALA 05)** Papel de los usuarios de masas de agua subterránea en la gestión del MAR. Chair: Fernando López Vera. (Spain). > IN SPANISH

09.40/11.00 >

SESSION 14: MAR IN COASTAL AREAS 98, 29, 43, 228
Chair: Dr. K. Yongcheol. (South Korea).

Assessment of aquifer storage and recovery efficiency in coastal aquifers. Hasan, Mohammad Imran; Bakker, Mark. (The Netherlands).

Monitoring and modeling MAR of desalinated seawater to a Mediterranean fresh - water aquifer, from ground - surface to wells' perforations Kurtzman Daniel, Katz Yoram, Ganot Yonatan. (Israel).

Risk reduction of water resource crisis using the managed recharge of coastal pliocenes aquifers in Marbella (Málaga, Spain). Ortuño Morales, A, Parellada Bezares, C, Espinosa Martínez, S, Barrera García, A, Bueso Sánchez, S, Corral Pérez, C. (Spain).

SESSION 12: MAR AND MODELING 120, 144, 158, 67
Chair: Dr. S. Ahmed. (India).

Modeling the influence of temperature in the infiltration rates and redox reactions of an infiltration pond located in the Llobregat River Basin. Rodríguez-Escales, Paula; Barba, Carme; Sanchez-Vila, Xavier; Marcé, Rafel; Folch, Albert. (Spain).

Groundwater recharge estimation for sustainable development of groundwater in Kandi Belt of Jammu, India. Singh, Vivekanand. (India).

Evaluating Managed Aquifer Recharge and Aquifer Storage and Recovery in Kabul, Afghanistan Using Regional and Site-Specific Groundwater Models Matti, Boris; Tookhi, Mohammad Naim; Klein, Hugh; Kissane, Stephen. (Afghanistan).

SESSION 13: MAR AND ECOSYSTEMS 198, 19, 117
Chair: Dr. J. Grima. (Spain).

Vulnerability of the aquifer system from the Nhartanda Valley (City of Tete, Mozambique). Bande, Ameno Délcio João Paulino & Antunes, Isabel Margarida Horta Ribeiro. (Portugal).

Mitigating the impact of a future high - capacity ship canal on the nearby wetlands of the Seine estuary nature reserve: an on-site pilot to demonstrate the efficiency of a managed aquifer recharge solution to preserve wetland integrity. Lenhardt, Florence; Boisson, Marc. (France).

11.00/11.30 >

POSTERS/COFFEE BREAK / EXPOSITION AREA / DRONES DEMONSTRATION AREA

11.30/13.50 >

ROUND TABLE 4. WATER MANAGEMENT AND DIGITALIZATION
Chairman: Mr. M. Navarro Head of ICT/R&D Tragsa Group.

RIEGOS IBERIA REGABER S.A.
Mr. Xavier Díaz
AMPHOS 21 S.L.
Mr. Jordi Guimerá
ODIN SOLUTION S.L.
Mr. Antonio Skarmeta
TECNITOP.
Mr. Jorge Angas
LANA SARRATE S.A. Mr. Carlos Lana

SESSION 12B: MAR AND MODELING 51, 244, 55, 65, 264, 265
Chair: Dr. R. Rossetto. (Italy).

Investigation of viscosity effects caused by seasonal temperature fluctuations during MAR. Glass, Jana; Li, Tailin; Sprenger, Christoph; Stefan, Catalin. (Germany).

Artificial Recharge of a Karst Groundwater System in Developing Country. El Khoury Ibrahim, Chalhoub Lara, Yazbeck Remy and Naji Khoury. (Lebanon).

Investigating a Strategic Aquifer Storage and Recovery Scheme in the Sherwood Sandstone to Improve Resilience Price, Victoria. (England).

SESSION 14B/15B: MAR IN COASTAL AREAS & ENVIRONMENT 103, 56, 159, 105, 83, 196
Chairs: Dr. S. de Lima. (Brazil).

How to control groundwater quality degradation in coastal zones using MAR optimized by GALDIT Vulnerability Assessment to Saltwater Intrusion and GABA-IFI models. Lobo-Ferreira, JP. (Portugal).

Reduction of the environmental impact of managed aquifer recharge. Jokela, Petri;Kärkkäinen Jari. (Finland).

Impact of geological heterogeneity on water quality at a decolmated river bank filtration site: A case study in Potsdam, Germany. Wang, Weishi; Hu, Bin; Matthias Munz; Oswald, Sascha. (Germany).

Managed aquifer recharge (MAR) in coastal aquifers, in brackish and saline groundwater – Cooperation between partners from European and GCC countries Klingbeil, Ralf; Groeschke, Maike. (Germany).

SESSION 20: TRAINING ON MAR 24, 96, 185, 84, 18 (SALA 05)
Chairs: Dr. W. Weiping. (China).

Combining social and hydrogeological factors for MAR site selection in southwest Bangladesh Floris Loys Naus, Kennard Burer, Frank van Laerhoven, Jasper Griffioen, Kazi Matin Achmed, Paul Schot. (The Netherlands).

Evidence dispels common myths on managed aquifer recharge in hardrock aquifers in Rajasthan, India Dillon, Peter; Maheshwari, Basant; Soni, Prahlad; Dashora, Yogita; Davande, Sham; Chinnasamy, Pennan. (Australia).

Using free web-based tools for strenghtening capacities and promotion of MAR Stefan, Catalin; Junghanns, Ralf; Glass, Jana; Sallwey, Jana, Barquero, Felix; Fichtner, Thomas; Schönekerl, Claudia. (Germany).

11.30/13.50 >

SESSION 14B/15B: MAR IN COASTAL AREAS & ENVIRONMENT 103, 56, 159, 105, 83, 196

Chairs: Dr. S. de Lima. (Brazil).

Determining allowable groundwater withdrawals to prevent sinkhole collapse, a case study of the Jiangcun water source, Guanghua basin, China. Meng Yan; Zhuojun Li, Long Jia. (China).

Managed of the ground water aquifer under the Nile Delta. Maha moawad and Mohamed abd-El-Mooty. (Egypt).

SESSION 20: TRAINING ON MAR 24, 96, 185, 84, 18 (SALA 05)

Chairs: Dr. W. Weiping. (China).

Water Planters – An Aquifer Recharge Case Study in Caparaó, Brazil. Shubo, Tatsuo; Dutra, Geraldo; Montenegro, Suzana. (Brazil).

How can NGOs support collective action among the users of local drinking water systems? A case study of Managed Aquifer Recharge (MAR) systems in Bangladesh. Hasan, Muhammad Badrul; Driessen, Peter; Zoomers, Annelies; Laerhoven, Frank VAN. (The Netherlands).

13.50/15.10 >

POSTERS/COFFEE BREAK / EXPOSITION AREA / DRONES DEMONSTRATION AREA

15.10/17.10 >

SESSION 16B/17: MAR WATER QUALITY/HEALTH ASPECTS 206, 95, 134, 181, 174, 106

Chairs: Prof. Dr. P. Stuyfzand (The Netherlands) & Dr. T. Leitão (Portugal).

Monitoring of Eh, DOM and water quality in a MAR surface pond: understanding changes in the infiltration rate. Folch, Albert; Barba, Carme; Marcé, Rafael; Rodríguez-Escales, Paula; Sanchez-Vila, Xavier. (Spain).

Seasonal Variations in Water Quality and NOM Removal in Natural Bank Infiltration of Boreal Lake Water. Jylhä-Ollila, Maija, Laine-Kaulio, Hanne, Koivusalo, Harri. (Finland).

Emerging organic contaminants in managed aquifer recharge: investigating their removal to ensure a sustained, safe, high quality water resource. Reeve, Peter J.; Wallis, Ilka; Hutson, John; Fallowfield, Howard J. (Australia).

Deciphering the long-term evolution of groundwater mixings at a multi-aquifer river bank filtration site Pontoreau Coralie, Baudron Paul, Barbecot Florent, Masse-Dufresne Janie and Patenaude Marc. (Canada).

15.10/15.50 >

FLASH SESSION 3 138, 53, 227, 240, 179

Chair: MSc. D. Bartlett. (USA).

Key hydrogeochemical processes (im)mobilizing trace metals (arsenic, iron, manganese) in MAR for drinking water provision in Bangladesh Rafiq, Muhammad Risalat, Ahmed, Kazi Matin, van Breukelen, Boris M. (The Netherlands).

The role of organic matter in the release of iron and manganese during bank filtration A. Abdelrady, S.k. Sharma, A. Sefelnasr, M. Kennedy. (The Netherlands).

Riverbank filtration in a narrow river valley of the Barranca river, Costa Rica Jones-Sánchez, Mark; Araya-Obando, José; Lazo, Andrés; Bonilla, José; Romero-Esquivel, Luis; Grischek, Thomas. (Costa Rica).

SUDS and resilience to climate change. Prieto Leache, Ignacio and García Ruiz, Luisa María. (Spain).

SESSION 19B/20B: R&D PROJECTS ON MAR & TRAINING 112, 151, 50, 110, 267

Chairs: Dr. J. Iglesias. (Spain).

An integrated system based on MAR and reclaimed water reuse for sustainable agriculture irrigation under climate change conditions in Mediterranean countries. Vurro, Michele; Portoghese, Ivan; Al-Raggad, Marwan; Bouden, Sarra; Doveri, Marco; El-Mansouri, Bouabid;Escalante, Enrique F. ; Giordano, Raffaele; Lobo-Ferreira, Joao Paolo; Mahjoub, Olfa; Michiel, Caroline; Monacelli Giuseppina; Rossetto Rudy; Santoro, Oronzo; Sapiano, Manuel0 & Tuccinardi, Francesco P. (Italy).

Evaluation of Operation and Performance of the Everglades C-111 MAR Project. Christopher J. Brown; June Mirecki. (USA).

The MAR portal: a web-based tool for sharing mar-related information Sterckx, Arnaud; Stefan, Catalin. (The Netherñands).

260 TBC

WORKING GROUPS MEETINGS (SALA 04 & 05)

15.10/17.10 >

SESSION 16B/17: MAR WATER QUALITY/HEALTH ASPECTS 206, 95, 134, 181, 174, 106
Chairs: Prof. Dr. P. Stuyfzand (The Netherlands) & Dr. T. Leitão (Portugal).

Coupling bank filtration to pond infiltration – a useful option in terms of quality improvement? BURKE, VICTORIA, Greskowiak, Janek, Sanz-Prat, Alicia, Rhode, Clara, Schröter, Ina, Drewes, Jörg, Hübner, Uwe, Sperlich, Alexander, Schimmelpfennig, Sebastian, Dünnbier, Uwe, Massmann, G. (Germany).

Combined removal of organic micropollutants and ammonium in a column study with reactive barriers simulating MAR. Modrzyński, Jakub J., Albers, Christian N., Wittorf, L., Canelles, A., Hallin, S., Aamand, J. (Denmark).

15.10/15.50 >

FLASH SESSION 3 138, 53, 227, 240, 179
Chair: MSc. D. Bartlett. (USA).

Anticipating pathways and timing for cyanobacteria breakthrough at a 2-lake bank filtration site via environmental tracers. Masse-Dufresne Janie, Baudron Paul, Barbecot Florent, Pasquier Philippe, Barbeau Benoit, Patenaude Marc, Pontoreau Coralie and Proteau-Bédard Francis. (Canada).

15.50/17.10 >

SESSION 18. URBAN MAR 11, 97, 153, 13
Chair: Dr. K. Zuurbier. (The Netherlands).

Managed aquifer recharge as a strategic storage and urban water management tool in the Darwin rural area, Northern Territory, Australia. Knapton, Anthony; Page, Declan; Vanderzalm, Joanne; Gonzalez, Dennis; Barry, Karen; Taylor, Andrew; Horner, Nerida; Chilcott, Chris; Petheram, Cuan. (Australia).

Principles for rainwater management in a multi-sponge city using soil, unconfined- and confined-aquifers. Dillon, Peter; Argue, John; Meyer, Wayne; Barry, Karen. (Australia).

Influence of temporal discretization of rainfall data on efficiency of an injection well. Victor S. G. Baptista, Victor H. R. Coelho, Nelson O. L. Caicedo, Suênio A. F. da Silva, Cristiano das N. Almeida. (Brazil).

Rooftop rainwater harvesting – way forward to meeting water crisis in urban India. S.K.Sharma. (India).

16.50/17.10 >

POST-CONFERENCE TRIPS INFORMATION

WORKING GROUPS MEETINGS (SALA 04 & 05)

17.10/17.40 >

POSTERS/COFFEE BREAK / EXPOSITION AREA / DRONES DEMONSTRATION AREA

17.40/19.00 >

SESSION 17B: MAR HEALTH ASPECTS 12, 191, 99, 225, (R: 126)
Chairs: Chair: Dr. D. Page (Australia) and Dr. B. van Breukelen (The Netherlands).

E. coli attenuation during infiltration of treated wastewater. Donn, Mike; Reed, Debbie; Vanderzalm, Joanne; Page, Declan. (Australia.)

SESSION 18B: URBAN MAR 70, 14, 195, 34
Chair: Arg. Ignacio Prieto. (Spain).

Groundwater and Water Bourne disease in Kabul Matti, Boris; Klein, Hugh; Tookhi, Mohammad Naim; Kissane, Stephen. (Afghanistan).

SPECIAL SESSION 3: SAT-MAR 268, 269, 270, 271
Chairs: DEA Simón Pulido. (Spain).

268 TBC

269 TBC

WORKING GROUPS MEETINGS (SALA 04 & 05)

17.40/19.00 >	**SESSION 17B: MAR HEALTH ASPECTS 12, 191, 99, 225, (R: 126)** Chairs: Chair: Dr. D. Page (Australia) and Dr. B. van Breukelen (The Netherlands). Fate of plant pathogenic bacteria in drainage water during managed aquifer recharge for agricultural irrigation. Eisfeld, Carina; van Breukelen, Boris. M.; van der Wolf, Jan M.; Schijven, Jack F.; Medema, Gertjan. (The Netherlands). Antibiotic Degradation during Riverbank Infiltration of Reclaimed Water at Beiyun River in the North China Plain. Ma, Yunjie; Ma, Meng; Yang, Yuxia; Li, Binghua; Zheng, Yan. (China). Water quality changes during river bank filtration at Budapest, Hungary Zsuzsanna Nagy-Kovács, János Davidesz, Katalin Czihat-Mártonné, Thomas Grischek. (Hungary).	**SESSION 18B: URBAN MAR 70, 14, 195, 34** Chair: Arg. Ignacio Prieto. (Spain). Recharge of aquifers through wells in urban areas of Mexico City Benton, Andrés. (México). Participatory Aquifer Management an Alternative Approach to Sustain Urban Water Supply – a case study of Bhuj City – Gujarat, India. Jadeja Y. J., Jadeja, M.J., Parmar, G.H., Reel, G.D., Gorasiya, J. G. (India). Preventing pluvial flooding and water shortages on various scales by integrating aquifer storage and recovery in urban areas. Zuurbier, Koen; De Doelder, Bert and Van Breukelen, Boris. (The Netherlands).	**SPECIAL SESSION 3: SAT-MAR 268, 269, 270, 271** Chairs: DEA Simón Pulido. (Spain). 270 TBC 271 TBC	**WORKING GROUPS MEETINGS (SALA 04 & 05)**
19.00/19.30 >		**CLOSING CEREMONY** Ministry of Science, Innovation and Universities Dr. Enrique Playán. European commission (EIP Water) Dr. Guido Schmidt . Tragsa Group MRs. Paloma López-Izquierdo. **ISMAR 11 ANNOUNCEMENT AND PHOTO**		

*Full time Simultaneous Translation in Auditory and Sala 02.
Except Wednesday and Thursday evening.

Crucial Role of Managed Aquifer Recharge as an Adaptation Strategy for Groundwater Sustainability in the Face of Climate Change in India

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KEY WORDS
managed aquifer recharge, energy-irrigation nexus , intelligent power rationing, synergy, conjunctive management

ABSTRACT
As per key findings of climate change projections for India, the increase in the frequency of extreme precipitation will also mean that much of the monsoon rain would be lost as direct run-off resulting in reduced groundwater recharge and increased ground water withdrawal, which might further exasperate the present scenario of imbalanced development. The adaptation strategies proposed for mitigating the increasing stress on ground water resources due to climate change for enhancing recharge of groundwater aquifers, mandating water harvesting and artificial recharge in urban areas, ground water governance, incentivising to promote recharging of ground water, intelligent power rationing for irrigation ,optimizing water use efficiency, conjunctive management etc. have been examined at great length in terms of the technical feasibility as well as social relevance of implementation in the light of extensive experience gained in the country. Sustainable development of ground water resources and various mitigation programs required in the event of possible climate change in the country can be accomplished only with the help and active cooperation of all stakeholders such as the Ministries of Government of India for Water Resources, Environment & Forests, Power, Rural Development, Agriculture, Science & Technology and the institutions working under them; State Governments & their organizations; Associations of Industry, Non-Government Organizations, District Administrations and Panchayati Raj Institutions and the individuals users. To be successful in this mission we also have to create conditions for complete synergy in the activities of all the stakeholders. The role and space for various stakeholders namely Farmers, NGOs, local communities, Canal system managers and Groundwater Recharge SPV, in groundwater recharge strategy as a major response to climate change is outlined.

Integration of Stormwater Capture at Flood Management Reservoir with Managed Aquifer Recharge, Orange County, California

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KEY WORDS
Integrated water resources management, groundwater recharge

ABSTRACT

The United States Army Corps of Engineers (USACE) and Orange County Water District (OCWD) are implementing an innovative integrated water resources management program utilizing Prado Dam in Riverside County, California. USACE owns and operates Prado Dam for flood risk management. The program provides for temporary stormwater capture at the dam and subsequent water release for groundwater recharge. Temporary capture (short-term storage) of stormwater cannot impact the dam's primary flood risk management purpose. Water pooled at the dam submerges lands with habitat for endangered species. The program required overcoming three obstacles: (1) capturing stormwater without impacting the dam's flood risk management purpose, (2) developing downstream facilities to recharge stormwater, and (3) solving endangered species habitat and nesting conflicts in the reservoir area where water is pooled. Capturing stormwater at Prado Dam without impacting flood risk management requires USACE to rapidly release stormwater captured under the program if holding the water would reduce flood management in a pending rainfall event. USACE and OCWD coordinate closely to release stormwater captured at the dam so that release rates are maximized but do not exceed OCWD's recharge capacity. USACE can temporarily store 24 Mm^3 at Prado Dam for downstream groundwater recharge. OCWD's recharge facilities are located approximately 20 km downstream of Prado Dam. OCWD constructed two inflatable rubber dams to divert Santa Ana River water released from Prado Dam. Water diverted from the river is recharged into the groundwater basin through 22 recharge basins. The recharge basins sustainably recharge 10 to 20 m^3/s of river water. OCWD's recharge capacity allows 24 Mm^3 captured at Prado Dam to be recharged in approximately 25 to 40 days. Environmental laws prioritize protection of endangered species. The Least Bell's vireo, a small songbird, is now breeding successfully in the lands upstream of Prado Dam. When the integrated water resources management program was proposed, wildlife management agencies initial reaction was negative due to the vireos near extirpation. However, OCWD and USACE developed a new program to increase vireo habitat and nesting success. In the last 30 years, the number of male nesting territories has increased from less than 20 to over 500 as a result of the program's efforts to expand habitat, control nest parasitism, and other management activities.   The program has successfully achieved an average of 62 Mm^3 of stormwater recharge per year.

Health risk associated with heavy metals content of harvested rainwater in Yatta area, Palestine

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[5]*Department of Civil Engineering, An-Najah National University, P. O. Box 7, Nablus, Palestine*.
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KEY WORDS
Cisterns; Heavy metals; Rainwater harvesting; Human health risk; Yatta area.

ABSTRACT
Rainwater is considered a dependable source for domestic purposes within rural areas in Palestine. Harvested rainwater stored in cisterns is used to leverage deficits from municipal water supplies. Harvested rainwater in areas surrounded with industrial and agricultural activities is usually contaminated with heavy metals. To study the effects of human exposure to heavy metals, 74 harvested rainwater samples of rain-fed cisterns were collected from different localities in the Yatta area of Palestine in the months of January and February of 2016.

The water samples were analyzed for Ca, Mg, Al, Fe, K, Na, Ag, Li, Co, Ba, Bi, Sr, Ga, V, Rb, Mo, Be and Tl elements utilizing ICP-MS (inductively coupled plasma mass spectrometry). The selected heavy metals were found within the concentration limits, in accordance with WHO and Palestinian standards, except for K and Al, which were found above the allowed limits. The potential risks of the selected heavy metals on the health of the local residents, as well as the possible sources of such heavy metals, were also studied. The Chronic daily intake (CDI) of each metal and health risk indexes (HRI) were calculated for both adults and children residents. The oral ingestion pathway was studied, including exposure via drinking water. The values for CDI were found in the descending order of: Ca > Mg > Na > K > Sr > Fe > Al > Ba > Li > V > Rb > Ag > Mo > Ga > Co > Bi > Tl > Be. The values of HRI were below 1 for most of the selected heavy metals, expect for Li for children, indicating potential health risk. The study also predicted that the local residents have a higher chance of developing cancer in their lifetime, especially children, regards to the carcinogenic risk (CR_{ing}) values for Na, Mg, Al, Ba, K, Ca, Fe, and Sr, which were greater than standardized limits ($>10^{-6}$). The rest of the selected elements were within the acceptable limit in the five different studied locations. Furthermore, univariate, multivariate and statistical analysis depending on one-way ANOVA, inter-metal correlation, cluster analysis (CA) and principal component analysis (PCA) results revealed that geogenic and anthropogenic activities were major sources of drinking water contamination by heavy metals in the Yatta area.

Application of fuzzy logic and wavelet transform in the estimation of groundwater table using ENSO indexes

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KEY WORDS
Ground water table, PNA, ANN, Fuzzy, Wavelet transform

ABSTRACT
Modeling and prediction of groundwater table (GWT) have more importance in water resource management, especially in warm and arid regions. In current years, application of intelligent models has had high accuracy in the simulation of GWT. In more investigations, the weather and hydrogeological parameters are used as input while the effect of ENSO phenomenon is evaluated on more events of hydrology and hydrogeology. The purpose of present study was an evaluation of intelligent models including artificial neural network (ANN), co-active neuro-fuzzy inference system (CANFIS), wavelet transform combined with ANN (WANN) and wavelet transform combined with CANFIS (WCANFIS) in forecasting the GWT base on ENSO indexes.

For this aim, the GWT information of Hormozgan province, where is located in the southeast of Iran, is used. The results showed that the PNA index had the more correlation with GWT changes. Application of different structures of intelligent models in four seasons indicated that the GWT prediction accuracy in summer was more than other seasons. Based on the best structure in the prediction of summer GWT, the value of normal root mean square error (NRMSE) and correlation coefficient were 0.014 and 0.986, respectively. Moreover, the performance of WANN was better than other methods in the estimation of GWT in spring, summer, and winter. However, the WCANFIS method was suitable for estimating the autumn GWT.

Totally, the results indicated that the accuracy of estimated GWT using ENSO indexes was more than previous studies which used weather parameters as inputs. It illustrates the importance of ENSO phenomenon in the assessment of GWT changes. So using intelligent models, especially wavelet transform combined with artificial neural network and the ENSO indexes can increase the estimated accuracy of GWT.

Comprehensive Guidelines for Managed Aquifer Recharge to Be Published by ASCE/EWRI

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KEY WORDS
Water management, education, dissemination, guidelines

ABSTRACT
In recent decades, Managed Aquifer Recharge (MAR) projects have been successfully implemented for water management around the world. However, many water resources professionals remain unaware of the benefits, techniques, standard practices and applications of MAR. Confusion abounds regarding basic terminology. Over the past 30+ years, much has been learned regarding how to design and implement a successful, cost efficient MAR project and what pitfalls exist that prevent MAR success. Although there are extensive resources about various specialized aspects of MAR in the scientific literature, the US water resources sector has lacked an up-to-date, comprehensive document describing the state of the practice for MAR projects.

In 2005, the American Society of Civil Engineers/Environmental and Water Resources Institute (ASCE/EWRI) formed the Guideline Development Subcommittee for MAR. The purpose of this Subcommittee was to provide a thorough and up-to-date document that describes the state of the practice for MAR projects. We began with the existing standard guidelines for Artificial Recharge of Groundwater (EWRI/ASCE 34-01; 2001), and restructured that document to include details on planning, design, construction, operation and monitoring of MAR projects, along with background information on groundwater and MAR concepts. The new document has been designed to meet the needs of water resources planners and stakeholders during the initial evaluation and planning phases, as well as the needs of engineers, hydrologists and other professionals for standardization of MAR practices from conceptualization to operation. The draft guidelines also include an extensive discussion on data collection and analysis for each phase of a MAR project, a listing of representative MAR regulations, and case studies.

The draft Guidelines on MAR will be made available for public review in late 2018 to early 2019. The Subcommittee will consider all public comments received, and revise the draft Guidelines accordingly before submittal to the ASCE/EWRI Standards Committee for review. The final Guidelines will be approved by a consensus of the ASCE/EWRI Standards Committee, and should be published by December 2019. This document will serve as a valuable resource for the water resources community.

Determining allowable groundwater withdrawals to prevent sinkhole collapse - a case study of the Jiangcun water source, Guanghua basin, China

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KEY WORDS
Karst aquifer, Sinkhole collapse, Allowable withdrawal, Safe yield

ABSTRACT
Aquifer structure can be damaged by the collapse of sinkholes in karst areas. This can cause wells and springs to dry up, dwellings to be damaged, and can make it easier for pollutants to enter aquifers. Controlling groundwater withdrawal to prevent sinkhole collapse is an important component of karst aquifer protection and sustainable use. This paper appraises three approaches for controlling groundwater withdrawals: water balance, allowable water level decline, and exploitation intensity. These approaches were investigated using pumping tests, statistical analysis, and numerical simulation.

The results show that: (1) to prevent sinkhole collapse, the allowable extraction must be smaller than the withdrawal, as determined using the water balance method; (2) water level decline is an important parameter that has to be considered to prevent sinkhole collapse; and (3) adjusting the intensity and mode of exploitation can increase the allowable withdrawal of groundwater without sinkhole collapse.

IWRM Approach and Rainwater Harvesting in Drought-prone Barind Tract, Bangladesh: Practiced Potential

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KEY WORDS
IWRM, RWH, Barind Tract, Bangladesh, Practiced potential

ABSTRACT

In Bangladesh, food security is a high priority national goal, and the use of water for irrigation has been crucial especially in water scarce and drought-prone Barind area in northern part of country recently for achieving national rice-based food security. Here water demand for agriculture and livelihood is needed to be balanced for the survival of people and environment. But water resource management remains fragmented in the country as: the approach to water management continues to be supply led; sector focused; technically driven; and top-down resulting unsustainably high economic, social and ecological cost.

The RWH technique has been implemented as an IWRM process as pilot study with technologically modified dug well recharge models, aquifer recharge well or MAR technology, re-excavated silted *Kharies*, ponds and *Beels* etc. The re-excavated *Kharies*, ponds and *Beels* help to improve their runoff water holding capacity and to conserve more surface water for further use in agriculture. Moreover, the re-excavated silted *Kharies* along with constructed cross dams for runoff conservation provide opportunities for irrigation, fisheries and duck rearing to beneficiaries. The runoff water is now conserved in re-excavated ponds which act as infiltration tank and provides water to people especially women for domestic use and farmers for cultivation of vegetables, fisheries and duck rearing. Before the re-excavation of ponds, pond water was available only for three-five months during and after rainy seasons whereas during rest of the months the ponds remained dry and inhabitants faced severe scarcity of water for domestic use. Here the evaluation of the achievements of the RWH techniques implemented under IWRM process through pre-set and tested questionnaire survey and focus group discussions (FDGs) is one of the most important output components of participation and thereby pursuance of citizens especially disadvantaged and underprivileged people. The piloted RWH technique reveals that as applied in the area the technique is socially, financially, economically and environmentally acceptable to the beneficiaries. Moreover, they themselves are hopeful about the sustainability of the implemented schemes in future and are ready to bear the responsibility of the recurring costs related to the maintenance of the project schemes by themselves, which is really most positive attitude of beneficiaries towards RWH technique in the drought prone Barind Tract.

Present study provides a guideline to water managers, planners and decision makers considering water availability, scarcity, demand, over-exploitation etc., to apply IWRM approach successfully for resource management and development at micro level in sustainable way. In this regard, appropriate strategies with governance performance should be kept in mind. Formulation of a ‘National Water Code’ in compliance with National Water Policy and Bangladesh Water Act is very crucial to ensure sustainable development of water resources in Barind area for Vision 2021 and 2041 of the government and the Sustainable Development Goals (SDG) for 2030, as well as Delta Plan 2100 framed for the country by the GoB with the help of Royal Dutch Government. Constant awareness building programs on IWRM should be conducted not only for the beneficiaries and villagers, but also for the representative LGIs, civil and political leaders, and policymakers at local level. Finally, it is urgent to aware peoples against development of any sort of water lordship in the area, and to encourage people's ownership, not the lordship. More intensive awareness about the misuse of drinking, irrigation water etc. among the people as well as representatives of the LGIs should be immediately prompted.

Is MAR adequate in Spain in the framework of natural aquifer recharge, water scarcity and water cost?

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KEY WORDS
Mar, Natural Recharge, Water Scarcity, Water cost, Spain

ABSTRACT
Managed artificial recharge (MAR) in Spain is still underdeveloped despite water scarcity and the recurrent drought situations. However some MAR activities are in operation since the early 1950s. This can be explained by the actual poor value given in many cases to groundwater in water planning at water authority level and by large supply companies and water groups. The real value has to be seen from the point of view of knowledge, confidence in the resource and its quality, involved costs and the correct application of water cost recovery. Hydrogeological conditions in many areas of Spain favour the existence of aquifers near water demand areas which are naturally well–recharged by river water and excess irrigation flows and also by groundwater transfers from mountainous areas, although this is poorly known in many cases.

In many areas depletion and even mining of groundwater reserves is a common situation with very slow recovery capacity. This storage is manageable and MAR may play a role if recharge water is available and operation costs are acceptable to users. Main handicaps are the existence of explicit or hidden subsidies that effort water costs, as well as the distance to rechargeable resources such as reclaimed waste water, desalinated sea water and water transfers in low demand moments. This has to be incorporated more in depth into water planning, considering conjoint and alterative use of water, but adequate specific legislation is needed, and water users have to be deeply involved in facilities operation.

MAR with salinization through the back door – Salinization of the Castricum coastal dune area by artificial recharge

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KEY WORDS
MAR, draught, salinization, drinking water

ABSTRACT
Groundwater in the coastal dune area of Castricum in the Netherlands is used for drinking water production. To combat salinization in the coastal dune area, pretreated water from the river Rhine and Lake Ijssel (IJsselmeer) is used for artificial recharge.

Generally the salinity of river water that is used for artificial recharge is at approximately 100 mg Cl/l. As a result of a relatively dry 2018 with low river discharges and draught mitigations, chloride concentrations increased up to 260 mg Cl/l in late August.

In this article we evaluate how increased chloride concentrations propagate through three MAR systems and how the attenuated (smoothed) concentrations in the abstracted water compare to the drinking water standard of 150 mg Cl/l.

We use 3D flow path calculations to evaluate travel times for all three MAR facilities and compare these to measurements of chloride, electrical conductivity and temperature. We will distinguish between three different MAR facilities which all have their own specific distribution of travel times; one with deep well injection and abstraction wells (ASTR) and two with open recharge via canals and abstraction wells of which one is more and one is less compact (BAR). Subsequently we consider how climate change may increase salinity concentrations when dry spells will grow more extreme. We evaluate this with a simple compartment model for Lake IJssel, using existing scenarios for river discharge based on climate scenarios of the Royal Dutch Meteorological Institute.

Assessing travel time through dune sediments with conservative tracer tests

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KEY WORDS
Dune, soil samples, tracer test, transit time, unsaturated zone

ABSTRACT
Groundwater recharge is a complex process, highly dependent on meteorological, hydrological and geological parameters, which are normally not measured and therefore recharge estimations normally rely on rough estimates making impossible a sound and sustainable management of water resources to meet long-term social economic and ecologic demands. The test explained here is one of the activities performed within a project financed by the former Spanish Ministry of Economy, Industry and Competitiveness (CLIGRO). The project aims to assess the natural groundwater recharge of the coastal Almonte-Marismas aquifer, a substantial water resource of the Doñana National Park wetland area (SW Spain), by using different techniques: one lysimiter (that directly measures the water balance), numerical modelling in the unsaturated zone (with VS2Dti) or infiltration measurements (by single ring infiltrometer method). The present work describes the assessment of the travel times through the unsaturated zone in dune sediments, which are crucial for the recharge of the aquifer in the study area. The experiment consisted in the application of three tracers harmless to health and environment (BrK, BrLi, NO_3K). On the 18th October 2017 a controlled micro-doses of three traces was applied superficially on an area of 6 x 3 m^2, divided in subareas of 1m^2, and on the surface of one precision weighing lysimeter. The injection system was a watering can. Undisturbed soil cores of 2 m depth were extracted manually in monthly intervals and a profile of the vertical tracer distribution was analysed with a resolution of between 5 and 10 cm. At the initial time, a natural soil sample core of 2 m depth was extracted to determine the background or natural content of the tracer and the hydraulic characteristics of the sediment such as saturated permeability, porosity, texture, density, humidity, field capacity and permanent wilting point. Drained water of the lysimeter was sampled every two weeks and analysed for major ions and tracer concentrations. Based on the interpretation of the results, travel times will be estimated.

Managed aquifer recharge as a strategic storage and urban water management tool in the Darwin rural area, Northern Territory, Australia

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KEY WORDS
Managed Aquifer Recharge (MAR); aquifer storage and recovery (ASR); strategic storage; northern Australia; water security

ABSTRACT
Since the early 1990s a substantial increase in the unlicensed extraction of groundwater for the purpose of irrigation has caused a decline in groundwater levels in the peri-urban rural living areas of Darwin, Northern Territory, Australia. At times, wet-season season groundwater recharge is not sufficient to sustain extraction in the dry season, and groundwater bores may run dry, leaving residents without domestic water supply. In addition to domestic supply, groundwater extracted from the Koolpinyah Dolostone aquifer (~25 Mm^3/yr) in the Darwin rural area is used for irrigationand supplies a minor component (~15%) of Darwin's reticulated water supply. Because of the seasonal nature of rainfall near Darwin and the water level in the Koolpinyah Dolostone aquifer, the feasibility of direct injection and infiltration Managed Aquifer Recharge (MAR) schemes were investigated. It was found that direct injection wells (Aquifer Storage Transfer and Recovery, ASTR) were more efficient in recharging the dolostone than infiltration basins due to the spatial heterogeneity in permeability of the overlying laterite. This assessment suggests that an ASTR scheme with injection early in the dry season when there is coincidence between source water availability and aquifer storage capacity, could alleviate the end of dry season decline in groundwater levels in the Darwin rural area. The use of a larger and potentially long-term aquifer storage and recovery (ASR) system (5 Mm^3/yr) was also assessed as a viable technical solution in the northern part of the aquifer where it is confined. The ASR scheme could potentially be scaleable to meet urban need for strategic long-term storage. ASR systems that could potentially store billions of cubic meters of wet season water could be developed to augment the urban water system. Careful consideration must be given not only to the strategic positioning of the ASR water bank, but also to the hydrogeology of the aquifers in which the systems would be developed. Not all locations and aquifer systems can successfully support a strategic storage ASR system.

E. coli attenuation during infiltration of treated wastewater

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KEY WORDS
E. coli, Managed Aquifer Recharge, Infiltration ponds, Treated Wastewater

ABSTRACT

Treated wastewater (TWW) infiltration has been used for decades in Western Australia for disposal and reuse. These wastewater treatment plants (WWTPs) are mostly pond systems infiltrating secondary TWW with a smaller number of activated sludge WWTPs; both treatment systems exclude disinfection pre-infiltration. Treatment type (pre and post infiltration) is dependent on the environmental receptor receiving groundwater and reuse regulation, determined via risk assessments and licence conditions. In this study, microbiological water quality data (*E. coli*) were evaluated using an advanced statistical method able to incorporate the highly censored data at full scale infiltration sites operating for decades across Western Australia. Significant subsurface *E. coli* removal from TWW was observed at all 17 infiltration sites investigated. Most sites (14) had less than six detections of *E. coli* in groundwater (58-100% non-detects; 7-117 samples/bore), thus the statistical method could not applied. For these schemes median *E. coli* numbers in TWW varied between 160 n/100 ML and >24,000 n/100 mL with the observations bores between 14 and 145 m from the infiltration basins. These observations could be used to infer between 1 and 3 $\log_{10}$ for *E. coli.* The remaining three sites had sufficient detections for probabilistic modelling analysis, the median removal efficiency for *E. coli* was quantified as 96% to greater than 99%, confirming at least 1 $\log_{10}$ removal with potential for several $\log_{10}$ removal. Reductions could not be explained through dilution with the native groundwater alone and are the result of bacteria retention and inactivation in the aquifer. The magnitude of microbiological water quality improvement, highlights the sustainable and reliable use of the aquifer to improve water quality without disinfection. The recycled water can be abstracted for appropriate non-potable reuse and/or enhance the groundwater receiving environment. Aquifer treatment is being utilised as a treatment barrier in Recycled Water Quality Management Plans, required for Health Approval, and can be further capitalized at other sites to increase non-potable reuse reducing demand pressures on valuable potable supplies and provide environmental benefits without disinfection.

Rooftop rainwater harvesting – way forward to meeting water crisis in urban India

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KEY WORDS
Aquifer, dwelling unit, recharge, roof-top rain water harvesting, water table

ABSTRACT
New Delhi is facing acute water shortage due to indiscriminate and over exploitation of groundwater to meet the water requirements of increasing population for various purposes. A dwelling unit with a roof top area of $150m^2$ in a total land area of $900m^2$ in Pratapganj in East Delhi where six adult persons reside, having the water requirement of 50 liters/person/day, was selected for the implementation of roof-top rain water harvesting system during monsoon period beginning from June to September in 2016. The total water requirement of the family during the dry period between two consecutive rainy seasons of 245 days is 245 x 6 x 50 or 73500 liters which is partially met by the Municipal Corporation of Delhi. The water table in Pratapganj is found to be at 5.5m in the hand pump of the dwelling unit which goes further down to about 6.5m or 7.0m during dry season making the hand pump defunct. This technique of roof-top rain water harvesting has been found the most appropriate in this area because not much of land is available due to increased urban activities. Given that the building has $150m^2$ roof top area, the average annual rainfall of Delhi is about 1100mm (1.1m) and the runoff coefficient is 0.85, the water harvesting potential comes out to be 150 x 1.1 x 0.85 = $140.2m^3$ (140250 liters). This volume of water is directed to the existing borehole via 4m long, 3m wide and 3m deep "collection and filtration pit" which has been constructed at about 15m away from the building wall but in the same campus of dwelling unit. The pit is filled with boulders at the bottom followed by pebbles and sand at the top. The roof-top rain water as well as the storm water is channeled through 10cm diameter pipe to the existing 12m deep hand pump which is used here to act as the recharge shaft that ends into the aquifer under gravity flow. It was observed that the harvested rainwater brought back the water table at 5.5m or even less and the hand pump which remained dry before the monsoon period started delivering the water again. This additional volume of water met the existing water requirement of six member family per day for the year. There has been an improvement in the yield of hand pump and the groundwater quality.

Recharge of aquifers through wells in urban areas of Mexico City

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KEY WORDS
Recharge Wells, geohydrology, clogging, rain.

ABSTRACT
In 2004, the General Direction for the Construction of Hydraulic Works in Mexico City, carried out with great success a program for aquifers recharge at the southern zone on the valley, in an igneous rock formation with high permeability characteristics, which finally allows the recharge of up to 6.0 m^3/sec during the rain, through the construction of 52 absorption wells in the unsaturated zone at shallow depth (between 10 and 15 meters).

Due to the difficulties of vehicular circulation that occur in that area during the rainy season, this program was developed with the dual purpose of recharging the aquifer existing there and else preventing flooding and vehicular clogging that take place as an urbanized area of hills and at the foot of the "Ajusco" mountain range.

For this program, it was necessary to consider the topography, the geology and define the small hydrological basins that would feed the structures designed for cleaning of papers, garbage, drag fines, grease and oils, going with the water through grids that cross the paved streets before discharging into the wells that finally allow the surface drainage and to recharge the aquifers.

These structures facilitate carrying out its maintenance periodically.

This program that allows the recharge during the rain, due to its effectiveness has already been duplicated.

The presentation details the procedures used to know the parameters of the igneous formations present in the area, in which the recharge capacity was calculated in each site of the wells, necessary data to design the capacity of the grids and structures that prevent the silting and plugging of the wells.

With the information obtained from the wells cuttings and the geohydrological interpretations carried out during the development of the works, the geology and geohydrology of the area obtained is integrated at the end of the presentation like it was defined.

An important part of these aquifer recharge systems is to carry out the maintenance work of the structures, cleaning these materials that have partially clogged, reducing the infiltration capacity, taking also the precaution of leaving the well completely clean and not damaging the slotted casing.

Methodology for assessing Managed Aquifer Recharge project implementation in Chile

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KEY WORDS
Chile, managed aquifer recharge, water scarcity, GIS analysis.

ABSTRACT

Nowadays, managed aquifer recharge (MAR) in Chile is contemplated in the National Water Resources Strategy (MOP, 2013) as an option to face the shortage of the resource in basins with negative water balance. Additionally, the National Irrigation Strategy (MOP, 2013) also contemplates this water management strategy to increase the reserves in the aquifers, to facilitate the transport and to improve the water quality. In addition, artificial recharge is already established in several Chilean regulations (Water Code, Regulations on Groundwater Exploration and Exploitation Standards, etc.). As a result, different individual and private studies of MAR were implemented in Chile in an increasing number from 70s years to the present. In 2013 the General Directorate of Waters (DGA) commissioned a study to evaluate the most favourable areas for MAR in Chile and to stablish the methodological procedures to apply for a MAR project in Chile.

A multicriteria analysis was applied to identify the most favourable areas for MAR. This methodology was developed using those variables of importance for MAR that were available at the national level: permeability, land uses, slope and existence of rivers. Each variable is represented in a cover map and transformed a to harmonized values depending on their dregree of favorability. Afterwards the different variables are weighted by their degree of importance with respect the total of variables in the final feasibility analysis. As a result, the different basins were ranked and those where a priori, the MAR strategy has more feasibility potential were defined.

Despite of this evaluation, all MAR projects need an administrative authorization which requires a series of studies including the hydrogeology of the area, the availability of water and the legal requirements together with a environmental aspects (monitoring plan and action plan). Once the project is approved, a pilot recharge experiment has to be conducted to validate and to ensure that the predicted (positive and negative) impacts.

Managed Aquifer Recharge in the Recycled Water Master Plans

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KEY WORDS
Water reuse master plan, reclaimed water, managed aquifer recharge, water scarcity, multiple water use

ABSTRACT
Water scarcity prompts to investigate alternative water resources to mitigate the balance between resources and demands in highly populated areas. In the last ten years, technologies for waste water treatment have evolved to the extent that reuse of reclaimed water is not only possible, but it is common practice. Despite the fact that the regulatory framework for water reuse is still different in different parts of the World, management practices in countries of long-lasting water scarcity are evolving due to the imperative needs to obtain additional sources of water – Europe, has not implemented yet a definitive framework directive of Water Reuse for the state members, only a recent proposal on minimum requirements for water reuse in agriculture (COM (2018) 337 final) - . Hence, programs for water reuse or for non-potable water exist and are being implemented in arid parts of the World, where alternative uses are given to reclaimed water.

Managed aquifer recharge with reclaimed water is an alternative strategy that is being implemented in these programs. Differently to conventional fresh water sources like river or rain water, reclaimed water needs to demonstrate a quality of water so that not only does not pose health threads to public, but also does not worsen the groundwater quality. Under these circumstances, aquifers candidates to receive reclaimed water for either replenishment or store-and-recovery must have specific features in a context of proximity of water treatment plants, presence of extractive infrastructure for water use -namely extraction wells or users- and potential for water store. In addition, the distance of the potential injection or infiltration sites must be such that the residence times of recharged reclaimed water complies with the requirements of risk analysis.

In this context, this article presents the methodology developed for the Recycled Water Master Plan of the Besós-Tordera river basins, two small catchment areas near Barcelona, that are highly populated, concentrate intensive industrial demand, require water for both agriculture and golf courses and need to complain with the quality and quantity standards of surface water under semi-arid climate conditions. As indicated above, the methodology combines multiple ratios of different nature -distance to water sources, infrastructure, hydrological regime and storage capacity of the aquifers- that results in a scoring tool that it is a relevant tool for decision making.

Groundwater Hydraulics. Computing Groundwater Into/Out Flow for Lakes (Study Case Lake Qarun, Egypt)

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KEY WORDS
Groundwater; Lake Qarun; out/inflow water; Water budget.

ABSTRACT
The evaluation and estimation of groundwater flow into/out lakes are extremely important for conservation and better management of water resources. Applying the hydrology budget balance for lakes take the interaction between the inflow and the outflow water from a lake into account very useful. Groundwater amount is the most difficult component to be measured or estimated in the water budget equation. Most of the previous studies assumed that the residual of water budget to be the groundwater flow to the lake. Study to estimate the groundwater towards the main Egyptian lakes took place. From this study a numerical module is prepared and presented in this paper. Lake Qarun in Egypt is taken as a study case. It is located in the North of the Western Desert of Egypt. Its region has a unique nature and a biological diversity. Lake Qarun serves as a drainage reservoir, a fishery and also as a touristic place. In addition, it is considered one of the oldest lakes all over the world. The groundwater magnitude was determined by using the presented model which based on Darcy's law. In addition, groundwater analysis included net flow analysis conducted for El-Fayum depression region which acts as a lake watershed. The net flow analyses show that the direction of most groundwater flow is towards the lake from the El-Fayum depression region. The model results show that the lake Qarun receive approximately 47.92 million m3 groundwater annually. Thus, Groundwater act as an inflow component in water budget equation. The presented model is suitable for application on the other lakes.

How can NGOs support collective action among the users of local drinking water systems? A case study of Managed Aquifer Recharge (MAR) systems in Bangladesh

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KEY WORDS
Managed aquifer recharge; coproduction; non-governmental organizations; collective action; drinking water systems.

ABSTRACT
The governance of shared local drinking water systems (DWSs) requires users to act collectively, particularly to guarantee continued operation and to avoid over-use. However, users rarely manage to organize such collective action successfully by themselves. These results in frequent premature abandonment of DWSs. Non-governmental organizations (NGOs) are frequently called upon to support local communities to set up local collective action required for sustainable DWS governance. However, the effectiveness of such forms of NGO support still remains unclear. Therefore, this paper attempts to assess the form and impact of this kind of NGO support. Combining insights gained from theory on institutions for collective action in the context of shared resource systems, we develop a set of requirements presumed necessary for guaranteeing both day-to-day and long-term collective action among local shared DWS users. We apply this framework to empirically explore if, how and why NGO support targets these requirements, and whether this support influences users' capacity for collective action. To this end we examine 11 cases where NGOs have worked with users of Managed Aquifer Recharge (MAR) systems in Bangladesh. We collected data through focus group discussions with users and semi-structured interviews with NGO officials, and project staff, and by reviewing project documentation. We find that NGO support favors long-term requirements over the requirements for day-to-day collective action. NGO activities seem based on the application of standard approaches to training and awareness raising, and less on empowering users to craft their own solutions. Our results imply that when attempting to organize effective and long-lasting forms of collective action among the users of shared resource systems, both NGOs and commissioners of projects need to engage more explicitly in learning what works and what doesn't.

Vulnerability of the aquifer system from the Nhartanda Valley (City of Tete, Mozambique)

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KEY WORDS
Groundwater, Vulnerability, GOD and DRASTIC indexes, Nhartanda Valley, Mozambique

ABSTRACT
Water is an essential and indispensable resource and must occur in appropriate quantity and quality. However, sometimes quantitative and qualitative water availability is not adequate to local requirements. Generally, groundwater has a better quality than surface water and is less vulnerable. The main objective of this research is the vulnerability assessment of the Aquifer System in the Nhartanda Valley, City of Tete, Mozambique. The floodplain area has approximately 6.76 km^2 and an altitude ranging between 125 m-130 m. The water is collected for public supply in the "ancient" city of Tete. In addition to this activity, there is a traditional agro-livestock farm in the Nhartanda Valley whose irrigation is guaranteed by artesian wells and domestic wastewater from the adjacent areas. These and other activities could affect groundwater quality. In situ water determinations and laboratory analysis were performed to assess water quality in the study area. Groundwater vulnerability was determined through the application of GOD index vulnerability for the wells and DRASTIC index for the holes. The vulnerability indexes of the Nhartanda Valley aquifer vary from moderate, high to very high. It is believed that during hot and humid seasons, the vulnerability index can reach to extreme levels, being reached relatively quickly by harmful organisms and substances. According this, a specific set of actions and measures will be necessary for Nhartanda Valley aquifer which main function is to provide water for human consumption. These actions necessarily must involve social and environmental awareness of civil society and local and regional population.

Alluvial Aquifer Filtration as a Pre-treatment Option for ASR

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KEY WORDS
Aquifer Filtration, ASR, Water Quality, Agricultural Demand

ABSTRACT
Water treatment is typically necessary prior to injection for Aquifer Storage and Recovery (ASR) wells to meet regulatory water quality requirements and/or reduce the potential of ASR well clogging. ASR water treatment can be a significant component of the overall cost of an ASR project and can limit the use of ASR in non-municipal areas where existing water treatment infrastructure is not present.

Fifteenmile Creek in rural north-central Oregon, USA is home to threatened fish populations that are exposed to low flow and high-water temperature conditions during late summer periods. ASR to support agricultural irrigation demands in lieu of Fifteenmile Creek summer time surface water diversions is being evaluated as a method to increase summer flows and alleviate high water temperatures. Under the ASR program, creek surface water would be injected into the deep basalt aquifer during the winter and early spring when surface water flows are more abundant. The injected ASR water would supplement agricultural demand pumping in the late summer to reduce surface water diversions and allow water to remain instream. A primary question for the proposed ASR program is whether the alluvial aquifer, through aquifer filtration, can be used to filter captured surface water for ASR injection.

A program to characterize the near-surface sediments and shallow alluvial aquifer along Fifteenmile Creek was performed to determine near-surface and aquifer properties and water quality improvement from aquifer filtration. Shallow test pits were geologically logged to evaluate the lithologic conditions of the vadose zone and alluvial aquifer. Test wells were installed in the alluvial aquifer and in-situ tests conducted to quantify alluvial aquifer permeability. Single-ring infiltrometer tests were performed to estimate surface infiltration rates for passive infiltration and collection systems. Groundwater and surface water samples were collected and analyzed for water quality parameters. Using the field investigation data, an analytical model was applied to evaluate drawdown resulting from alluvial aquifer pumping wells near the creek and to determine well design criteria. The presentation will present test program methods, results, and feasibility of aquifer filtration to cost-effectively improve water quality for ASR injection.

Correlation of the infiltration velocity with the hydraulic load of operation on a treated wastewater infiltration basin

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KEY WORDS
Hydraulic load, SAT, Wastewater, Correlation.

ABSTRACT
The aim of this project was to artificially recharge an aquifer. To achieve such task, it is fundamental to have a recharge source of adequate quantity and quality. Using treated wastewater to as recharger establishes predictable volumes of acceptable quality and velocity. The state of the aquifers that supply potable water to a city in Mexico, Chihuahua city, the infrastructure, and the secondary treatment that wastewater undergoes there makes it a possible candidate for stablishing an artificial recharge project in the area. In this context, the recharge site was selected in the southeast part of the city, where a treatment plant is located. An infiltration basin was built 5 m deep and with a width of 20 x 20 m2. The site is located on an unconfined aquifer with a 75 m average depth to the groundwater table. This aquifer is formed of alluvial deposits, with an estimated thickness of 400 m and an average vertical hydraulic conductivity in the order of 10-5 m/s. The soil-aquifer treatment was put into operation in two different phases: the first one composed of a hydraulic test, and the second one testing the elimination of contaminants. This research project focuses on the first phase. As for the objective of the first phase, it was to determine the hydraulic load of operation that favors vertical infiltration in the system. This recharge pilot's operation takes place under a scheme of alternative cycles of flooding and drying. These flood/drying cycles maintain the aerobic conditions of the site's subsoil, favoring the photochemical processes due to the high solar radiation in the area. Correlating other indirect testing, in the way of geophysical investigation, with infiltration and pumping test, allowed to propose an array of diverse hydraulics loads. Applying directly the obtained hydraulic loads, as well as the cycle time, helped determine the optimal operational hydraulic load. The result of this investigation establishes the adequate residence times, flood/drying cycles and hydraulic load, that adapt to the hydrogeological characteristics of the area. This contribution aims to provide a methodology for the implementation of soil aquifer treatments for operative agencies.

En un proyecto de recarga inducida de acuíferos, es fundamental contar con una fuente de recarga de agua de calidad y cantidad suficiente. Utilizar agua reciclada para recargar establece un volumen predecible, a una velocidad uniforme y de calidad constante. Las condiciones en los acuíferos que suministran agua potable a la ciudad de Chihuahua; además de la infraestructura de saneamiento y tratamiento de aguas residuales a nivel secundario, otorgan la factibilidad para un proyecto de recarga inducida. En este contexto, el sitio de recarga fue elegido en la parte sureste de la ciudad de Chihuahua donde se encuentra la planta de tratamiento sur. La balsa de recarga fue construida de 5 m de profundidad y 20 x 20 m2 de ancho. El sitio se encuentra emplazada en un acuífero libre con profundidades promedio del nivel estático de 75 m. El acuífero está compuesto de depósitos aluviales de un espesor estimado de 400 m con una conductividad hidráulica vertical del orden de 10-5 m/s. El sistema de tratamiento suelo-acuífero se puso en funcionamiento en dos fases: la primera es una fase de prueba hidráulica y la segunda es una prueba para la eliminación de contaminantes. Este trabajo de investigación se enfoca en la primera fase. El objetivo fue determinar la carga hidráulica de operación que favorezca la infiltración vertical. La operación de este piloto se lleva a cabo bajo el esquema de ciclos alternativos de inundación y secado en una balsa de infiltración. Los ciclos de inundación/secado mantienen las condiciones aeróbicas en el subsuelo, además de favorecer los procesos fotoquímicos por la alta radiación solar. Correlacionando los estudios indirectos (geofísica de los estratos rocosos) con pruebas de infiltración permitieron proponer diversas cargas hidráulicas. Mediante la aplicación directa de las cargas hidráulicas y los tiempos de ciclo seleccionados, se determinó la carga hidráulica óptima operacional. El resultado de esta investigación permite establecer los tiempos de residencia, ciclos de inundación-secado y carga hidráulica que se adaptan a las características hidrogeológicas de la zona. La contribución del estudio otorga una metodología de implementación del manejo del sistema de tratamiento suelo-acuífero a organismos operadores.

Managed Aquifer Recharge to Support Environmental Outcomes on the Katarapko Floodplain

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KEY WORDS
Katarapko, Floodplain, Recharge, Groundwater, Environmental

ABSTRACT
The Katarapko Floodplain has significant cultural, social, recreational and environmental value, with most of the floodplain included in the Murray River National Park, and Katarapko Island gazetted as a National Park in 1970. The health of many riverine floodplains has been in decline for several decades because of river regulation, over allocation and use. This decline in health and loss of ecological habitat has been exacerbated over the period of the Millennium Drought (2000 to 2010). The percentage of healthy trees (River Red Gum, Black Box and River Cooba) on Katarapko dropped from 43% in 2002 to 22% in 2007.

The South Australian Riverland Floodplain Integrated Infrastructure Program (SARFIIP) aims to create an interconnected mosaic of manageable floodplains. Infrastructure has been proposed to improve the ecology of the Katarapko floodplain including groundwater management schemes to reduce the regional saline groundwater influx to the floodplain and to protect or enhance the availability of lower salinity groundwater to vegetation.

The works and measures aim to provide a more natural (albeit engineered) pattern of inundation frequency and duration over approximately 1,300 ha of the Katarapko Floodplain. Inundation of the floodplain is anticipated to provide some vertical infiltration of low salinity surface water, creating and replenishing the freshwater lenses, improving soil moisture content, and reducing soil salinity. However, some key risks have been identified because the groundwater and soil profiles have salinity concentrations greater than 15,000 mg/L. It is predicted that groundwater level rise in response to managed inundation events may mobilise highly saline groundwater displacing the existing freshwater lenses and increasing salt loads to the river. Therefore, vegetation benefits may not be fully realised due to existing high soil salinity levels not being reduced under managed inundation or potentially increased salinization due to raised groundwater levels.

Injection of freshwater using managed aquifer recharge approaches to the more saline groundwater system is being trialled as a potential option to mitigate against the possible displacement of the existing freshwater lenses and expand existing zones of lower salinity groundwater. A key knowledge gap for the future design of groundwater management infrastructure on floodplains is validation of injection as a reliable mitigation option to preserve the freshwater lenses. This paper presents the results of the first stage of the managed aquifer recharge trial aimed at increasing the understanding of the technical feasibility of injecting river water into the floodplain via bores; the effectiveness of the injected water in freshening the groundwater noticeably and extensively; the timing of changes; and the impact on surrounding groundwater gradients.

Managed basin recharge – enhancements to overcome hydrologic issues

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KEY WORDS
Site characterization, vadose zone, aquifer anisotropy, perched aquifer, enhancement features

ABSTRACT
Managed aquifer recharge (MAR) through the use of infiltration basins has been practiced for many years. Over the past 20 years, the use of infiltration basins for direct or intentional MAR has increased dramatically. Further, the sources of water to be recharged have also expanded to include treated effluent or reclaimed water, surface water, storm water, and in some cases treated potable water.

Some basins have the ability to recharge water within hours of application while others may take days. Basin design can influence infiltration rates to some degree but subsurface hydrogeologic conditions play a much greater role. Therefore, investigation of the subsurface hydrogeology is essential during the initial siting of basin recharge facilities. The initial siting may be based on published literature, groundwater well records, driller's logs, geophysical surveys, and/or other public records. However, once a preferred location is established, detailed analysis of the subsurface lithology is essential to identify site-specific conditions that may reduce or inhibit effective MAR. Such conditions may include formation heterogeneity, confining layers, elevated percentages of fine-grained sediments, clay layers, caliche, and shallow regional and/or perched groundwater tables. The investigation of subsurface conditions can be accomplished through the collection of data from test pits, geotechnical borings, ring infiltrometer tests, pilot basin tests, and/or piezometers.

The concepts of anisotropy and hydraulic conductivity (both vertical and horizontal) must be understood such that infiltration rate calculations can be performed to estimate performance of a proposed facility. Additionally, if problems are identified during the detailed analysis, infiltration enhancement techniques can be built into the design, increasing performance and thus adding value to the project. For example, the presence of shallow confining layers may require the installation of drainage trenches to facilitate infiltration of water to deeper portions of the vadose zone. Deeper restrictive subsurface conditions may require the use of drain holes to create preferential pathways. Combined enhancement technologies may also be required. While these infiltration enhancements can be added after a facility is constructed and operating, the facility will have to be taken off line during the rehabilitation so the costs will be higher, and valuable aquifer replenishment will be lost. Therefore, proper planning including a detailed hydrogeologic investigation will ensure that your next MAR project will be a success.

Combining social and hydrogeological factors for MAR site selection in southwest Bangladesh

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KEY WORDS
Bangladesh, hydrogeology, demand, site-selection

ABSTRACT
In southwestern Bangladesh, the groundwater salinity, surface water pollution and high seasonality of rainfall lead to a large scarcity of clean drinking water. For this reason, community scale MAR-systems have been proposed and have been implemented. However, the success rate of these MAR-systems varies due to a variety of reasons, and some have already been completely abandoned. Therefore, a suitable site selection method should be developed before MAR-systems are to be implemented at a regional scale. For this, it is important to determine why people would actually switch over to MAR water from their current water option. A suitable aquifer where the MAR-technology would work well is a necessary but not necessarily sufficient conditions for such a switch-over. In this study, we analysed site selection factors for small scale MAR-systems from both a socio-economical and hydrogeological viewpoint. For the socio-economical factors, a survey based on the RANAS model was conducted to assess what motivates the target population for their current water option, or which factors render people receptive to MAR. Hydrogeological MAR potential has been based on the understanding of groundwater salinity variation using a spatial database of 2440 groundwater salinity observations.

The preliminary results hint at a mismatch between the hydrogeological potential for MAR and the willingness-to-accept MAR. People that live in suitable areas for hydrogeological potential generally have access to fresh groundwater, and are therefore less willing to change to MAR water. In those areas, the MAR water needs to offer more benefits than it currently does for people to adopt it. At the same time, in areas where people can be expected to be willing to change to MAR systems, the groundwater is more likely to be very saline, and it will be much harder for the MAR systems to function well. In those areas, a proper MAR-design is required to produce fresh enough drinking water.

Dipolic MAR "Bubble" Inside Confined Brine Formation or Floating "Lens" on Top of Unconfined Saline Aquifer

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KEY WORDS
sharp seawater interface; phreatic surface;; mathematical modeling, ; MT3DMS–SEAWAT, MAR

ABSTRACT
In desert environments as Oman and Turkmenistan, MAR sites are often characterized by high salinity of the ambient target aquifer (ATA) and intensive evaporation (Kunin, 1959). We present mathematical modeling of two scenarios: 1) injection-abstraction of fresh (tertiary treated or desalinated) water through two horizontal wells into a confined ATA containing a pristine brine and 2) infiltration from a surface pond of "takyr" type (mild topographic depression of desert surface, with a cake of fine and cracked silty sediments, Babaev, 1999) into an unconfined saline ATA. A fresh water "bubble" bounded by a sharp interface and a UFO-shaped lens capped by a phreatic surface and subtended by a sharp interface are formed in the two corresponding scenarios. Our analytical solutions for steady, 2-D and axisymmetric Darcian flows of fresh water interfaced by stagnant saline water utilize two types of mathematical dipoles: combination of a line sink and source (Strack, 2017) and superposition of a Tothian distributed sink and source. For 2-D dipoles, the theory of holomorphic functions is used (conformal mappings and the Keldysh–Sedov representations of characteristic functions via singular integrals, Kacimov et al., 2018). Explicit closed-form expressions for the interface, flow net, isohypses, magnitudes of the Darcian velocity and Riesenkampf's resultant force (determining stability of the ATA skeleton against heaving, suffusion, colmatage and other deleterious phenomena) are obtained and discussed. MT3DMS and SEAWAT are also used for delineation of isoconcentric lines, which qualitatively corroborate the analytical solutions in delineation of the "bubble". For axisymmemtric floating lenses, which are partially recharged from the "takyr" bed and partially exfiltrate to the vadose zone due to intensive evapotranspiration, U-turn topology of fresh water circulation is similar to the 2-D case of Strack (1978). For the Dupuit-Forchheimer approximation, a boundary value problem for an ordinary differential equation in terms of the Strack potential is explicitly solved. The total volume of fresh water circulating within the lens is evaluated. Constant MAR and evaporation rates, as well as evaporation linearly decreasing with depth of the phreatic surface are considered.

Integration of time-variable scaling factors in HYDRUS to simulate the reduction of hydraulic conductivity due to clogging during managed aquifer recharge operation

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KEY WORDS
Numerical modelling, managed aquifer recharge, clogging, HYDRUS

ABSTRACT
Clogging represents one of the most important issues during the operation of managed aquifer recharge (MAR) schemes as it reduces the infiltration capacity of the system, which can significantly decrease the system efficiency and can lead to the failure of the whole system. Nevertheless, the assessment, quantification, and prediction of clogging is not trivial as it very much depends on multiple processes that cause clogging and that are specific for each MAR scheme. A number of studies have attempted to estimate the clogging rate in injection wells and infiltration basins in laboratory or field experiments. However, modelling of clogging has been limited. For a realistic simulation of processes occurring at the infiltration interface between spreading methods and unsaturated zone wells, the use of a model that is able to simulate unsaturated water flow and solute transport is required.

The variably-saturated water flow model HYDRUS, which was used in the past to simulate MAR schemes (e.g., Ringleb et al., 2016), was modified to include time-variable hydraulic conductivities to more realistically simulate clogging in the vadose zone of infiltration basins and/or recharge wells. An exponential function with a time-variable scaling factor was integrated into HYDRUS to change the soil hydraulic conductivity over time. In combination with the reservoir boundary condition (Šimůnek et al., 2018), the new approach was tested by simulating 2D cross-sections of 3D laboratory experiments representing recharge by infiltration basins and wells. With the help of the time-variable scaling factor, the increasing ponding depth in both experiments due to clogging was reproduced.

The simulations showed that the time-variable scaling factor, especially in combination with the reservoir boundary condition, is a simple and useful approach to more realistically simulate MAR schemes exposed to clogging. It can be applied to numerically evaluate the resulting infiltration capacity and help in the operation and design of MAR facilities. Nevertheless, it is only a very simplified way to represent clogging, and further research is required to fully understand and simulate the processes that lead to clogging in MAR schemes.

Title – Slippage Effects of Managed Aquifer Recharge within Agricultural Lands: Evidences from a Landscape Level Model

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KEY WORDS
Slippage, agricultural managed aquifer recharge, surface reservoir storage, crop choice, groundwater conservation policies

ABSTRACT
In response to irrigation efficiency adoption's failure to reduce aquifer depletion, and social and environmental oppositions to surface reservoirs, water policy makers are shifting the focus on water supply augmentation effort through managed aquifer recharge (MAR) by capturing of excess surface water during non-irrigation periods and putting the water into partially empty aquifers for future use. However, previous studies rarely address economic tradeoffs, such as whether rising groundwater levels will influence crop choice and groundwater pumping dynamics, or whether, given the availability of surface water, whether surface reservoir storage would be more cost effective than MAR. We address this knowledge gap by using a landscape level model to examine the optimal interaction among MAR, surface reservoir storage, crop choice, and groundwater conservation polices in Eastern Arkansas, USA. The results show that the optimal MAR requires a cost of recharge much lower than the average groundwater pumping cost to significantly increase the aquifer level and there is evidence of a large slippage coming from the MAR, ranging from about 20% to 90%. At a cost of MAR that is half the average groundwater pumping cost, about 40% of recharged water is offset through increased groundwater use due to extensive margin changes into irrigation, leaving about 60% of recharged water as a true method of offsetting overdraft. The true offset is at the lowest level at cost of MAR that is approximate to average groundwater pumping cost. At higher MAR costs, the share of recharged water that is a true offset is much higher than 60%, but the total quantity of MAR is much lower. Polices to conserve groundwater are more cost-effective for society with the availability of MAR.

Conjunctive Use of Aquifer Storage Recovery Wells and Desalination to Mitigate Salt Water Intrusion and Achieve Water Supply Reliability

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KEY WORDS
Aquifer Storage Recovery, Desalination, Salt Water Intrusion

ABSTRACT
As a water management tool, ASR is increasingly utilized in conjunction with desalination and other advanced water treatment processes, particularly in coastal and other areas subject to salt water intrusion. This reduces overall capital and operating costs while achieving water supply reliability, providing drought and emergency water supplies when needed, plus meeting peak seasonal demands from aquifer storage. Examples include two ASR programs at Hilton Head Island, South Carolina, which have now been operating for about five years, plus three in Texas which are in development. There are many other examples, but these will be discussed, including lessons learned during the development and implementation of these projects.

The two projects at Hilton Head Island are storing seasonally-available desalted water from a local aquifer in which freshwater production wells are being steadily lost to salt water intrusion. Aquifer recharge is augmented by importation of water from the mainland during winter months. These are two of eight ASR wellfields in coastal South Carolina, one of which has been operational for more than 25 years. Analysis of five years of operating data from these two Hilton Head projects provides a useful perspective on their success.

The three ASR projects in Texas include Barton Springs, New Braunfels and Galveston, all of which are in early stages of development and include ASR storage in deep, confined, brackish to saline aquifers, primarily to provide drought water supply reliability but also to meet normal seasonal peak demands. For Galveston, a key additional ASR objective is to prevent any further subsidence in this low, coastal area which has already experienced up to about 2 m of subsidence due to historic groundwater withdrawals. An interesting element for two of these ASR projects is the planned vertical stacking of ASR storage in two or more aquifers at the same location.

If selected for presentation, and depending on whether this abstract is assigned to Session 14 or 8, the content will be oriented more toward the theme of that session.

Assessment of aquifer storage and recovery efficiency in coastal aquifers

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KEY WORDS
Aquifer, storage, recovery, efficiency, model

ABSTRACT
Aquifer storage and recovery plays a significant role in effective freshwater management in coastal areas. Recovery of fresh water from an ASR system in a coastal aquifer depends on many factors, including the operating system, salinity, aquifer properties, and the regional hydraulic gradient. 100% recovery efficiency is not possible. The main reason for a decrease in the recovery efficiency is the density difference. As the fresh water is lighter than the saline water, the injected fresh water flows slowly upward to the top of the aquifer. This results in an inclined interface during injection and recovery. Recovery of the fresh water has to be stopped when the interface reaches the bottom of the well to prevent withdrawal of the saline water. The rest of the fresh water remains unrecoverable. Moreover, if the storage period is considerable, all fresh water may flow to the top of the aquifer, resulting in a recovery efficiency of zero. Bakker (2010) studied aquifer storage and recovery efficiency with a radial model with injection and recovery over the entire aquifer thickness. The objective of this study is to increase the recovery efficiency by injecting and recovering fresh water at different depths in the aquifer. A radial one-dimensional multi-layer model has been developed. The model has been applied to investigate various scenarios to determine optimal operation of ASR and higher recovery efficiencies. A tool is developed that is computationally far more efficient than a complex salt water intrusion model. This tool can be applied to assess the feasibility of an ASR scenario and determine the optimum operation method to maximize recovery efficiency.

Managed of the ground water aquifer under the Nile delta

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KEY WORDS
Sea level rise, saltwater intrusion, Low lands

ABSTRACT
Sea level variations have occurred throughout history. Sea level changes are caused by several natural phenomenon such as the rise of global temp causing the melting of ice at the poles and on the mountains. The rise of sea level might drown some low lands in the world. One of the dangerous effect of the sea level rise is the salt water intrusion under the Delta and may be drowned unless certain precautions to be taken. According to the previous researches, the relative rise during the century at the Egyptian coasts might reach 1 m.

This paper presents the expected effect of this rise on the delta. Study of the salt water intrusion under the delta and the necessary precautions to safeguard the coastal area of the delta against drowning are presented .Suggestions to protect the delta against the sea level rise are included in the paper .the groundwater resevoir under the nile delta is studied carefully. Some of this water is pumped for the purpose of irrigation and some of the water perculate towards the sea. The recharge of this reservoir comes from the seapage water of the irrigation system in the delta and the precipitaion of the land. This study concentrated on the flow towards this aquifer and the outflow seapage to the sea. Also the salt water intrusion under the delta take big attension in the study presented in this paper. Van der veer solution is used in the analyses of intrusion and determining the aquifer outflow at the sea.

Retrospective on 10 years of risk-based guidelines for managed aquifer recharge

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KEY WORDS
Environment protection, health protection, safety, ecosystems, contaminants, recycling, drinking water, regulation, governance

ABSTRACT
The first Managed Aquifer Recharge Guidelines based on risk-management principles that underpin World Health Organisation's Water Safety Plans were published in July 2009. These were the Australian MAR Guidelines which were one of the Australian Water Recycling Guidelines set within the framework of the Australian National Water Quality Management Strategy. The MAR Guidelines were developed consultatively over three years and approved by three Council of Australian Governments (COAG) Ministerial Councils involving all state and national ministers representing natural resources management, environment and heritage protection and public health. They were immediately welcomed and implemented in the three states most active in MAR: South Australia, Victoria and Western Australia. In 2015 a survey was conducted of Australian MAR project proponents, consultants and regulators and revealed broad support for these guidelines. However the rate of uptake of MAR has varied widely among jurisdictions, for reasons that are not explained by the drivers for and feasibility of MAR. The guidelines were lauded for giving certainty on approval processes and being pragmatic to use, but there were also comments on onerous data requirements and lack of clarity in some areas. It was originally intended that these guidelines would be revised after five years, informed by experience, new scientific developments, advances in monitoring and control methods and ecosystem health indicators, and exposure to any hazards not considered in the guidelines. This has not occurred and now Australia is reaching ten years of application of its MAR guidelines. This paper, which has broad authorship, reviews each of those topics and identifies improvements that warrant consideration in their revision. It is intended that this will inform Australian water regulators and also interested international observers who may be considering adopting or developing their own guidelines based on a scientifically supported approach to risk management. The paper will also draw conclusions where possible on the value to Australian jurisdictions of having MAR guidelines. It will also identify factors affecting international applicability of these guidelines, particularly with regard to capabilities required for implementation.

Large scale soil-aquifer-treatment (SAT-MAR) physical model experiments to remove rice paddy field contaminants

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KEY WORDS
Agriculture water reclamation, Soil-Aquifer Treatment (SAT), physical model, water reuse.

ABSTRACT
The effluents from agriculture practices, namely from rice paddy fields, usually contain several contaminants creating an environmental concern to downgradient water bodies. The use of Soil-Aquifer-Treatment (SAT) systems to improve the effluents water quality, during the transport of infiltrated water through the unsaturated and saturated zones, can bring a solution for water reclamation, water reuse (e.g. for recharge), and overall as a water resources management tool.

The research described in this paper was carried out under MARSOL (Demonstrating Managed Aquifer Recharge as a Solution to Water Scarcity and Drought) EU project, whose main objective was to demonstrate that MAR is a sound, safe and sustainable strategy that can be applied with great confidence and therefore offering a key approach for tackling water scarcity in Southern Europe.

SAT-MAR experiments were developed in a physical (sandbox) model (3.5 m x 1 m x 2 m)[1] built during MARSOL project. These experiments aimed to contribute solving the problem of removing rice field contaminants from water, using a soil-aquifer prototype basin to treat water prior to its discharge in Melides lagoon, Alentejo, Portugal. The sandbox model was divided into three sections (A, B and C) to test the adsorption and degradation capacity of three soil profiles, two of them including soil mixtures of sand with vegetal compost with different layouts. In each section, two tracer experiments were performed with spiked fertilizer and hydrocarbons. To analyse the behaviour of the tracers, monitoring devices were installed in each section: two Prenart capsules, at 30 and 60 cm depth, and one piezometer with continuous *in situ* reading of T, EC, water level (and discrete analysis of pH and redox). Each section was modelled with FEFLOW using the data collected.
The results obtained in the SAT-MAR experiments gave useful knowledge necessary to build in the future an *in situ* SAT-MAR facility.

Figure – LNEC physical (sandbox) model

[1] http://www.lnec.pt/en/research/research-infrastructures/fluvial-hydraulics-experimental-facility/

Suitability maps for managed aquifer recharge: review and tool development

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KEY WORDS
Managed aquifer recharge, webGIS, multi-criteria decision analysis, suitability mapping

ABSTRACT
Suitability maps for managed aquifer recharge (MAR) sites are increasingly derived through GIS-based multi-criteria decision analysis (GIS-MCDA). To date, there are no guidelines or common understanding on how suitability mapping should be conducted. There is considerable variability concerning the base GIS maps used and how they are weighted. To showcase the development as well as the state of the art of GIS-MCDA in the context of MAR site selection, we retrieved information on used criteria, assigned weights and utilized methodologies from 63 related studies.

The data was compiled into a web-based query tool that makes the information easily accessible and the utilization of the database more user-friendly. Based on the most commonly used practices in the assessed studies, we conceptualized and implemented an online tool that comprises a simplified webGIS as well as supporting tools for weight assignment and standardization of criteria. The online tool guides the decision maker through a structured process of suitability mapping, starting with problem definition, followed by constraint mapping and finishing with suitability mapping. Different weighting procedures, such as rank method, multi-influence factor or pairwise comparison are implemented as well as decision rules in form of weighted linear combination and analytic hierarchy process. Starting from uploading the base GIS maps for the assessment to the final suitability map, the user is supported by relating information from the database to each step of the decision making process.

This review as well as the created web-tool will help planners of MAR sites to engage in MCDA in a more structured and informed way by referring to previously conducted studies and by finding information suitable for their specific project. Suitability maps for MAR hold a strong potential for integration into sustainable groundwater management plans. However, quality of the maps strongly depends on input data quality as well as expertise of the decision maker. To decrease the uncertainty related to the decision makers, we need a common standard on how suitability maps should be derived. This tool as well as the underlying review help to guide the discussion and show advantages and disadvantages of the maps.

Preventing pluvial flooding and water shortages on various scales by integrating aquifer storage and recovery in urban areas

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KEY WORDS
ASR, urban, stormwater, rainwater harvesting

ABSTRACT
Water management in urban areas forms a bigger-and-bigger challenge due to intense rainfall events and the increasing water demand for e.g. irrigation, non-potable use, and replenishment of city ponds during droughts. Rainwater harvesting and reuse is more-and-more applied and can be successful in providing a high-quality additional water source. But, creating large storage volumes is dense urban areas is generally costly or unfeasible and poses water quality threats. However, managed aquifer recharge can be used to 1. open up vast storage volumes in aquifers to really capture the majority of local rainwater and 2. provide water quality improvement before reuse. Due to its limited spatial footprint, especially aquifer storage and recovery (ASR) can be an interesting MAR-technique in urban areas.

The Urban Waterbuffer concept was developed and tested by KWR together with city planners, industrial designers, urban water managers, and Delft Technical University. It aims to collect and retain rainwater on a 'building to neighbourhood scale' and pre-treat it with green infrastructure (wetlands, pond bank filtration, green roofs, sand filtration) such that it can be used for infiltration by an ASR system. This sets strict limits for the chemical water quality to prevent groundwater pollution and well clogging. With the proper set-up of the rainwater collection and treatment scheme, water quality demands can however be met. By incorporating short-term retention on roofs, in ponds, and at the street level, most of the rainfall in the moderate Dutch climate could be harvested and infiltrated, despite the relatively low infiltration rate of ASR wells (compared to the rainfall intensity).

Examples are presented from the area of Rotterdam (The Netherlands) to demonstrate the set-up and performance of the Urban Waterbuffer on a building-scale (425 m^2; recharging 250 m^3/yr), on a neighbourhood-scale (30 000 m^2; recharge and recovery of 15 000 m^3/yr for urban irrigation), and on the interconnection of neighbouring urban and horticulture areas (1 200 000 m^2; 600 000 m^3/yr recharge and recovery for greenhouse irrigation) via ASR.

Enhanced oxygen saturation during SAT: experiences from large-scale column experiments

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KEY WORDS
Soil aquifer treatment, laboratory experiments, Israel, waste water treatment

ABSTRACT
The soil aquifer treatment (SAT) plant in Shafdan, Israel, is a long operating managed aquifer recharge site where conventionally treated waste water is infiltrated into large-scale basins and later recovered from the groundwater to irrigate agricultural sites in the Negev desert. During the course of a preliminary project, a laboratory column was built of 6 m height, 15 cm diameter and filled with original soil from the Shafdan basins (Yavne 2). The column provides a good representation of the hydraulic conditions at the field site and is well equipped to assess hydraulic as well as biogeochemical processes in the unsaturated soil zone. It is operated with synthetic waste water or with treated waste water from Dresden (Germany) waste water treatment plant.

This study aims to find optimal infiltration scenarios for the existing site in Shafdan in order to increase infiltration while meeting all qualitative requirements for groundwater recharge. In order to improve the efficiency of organic compounds degradation of the basins, we try to optimize the oxygen saturation in the soil. Increasing oxygen in the soil matrix leads to a higher treatment efficiency but it simultaneously decreases the recharge rate to the aquifer. We seek to balance the optimal oxygen saturation and infiltrated volume, such that both factors are maximized. Thus, we are assessing different hydraulic loading ratios of 1:2, 2:5 and 1:4 (wet: dry) as well as varying lengths of the infiltration phase by increasing it 30 min per scenario.

Preliminary results show that longer drying periods can avoid a complete depletion of oxygen and maintain an oxidative redox condition in the upper soil layers (above 2m depth), as well as keep a balanced oxygen concentration in the lower layers (below 2m depth). Organic analyses (DOC, NH_4^+, among others) showed that with high oxygen levels these compounds can be reduced nearly completely. A hydride configuration of the infiltration (e.g. intermittent ratio of 1:2 & 1:4) can keep the recharge on a high level but when the oxidative capacity of the media is reduced below a threshold value, a longer dry period can be established to let the system regenerate for further infiltration cycles.

Effects of ionic strength on the bio-clogging formation in MAR

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KEY WORDS
Bio-clogging; ionic strength; managed aquifer recharge; clogging removal

ABSTRACT
Biological clogging is one of the most common types of clogging which may occur during managed aquifer recharge. The dynamics of bio-clogging are influenced by a wide range of factors such as chemical conditions of the aqueous and solid phase. A series of experiments were carried out to determine the most suitable and limited conditions of ionic strength. Environmental characteristic parameters (pH, ORP, Eh…), and protein content was measured to characterize the retention of biomass in sand columns. A second objective was to elucidate the mechanism responsible for this process. It indicates that alkaline substances produced by Pseudomonas aeruginosa causing the dissolution of SiO_2, CaO, MgO Al_2O_3 in sand, and as a result, there is a relative balance between the space occupied by EPS produced by bacteria and the gaps released by the dissolution of soluble substances in quartz sand during the early stage of bio-clogging, which will make the prediction of clogging more difficult. And more ions of Ca^{2+}, Mg^{2+}, Al^{3+}, Si^{2+} which dissolved from sand, were absorbed and deposited by EPS which were gelatinous substances. Finally, the reprecipitation of Ca^{2+}, Mg^{2+}, Al^{3+}, Si were absorbed and deposited by EPS might cause further clogging of porous media.

Experiments about bio-clogging removal also have shown antibacterial treatment has an effect to restore permeability of the porous media. Solution of ClO_2 0.5mg/l was pumped into the column and the porous media was infiltrated totally, then, the column was washed continuity by DI water, and hydraulic conductivity recovered from 0.01% to 74% of K_0 after solution of ClO_2 0.5mg/L was added 4 times during 5 days.

These tests present that biological clogging is significantly affected by ionic strength of recharged water, and suggest that the stability of biomass causing the permeability reduction in porous media was probably very strong. It has been proved that solution of ClO_2 0.5mg/L has an effect to restore permeability of porous media and improve the efficiency of MAR.

Recharge System as a Method of Groundwater Recharging

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KEY WORDS
Drainage, Con-water mazhab, Recharge system, Pro-water mazhab, Groundwater storage

ABSTRACT

Drainage engineering is a technique which was implemented since ancient civilization to maintain some places from excess water. Usually the excess water comes from precipitation, which inundates the low elevation of ground surface. The technique implemented till now days is to allow water flow from inundated area to drainage canal then to river and finally to the sea. This technique is not in accordance with sustainable development due to less rain water can infiltrate to the ground and this technique is called Con-water mazhab. Since the last twentieth century many countries had developed manual of storm water management which are compatible to the Pro-water mazhab for instance from USA, Australia, Japan, Malaysia and many formulas from Indonesia. But almost of all the computation of dimension formula of this system in this case recharge well and recharge trench, all together base on the volume water stored it in the certain duration. These formulas are not compatible to the natural flowing of storm water to recharge system drainage engineering which is consist of two types are recharge well and recharge trench. Sunjoto S. (1988), developed analytically a formula of computation of recharge well dimension and for the recharge trench was in 2008. All of those computation formulas will be implemented to compute the dimension of recharge well and recharge trench for the same data and the results will be analysed to get the most reliable formula.

Management of aquifer recharge area as a new approach to tackle groundwater scarcity (Case study: Golestan province, Iran)

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KEY WORDS
Climate Change, Groundwater scarcity, Confined Aquifer

ABSTRACT
Climate change is one of the major challenges of our time which have drawn many experts' attention to. Changing of precipitation patterns as a result of climate change has made negative issues on the sustainability of water resources. So there is increasing trend of serious concerns about adapting and mitigating impacts of climate change. In recent years, Golestan province as a humid and northern province in Iran due to storming rainfalls, flash floods, change of precipitation types from snow to rainfall, and development of residential area on recharge areas of aquifers especially alluvial fans has faced to scarcity of water resources as if annual discharge of some important rivers was reduced more than 50 percent. Furthermore, as far as Golestan province is located on a coastal area, quality of groundwater resources in northern part of Gorgan plain is under threat by seawater intrusion. In this situation, management of recharge area of aquifers in upland watersheds, not just on alluvial fans and floodplains, acts as a key strategy subjected to climate change adaption and groundwater sustainable management. 20 percent coverage of mountain areas by Limestone formations and existence of 7 to 8 confined layers that lies beneath Gorgan plain along with outcrops in uplands have strong potential to recharge aquifers. In this sense, focus on managing recharge area and identifying outcrop zones in upland watersheds has a key role to meet water crisis resources and achieving to Goal 6 Sustainable Development Goals.

New methodology to evaluate the risk failure of Managed Aquifer Recharge in Mediterranean region

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KEY WORDS
Risk-Assessment, Fault-Tree, Recharge, Mediterranean region

ABSTRACT
In this work, a methodology to evaluate the risk of failure of Managed Aquifer Recharge (MAR) has been developed. We applied it to six different facilities located in the Mediterranean Basin: Spain (2 sites), Portugal (1), Italy (1), Malta (1), and Israel (1). The methodology involves the development of a Probabilistic Risk Assessment based on Fault Trees. We considered different categories affecting the operation of the facility. Sixty-five events were defined and they were related to technical and non-technical aspects. When those basic events are combined they form more general events which finally, produce a global failure of the MAR installation when combined. The probabilities of the basic events were defined by expert criteria, based on the knowledge of the different managers of the facilities. It was found that the non-technical aspects can be the most significant ones, contributing more than the technical issues to the overall assessment of risk. We found out that in the facilities analyzed, the major contributors to overall risk were, in decreasing order of importance: Legal constraints, Social aspects, Economic constraints, Quantity issues, Structural damages, Specific targets and Quality issues. Regarding the results on perception of risk for the individual sites, it was surprising that three of them (the two Spanish facilities and the Portuguese one) above 0.90 in a 2-6 year period. The main contributors to failure were related to non-technical reasons and to quantity aspects. In fact, in recent years the three facilities had to be interrupted at least once, indicating that the evaluations provide reasonable estimations. Finally, the Malta site is a very recent one, with little history behind, and thus it is not possible to evaluate whether the perception of risk of 75% is high or low. On the other hand, the perceived risk for the other two sites, located in Italy and Israel, can be considered low (18% and 29%, respectively). One possible reason is that they are the oldest facilities, so experience has been accumulated for decades.

The Effect of Soil Tillage Equipment on Recharge Capacity of Infiltration Ponds

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KEY WORDS
SAT, Tillage, Infiltration pond, Infiltration rate, Soil compaction

ABSTRACT

The Dan Region Reclamation Project (Shafdan) reclaims approximately 125 MCM/y of treated wastewater from the Tel Aviv Metropolitan area. Following secondary treatment, the effluent is recharged into a sandy aquifer for a complementary Soil Aquifer Treatment (SAT), resulting in recovered water of excellent quality and no irrigation limitations. The SAT system also provides a vast storage that cannot be replaced by surface reservoirs. During the last 3 years a trend of decrease in recharge capacity was noticed. Several operational causes for this were considered, including doubts on the exiting tillage procedure of the recharge ponds.

Tillage of the recharge ponds serves for aeration of the upper layer, breaking surface crusts and remove vegetation. The procedure includes a deep (40-60 cm) plowing every 3 months, and shallow (10-20 cm) tillage by sweep-knifes cultivator or discus every 2-3 weeks. However, during the last 2 years the plowing frequency increased to every 3-4 weeks in attempt to maintain the recharge capacity. In this research the existing tillage equipment was compared to chisel-knifes (CK) cultivator and to a deep subsoiler, which may ease soil compaction processes. The tested tillage tools were operated by a stronger tractor, equipped with automated systems for tillage depth and navigation control. The effect of every tool on the infiltration rate (IR), the recharge capacity and the soil compaction was examined. The experiment was conducted during June – August 2018 within a recharge field divided into 9 recharge ponds (~1.5 hectare each), where 6 ponds were treated by the new tillage tools and 3 were treated as usual for comparison.

The results suggest a significant improvement of the recharge capacity: following the subsoiler and the CK cultivator treatments, the IR increased in an average factor of 1.95 and 1.15, respectively, in respect to IR after the plowing treatment. The IR resulting from both treatments was also significantly higher compared to IR of previous years (factors up to 2.3 and 1.4 for the subsoiler and for the cultivator, respectively). In addition, the depth of the compacted soil layer was increased from ~30 to ~55 cm after subsoiler treatment. Important understanding on other operational factors such as drying periods, preparation of the field and soil micro-topography, was also achieved.

Accelerating quality water improvement with horizontal reactive barriers during artificial recharge of aquifers (notes from ACWAPUR project)

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KEY WORDS
Reactive barriers, Redox, Quality improvement acceleration, Infiltration basins.

ABSTRACT
Artificial recharge of aquifers is a robust, low-cost, low-energy technique to deal with the worldwide increasing demand of water. Quality of recharged water is improved during its passage through the soil and concentration of organic matter, inorganic nutrients, emerging organic compounds, and pathogens is reduced as a result of filtration, sorption and biodegradation. The improvement of recharged water quality can be accelerated with the installation of horizontal reactive barriers, to promote sorption and biodegradation, in the bottom of the infiltration basins.
Six meso-scale recharge system were built to test the effectiveness of diverse reactive barriers reducing the leaching of emerging contaminants, pathogens, and inorganic nutrients. Each system (2.5 x 15 m) (Figure 1) emulates an aquifer with an infiltration basin. Wastewater treatment plant secondary effluent is used as a recharge water for the systems and applied only in the section emulating the recharge area. The flow is vertical and under unsaturated conditions in the first meter below the infiltration basin and horizontal and saturated in the rest of the system.
The barriers consist on sand and organic rich components (compost and woodchips) which will promote sorption of organic compounds and release Dissolved Organic Carbon (DOC) into the recharged water. The increase on DOC aims to facilitate the creation of different redox conditions to accelerate both aerobic and anaerobic degradation processes.
The effectiveness of the barriers accelerating water quality improvement has been proven in diverse recharge events.

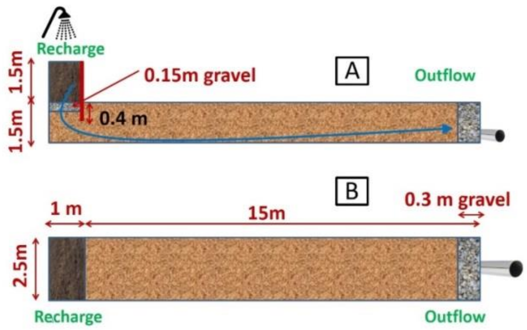

Figure 1 Cross section (A) and plant view (B) of one meso-scale recharge system.

MAR of Geneva: when climate change implies to reassess management perspectives

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KEY WORDS
MAR, climate change, Geneva transboundary aquifer, Arve river floods

ABSTRACT
For nearly 40 years, an artificial recharge system in Geneva has provided more than 300 million m^3 of drinking water in the “nappe du Genevois” main regional aquifer, and transboundary aquifer between Switzerland and France as well.

This system retrieves water from the Arve River, the main natural source of water supply and inject it, after a light treatment, into the Geneva aquifer. The source of the Arve River sits in the Mont-Blanc massif at an altitude of 2000 m. Its watershed collects meltwaters from glaciers culminating up to 4000 m, giving to this river a typical torrential regime. Since the first major drought warning in Western Europe in 2003, it has been noted that high temperatures at high altitudes modify the water quality of the river by increasing significantly its turbidity in summer and therefore prevent any artificial recharge in the Geneva aquifer. The climatic hazards of recent years have then created a change in paradigm regarding the management of artificial groundwater recharge in Geneva. Indeed, on May 2nd 2015, Geneva underwent a 100-year recurrence flooding event of the Arve River that deeply changed the geological conditions of the river bed and banks.

Flows, up to 100 times higher than normal, cleared the river bed from its argillaceous cover, increasing consequently drastically the natural recharge of the aquifer. This results nowadays in an extremely high water table level, leading to conflictual situation regarding important construction sites, but also likely to cause risks for the protection of the resource. Adding on this already critical situation, a pollution situation by micro-pollutants having been discovered in several wells of this aquifer, it is now very difficult to reduce its water table level by pumping since the natural recharge is totally dependent on the meteorological conditions and while the artificial recharge has of course been stopped for several months.

The management of the entire aquifer and future solutions to regain a controlled and sustainable management of its artificial recharge, complicated by the transboundary status, are described in this paper.

Monitoring and modeling MAR of desalinated seawater to a Mediterranean fresh-Water aquifer, from ground-surface to wells' perforations

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KEY WORDS
Desalinated-Seawater MAR, Infiltration-Recharge Dynamics, Geochemical Evolution, Variably Saturated Zone, Spread in Aquifer

ABSTRACT
Reverse-osmosis desalinated-seawater produced in large desalination plants, are becoming a significant source of fresh water also in countries of Mediterranean climate. Halting the production for short times (days, weeks) is in many circumstances undesirable and storage of large volumes (~ 10^6 m^3) is preferable. In this work, we summarize 4 years of field research and modeling of a MAR site in Israel in which desalinated-seawater are let to infiltrate in a sandy basin. We focus on 3 topics:

(1) Infiltration-Recharge Dynamics. Infiltration rates in the sandy basin decrease from 10 m/d in the beginning of the infiltration event to 2-3 m/d after a day and 0.4 m/d after 4 weeks. Deep clayey layers between land surface and the pre-infiltration water-table control the infiltration-rate decrease, whereas clogging effects can be neglected. A variably saturated flow model was calibrated (validated) to basin-scale infiltration rates. This flow model yields the advection for the reactive-transport model (2) and produces transient recharge fluxes for the groundwater model (3) (Ganot et al., 2017, HESS).

(2) Geochemical Evolution. High Ca/Mg ratio in the post-treated-with-$CaCO_3$ desalinated-seawater promote a cation exchange process during infiltration and enrichment of percolating water with Mg. A reactive-transport model (cation exchange and $CaCO_3$ dissol./precip.) was calibrated to water and sediment data. Model simulations show that infiltration can replace the costly industrial post-treatment and will be sustainable for centuries. The exchangeable Mg, is limited and enrichment of the percolating water with Mg decreases ~ 5% per decade (Ganot et al., 2018, WRR).

(3) Spread in Aquifer. Reverse osmosis desalination produces fresh water with stable isotopes signature of ~ seawater. Whereas all natural fresh water have a significantly lighter isotope content (in this case-study δ^2H ~ +10 and -20 for desalinated and natural fresh water, respectively). A transport model of δ^2H was dressed over a regional hydrogeological flow model of the aquifer surrounding the infiltration site. Desalinated seawater consisted up to 20% of the water in a few abstraction wells at the end of 2017, evident in isotope data and captured by the model. Development of the desalinated water plume is shown by model simulation (Ganot et al., 2018 HESSD).

MAR assessment through physical models: comparison of laboratory and field experiments

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KEY WORDS
Managed aquifer recharge, laboratory experiments, field experiments, scaling, statistical comparison

ABSTRACT
The planning of MAR sites is often accompanied by field and laboratory investigations. These physical models help to assess and define the requirements and constraints of applying MAR as well as optimize the actual MAR site in terms of dimensions, monitoring, and operational parameters. Especially infiltration experiments are used to understand the processes governing infiltration into the unsaturated soil zone.

For the experimental design, different spatial scales are being utilized. Often laboratory experiments are preferred as field tests are time-consuming, costly and often impractical for detailed process assessment. The extrapolation of results from laboratory investigations to the field scale is highly uninvestigated. There are a multitude of assumptions and scale-related limitations that can lead to over- or underestimation of infiltration processes.

To understand the restrictions and potential of different physical models for MAR assessment, we set up surface infiltration experiments in different scales (field, laboratory) and dimensions (1D, 3D) but with the same operational parameters (soil type, infiltration scenarios). The results from the different setups were compared regarding the reproduction of soil clogging processes, water flow, oxygen dynamics and degradation of organic substances during operation.

Assessments of the results from all physical models indicate that 3D experiments (field, laboratory) are more suitable to characterize processes taking place in unsaturated soil during operation of MAR. In 1D column experiments water flow velocity, water saturation and oxygen consumption are often overestimated. Even though the 3D representation of MAR sites was more suitable to represent the reality, restrictions and uncertainties could be made out. Overall, for in-depth analysis of the infiltration processes 3D experiments, such as tanks or field experiments deliver more realistic representations. The attractiveness of column studies lies within its cost and time-effectiveness while delivering an initial assessment of processes relevant for MAR site optimization, such as clogging development or biodegradation processes.

Specific types and adaptability zoning evaluation of managed aquifer recharge for irrigation in the North China Plain

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KEY WORDS
Types of MAR for irrigation; Yellow River irrigation area; adaptability zoning evaluation

ABSTRACT
The North China Plain is the main grain production area with a large area of well irrigation resulted in a large groundwater depression cone. In the 1970s and 1980s, a variety of small-scale MAR projects were developed to increase the amount of shallow groundwater, playing an important role in ensuring stable and high yield of crops. Characteristics of MAR as a component of irrigation and drainage system are small scale, short service life, low investment as well as fixed irrigation water sources and crop planting structure. Considering these characteristics and the relationship between surface water and shallow aquifer, MAR is divided into three types of water spreading, well recharging and combination of both. MAR can be further divided into 10 forms through the specific farmland water conservancy projects. So far, the conjunctive use of well and canal irrigation has been widely used in the Yellow River irrigation area of Shandong Province for nearly 40 years, in which the canal has multiple roles of transporting, storing the Yellow river water or local surface water, recharging groundwater and irrigation by pumping water. Meantime, it also solves the potential clogging problem of aquifer resulting from high silt concentration by desilting basin at head works and canal silting where the sediment can be dredged. Moreover, the new developed open canal-underground perforated pipe-shaft system further expands the scope and amount of groundwater recharge and prevents the system clogging through three measures. Methodology of integrating MAR into irrigation and drainage agricultural facilities to form a farmland water conservancy system of diversion, storage, infiltration, water saving, irrigation and drainage is proposed in order to achieve the goal of comprehensive control of drought, flood and salinization as well as groundwater overdraft. Finally, Liaocheng City of Shandong Province is selected as study area and an adaptability zoning evaluation system of water spreading is established by AHP, in which six factors of groundwater depth, depth of aquifer, permeability coefficient, specific yield, irrigation return flow, groundwater extraction intensity. It is concluded that the MAR is more adaptable for the western region than the eastern and central regions.

Water Quantity and Quality Risk Assessment of the Karst Aquifer Recharge with Multi-source Water in Yufu River of Jinan, China

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KEY WORDS
Channel infiltration; Water quality; Water quality risk assessment; Multi-source water

ABSTRACT
Jinan is well known as Spring City in China and the spring water originates from the precipitation infiltration in the southern mountain area. With the industrialization and rapid urbanization, the flowing of spring is disturbed seriously because of new urban areas expanding towards the south. Therefore, multi-surface waters recharging into karst water by building MAR in the Yufu River of west spring catchment is an important measure to solve the contradiction between spring protection and water supply security. The studied area was selected at the strong seepage reach in the Yufu River upstream, where two managed aquifer recharge projects have been built. The local surface runoff is stored and regulated by Wohushan reservoir at the upstream of Yufu River which can release water into leakage reach to recharge aquifer during non flood season. Some lower pumping stations pump the Yellow River or South-North Water Transfer of China water through pipeline to the upstream with the design rate of 300,000 m^3/d. How to determine the reasonable discharge quantity of water and period of time in the channel is the key problem. According to the hydrogeological conditions of the study area, the maximum infiltration volume was calculated by the methods of field surveys, monitoring, test and numerical simulation. The recharge schemes of three scenarios, the maximum, medium, minimum groundwater depths, were analyzed to maximize water recharged into the karst aquifer effectively. In addition the Yellow River water source quality is inferior to karst water and it may be a threat to groundwater quality if it infiltrates into karst aquifer. And the various waters were monitored by sampling for each event of water releasing with physical and chemical indicators. Meanwhile, the risk of this project was assessed based on the MAR guidelines of Australia. The results showed that karst aquifer recharge with multi-source water can be optimized to improve the recharge efficiency and reduce water loss. There still exist some potential risks from the analysis result of the conventional water quality indicators when Yellow River water being released in a long period of time and large quantity.

Urban Response to Clean Air and Carbon Reduction Targets of Managed Aquifer Recharge from Open Loop Ground Source Heat Pump Systems; Two Case Studies

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KEY WORDS
Geoexchange, ground source heat pump, open loop, managed aquifer recharge

ABSTRACT
Based on estimates of market share (Fry, 2009 and Abesser, 2010), around 1,000 of the 1 million heat pumps sold in the EU in 2016 (EPHA, 2017) were Open Loop Ground Source Heat Pump (GSHP) systems. In 2017 heat pump sales grew 13%, the third consecutive year of growth (EPHA, 2017). As a result, Managed Aquifer Recharge (MAR) activity is expected to continue to rise with the proliferation of Open Loop GSHP systems.

In England and Wales, the Environment Agency (EA) regulates Open Loop GSHP systems by abstraction licence and Environmental Permit (discharge) requirements (Abesser, 2010). Since the first Open Loop GHSP in 2000, London has 44 licensed systems (EA, 2018). In this time, the EA have noted raised abstraction temperatures reducing the efficiency of some systems (EA, 2018). Stakeholder's agreed that thermal impacts of Open Loop GSHP systems should be given more consideration in the regulatory process, particularly thermal interference between systems (Le Feuvre, 2009). The EA responded with a Legislation and Policy document (EA, 2008) identifying key Open Loop GSHP issues. However, the regulatory focus is on protecting groundwater, not guaranteeing abstraction volumes or temperatures. In that sense, it is the applicant's responsibility to assess if the proposed system will impact other systems (Fry, 2009).

In Christchurch (NZ) rapid uptake of Open Loop GSHP technology occurred in response to the 2011 earthquakes, and with incentives including streamlined planning and funding grants (Seward et. al. 2017). Up to 20 systems are operational or planned in Central Christchurch, the majority being installed since 2012 (Rekker, 2017). The regional regulator Environment Canterbury, commissioned a groundwater model to investigate water table mounding (Rekker, 2017). At worst, anecdotal evidence and numerical modeling highlighted instances or potential for surface and buried utility and structure groundwater flooding, reactivation of springs and problematic recharge pressures at the injection wells.

Open Loop GHSP systems account for a considerable number of MAR schemes. Continued and closer collaboration between MAR practitioners, local regulators and building services engineers will be required to ensure green targets can be met by operationally reliable and environmentally sustainable Open Loop GSHP systems.

Scaling-up river water-fed Managed Aquifer Recharge in the deeply anoxic Makauri Aquifer, Gisborne (New Zealand)

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KEY WORDS
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ABSTRACT
The long-term water availability in the Poverty Bay area, Gisborne, New Zealand, is a potentially limiting factor in future regional development due to increasing groundwater abstraction for irrigation purposes for horticultural purposes. Therefore, the Gisborne District Council (GDC) identified declining groundwater level trends in the Poverty Bay area as an environmental and water supply reliability issue.
The ability to replenish the local Makauri Aquifer with water from the Waipaoa River for ensuring sustained yields from the aquifers beneath the Poverty Bay Flats, a Managed Aquifer Recharge (MAR) pilot was performed. The Makauri Aquifer was selected for the MAR pilot project due to its relatively high usage, declining groundwater level trends, broad regional extent and high transmissivity.
The installation of a Makauri Aquifer injection well, headworks and filter system was completed in May 2017 and injection trial undertaken between June and September 2017. Waipaoa River water was sourced via an existing infiltration gallery at Kaiaponi Farms and after filtering injected into the Makauri Aquifer at the MAR site. The 2017 injection trial showed that augmentation of the Makauri Aquifer is technically viable (73,000 m^3 was injected in 59 days, approximate injection rate was 15 L/s). An increase in groundwater heads during injection were recorded up to 1,500 m away from the injection well.
Based on the hydrological response analysis, a full MAR scheme is likely to have a stabilising effect on Makauri Aquifer groundwater levels enhancing aquifer yield and prevent potentially occurring sea water intrusion of the aquifer. In addition, hydrochemical and sediment analysis, indicate that the injection of surface water could have beneficial effects on the water quality abstracted by horticulture. However, results also indicate that for reliable full scale development of the MAR system, risks for physical (gas, suspended load) and chemical (iron/carbonate minerals) need to be properly addressed and mitigated. In addition the fate of contaminants in the infiltrated river water during aquifer passage needs to be investigated.

Reactive Transport modeling of Emerging Organic Contaminants (EOCs) and inorganic nutrients in columns simulating MAR fed with treated wastewater

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KEY WORDS
Numerical modelling, Reactive Transport, Recharge, Column Experiments, Biofilm, EOCs

ABSTRACT
A reactive transport model has been performed for a set of laboratory columns simulating degradation of nutrients and EOCs through different MAR scenarios using treated wastewater. The experiments were constructed in a way that some reactive barriers were amended with organic carbon source (vegetable compost) in order to serve as source of nutrients and electron donor to the system and enhance redox reactions. This design simulated a potential reactive layer situated in the bottom of an infiltration pond. Three different scenarios for the reactive barrier have been modelled, with the sand-based barrier amended with: 0%, 10% and 50% compost. The main geochemical processes modelled were aerobic degradation of organic matter, nitrification, denitrification, dissimilatory nitrate reduction to ammonium, and nutrient release from compost. Most of these processes imply a Monod kinetic model using the experimental data to fit the different degradation constants and parameters. Once the main geochemical processes were modelled, we coupled them with the degradation of EOCs considering a co-metabolic degradation. It was observed that different reactive barrier compositions implied different kinetic rates of nutrients and EOCs degradation, with different kinetic processes present depending on the reactive barrier composition. The dynamics of the nutrient degradation showed changes in the EOCs degradation dynamics as well. In addition, the hydrological model of the different column settings was developed using a double porosity model. This flow model showed that hydraulic properties of the column experiments changed during the experiment, suggesting significant development of a biofilm showing a reduction of porosity, increase of immobile region porosity and increase of heterogeneity. In addition, it has been observed that there is a relation between barrier composition, flow properties change, and degradation mechanics which show that a certain composition of a reactive barrier during MAR can significantly affect the degradation of nutrients and EOCs.

Evaluation of Operation and Performance of the Everglades C-111 MAR Project

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KEY WORDS
Restoration Planning, Everglades, Hydrology, Water Control, MAR

ABSTRACT
The C-111 project, which includes a large managed aquifer recharge component, has been operating since before 2000. The project includes a series of giant infiltration basins constructed along the eastern edge of Everglades National Park in Florida, USA. The C-111 project was conceived as a means to improve the hydrology of Everglades National Park and to decrease high-flow, pulse releases of freshwater into Barnes Sound and Florida Bay, both ecologically sensitive areas. The C-111 project typically infiltrates billions of liters of water per year into the shallow Biscayne aquifer and probably represents one of the largest MAR projects in the world located in a sub-tropical climate. An initial evaluation of the project operation and performance from 1998 to 2010 was previously completed by one of the authors herein. This study undertakes an additional performance evaluation of the project through 2018. The overall operation and performance of the project is assessed using a variety of metrics ranging from improvement in wetland hydroperiod to reductions in pulse discharges to Barnes Sound. The research team will also organize the assessment into quantity, quality, timing, and distribution (e.g. QQTD) metrics consistent with the overall restoration objectives of the Everglades system in general. The current operational period from 2010 to 2018 will be compared to the previous operational period from 1998 to 2000 and to pre-project conditions for the purposes of the performance assessment. The overall assessment is also unique since one of the original design engineers is granted the opportunity to see how well the original design actually worked in terms of hydrologic restoration.

Investigation of viscosity effects caused by seasonal temperature fluctuations during MAR

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KEY WORDS
Numerical modelling, managed aquifer recharge, residence time, seasonality, FloPy, heat transport, viscosity

ABSTRACT
The subsurface travel time between the area of recharge and the abstraction location is a critical parameter for managed aquifer recharge (MAR) schemes as it influences the attenuation of hygienic parameters and the removal of various substances such as nutrients and micropollutants. Some national regulations including German regulations thus specify a minimum travel time between recharge and abstraction.
Temperature is an inexpensive but excellent tracer that has already been used to determine subsurface travel times at MAR sites. A recent study at Berlin-Spandau determined travel times between the infiltration basins and extraction wells based on seasonal temperature fluctuations. Temperature time series from infiltration basins and abstraction wells were fitted to sinusoidal functions to reproduce the seasonal peak values. Monte Carlo simulations of the fitted curves helped to assess uncertainty, which was in the range of 7-19 days. The high uncertainties in combination with differences between summer and winter residence times require a more detailed investigation using numerical modelling.

In the current study, a numerical two-dimensional cross-sectional saturated flow and heat transport model was designed to determine flow paths and travel times considering viscosity effects caused by temperature fluctuations. The cross-section includes two infiltration basins and the in-between located abstraction well. The model was setup using the Python package FloPy based on MODFLOW, MT3D and SEAWAT. Calibration was conducted using groundwater head observations and temperature measurements. The influence of thermal retardation as well as viscosity on the residence time of the water in summer and winter between the two infiltration basins and the extraction well was evaluated.

The model is capable of reproducing the groundwater levels and temperature signals of the cross-section. The inclusion of viscosity effects and retardation results in a more realistic simulation of the temperature distribution in the subsurface and as a consequence a more precise determination of the residence time compared to previous investigations.

Building more collaborative approaches in Contentious MAR projects – Findings from Finland

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KEY WORDS
legitimation, strategic thinking, relational innovations, co-creative planning, governance

ABSTRACT
Community water supply in Finland has increasingly relied on natural groundwater and artificially recharged groundwater as raw water source. Currently, their combined share of the water supplied is some 66 per cent, out of which 16 percent is artificially recharged and 50 natural groundwater.

Several MAR projects have proceeded considerably well in co-creation between the involved parties, while there are several cases that have raised considerable resistance among the public. It seems that success or failure in MAR cooperation is related to management cultures and ways in which various interests are taken into account, from the very beginning throughout the process. Conventional management approaches, drawing from expert-based instrumental rationality, are often insufficient.

Empirically, the paper builds on comparison between two conflictual case studies in Finland. The Turku regional water scheme adopted the MAR option in the late 1980s, completed in 2012. Delays in planning and implementation resulted in extra costs but provided time for more thorough aquifer exploration. In the Tampere region, a MAR plant has been planned since 1992 with several delays. The process is ongoing.

Legitimacy for the groundwater projects should be gained through joint knowledge production and interaction for creating options for collaboration. By more strategic thinking, relational innovations, and co-creative planning between stakeholders, better results are likely to be gained. Yet, these have to be considered case by case based on local conditions.

The most challenging aspects of MAR projects in Finland are related to management, institutions and governance. The emerging paradigm emphasizes more collaborative approaches for natural resources management and urban planning. These issues should be taken more seriously in research, education, and practise, if the aim is to promote MAR systems with huge potential.

The role of organic matter in the release of iron and manganese during bank filtration

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KEY WORDS
Bank filtration, iron and manganese release, anaerobic conditions, organic matter, PFFCA-EEM

ABSTRACT
Bank filtration is a well-accepted, robust and environment-friendly managed aquifer recharge method for water supply which is practiced worldwide. The release of iron and manganese from aquifer materials during the bank filtration (BF) process is a common problem which increases the cost of water treatment and thus restricts the usage of this technique for water supply. The release of iron and manganese during BF is dependent on source water quality, hydrogeology of the aquifer and abstraction well design and operating conditions applied. Laboratory-scale column studies simulating BF were conducted at controlled room temperature (30°C) to assess the impact of dissolved organic matter (DOM) composition of the feed water on the iron and manganese release in the bank filtrate. Fluorescence excitation-emission matrix spectroscopy coupled with parallel factor framework-clustering analysis (PFFCA) was used to characterize the organic fractions of the feed water. Four fluorescence components were identified, three of which matched to humic-like compounds and the last one was linked to protein-like component. The results highlight the vital role of DOM constituents in releasing iron and manganese from the sediment during the BF process. A positive relationship (R^2 =0.72) was observed between the effluent iron concentration and terrestrial humic content in the feed water. This indicates the role of these electron-rich compounds in releasing iron from the sediment via shuttle electron to enhance the iron microbial reduction as well as to complex with iron minerals and thus changing its redox state. Likewise, manganese release was found to be associated with processed humic (R^2 =0.76) and terrestrial-derived humic (R^2 =0.63) content of the feed water. In contrast, protein-like component was found to be highly removed during the BF process and thus plays a minor role in the release of iron and manganese from sediment. In general, this research revealed that humic components (terrestrial and processed) play the major role in the release of iron and manganese during the BF process with a minor effect of labile compounds, which should be considered during the BF well site-selection process.

Pathways for effective development of managed aquifer recharge to enhance water security in Chile

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KEYWORDS:
Water rights; green economy; risk-based management; water bank; pilot site; social license

ABSTRACT:
Implementation of managed aquifer recharge (MAR) to enhance water security in new regions requires strategies to minimize risks of early failures that negatively influence perceptions and confidence in MAR technologies potentially for an entire generation. High-level guidance for integrating MAR with water management policy and economic frameworks, and applying a risk-based approach to assessing MAR projects facilitates uptake. MAR policy, regulatory and economic principles applied in Europe, North America and Australia are reviewed and contrasted with current guidelines for assessing MAR projects in Chile. This is highlighted through a case study examination of MAR implementation in the Rio Aconcagua region, about 100 km north of Santiago, Chile. Allowing those who recharge access to recharged water is a critical policy principle. Integration of MAR with existing water markets and stimulating investment from the private sector allows MAR schemes to become economically self-sustaining. Regulations that allow for strategic water storage using MAR enhance long term water security e.g. against extended droughts. Staged, risk-based assessment effectively manages investment, health and environmental risks thereby increasing investor confidence and is useful for gaining community acceptance showing that risks are systematically managed. The importance of successful demonstration sites and establishing local communities of practice for increasing industry confidence cannot be overstated.

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Development of ANN model for artificial recharge basin selection and its application in South Korea

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KEY WORDS
Artificial neural network, AHP, Drought, Artificial recharge

ABSTRACT
Climate change brought a local severe drought in South Korea and it increased interest in the groundwater abstraction as well as a reservoir construction. Additionally, for the recent 15 years, there has been a growing need to introduce and expand artificial recharge of groundwater that stores water in unconsolidated sedimentary basins. In the winter of 2015, the local government, Chungcheongnamdo province, had a severe drought and water supply at some rural areas was stopped. In many small alluvial basins, groundwater levels descended and lack of irrigation water happened in this period. In order to evaluate the potential of alluvial basins in Chungcheongnamdo province as a site of an artificial recharge, a AHP (Analytical hierarchy process) model consisting of three primary (social factor, hydrogeological factor, and source water factor), and seven secondary factors (water demand, land availability, topographic slope, depth groundwater level, soil thickness, quantity of source water, quality of source water) is developed. The AHP model is applied to 10 regions in the province and a priority for artificial recharge is delineated. The AHP model shows that the final evaluation score for each site ranges from 0.9 to 2.3. AHP model has a weakness that when the candidate site is added, the final evaluation score is changed through a mathematical calculation process. The AHP model just provides a relative importance for artificial recharge but does not present a standard for a compatibility of artificial recharge. On the other hand, ANN (Artificial neural network) model always provides an unchanged final evaluation score for each candidate area. The ANN model is constructed by using the input and output data of 10 regions used in the AHP model and the final ANN model shows that Pearson correlation coefficient between original and estimated values is about 0.997 and the model is very adaptable. The estimated value by the ANN model, which means a final evaluation score, can be used as a selection criterion for artificial recharge possibility in this province. Field survey and existing data analysis indicate that artificial recharge is possible if the estimated score of the ANN model is more than about 1.5. Below this value, decision makers should conduct more thorough investigation and analysis for the target areas.

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Characters of karst collapes in different stage of Groundwater level recovery after mine closure

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KEY WORDS
karst collapes, groundwater level recovery, seepage erosion, mine closure

ABSTRACT
Long-term draining groundwater of karst full water mine usually induce karst collapses, which destroy farmland, fishpond, road, house and so on. Because of Coal Recourse Extinction and Environmental Protection Demand, many coal mines are closed. During the water level recovery of karst aquifer, the karst collapses disaster become active again, which made serious impact on mining area environment.

After mine closure, the water level recovery of karst aquifer can be assumed to a recovery of a single well steady flow pumping test. The recovery can be divided into three stages: fast-rising period, slow-rising period and stable period. Obviously, in different stage of water level recovery, the hydrodynamic condition is different. Accordingly, the magnitude and character of karst collapses are different, which are shown as follows:

1. Fast-rising period: In this period karst collapse disaster become active again. Rainfall, especially heavy rain or rainstorm, are easy to induce karst collapses. Sometimes the groundwater level rise dramatically, which directly breakdown the soil and make collapses. The collapses are usually much greater and much more. The collapses are usually induced by seepage erosion or high-pressure in the soil cave.

2. Slow-rising period: Rainfall is relatively easy to induce karst collapses. The magnitude and scale of collapse are usually small. The collapses are usually induced by seepage erosion. However, under rainstorm condition, many karst collapses will appear.

3. Stable period: the groundwater lever will return to the level before mining, which are above the bedrock or around the bedrock. The collapses are not sensitive to rainfall and mainly induced by the groundwater level seasonal variation. The magnitude and scale of collapse are small and the time intervals between collapses are become long. The collapses are induced by seepage erosion.

Strategic Water Storage and Recovery with Desalinated Seawater in Liwa, UAE

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KEY WORDS
ASR, desalinated seawater, strategic storage, dune sand aquifer

ABSTRACT
The secure supply of municipalities with potable water is a major concern for governments worldwide and particularly in arid regions. The Emirate of Abu Dhabi, United Arab Emirates, has only limited natural freshwater resources and therefore relies on desalinated seawater for domestic water supply for its population of 2.9 million.

The storage capacity within Abu Dhabi's water distribution network was only sufficient for supplying potable water for about two days. Taking into account a certain vulnerability of desalination plants to environmental or technical hazards, the security of water supply was considered low. Therefore, a feasibility study for a Strategic Water Storage and Recovery (SWSR) facility to increase storage capacity and enhance resilience of the water supply was initiated in 2001, followed by a pilot project (2003-2004) and the planning and implementation of the final project (2005-2018).

The SWSR project is located near Liwa in the Western Region of Abu Dhabi Emirate. Desalinated seawater is used to recharge a dune sand aquifer containing fresh to brackish native groundwater. The facility consists of three individual schemes, each constructed with one infiltration basin for recharge and 105 wells for recovery. During recovery, the pumped water is returned to the water supply system without further treatment. A network of 179 monitoring wells continuously monitors water levels, water temperature and electrical conductivity across the three schemes and the wider area. Water quality is monitored through a sampling program to ensure adherence to Abu Dhabi's drinking water quality regulations.

The recharge capacity of the SWSR facility is 11.6 million m^3 per year and the total recharged volume is 26 million m^3. About 16 million m^3 can be recovered over a period of 90 days without compromising the desired water quality. This is sufficient water to supply a population of 1 million with 180 L per person per day over this period.

The SWSR project has significantly increased the security of water supply in Abu Dhabi. Despite comparatively high costs of desalinated seawater relative to groundwater or surface water, such projects are deemed feasible and highly needed to secure the well-being of the population in the absence of natural freshwater resources.

Study on the groundwater recharge based on South to North Water Diversion Project in Hutuo River Alluvial Plain, North China

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KEY WORDS
North China Plain, South to North Water Diversion, Shijiazhuang, groundwater table, hydrochemistry

ABSTRACT
The North China Plain (NCP) is the largest alluvial plain and one of the most densely populated regions in eastern Asia. Population, economic activity, and agricultural production of the area have grown strongly over the last decades, resulting in increased water demand. The groundwater plays a critical role in northern China, contributing to nearly 75% of the total water supply in NCP, especially for the Hutuo River Alluvial Plain. The Hutuo River Alluvial Plain is adjacent to the west of Tai Hang Mountain, located in the west of NCP. In history the groundwater of Hutuo River Alluvial Plain could got abundant recharge from Hutuo River-a main river in North China Plain.

Since the 1980s, the demand of water resources has been spurred by the expansion of the agricultural production, population and industrial & mining enterprises, leading to decreasing depth of groundwater. Owing to the continuous and excessive pumping of groundwater, the regional groundwater depression cones have formed, giving rise to a series of environmental and geological problems, represented by the deterioration of water quality and land subsidence, etc. The groundwater table depression was up to 40 meters in some regions. So the South to North Water Division Project could be an ideal groundwater recharge source in Hutuo River Alluvial Plain. In July 2018, The Ministry of Water Resources and the government of Hebei province jointly issued the pilot program for comprehensive control of groundwater over-exploitation in North China, and decided to carry out the pilot project of groundwater recharge in Hutuo River Alluvial Plain. The Managed Aquifer Recharge will be carried out during 2018-2020.

The east part of the research area is connected with the alluvial plain in the river course along the north-northeast trend; the north part and the south part are both flanks of the alluvial fan and the water-bearing level is gradually worsened; the water-bearing level represents the inter-fan low land phase accumulation, and the depth of the quaternary loose deposits increases from 200 m in the piedmont to 600m in the east part. In the lithology of the water-bearing layer, the west part is mostly thick-layer sandy gravel, part of which is gravel; the sandy gravel gradually becomes finer to the east, mainly coarse sand. In the transitional zone between the east part and the fan edge, medium fine sand and powder fine sand are commonly distributed, and mainly distributed in partial zone. So in this research area, the groundwater recharge is easily carried out.

Along the Hutuo River, there are nearly 30 wells for monitoring the groundwater table changes during the recharge period, and 20 groundwater samples have been tested for chemical compounds, which has been done 3 times per year. During July to October in 2018, the average groundwater table rised by 1.5 m along the Hutuo River area, and the most groundwater table raise was 7.51m. Now the monitoring work is still in the process. There are three main questions to be discussed,1) How will the groundwater table change in the Hutuo River Alluvial Plain; 2) How will the groundwater geochemistry evolve during the recharge period; 3) What's the main factor of influencing the recharge effect.

Laboratory Research on the Laws of Fe(III) Clogging during Urban Storm-water Groundwater Recharge

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KEY WORDS
Iron clogging Laboratory research Groundwater artificial recharge.

ABSTRACT
The increase of population, climate change, water pollution, over-exploitation of groundwater and other problems make the shortage of available water resources on Earth. Groundwater artificial recharge (GAR) technology has become one of the important means to deal with water shortage and corresponding environmental geological problems. In the process of GAR using rainwater, the infiltration medium is obviously clogged with increase of recharge time, which leads to decrease of the efficiency of the recharge facilities and even the service lifetime. Therefore, solving the problem of clogging has become a key in use of rainwater for GAR.

In this research, based on the results of urban rainwater and water quality survey, the laws of iron ion clogging in urban rainwater AR is studied. The phenomenon of iron clogging and its mechanism in the process of AR using urban rainwater are studied by laboratory recharge experiment, adsorption experiment and computer simulation.

The result shows, Fe (III) mostly remained near the surface of porous medium, and its retention rate, retention quantity, the occurrence time and the depth and the degree of Fe (III) clogging are all affected by the particle size of porous medium, the infiltration Fe (III) concentration and the infiltration velocity. The main mechanism of iron clogging can be concluded as filtration and also has part of adsorption.

Effectiveness of riverbank filtration in combination with sustainable and engineered disinfection systems for rural water supply in Uttarakhand, India

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KEY WORDS
Koop well, pathogens, disinfection, electro-chlorination, inline-chlorination

ABSTRACT
India has the largest rural water supply improvement programme worldwide, covering a rural population of more than 700 million (World Bank / WB, 2013). Uttarakhand, located in the Himalayas, has become the first to decentralise rural water supply across the entire state. Despite 96 % of the rural population having access to an improved water source, many rural water supply systems are not functional (WB, 2013). Conventional surface water treatment systems are vulnerable to droughts, to damage and to the breakthrough of pathogens and turbidity in monsoon. Disinfection by manual chlorination is often not functional or is ineffective.

As an alternative, the state water supply organisation developed the “Koop”. Koops, or small-scale riverbank filtration (RBF) wells, abstract filtrate from the river bed and supply it by gravity to villages. They are protected from floods, droughts and have low operational and maintenance costs. In order to propagate RBF as a sustainable treatment technology and to enhance its acceptability in rural areas through community participation, new Koops with improved filter design were constructed in 5 villages (CCRBF, 2016–2019). In one village, the filtrate abstracted by the Koop was fed into a stand-alone photovoltaic-powered electro-chlorination (ECl) unit to demonstrate the feasibility of coupled natural and engineered systems (cNES) as an alternative to conventional chlorination systems (AquaNES, 2016–2019).

River and Koop well water quality monitoring for > 1 year (since 2017) in 2 villages showed a mean E.coli removal of 69–82 % (n = 27), with a maximum removal of > 4 $\log_{10}$. Occasional monitoring at the other 3 remote villages showed an E.coli removal of 83–91 %. Other major water quality parameters were within drinking water limits, except slightly elevated iron (mean 0.4 mg/L) in Koop water in one village. A continuous and complete removal of E.coli was observed for the cNES system. Overall the water quality from the Koop wells is of superior quality compared to river water and most importantly a sustainable pre-treatment is achieved by RBF, with complete disinfection in combination with ECl. The results are discussed in context to other alternatives (mechanical inline-chlorination) and the impact on the communities will be presented.

Emergency response to drought – the City of Cape Town's groundwater abstraction and MAR scheme (South Africa)

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KEY WORDS
resilience, seawater intrusion, urban, groundwater supply, primary aquifer

ABSTRACT
The Western Cape region in South Africa is currently experiencing its worst drought since 1904. As a result, the City of Cape Town (CoCT) implemented emergency response projects to augment water supply through desalination, re-use of treated effluent and groundwater abstraction from several groundwater systems. Amongst the targeted aquifers, the Cape Flats Aquifer (CFA) presents unique challenges and opportunities for abstraction and managed aquifer recharge (MAR). The CFA is a coastal unconfined primary aquifer within the urban and peri-urban environment. As such it is well situated to take advantage of enhanced recharge from treated effluent and urban stormwater. MAR is currently being tested and implemented with a three-fold purpose: (1) create hydraulic barriers against seawater intrusion and other contamination sources, (2) protect groundwater dependent wetlands and RAMSAR sites and (3) increase storage to enhance resilience to drought. Due to local hydrogeological characteristics and a high demand for open land, in the short term, high quality treated effluent will be injected directly through boreholes. Numerical modelling has supported siting and quantifying necessary injection rates. Current estimates indicate that available treated effluent will increase sustainable yields from the aquifer two-fold, as well as providing an additional storage volume equivalent to 2 to 3 years abstraction. In the future this is expected to be complemented with the re-design of urban water drainage to further enhance the recharge of stormwater. Given the time-constraints of an emergency response project, long-term testing and study of the system to support design and implementation have been significantly reduced and had to be replaced by a 'learn by doing' approach. We aim to present the on-going challenges of implementing MAR to complement an emergency response, as well as an overview of the scheme, new data and insights gained through the process.

Investigation of the role of operational dynamics in biochemical efficiency of a soil aquifer treatment system - A long-column experiment

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KEY WORDS
Soil Aquifer Treatment, Waste water treatment, Tertiary treatment, Long-column experiment

ABSTRACT
In soil aquifer treatment (SAT), a subfield of MAR, biologically-treated wastewater are infiltrated periodically through infiltration basins, into the aquifer, improving their quality in the process through various bio-chemical reactions. As population grows, the amount of waste water directed to SAT sites increases, causing a strain on existing sites, in some cases results in either insufficient filtration through the vadose zone, or untreated water directed to the sea or local steams. Therefore, hydraulic and biochemical optimization of the infiltration process is the motivation for this study. In this work, we present a series of column experiments, designed to examine the effect of hydraulic operation and influent composition on oxygen content and redox potential in a 6-meter sand column. Four main experiments were considered, in which different influent solution types were infiltrated in cycles of wetting and drying. Water content, surface head, dissolved oxygen and redox potential were continuously tracked. We hypothesize that the hydraulic operation of the column (i.e. different wetting-drying regimes) and the different influent composition would result in significant difference in oxygen content and redox potential in the upper vadose zone while affecting the deeper parts to a lesser extent. Our results show that while the deeper parts of the column are indeed less effectively aerated during the drying periods, the longer (240 min) drying periods had an advantage over the shorter (150 min) periods in terms of oxygen concentrations through the column. Chemical analysis of the outflow revealed that Nitrogen species concentrations were lower for the longer drying periods. When increasing the drying periods after several cycles of shorter periods, oxygen concentrations increased immediately and dramatically in the upper part of the profile, while in the deeper parts it displayed a delayed, moderate yet noticeable response. The data we gathered show that the duration of the drying periods is detrimental for the bio-chemical state of the soil profile. Short drying periods might be beneficial for the aeration of the upper vadose zone but may not be substantial enough to allow oxygen recovery in the deeper parts which is essential in deep vadose zones and in cases of substantial organic load in the inflow.

Assessment of a Novel Aquifer Recharge Technology: A Case Study in Nanoor, West Bengal, India

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KEY WORDS
Managed Aquifer Recharge, Siphon, Injection, Innovative Technology, Groundwater Balance

ABSTRACT
Groundwater represents the largest proportion of defrosted freshwater on Earth. It is more resilient to the effects of climate change than surface water owing to its buffer capacity. Hence, with the advancement of climate change, groundwater is more likely to play a dominant role in freshwater supplies. This results in over-exploitation, triggering unprecedented changes in terms of quantity and quality of groundwater systems. To secure freshwater availability, sustainable management of groundwater is of vital importance to society and the environment. The process of natural aquifer recharge is very slow and often inadequate compared with the current rate of groundwater abstraction. Here we describe a technology that injects sufficient quantity of runoff rainwater into the aquifer continuously at an average rate of 30 cu. m per hour without any clogging. The speed of recharge depends on the water level of the aquifer, not on the quantity of water available on the earth's surface. The injected water spreads radially from the injection well. It functions with the principle of siphon by the help of atmospheric pressure forming a recharge cone in the aquifer, without any constant supply of energy. The technology basically comprises of two stages. Firstly, the turbidity of runoff water is filtered and decontaminated. Subsequently, the treated and decontaminated water is injected through two sets of pipes pushed down to the aquifer. To assess the impact of the developed technology on the local groundwater resources, local groundwater budget is estimated. The groundwater balance showed (a) the amount of natural recharge, (b) the impact of artificial recharge at the local level against groundwater withdrawal and (c) extends it to define proper sustainable management of groundwater at basin level.

Enabling the reuse of industrial wastewater to meet freshwater demands of greenhouse agriculture by using aquifer storage and recovery (ASR)

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KEY WORDS
ASR, wastewater, reuse, greenhouse, industry.

ABSTRACT
The continuous availability of reliable freshwater is a precondition to meet domestic, industrial, and agricultural demands. Meeting these demands is challenging, especially in areas with a high economic importance, strict water quality requirements, and a limited availability of freshwater. In Dinteloord (The Netherlands), a greenhouse area of 260 hectares is under development. Since local groundwater is brackish or saline and inflow of fresh surface water is limited, the irrigation water demand is largely satisfied through the collection of rainwater and storage in surface basis. However, serious water shortages arise during droughts.

To guarantee the continuous availability of irrigation water, an advanced sustainable freshwater supply was realized. Wastewater from an adjacent sugar factory is treated and purified to large volumes of high-quality irrigation water by rapid sand filtration, ultra-filtration (UF) and reverse osmosis (RO). The production of wastewater occurs in autumn, while the demand for irrigation water occurs during periods of drought mainly in spring and summer. To balance the availability of reuse water and demand for irrigation water, a large scale aquifer storage and recovery (ASR) system was realized.

The ASR system is equipped with eight multiple partially penetrating wells that allow for the counteraction of buoyancy induced recovery losses, and has been in full operation since February 2018. Early test cycles have revealed the enrichment of Na in recovered water, which is caused by cation-exchange and which, based on reactive transport modelling of subsequent cycles, is expected to cease in the future. Fe and Mn are released to the recovered water by the dissolution of carbonates, which poses risks of clogging the irrigation system. This necessitates further research on the direct use of recovered water.

ASR System, greenhouses, sugar factory and neighbouring food processing industries are all connected through a 5 km distribution loop. The system has the potential to provide the local greenhouse sector with 300,000 m^3 of irrigation water every year, with a maximum supply capacity of 200 m^3/h. The system demonstrates the feasibility of hybrid grey and green infrastructure, and demonstrates how managed aquifer recharge (MAR) can contribute to water reuse in the circular economy.

Investigating a Strategic Aquifer Storage and Recovery Scheme in the Sherwood Sandstone to Improve Resilience

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KEY WORDS
Modelling; aquifer storage and recovery

ABSTRACT
Water Resources East is a project led by Anglian Water which comprises the development of a long-term strategy to meet the water resource requirements for the East of England until 2085, including domestic, industrial and agricultural supply. Various supply options and demand scenarios were analysed to inform strategic development in the region.

One supply option investigated was the construction and operation of an aquifer storage and recovery (ASR) scheme in the Sherwood Sandstone Group (SSG) aquifer near Lincoln, UK. The basic scheme concept is that water will be abstracted from a surface water source during periods of high flow, treated to potable standards and recharged into the confined SSG, which is present at 250-440m below ground level. Recharged water would remain in the confined SSG until it is abstracted, treated and pumped into supply. The proposed wellfield extends over 40km along the banks of the River Trent.

As the SSG aquifer is of regional importance for water supply and provides baseflow to environmentally sensitive streams which flow across the outcrop, an investigation was undertaken to consider the potential impacts of the scheme on identified receptors. Scheme capacities up to 50 Ml/d and different operational strategies were considered as well as potential constraints on the wellfield construction and borehole spacing.

The Environment Agency's East Midlands-York regional groundwater model was adapted to simulate different operational schemes and their potential impacts. Results from the modelling were used to inform the maximum recharge rates at each borehole and to optimise the wellfield layout and maximise the capacity of the scheme. In particular, the simulated increase in groundwater levels at each of the boreholes was compared with a calculated maximum pressurisation value to prevent the potential for adverse geotechnical impacts. Particle tracking was used to simulate the movement of recharge water away from the recharge boreholes. During the simulated abstraction periods, groundwater abstraction was reduced such that the modelled impact on flows in the streams across the SSG outcrop were less than 2% of the modelled baseline flows.

Model results indicated that maximum scheme size could have 18 boreholes along the River Trent, a recharge rate of 42 Ml/d and an abstraction rate of 46 Ml/d.

The Atlantis Water Resource Management Scheme – resource management is people management

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KEY WORDS
integrated water resource management, South Africa, biofouling, resilience

ABSTRACT
The Atlantis Water Resource Management Scheme (AWRMS) has operated since the 1970's and is renowned within Southern Africa. It demonstrates cost effective and wise water use and recycling through visionary town planning and Managed Aquifer Recharge (MAR) that offers water security to both residential and industrial sectors of the town of Atlantis near Cape Town, South Africa. For AWRMS to be a success, it required the integration of its water supply, wastewater and storm water systems, each of which require a multidisciplinary management approach. In previous years, this proved an easier task than it does today where the numerous components are distributed between several different departments of the larger City of Cape Town Municipality. Adding to challenges of inter-departmental co-operation and communication is the heterogeneity and vulnerability of the primary sand aquifer. A combination of mismanagement, biofouling, vandalism and readily available surplus surface water were negative drivers for the AWRMS. Atlantis was connected to a surface water supply system in the year 2000, after which the scheme fell into disrepair with elevated groundwater levels and contamination risk due to continued uncontrolled MAR. The emergency response to the drought experienced in the Western Cape of South Africa has driven the refurbishment of the system and since early 2018 groundwater has once again replaced surface water as the sole source of supply to the town. Assurance of supply from the scheme has improved through enhanced understanding of groundwater flow paths, aquifer characteristics, response to long term abstraction and MAR. Geophysical investigations, exploratory drilling and wellfield optimisation are reducing uncertainties in stratigraphy, palaeotopography, and potential interflows between basement rocks and the overlying aquifer. Resilience is assured by institutions, individuals and communities taking timely and appropriate decisions. Initiating or facilitating inter departmental communication and upgrading knowledge and insight through improved investigative techniques, monitoring, modelling and adaptive management are the first and foremost steps to eliminating the risks to the AWRMS.

Evaluating Managed Aquifer Recharge and Aquifer Storage and Recovery in Kabul, Afghanistan Using Regional and Site-Specific Groundwater Models

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KEY WORDS
MAR, ASR, Kabul, Regional, FEFLOW

ABSTRACT

The Kabul Managed Aquifer Recharge Project (KMARP) is focused on the hydrogeological conditions in Kabul with particular attention to pilot schemes for Managed Aquifer Recharge (MAR). Despite the apparent simplicity of MAR approaches and their large implementation worldwide, the complexity of site-specific hydrogeological conditions, and processes occurring at various scales, require a thorough understanding of the hydrologic system's response to proposed measures. Characterizing a hydrologic system, including any heterogeneity and anisotropy, is most effective when the investigation includes, but is not limited to, exploratory drilling and sampling programs, and additional pumping tests. Numerical modelling, used in conjunction with a conceptual model of the hydrogeologic system, and the results of field investigations can allow for various scenario analysis and future predictions of aquifers and the associated hydrologic system(s). Five major attempts have been undertaken to create a numerical model of the Kabul area within the last two decades, targeting different objectives with varying success. An underlying weakness of many of these studies is a lack of continuity to integrate all these activities into a seamless knowledge base, as projects are undertaken independent of others, with little regard to past findings. Two types of models are built for KMARP: 1) A regional model for the entire Kabul Basin, and 2) Site-specific local models to meet the following objectives: a) To understand the groundwater regime, b) To prepare a water budget and quantify recharge, c) To estimate the feasibility of MAR methods at various locations, d) To compare different operational schemes, and e) To provide future predictions and operational strategies. Initial numerical modelling efforts for KMARP begin with a regional steady state model for the Basin, utilizing the knowledge and findings to date to prepare a comprehensive conceptual model for Kabul's groundwater system.

Managed Aquifer Recharge and Aquifer Storage and Recovery in Kabul, Afghanistan

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KEY WORDS
MAR, ASR, Kabul, Afghanistan, Health

ABSTRACT
Kabul City is one of the most water stressed cities in the world, with an average per capita water supply of 20 liters per day (Lcd), compared to a desirable minimum level of 80 Lcd. Residents of Kabul are suffering from the lack of accessible potable water. The City does not capture surface runoff, in the form of snowmelt or rainfall, for productive use due to a lack of storage infrastructure. Kabul is primarily reliant on groundwater, but the available groundwater is of poor quality and deteriorating due to human factors such as leaching, contamination from pit latrines, and waste disposal. Groundwater is further stressed due to the over-abstraction created by continued population growth. To deal with groundwater problems the Asian Development Bank is working with Landell Mills and the Afghanistan Ministry of Energy and Water by funding the Kabul Managed Aquifer Recharge Project (KMARP). The intent of KMARP is to investigate the use of managed aquifer recharge (MAR) techniques as a means of improving groundwater levels, groundwater quality, and the access to potable water for the populous of Kabul. The feasibility study is investigating the use of the following methods of MAR at up to six sites: spreading basins, above ground intake wells set in retained water, and injection wells. The results of the assessment will be used, along with the infrastructure at the sites, to evaluate the feasibility of MAR in the City. Furthermore, to understand the relationship between groundwater and human health, surveys are being conducted at hospitals and clinics in Kabul to ascertain what nexus may exist between water-borne illnesses and groundwater. The relationship between declining water levels, resulting from over abstraction, and/or rising water levels, resulting from disposal of contaminated groundwater, is also being investigated to quantify the effect on human health in Kabul.

The Suggestion for Transferable water rights in the Kabul Basin

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KEY WORDS
Kabul, Afghanistan, Groundwater, MAR

ABSTRACT

An Afghan perspective

The over-abstraction of groundwater in the city of Kabul is a chronic condition. While landowners do not own the water beneath their land, there is no limit on the volume of groundwater they may abstract, even if this has the effect of depriving neighbours of water, water that they may have long used. Each well owner has a water right; the problem is that it is not secure as someone else may first capture the water.

To overcome these challenges, a combined system of Managed Aquifer Recharge and Transferrable Water Rights is suggested. The first legal step in the process of introducing modern water rights is to formally place water under national ownership, trusteeship or control. Following the enactment of the necessary legislation, the process of registering water rights is a task that may take years to complete.

Legal and institutional framework

The suggestion is to assign formal tradable water rights to existing users of water within Kabul under which the rights are independent of land and could be traded separately through enforceable contracts. The rights would relate to abstraction and artificial recharge. A system is proposed that would ensure transparency in decision making and which would lead to the sustainable use of the urban aquifer system. It would enable sale and purchase of water rights while at the same time taking account of possible social and environmental impacts.

A major issue is that of support of the general population together with government and religious authorities. Without such support, whatever proposal is subsequently adopted and even enacted simply will not work. The degree to which the proposed system can address issues of sustainability and social and economic equity while conferring substantive benefits on water users will determine how far the proposal will be successful.

Groundwater and Water Bourne disease in Kabul

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KEY WORDS
MAR, ASR, Kabul, Afghanistan, Health

ABSTRACT
Landell Mills has been commissioned by the Asian Development Bank to undertake the project: 'Kabul Managed Aquifer Recharge Pilot Project'. A component of the Project requires an assessment of the health impacts of groundwater levels and to consider improvements which may result from improved groundwater management measures, such as Managed Aquifer Recharge.

Health surveys have been conducted through structured interviews of key informants in 81 government and private health centres across Kabul. Results were interpreted to prepare a risk assessment, which indicated that the incidence of potential water borne diseases is high and associated with shallow groundwater levels, notably in eastern Kabul. In areas where groundwater levels are shallow, there is a higher incidence of Hepatitis, Typhoid, Dysentery, Shigellosis and Salmonellosis. Regrettably, dysentery is almost ubiquitous across Kabul regardless of groundwater depth.

There is a clear link between the occurrence of multiple water borne diseases and shallow groundwater levels. This is explained by the concept of "Source – Pathway – Receptor" with the source being shallow groundwater contaminated by waste water soakaways. The qualitative risk assessment indicated a moderate risk of health impacts in areas with polluted groundwater more than 15 m below the surface and mainly associated with dysentery and the operation of hand pumps. There is a reduced risk in areas of the City where groundwater levels have declined below a depth of 40 m.

The conceptual model and qualitative risk assessment indicate a sewage system in Kabul and Managed Aquifer Recharge, using clean water to re-saturate dewatered aquifers and displace deeper polluted groundwater in western Kabul, would eliminate the transmission pathway(s) for diseases.

Finally, the project survey has helped to quantify the population and its distribution across Kabul via numbers of people registered with clinics. Based on this, the enumerated population is 2,903,549, which enables quantification of the population exposed to the various water borne diseases.

On the mechanisms affecting and controlling SAT operation

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KEY WORDS
Soil Aquifer Treatment; Recharge optimization; Infiltration pond; Air entrapment

ABSTRACT
Soil aquifer treatment (SAT) systems utilize spreading basins for recharging secondary-treated effluent into the aquifer for water quality improvement. The Shafdan (Dan Region Sewage Reclamation Project) SAT is based on intermittent flooding (1–2 days) and drainage (2–3 days) cycles, referred to as the operational mode. The ponds are located at the surface of a 40-m-deep vadose zone above the Israeli Coastal Plain Aquifer. This study focuses on: (1) the biochemical conditions in the upper 1-m section just below an SAT pond; and (2) the effects of air entrapment below the flooding ponds on the infiltration process. We also explore the role played by seasonal effects in the SAT's efficiency. Our objective is to provide operational variables and formulas that will enable the design of an optimal and seasonally based operational mode.

The results reveal that the diurnal amplitude of the saturation percentage of dissolved oxygen (DO) is larger in summer than in winter (i.e., 4.0 compared to 2.5 DO% and 3.4 compared to 1.5 DO%, at 10 and 30 cm depth, respectively). These results suggest that environmental oxygen-related mechanisms (photosynthesis and respiration) are enhanced in summer. Seasonality was also observed in the infiltration rate (3.6 ± 0.6 and 2.5 ± 0.6 [cm h^{-1}], during summer and winter, respectively).

The results indicate a clear infiltration rate increase for inclined surfaces by about 50%. Furthermore, we have observed a difference in the air pressure dynamics, indicating that under an inclined surface (mimicking the surface topography of the ponds after plowing), air is continuously released, while under flat surface conditions, air is intermittently released. This behavior is explained by differences in the air-breaking and air-closing values across the soil column, while air pressure is practically uniform beneath the wetting front.

Operational parameters were determined, formulated and examined in light of seasonal variability throughout the study. The newly determined operational parameters and their inter-relation form a basis for the design of an optimal and seasonal operational mode. Operating according to an "optimal aeration operational mode" requires performing one or more of the following setup modifications: (1) leveling the pond's bed; (2) constructing additional inlet positions; and (3) enhancing the infiltration rate.

Geo-electrical monitoring of soil aquifer treatment

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KEY WORDS
Soil aquifer treatment (SAT); Electrical resistivity tomography (ERT)

ABSTRACT
Global concerns such as climate change and population growth make soil aquifer treatment (SAT) an important and likely increasingly used technology for water and wastewater purification and storage, both in arid and wet regions. However, land areas for SAT are limited in general and particularly in populated regions such as Israel. Therefore, optimization of the infiltration and biochemical processes becomes a necessity. To assure proper aeration of the subsurface intermittent infiltration is required, which means that the wetting-drying timing is the key for the success of the technology. The Shafdan site, one of the world largest SAT facilities, is rapidly approaching its potential limits. Our project aims at improving the infiltration process of secondary treated wastewater in a manner of SAT, primarily using online geophysical monitoring tools in combination with hydrogeological monitoring and modelling. We demonstrate the idea at an infiltration pond at the Shafdan site close to Yavneh, south of Tel Aviv. The pond was equipped with electrodes for electrical resistivity tomography (ERT) monitoring, ground penetrating radar and hydrogeological measurements.

Using dense ERT measurements, we were able to monitor in close to real time the water dynamics in the deep subsurface (to 10 m and above), and to study the subsurface heterogeneity. More importantly, we show that once calibrated, even the raw electrical data may serve as a great monitoring tool for the entire pond. We suggest that simple resistivity monitoring may be added to SAT and MAR facilities as a simple and reliable monitoring tool.

Riverbank filtration with siphon wells – breathing new life into an old idea

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KEY WORDS
River bank filtration, siphon wells, hydraulic design, energy efficiency, construction

ABSTRACT
Many of the existing siphon well systems at riverbank filtration (RBF) sites were built before the 1950s and require rehabilitation. Siphon wells offer significant advantages over individually operated wells (IOW): high operational safety in floodplains (no electricity supply), lower maintenance costs due to a reduced number of pumps, and easier accessibility and maintenance of the dry mounted pumps. Their most important advantage is that they can contribute to long-term reductions in energy consumption. Instead of pumping from every single well, only two to three high-performance pumps are usually installed to abstract water from a collector caisson. However, siphon operation is not feasible at every site and is not as flexible and controllable as IOW. The suction head between the crest of the siphon pipe and the lowest pumping water level inside the collector caisson should not exceed 8 m. The economic depth for trenching and bedding siphon pipes is 4–5 m for a large number of wells. Thus, the maximum depth for the pumping water level is considered to be around 12 m below the surface.

Siphon systems are still being operated at more than 60 sites in Germany, Poland, Hungary, and the Czech Republic with capacities ranging from 500–100,000 m^3/day. Planners often have difficulties to mathematically prove the capacity of such systems during the design stage. The design still remains somewhat challenging, but the freeware tool SIPHON can be used to plan the rehabilitation of an existing system or to design a completely new one (Bartak & Grischek, 2018). The construction of vacuum-tight pipes and robust vacuum systems is manageable with current technology.

The presentation describes 1) examples of old but operational siphon wells at RBF sites, 2) the design of new siphon well systems using the freeware Excel tool SIPHON, and 3) the energy-saving potential of siphon wells per cubic meter of abstracted water based on real data from two RBF sites operating both siphon wells and IOW. Real energy data from two investigated RBF sites indicate savings in the range of 36 to 52% for the WW Dresden-Hosterwitz (Germany) and on average 69% for Szentendre Island, Budapest (Hungary).

Science-based master plan for bank filtration water supply in Vietnam

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KEY WORDS
River bank filtration, Vietnam, micropollutants, ammonium, arsenic, monitoring, post-treatment

ABSTRACT
In Vietnam approximately 70% of urban drinking water supply depends on surface water (SW) abstraction and 30% on groundwater (GW) abstraction (ADB, 2008). Treatment of SW is usually accomplished by conventional flocculation-sedimentation-filtration-chlorination. Many surface waters in Vietnam are heavily polluted by the discharge of untreated wastewater. Up to now, riverbank filtration (RBF) has not been discussed as a common alternative to SW or GW abstraction in Vietnam. During a first research on RBF sites, only the site in Bac Ninh city was identified as RBF site. Temporarily operated flood relief wells along a dyke at Hanoi receive bank filtrate during floods but are not used for water supply (Feistel et al., 2014).

A German-Vietnamese research consortium has been started a project to develop a science-based masterplan for RBF in Vietnam. The project aims are to assess the feasibility of RBF in Vietnam with special focus on riverbed clogging and redox conditions in the aquifer, to screen river water quality for RBF-relevant micropollutants, to develop treatment concepts for bank filtrate with a focus on ammonium, iron, manganese and arsenic, to apply alternative spectroscopic online-techniques (fingerprints) to determine the portion of bank filtrate, to establish two demonstration sites at the Red River and the Cau River, and to test various innovative, real time, automated water quality monitoring and disinfection technologies under field conditions.

Besides the conceptual approach first results from sampling campaigns from November 2018 to April 2019 will be presented. A first assessment of river water pollution with organic trace compounds and of high ammonium and arsenic concentrations in groundwater and bank filtrate will be compared with recent results from other authors (e.g. Chau et al., 2018; Postma et al., 2016).

Infiltration of reclaimed wastewater for drinking-water production : experience of Europe's first project of this kind

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KEY WORDS
Infiltration, managed aquifer recharge, water reuse, drinking-water production

ABSTRACT
In July 2002 the Intermunicipal Water Company of the Veurne region (IWVA) started reusing wastewater effluent at WPC Torreele for infiltration of an unconfined aquifer in its dune water catchment St-André (Van Houtte and Verbauwhede, 2012). According to Lazarova (2011), IWVA is one of the pioneers in water reuse for indirect drinking-water production and the first in Europe.
The two consecutive draughts in Europe (2017 and 2018) have shown that the combination of reuse and infiltration enabled the IWVA to maintain groundwater levels high enough to ensure drinking-water production and protect its quality. This is in contrast with numerous other areas in Europe suffering from water shortage due to declined river water discharge, increased salinity or depleted aquifers. In these circumstances IWVA's drinking-water production was less vulnerable (than in these other areas) and this experience proved that water reuse can help to mitigate the impact of climate change. Water recycling, if possible combined to aquifer recharge, will become more important to meet the growing global fresh water demand. According to the United Nations the (2017) world population of 7,6 billion is expected to reach 8,6 billion in 2030, 9,8 billion in 2050 and even 11,2 billion in 2100.
Compared to the period prior to reuse/infiltration the current groundwater extraction is less than 50% resulting in higher groundwater levels and enhanced natural and ecological values. Typically around the infiltration pond wet grasslands emerged and consequently typical plants like orchids and Parnassia are back in the dunes. They disappeared over 50 years ago.
An evolution of infiltration capacity was observed since the start-up in 2002. In October 2018 the western part of the infiltration pond will be extended with 100 m. An additional infiltration capacity is foreseen beginning 2019 when the old 'rinse water channel' will be converted into an infiltration channel. This will involve a reduction of groundwater extraction and thus furthermore contribute to sustainable groundwater management.
Since the start-up of infiltration there have been no quality issues. The quality of the infiltration water is excellent as was demonstrated in different European projects (Böckelman et al., 2009, Ernst et al., 2012, Tandoi et al., 2012). From the start of infiltration the ambient groundwater (700 µS/cm at 20°C) was replaced by infiltration water. During the soil passage the water takes up some minerals. The electrical conductivity of the water in every well is yearly checked. Of the 124 wells operational in 2018, the average conductivity amounted 327 µS/cm varying from 127 to 928 µS/cm. There is a relation between the salinity and the distance from the well to the infiltration pond and this distance varies from 33 to 153 m with an average of 59 m. The extracted water is bacteriologically safe and is treated with aeration and rapid sand filtration prior to distribution. However, compared to the quality of the drinking-water prior to the project the main advantage for the customer is that the hardness halved.
More than 16 years of experience at IWVA's water reuse/infiltration project in the Flemish dunes have shown that reuse combined to infiltration or managed aquifer recharge is able to ensure drinking-water of good quality and produced in a sustainable way. This project shows that water reuse is one of the solutions to remedy increasing water scarcity, the negative impacts of climate change and to provide drinking-water for the growing population worldwide.

Mapping potential sites for aquifer storage and recovery in the MENA region: A hydrologic modeling and remote sensing approach

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KEY WORDS
Aquafer Storage and Recover, Remote sensing, hydrologic modeling, Jordan, Palestine, Lebanon

ABSTRACT
Aquifer Storage and Recovery (ASR) means capturing water when it is abundant, storing water in the subsurface aquifers, and recovering water when needed. ASR techniques provide several benefits such as minimizing evaporative losses, modulating floods, controlling groundwater depletion and improving water availability during dry season especially in water scarce regions. However, ASR is currently under-utilized in the Middle East and North Africa (MENA) region due to the high cost of site identification and difficulty in matching ASR technology to site conditions. The goal of this study is to improve water security in the MENA region by accelerating ASR. Under this study, we identify and map high potential ASR locations using remote sensing data, hydrologic modeling and geospatial analysis techniques. This study is implemented over 1980-2015 in Jordan, Lebanon and the West Bank areas. First, 26 watersheds were identified from the Shuttle Radar Topography Mission elevation data. Second, we generated a reliable monthly rainfall product for the region by evaluating seven global gridded rainfall products generated using satellite observation and/or in situ data. Then, we used hydrologic modeling approach to model gridded runoff estimates. The modeled runoff estimates were validated and calibrated using in situ data. We carried out statistical analysis of the precipitation and runoff time-series data to understand the long-term trends. A frequency analysis on the daily mean rainfall and runoff volume data for 36 years was conducted to estimate annual exceedance probability curves and average recurrence intervals for each watershed. Based on the analysis, preliminary regions for potential ASR sites were identified. These regions were then tested for suitability by our regional partners (national agencies in each country). Suitability analysis included geospatial analysis techniques to identify sites based on water quality, soil characteristics and infiltration/recharge capacity. Finally, potential ASR sites were identified. This study provides information on the spatio-temporal variability of recharge potential within selected watersheds. Such information, particularly in the data-scarce environments, will help managers in efficient water resources management.

Integrating weather and remote sensing datasets for historical (1980-2015) runoff simulations and mapping in the MENA region

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KEY WORDS
Runoff simulation, Remote sensing, VegET model, Aquifer Storage and Recovery, Jordan, Palestine, Lebanon

ABSTRACT
The arid climate of the Middle East and North Africa (MENA) region presents numerous challenges for sustainable water resources management. The MENA countries have the lowest renewable water resources mainly due to scarce rainfall, high evaporation, limited surface water, and depleting groundwater. Aquifer storage and recovery (ASR) techniques offers several advantages over conventional surface storage in supplementing water resources in arid regions. However, ASR is currently underutilized in the most MENA countries due to data scarcity and the high cost of site identification. Remote sensing and weather satellites provides consistent data across the globe at low cost that could be used to address current limitations of ASR. In this study, we use globally available weather and remote sensing datasets for historical (1980–2015) runoff simulations to aid in mapping of potential ASR sites in Jordan, Lebanon and the West Bank. These regions receive most of the rainfall in winter months (October-March) which coincides with low potential evapotranspiration (PET), resulting in high runoff volumes, flash floods, property loss, and loss of life. ASR technologies in the region would mitigate floods, increase groundwater recharge in wet seasons, and improve water availability in the dry season. We used a spatially-explicit, one-dimensional root-zone water balance (VegET) model that is driven by precipitation-normalized difference vegetation index (NDVI), soil characteristics, and PET to generate historical runoff based on saturation excess. The modeled runoff estimates were validated and calibrated using in situ data obtained from the country agencies. Our results indicate that the model captured the variability in runoff volumes such as high runoff generated in the mountains of Lebanon or extremely low runoff generated in the eastern arid regions of Jordan. Model-generated rainfall-runoff coefficients were found to range up to 30% in the Jordan and West Bank areas but exceeded 30% in Lebanon. These high rainfall-runoff coefficients coincided with the winter months where high rainfall results in low evapotranspiration and higher runoff coefficients. This study provides 36 years of runoff data that will be used in the identification of potential sites for ASR.

Review of groundwater recharge experiences in Madrid tertiary detrital aquifer

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KEY WORDS Groundwater recharge, water management, artificial recharge, aquifer, Canal de Isabel II. Tertiary aquifer.

ABSTRACT

Canal de Isabel II (CYII) is the main water and wastewater service provider in Madrid Region, supplying services to more than six million consumers. Water supply is accomplished through 14 dams which storage 946 hm^3. In extended periods of drought and/or disruptions in the water supply system, CYII is able to produce up to 70 hm^3 per year from 65 wells located in the Tertiary Detrital Aquifer of Madrid (ATDM). Over the last 23 years, CYII has produced 289 hm^3 from the ATDM during five significant pumping periods, each of them ranging from 12 to 18 months. Between extraction periods, groundwater level recovers its initial position. In 2004, a residual drawdown of 20 m average was observed in the well network. In 2008, Tajo River Basin Authority (CHT) published “Schema of Important Issues” (ETIS), outlining aquifer recharge as a measure to reach good quantity status of groundwater bodies.

During the last 10 years, CYII has been involved in the ETIS by developing several projects about experimental water recharge. These projects include from the study and construction of several facilities in order to prove the feasibility in 2 different groundwater bodies to legal processing and administrative procedures.

Aquifer Storage and Recovery (ASR) wells will give the company an opportunity to use Managed Aquifer Recharge (MAR) techniques in a great management network, increasing water supply system in Madrid with groundwater resources.

Three different approach to ASR, considering several perspectives: legal procedures, facilities design, monitoring and water recharge experience are shown. Suitable areas where groundwater recharge has been proved according to previous experiences, there will be a future expansion adapting CYII’s groundwater facilities to recharge units. A set of activities should be taken with the aim of adapting existing wells to be used as recharge units and dealing with legal procedures are shown as next future steps that CYII should accomplish.

This document summarizes all the solutions that were taken along with CHT (Water Authority) to obtain permits to develop experimental recharge tests, optimizing ASR well design to analyze feasibility to expand recharge designs to existing wells and choosing optimal areas for recharge in some of the existing well fields.

Reclaimed water discharge in the Maneadero coastal aquifer, Baja California, Mexico: Hydrogeochemistry

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KEY WORDS
Coastal aquifers, Salinization, Reclaimed Water, Groundwater quality, Hydrochemical processes

ABSTRACT
In 2014 reclaimed water started to be used for agricultural irrigation and to be discharged into receiving water bodies in the Maneadero aquifer, Baja California, Mexico. To determine the effects of reclaimed water on groundwater quality, samples of reclaimed water and groundwater were collected spatiotemporal and analyzed using stable isotope ($\delta^{18}O_{H2O}$, $\delta^{2}H_{H2O}$, $\delta^{18}O_{NO3}$ and $\delta^{15}N_{NO3}$) and geochemical signatures, jointly with multivariate statistical methods and a 2D electrical resistivity tomography. Reverse ion exchange and mineralization are the main processes influencing the groundwater composition. The Cl/Br ratios identified seawater intrusion and solid waste, wastewater and animal waste as the main sources responsible for these processes, overlapping with the ratios of reclaimed water. Nitrates are pervasive throughout the aquifer and $\delta^{18}O_{NO3}$ and $\delta^{15}N_{NO3}$ attributed wastewater and animal waste as the major nitrates inputs. Multivariate statistics were able to separate seawater and human derived processes. The $\delta^{18}O_{H2O}$ and $\delta^{2}H_{H2O}$ showed the effect of mixing with *d*-excess of 5—6‰, indicating recharge other than precipitation. A mixing model using Cl^- and $\delta^{18}O_{H2O}$ and principal components revealed the mixing proportion of seawater; whilst the over— and under—estimates of reclaimed water contribution are indicative of missing end-members. The Na—Cl—Br—B systematics, however, suggest that reclaimed water result in cation-exchange and adsorption reactions and once the adsorbed sites become saturated with respect of Na^+, Br^- and B^- can be reflected in the groundwater composition. Additionally, resistivities indicate that reclaimed water interacts between the fresh and brackish groundwater by density-differences convection. Monitoring the efficiency of the vadose zone to retain contaminants other than mineral content of water, such as emerging medial residues and pesticides, and distinguish them from reclaimed water is essential for evaluating groundwater quality.

Regulatory challenges for the use of reclaimed water in Mexico

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KEY WORDS
Reclaimed Water, Water planning, Integrated Water Resources Management, Legal framework, Legal and Management instruments

ABSTRACT

In Mexico, water planning is based on the National Water Law, the core of which is Integrated Water Resources Management (IWRM). The municipality provides wastewater treatment and reuse, and an integrated approach is mandatory for these processes. However, a traditional (non-integrated) management regime has prevailed in water legislation, resulting in pollution and the inefficient use of water. The objectives of this research were to analyze the Mexican legal framework and international guidelines in the use of reclaimed water for agricultural irrigation and environmental discharges, and to evaluate challenges facing reclaimed water in the Maneadero Valley, Baja California, as a case study. Results show that reclaimed water reuse was executed in the absence of integrative planning and assessment of the potential impacts on the environment and public health. In addition, four main gaps between decisions linked to the legal attributes of the relevant institutions were identified. Defined roles across the three levels of authority, transparent and congruent funding, coherent water-quality requirements and the strengthening of stakeholder participation found to be needed to adopt integrated water resource management for reclaimed water use. The alignment of common goals on public health, environmental protection and agricultural development between authorities and the different sectors, along with the recommended procedure of Integrated Water Resources Management by the international guidelines are crucial to bridge these challenges. However, its efficient application will depend on the trust, commitment and shared knowledge between local authorities and the different sectors.

Migration of pharmaceuticals from the Warta River to the aquifer on riverbank filtration site in Krajkowo (Poland)

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KEY WORDS
river bank filtration, pharmaceuticals in groundwater, contaminant retardation/removal

ABSTRACT
On the riverbank filtration site in Krajkowo, pharmaceuticals research was carried out in the water of the Warta river and in wells located at different distances from the river on two transects. Three series of tests were carried out in July, August and October 2018. 81 different pharmaceuticals were tested, of which 31 were detected. The results of the research showed a significant reduction of the pharmaceuticals relative to the river in two wells located at a distance of 60-80 m from the river (average 71-78%). A similar reduction rate (on average 71%) was also found in the observation well 250 m from the river. The lowest reduction rate (38.7%) was obtained for a horizontal well with drains located 5 m below the bottom of the river. However, in the observation well distant 38 m from the river an average reduction of 61.5% was achieved. The article will also present the differentiation of the degree of reduction in individual research series and for various pharmaceuticals.

Applications of Geochemical Tracer Experiments Near MAR Facilities to Determine Subsurface Travel Times and Hydraulic Connections to Nearby Production Wells

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KEY WORDS
Intrinsic Tracers, Deliberate Tracers, Environmental Tracers, Orange County Water District, CA, USA

ABSTRACT
A commonly used method to supplement natural recharge is managed aquifer recharge (MAR). MAR could possibly offset some of the storage losses expected from decreases in the snow pack associate with climate change in California, USA, and elsewhere around the globe. It is also a viable low-cost, drought-resistant option to increase local water supplies. As reclaimed water becomes a larger portion of the source water supply, water quality concerns are raised and it is paramount to understand the fate and transport of potential contaminants near MAR sites. One of the best options is to conduct geochemical tracer experiments. When conducted properly, these experiments can establish subsurface residence times and hydraulic connections between MAR facilities and downgradient production wells. The three tracer types, 1) intrinsic, 2) deliberate, and 3) environmental, must overcome the typical recharge volumes needed to be traced. At the largest MAR facilities, infiltration rates from spreading basins can exceed 10^5 m^3/day (~3 x 10^6 cfs). All tracer experiments, especially deliberate tracers, must be able to cope with such large discharge rates. The three different classes of tracers will be discussed and illustrated using examples for the Orange County Water District (OCWD) MAR facilities in Southern California, USA, that include a series of three large northern spreading basins and a 8-km reach of the Santa Ana River. New data mapping high quality reclaimed water from the Groundwater Replenishment System near the large basins recharging this water will also be presented. Results show that the different types of tracers give complementary information about travel times and hydraulic connections to both monitoring and production wells near OCWD MAR facilities.

Managed of the ground water aquifer under the Nile delta

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KEY WORDS
Groundwater recharge, saltwater intrusion, Low lands

ABSTRACT
Sea level variations have occurred throughout history. Sea level changes are caused by several natural phenomenon such as the rise of global temp causing the melting of ice at the poles and on the mountains. The rise of sea level might drown some low lands in the world. One of the dangerous effect of the sea level rise is the salt water intrusion under the Delta and may be drowned unless certain precautions to be taken. According to the previous researches, the relative rise during the century at the Egyptian coasts might reach 1 m.

This paper presents the expected effect of this rise on the delta. Study of the salt water intrusion under the delta and the necessary precautions to safeguard the coastal area of the delta against drowning are presented .Suggestions to protect the delta against the sea level rise are included in the paper .the groundwater resevoir under the nile delta is studied carefully. Some of this water is pumped for the purpose of irrigation and some of the water perculate towards the sea. The recharge of this reservoir comes from the seepage water of the irrigation system in the delta and the precipitaion of the land. This study concentrated on the flow towards this aquifer and the outflow seepage to the sea. Also the salt water intrusion under the delta take big attention in the study presented in this paper. Van der veer solution is used in the analyses of intrusion and determining the aquifer outflow at the sea.

Water Planters – An Aquifer Recharge Case Study in Caparaó, Brazil

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KEY WORDS
Managed Aquifer Recharge, Unmanaged Aquifer Recharge, Water Planters, social technology

ABSTRACT
In a Climate Change scenario, an agriculture almost entirely dependent on rainfed irrigation is under threat. Thus, the trend is to depend on irrigation for food production. That's the case of Brazilians Agriculture, especially small farmers in Serra do Caparaó, Espírito Santo. Although, Brazil has lots of MAR cases, most of them are Unmanaged Aquifer Recharge, mainly small infiltration dams (known as "barraginhas") and infiltration ponds and trenches. Almost all are located in the Northeastern of the country, in the semiarid region. In 2012, in order to face the drought and the depletion of water resources in a degraded region mostly dominated by coffee-growing and livestock, a group of small farmers of the Municipality of Alegre (Espírito Santo) joined with several local organizations to apply a project to Petrobras funding. The project called "Water Planters" was based on a set of techniques used to slowing down the runoff and its consequent loss of soil, providing the aquifer recharge. The "water planting" approach includes among others social technologies, the spring isolation, the construction of small infiltration ponds and infiltration trenches in terraces. The project was carried out in eight proprieties, involving among family farmers, students, researchers, teachers and civil society representatives interested in the subject, more than 5.000 people in the region. The Water Planters Project could be highlighted by its different approach not focused only in the techniques, but mostly in exchange of experience, raising the awareness and changing behavior patterns related to land use and water resources management. This approach was adopted aiming to overcome the farmers' lack of knowledge in these areas. The water table recovering has ensured the water security, allowing family farmers to produce food for their own subsistence and, in some cases, selling the surplus in local markets, enhancing thus their incomes. The project was so successful that those who were involved are now organized in a cooperative called PLANT'ÁGUA in order to continue the work.

The importance of bore conditioning to maintain optimum recharge capacity

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KEY WORDS
Clogging, Aquifer storage and recovery, Treatment, Biological Fouling

ABSTRACT
With the increasing emphasis on water conservation and management in Australia and internationally, Managed Aquifer Recharge (MAR) operations are becoming increasingly popular as a management approach to meet seasonal demand and deliver water security. Where Aquifer Storage and Recovery (ASR) is the adopted method of MAR a bore may undergo a shut-in period of several months, often following completion of the initial recharge trials, or during operations due to maintenance or some other operational requirement. One of the most common problems experienced with ASR bores is the issue of clogging of the screened areas of the bore and the surrounding aquifer. Biological clogging can be triggered due to the altered redox state in the bore following initial trials or operations therefore, it is important to consider well conditioning approaches prior to shutting in the well. Tom Morris and David Pyne of ASR Systems (USA) have pioneered ASR well pre-conditioning steps that should be routinely employed during initial well development or during remediation to reverse clogging. What this paper describes is a practical approach to condition an ASR well prior to a period of shut-in and steps that should be followed prior to start-up of reinjection.

A successful approach to maintaining injection capacities in bores that have been shut-in for several months involves combined mechanical and chemical applications. Initial CCTV inspection of the bore is a key step in identifying the problem zones and adopting the correct approaches for remediation. Mechanically brushing the bore to scrub and surge the casing and screened, water producing area removes the bacterial and mineral clogging. Whilst brushing the bore, the removed waste material is vacuumed from the bore and lifted to surface using a dual-tube airlifting system. The advantages of this system are that the vacuum can target any area of the bore and can also clear the sump and screened area of any silt, sands, and debris. Another important benefit of this method is that is does not introduce air into the bore and aquifer as other more aggressive methods of airlifting can. Applying the correct chemical treatment following cleaning can significantly reduce the frequency of remediation work required to maintain bore injection capacity. It is not only critical to select the correct chemical treatment for the bore to suit the water chemistries, but equally important is the method that the chemical is applied and distributed throughout the casing, screened area and surrounding aquifer.

Mapping managed aquifer recharge potential in the tropical Mitchell River catchment in northern Queensland, Australia

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KEYWORDS:
Site suitability; GIS; digital soil mapping; constraint mapping; multi-criteria analysis

ABSTRACT:
Assessing managed aquifer recharge (MAR) potential across river basin scale requires screening to identify sites for detailed investigation. In remote areas with limited hydrogeological information landscape attributes form surrogates for hydrogeological data. Advances in probabilistic mapping of soil and geological properties e.g. depth of regolith and permeability, with coverage at scale provides additional information for MAR mapping including quantifying uncertainty. The 72,000 km^2 Mitchell River catchment in northern Queensland, Australia is sparsely populated and receives highly seasonal monsoonal rainfall that currently supports extensive grazing across 95% of the area. This assessment identified and prioritized areas to focus further infiltration-based MAR investigation to support high-value irrigated agricultural development. Initial constraints on hydrogeology, permeability, slope, regolith thickness and source water proximity indicated MAR potential for 9100 km^2 or 13% of the catchment. Further screening of protected reserve and conservation areas, source water hydrology and agricultural land versatility narrowed the area to 4521 km^2 or 6% of the catchment. Suitability was scaled through a weighted linear combination of objective criteria. Reliabilities of probabilistic data were integrated and scaled using a fuzzy membership function and weight sensitivities were analyzed. Of the 4521 km^2 of potentially suitable area, 58%, 26% and 17% was assessed with high, medium and low reliability respectively based on probabilistic mapping data. Additional uncertainty regarding aquifer boundaries and properties, and stream hydrology were not explicitly quantifiable but were contextualized using additional lines of evidence. Future site scale investigations are more likely to be successful if they target areas with higher suitability and reliability. Areas with high suitability but low reliability require additional data to increase confidence in the assessment.

Integrated Water Management Utilising the tools of Managed Aquifer Recharge (MAR): Developing a Catchment-Scale Groundwater Replenishment System for the Hekeao/Hinds Plains, Canterbury, New Zealand

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KEY WORDS
Catchment-scale, integrated water management, groundwater storage and quality, community governance, MAR cost-benefits analysis, business case, and climate resiliency

ABSTRACT
The Hekeao/Hinds Plains catchment is one of the most intensely developed and economically productive agricultural areas in New Zealand. Dramatic increases in groundwater usage coupled with a shift toward more efficient (less leaky) irrigation and water conveyance systems has resulted in catchment-scale declines in groundwater storage and spring-fed baseflows. A corresponding rapid shift to high-intensity farming systems has contributed to declining groundwater quality, measurable impacts to drinking water supplies and the loss of environmental and cultural values in surface water bodies.

Starting in 2014, a community led consultation process sought to develop an adaptive management programme to address these catchment-scale issues. A Hinds MAR Governance Group has been appointed to oversee the development of a MAR Trial programme. Since 2016 18 testing sites have been developed in varied spatial and physical conditions. An initial community target is the recharge of 125,000,000 m^3 (101,339 acre-feet) of high-quality alpine-sourced per annum to restore aquifer storage and help improve aquifer quality.

The Trial programme results have helped inform the development of New Zealand's first Groundwater Replenishment System. The community's over-arching objectives for the catchment-scale GRS are:

- Increase groundwater storage (levels),
- Improve water quality in groundwater, streams and rivers,
- Enhance and protect groundwater-sourced drinking water supplies, and
- Increase baseflows in the Hinds/Hekeao River and spring-fed streams (drains) for environmental, cultural and recreational values.

This paper will focus on the business case and master planning programme, including the MAR cost-benefit analysis, catchment GRS system design and site testing, implementation timeline, regulatory setting and challenges, and the formation of a community trust (not-for-profit) to govern the GRS starting in 2019. The Trust includes representatives from the community, local, regional and national government plus local environmental and Maori stakeholders. Collaboration between the stakeholders enables a broad set of values to be incorporated and managed through ongoing adaptive development of the GRS.

Initial Results from Managed Aquifer Recharge Trials in the Hekeao/Hinds Plains, Canterbury, New Zealand

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KEY WORDS
Catchment-scale, Integrated water management, Water quality, Community collaboration

ABSTRACT
The Hekeao/Hinds catchment lies on the Canterbury Plains, South Island, New Zealand. Groundwater quality in the catchment is degraded with areas of elevated nitrate concentrations related to recent agricultural intensification. In addition, the catchment has long-term declining groundwater levels and decreasing coastal spring-fed stream and river baseflows. The reduced groundwater storage and spring base flows are attributed to irrigators moving to more efficient irrigation systems, a reduction in unlined stockwater races, increased groundwater pumping and a changing climate.

The Hekeao/Hinds Managed Aquifer Recharge Trial (the Trial) was established to explore the application of various MAR techniques, including surface infiltration and passive shallow injection, to the diverse hydrogeologic conditions of the Hekeao/Hinds Plains (Catchment). The goal of this five-year trial is to provide a set of catchment-specific MAR tools that can be incorporated into the overall development of a community-led Groundwater Replenishment Scheme. By Year 3 the Trial programme totals 18 test sites, including a flagship infiltration basin (*Lagmhor*), spatially distributed smaller-scale soakage sites and a recharge site on a historic floodplain area near the headwaters of the Hekeao/Hinds River.

This paper focuses on the technical results from the *Lagmhor* basin since its commissioning in 2016. During the first two years of operations a total of 4,296,000 m^3 was recharged at a rate between 95 and 135 L/s. Groundwater level responses were observed in two aquifer levels in excess of 2 km from the site. Average nitrate-nitrogen concentrations in receiving groundwater decreased from 14 to 4 mg/L. Decreasing nitrate-nitrogen concentrations indicate the movement of a 'clean water plume' past nearby rural water supply bores. During the second year, a site upgrade was pursued to overcome the effects of shallow aquitards which limit overall infiltration rates. Geophysical field surveys were used to better understand sub-surface aquitards and a *soakage system (dry well)* was designed and tested. This project represents a first of its kind for New Zealand, where MAR is being tested and applied at a catchment-scale to address water quantity and quality issues.

Evaluation of MAR methods for semi-arid, cold region

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KEY WORDS
Ulaanbaatar, drainage canal, Icing, Ice storage, Underground dam scenarios

ABSTRACT
The semi-arid and cold environment shows a high variability in precipitation and river discharge. The groundwater aquifer located near Ulaanbaatar capital city of Mongolia, is the only source of water supply and it is important to ensure that groundwater is available now and for the future.

The main watercourse near the city is the Tuul River, fed by precipitation in the nearby Khentii Mountains. However, due to the absence of precipitation during winter and spring, the riverbed usually runs dry during that time, and observations show that the dry period has been extending within the last years.

However, in parallel with the city's development, the extended groundwater aquifer shows a clear decline, and the groundwater levels drop significantly. Therefore, a groundwater management system based on managed aquifer recharge is proposed and a strategy to implement these measures in the Tuul valley is presented. It consists of an enhancement of natural recharge rates during the summer wet period, an increase of groundwater recharge through melting ice storage in dry period, as well as the construction of underground dams to accumulate groundwater.

In this study considered an increase of groundwater natural recharge rates during the early winter cold period, through creating ice storages, due to keep water source as in ice form on surface. In dry season March to May stored ice to recharge surface and groundwater by melting where Tuul river is in non-flow condition. In this paper also written MATLAB icing code for ice storage on limited and unlimited area where water supply wells located.

The study of icing was processed in FEFLOW simulation scenarios for artificially recharging groundwater resources. The results shown that it's one of possibilities keep water in ice form use in dry season where in upper mountainous area still cold covered snow and ice, but down in river valley is non-flow condition.

Underground Taming of Floods for Irrigation (UTFI): Global to field scale assessments

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KEY WORDS
Recharge, Flood, Drought, suitability, economics

ABSTRACT
Dealing with inherent intra and inter year water resource variability, manifested in extreme flood and drought events and also expected to get more intense under climate change, represents one of the most critical water management challenges globally. UTFI provides a nature-based approach to co-manage floods and droughts at the river basin scale. It involves targeted groundwater recharge of seasonal excess surface water flows that potentially pose a flood risk to mitigate downstream flooding and increase groundwater storage. Here, we provide a multi-scalar assessment of UTFI by linking global suitability with basin economic feasibility and hydro-economic impact on village scale. First, biophysical UTFI suitability assessment was conducted at global scale. Datasets on flood and drought hazard frequency, mortality, economic losses, groundwater level and depletion, aquifer type and salinity were used. The results showed high UTFI suitability areas extend over 622 million hectares of cropland, supporting around 3.8 billion people. Second, economic analysis, was done for three basins showing high UTFI suitability in different sub-regions: Awash basin in Ethiopia, Ramganga basin (part of Ganges basin) in India and Chao Phraya basin in Thailand. These basins show high economic viability with IRR values ranging from 20 to 122%, although major benefits vary driven by contrasting regional contexts. Third, hydro-economic impact was analysed for the ongoing pilot at Jiwai Jadid village in Ramganga basin. The major benefit has been additional annual recharge of ~60,000 m^3 of surface water which is 13-16% of village rainfall recharge, enough to irrigate 8 hectares of summer rice or 11 hectares of maize. However, due to the limited scale of the pilot system applied, combined with the high specific yield for the alluvial aquifers in the region, the observed increase in groundwater level is small with limited benefits for individual farmers. Benefits can be expected to increase as the number of UTFI structures is increased for which large number of potential recharge sites are available. The information and knowledge from this study are useful in early identification of the likely prospects for UTFI and provide the basis and framework for more detailed implementation and research at the country, basin and village level scales.

Delineating aquifer hetereogeneity through a tracer test in the unconfined sandy aquifer in Tongzhou, Beijing of the North China Plain

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KEY WORDS
preferential flow path, managed aquifer recharge, tracer test, heterogeneity, North China Plain

ABSTRACT
To address water scarcity problems of the North China Plain where per capita water resources is a meager 335 cubic meter per year, the Chinese government has completed the central route of south-to-north water diversion (SNWD), delivering 2 billion cubic meter of surface water to NCP. In 2017, Beijing, the Capital of China and a megacity of 21.71 million people, received 0.88 billion m^3 from SNDW. Nearly all of this water was used for domestic purposes, alleviating in part the stress on the overly extracted aquifer system. In Beijing, groundwater tables have declined at rapid rates of up to 1 m/year. Because of the availability of SNWD water and the increasing volume of better treated waste water, there are now opportunities to develop appropriate managed aquifer recharge techniques to restore the severely deleted aquifer as well as to improve water quality of reclaimed water. However, successful MAR projects require understanding of aquifer properties. Heterogeneity in aquifer influence transport of chemical constituents thus is important to constrain.

A single-well natural gradient tracer test and a multi-well forced gradient tracer test were conducted in Tongzhou Groundwater Experimental Site (116.72°E 39.848°N) to evaluate aquifer heterogeneity. The experimental site is located in the southeastern suburbs of Beijing, on a Quaternary alluvial plain of Chaobai River, 500m northeast of Cold River. The annual average rainfall and evaporation is 533 mm and 1822 mm, respectively. The shallow groundwater system at the experimental site consists of two aquifers: a fine sand aquifer at a depth of 5m-14m and a medium sand aquifer between 20 -30m with a silty clay aquitard at a depth of 14m-20m. The water table is typically ~5m below ground level. Three pumping or injection wells and 50 nests of continuous multichannel tubing (CMT) wells at seven different depths of 5, 10, 15, 17.5, 20, 25 and 30 m are available at the site.

For the single-well natural gradient tracer test, 1000L local groundwater spiked with 790 mg/L Br^- were injected into injection well 4-4 at a depth of 9 m. The natural hydraulic gradient is low at 0.52%, hence the advective flow can be ignored. The samples were obtained from the four nearby observation wells at all seven depths in the next 15 days at a time interval of 8 hr. A peak with 500mg/L of Br with a mostly symmetrical breakthrough curve was observed only for well 4-5 at the depth of 10m, while no peaks were detected in other wells or depths.

During the multi-well forced gradient tracer test, the hydraulic gradient between the injection well 4-4 and the pumping well 8-3 with packers both set at a depth of 15m is 1.67% induced by continuous pumping at a rate of $1m^3/h$ in the pumping well 15 m away from the injection well. Then, $0.35m^3$ solution with Br^- concentration of 10 g/L was injected to the depth of 15 m of injection well 4-4. The samples were taken from the 15 CMT wells located between 2 m and 15.8m distance from the injection well at all seven different depths over 40 days. A breakthrough curve of Br is observed in CMT well 4-5 which is 2 meters away from the injection well 4-4 and in the direction perpendicular to the regional groundwater flow direction. A bromide peak of 27 mg/L in the breakthrough curve occurred at the depth of 17.5 m in CMT well 4-5 on the 9th day and by 40th day the Br concentration was 10 mg/L. In other CMT wells, there were no obvious peaks, Br maximum concentrations were lower and ranged from 2 to 9 mg/, and on the 40th day, the concentrations were 0.4 to 3.2 mg/L.
That Br peaks were evident in the same observation well in both tracer tests suggest that there is a preferential flow path between injection well 4-4 and observation well 4-5 or there are groundwater flow barriers in other directions. Based on the breakthrough curve of forced gradient tracer test, the dispersity calculated was 0.35 m which is typical for this field scale. Further interpretation of the Br trace test data will consider dual-domain modeling to estimate the mass rate transfer coefficient. Our results showed heterogeneity in NCP Quaternary aquifer is prominent, a characteristics that needs to be better constrained when MAR projects are planned.

The migration of pesticides in bank filtrate (Mosina-Krajkowo well-field, Poland)

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KEY WORDS
River bank filtration, pesticides in groundwater, contaminant removal

ABSTRACT
The river bank filtration (RBF) is worldwide used system for water supply purposes because enable reducing of some contaminant concentrations during relative short water movement between the river bottom and abstraction wells. This is important especially in case of specific micropollutants that appear seasonally in river water.

In this work the behavior of pesticides is analyzed in case of Mosina-Krajkowo well-field where different methods of water abstraction are used. The water is extracted by two well schemes (one located at the distance of 60-80m and second one located more than 400m from the Warta river) and also by collector horizontal well with radial drains located 5m bellow river bottom. This situation allow to analyze the rate of pesticides removal in wells located at different distances to the river channel.

The results of the six sampling series performed between autumn 2017 and autumn 2018 indicate presence of pesticide compounds in Warta river (max. total concentration of 0.472 µg/l). The pesticides were also present in horizontal well (max. total concentration of 0.191 µg/l). While in wells located at distance 60-80m from the river much smaller concentrations were found (max. 0.064 µg/l). In the well located at the distance of 400m from the river the concentration of pesticide residues is below detection limits (<LOQ). During the winter 2018 sampling campaign, significantly lower total pesticide concentrations were detected, and only the most persistent constituents (e.g., prometryn, isoproturon and chlortoluron) were observed in the river and groundwater.

The research confirms earlier findings that, from a quality perspective, suggest RBF wells should be located a minimum of 150-200 m from a river (ensuring a 0.5-year residence time of bank filtrate in an aquifer) to achieve significant contaminant removal. The results also reflect the need for groundwater protection in the catchment area to maintain and improve the source water quality at RBF sites.

Optimal Trenches for MAR by Tertiary Treated Water: HYDRUS2D versus Vedernikov's Sepage Theory Revisited

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KEY WORDS
Normal surface flow in channel (Manning's equation) conjugated with 2-D flow in porous medium (Richards' and Laplace's equations); Recharge through trenches; Optimal MAR-maximizing shapes

ABSTRACT

Haya company in Oman is the main producer of treated wastewater (TWW, currently 150,000 m3/day). Feasibility of using TTW for MAR is currently studied (Zekri et al., 2014), e.g. surface lagoons (Kacimov et al., 2016) and injection wells. We suggest an alternative method, viz. small-size channels constructed on the pedestals of sand dunes or in the interdunal valleys. At the inlet of a lattice (period is L) of equidistant trenches laid at a topographic slope $s_t \square 0.01-0.2,$ TTW can be released through trenches' cross-sectional area A0(0) at a volumetric rate Q (cm3/day). Sand's hydraulic conductivity and bed's roughness are Ks and n (day/m1/3). Longitudinal flow downslope (in the x-direction) is gradually varying (Swamee and Chahar, 2015) and MAR takes place at the trench segment 0<x<xt [A0, Ks, n, st] where xt is the "extinction length" (front) of the MAR "jet". Surface flow is 1-D, quasi-normal, of an area A(x) obeying an ODE (integrated by computer algebra routines). The mass losses (2-D infiltration, rate Qi cm2/day per unit length in x-direction) obey either Richards's PDE (Van Genuchten's –VG- sand) or Vedernikov's theory (non-capillary sand). Conjugation of surface and subsurface flows is terminal to transient regimes in furrow irrigation or flash floods in ephemeral streams (Brunetti et al., 2018, Mudd, 2006, Wöhling et al., 2006). The bed is not clogged (no colmatage and/or bed erosion) and the groundwater mound (Dillon and Liggett, 1983) does not impede infiltration. By HYDRUS2D, triangular trenches of different slopes, □, were simulated (initially dry sand, pressure head of -1000 cm, hydrostatic head along a wetted perimeter and free drainage along the outlet segment of the flow pentagon). Fig.1a shows the Morel-Seytoux shape factor □=Qi/(KsA01/2) as a function of □ for a set of VG-parameters. If Qi<< Q, then we confirmed the results of Kacimov (1985, 1992), viz. at a given A0 there is a unique minimum of fig.1a). If Qi is not small, we determine the trench shape of a given A0 which maximizes the total volume of water infiltrated from the trench. For Vedernikov's steady seepage from solitary trenches we evaluated □=V/(KsA0). Fig.1b shows □□□□□for a given dimensionless parameter e=Ks n/(st1/2 A01/3). A maximum of □□□□□ (an optimal shape of MAR-trench) is found. Other optimization criteria-constraints are discussed.

$$V = \int_0^{x_t} Q_i(x)dx$$

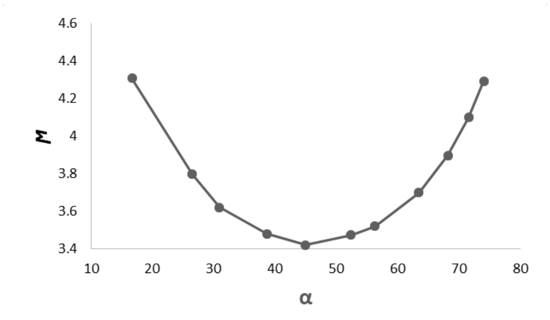

Fig.1a

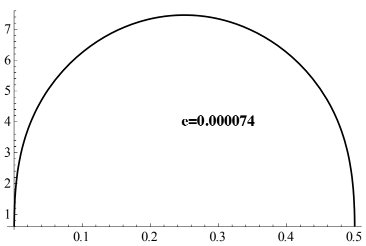

Fig.1b

Title – Managing Aquifer Recharge at Local Level in India: Developing a Framework for Village Groundwater Co-operatives

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KEY WORDS
Groundwater sharing; Cooperative MAR; Transdisciplinary approach; Engagement model; and Groundwater sustainability

ABSTRACT
In this paper, we report on a transdisciplinary approach for cooperative monitoring and management of groundwater in the project 'Managing Aquifer Recharge and Sustaining Groundwater Use through Village-level Intervention (MARVI)'. The study was conducted in two watersheds in the States of Gujarat and Rajasthan, India. We discuss here the challenges of MAR and groundwater sharing at village level in areas characterized by hardrock aquifers and what has worked in the past to cooperatively manage and use groundwater on a sustainable basis. We propose a framework for 'Village Groundwater Co-operatives' (VGC) following Ostrom's eight basic principles for managing the commons (Ostrom, E., 1990; Dietz et al., 2003). In particular, we focus on assisting farmers to understand the dynamics of the stocks and flows of groundwater and cooperatively manage aquifer abstractions. We describe processes to assist farmers to independently measure groundwater levels, design and agree on options for MAR at the local level, and implementing monitoring at a temporal frequency and spatial intensity that helps farmers to understand the dynamics of common pool groundwater resource at the village level. Armed with this shared knowledge, they are further given the means to predict the availability of groundwater resource for the coming rabi season, thus enabling them to cooperatively address the sustainability of groundwater use.

One of the significant outcomes of this study is the formation of pilot 'Village Groundwater Co-operatives' (VGCs) in the two study watersheds. A series of village level meetings were held during the last 12 months to identify issues and challenges related to the sharing of groundwater among farmers and options for MAR to improve groundwater availability. Based on these discussions, key principles for operationalising VGCs emerged and were agreed to by the interested groups of farmers. As a result, three VGCs in the Dharta watershed and two in the Meghraj watershed have been formed and formally registered. The VGC members are now working towards sharing groundwater, reducing groundwater demand and implementing suitable MAR actions at the VGC level. Overall, the project has been successful in a) developing an engagement model for VGCs; b) translating data and experience into farmer friendly groundwater knowledge and tools to help change farmer behavior and practices; and c) save water while improving livelihood opportunities in the two states of India and beyond.

Seasonal Variations in Water Quality and NOM Removal in Natural Bank Infiltration of Boreal Lake Water

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KEY WORDS
Natural organic matter, managed aquifer recharge, bank infiltration, dissolved organic carbon, groundwater

ABSTRACT
In Finland, managed aquifer recharge (MAR) is mainly used in drinking water production to improve water quality by removing natural organic matter (NOM) from surface waters. Increased NOM concentrations, widely reported in surface waters of the northern hemisphere, cause concerns for domestic water producers at both surface water treatment plants and MAR sites.

Here, we assessed the long-term sustainability of MAR by using a natural lake-aquifer system as a surrogate. The natural bank infiltration site, located in Southern Finland, was selected to investigate aquifer recharge over a greatly longer time scale than can be achieved by studying existing MAR sites or by column tests. Our objective was to quantify NOM degradation and accumulation in the aquifer. Lake and groundwater samples were collected, and total organic carbon (TOC), dissolved organic carbon (DOC), chemical oxygen demand (COD_{Mn}), molecular structure of NOM, dissolved inorganic carbon (DIC), pH, dissolved oxygen (DO), iron, manganese, conductivity (EC), and stable isotopes of carbon, oxygen, and hydrogen were measured. The lake infiltrate fraction was estimated at each sampling location in the aquifer by the isotope tracers.

In the studied aquifer, the average fraction of lake water, based on the composition of stable oxygen and hydrogen isotopes, was up to 0.95 – 0.97 near the shore and 0.75 – 0.76 in the springs representing the aquifer outflow. With the high percentage of groundwater originating from the surface waterbody, the area served as an analogy to MAR. NOM along the groundwater flow pathway was found to be rapidly removed with an even higher reduction than at existing Finnish MAR plants. Seasonal temperature dependent changes in oxygen, iron, and manganese levels at the lake shoreline were observed. The main conclusion was that an aquifer can sustainably remove NOM from infiltrating water, without losing its efficiency. However, temporal variations in the process are evident. They are triggered by the contrasting northern seasons which have a clear impact on the properties of the groundwater.

Evidence dispels common myths on managed aquifer recharge in hardrock aquifers in Rajasthan, India

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KEY WORDS
Streambed recharge structures, check dams, recharge wells, natural recharge, monsoonal, semi-arid, hydraulic connection, stream-aquifer interaction, irrigation

ABSTRACT
Four commonly held views on the effectiveness of managed aquifer recharge in hardrock aquifers have been exposed as myths based on scientific data recorded in southern Rajasthan. It has long been claimed that rise in groundwater levels demonstrates that managed aquifer recharge is effective. Field data shows that natural recharge dominates groundwater level rise, and in the absence of spatial and temporal controls, it cannot be concluded by rise in groundwater level alone that MAR structures are effective. Further it can be shown that the view that the greater the rise in groundwater level, the more effective is the MAR, is generally incorrect especially in aquifers with low transmissivity. The third myth, that recharge is greater when the water table is shallower, does not apply for streambed recharge structures. It was found that when water table is shallow, groundwater mounding can cause hydraulic connection between pools of streambed recharge structures and aquifers and radically reduce recharge rates. Finally, the belief that streambed recharge structures only benefit farmers in very close proximity is incorrect for the studied catchment. Water quantity benefits can occur over very large areas, although water quality benefits are localized. The studies involved several recharge wells together with four check dams on ephemeral first and second order streams in hard rock aquifers of the Aravalli Hills in the Udaipur, District of Southern Rajasthan. The hydrogeology of this area is also not atypical of hardrock aquifers over much of the Indian Deccan and Western and Eastern Ghats. There are various consequential corollaries of these findings. Firstly, the actual benefits of checkdams may be the inverse of the perceived benefits. Secondly, that a planned monitoring regime with controls, is essential to accurately claim the recharge effectiveness of stream bed recharge structures. Thirdly, that siting of streambed recharge structures should avoid locations where ambient groundwater levels during the wet season are shallow, or where there are long periods of baseflow. Finally, benefits of checkdams may be wider spread than has been appreciated previously and so their inclusion in village groundwater management and catchment water management plans is warranted.

Principles for rainwater management in a multi-sponge city using soil, unconfined- and confined- aquifers

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KEY WORDS
Managed aquifer recharge, water sensitive urban design, stormwater, infiltration, evapotranspiration, aquifer storage and recovery

ABSTRACT
Impervious surfaces in urban areas negate the ability of soils and unconfined aquifers to soak up rainwater, hence they radically increase runoff and reduce evapotranspiration. Water sensitive urban design, called “sponge city” in China, aims to compensate by retaining as much water as possible near where it falls, hence reducing local flooding, and improving the quality and moderating flow reaching streams. Importantly retained water in aquifer stores can also supply water for irrigation and some non-potable- or even potable- uses. Linking stormwater infiltration and soil water storage with summer evapotranspiration of trees, and groundwater recharge would be helpful for setting stormwater management targets within an urban water planning framework. Given the heterogeneity of soils, and hydraulic properties and ambient water quality in aquifers, both unconfined and confined, it is necessary to establish principles to prioritise sponges for stormwater storage, to avoid problems and maximise benefits. The city of Adelaide will be used to demonstrate the application of these principles. Aquifer storage and recovery of stormwater has been practiced in some parts of Adelaide in confined limestone aquifers since the 1990s and subsequently in confined and unconfined hardrock aquifers, and in unconfined alluvial aquifers. Stormwater infiltration systems to some unconfined shallow saline aquifers in these catchments could cause waterlogging and salinity problems and reduce recoverable water supplies. In some other areas unconfined aquifers are deep and fresh and confined aquifers are absent. Elsewhere, unconfined aquifers have limited storage but soil storage could sustain trees over summer months and improve city amenity without requiring irrigation systems. While managed aquifer recharge has had risk-based guidelines to protect groundwater quality and levels, the infiltration systems in Adelaide as yet have not been investigated for impacts on groundwater, nor in a rigorous way for vegetation benefits and impacts on footings in expansive clay soils. Hence this paper will focus on the principles for reliance on multiple “sponges” in a city, making use of published information for Adelaide and outline the research needed to address remaining technical and policy issues for identifying best-practice.

MAR on the Island of Gotland, Sweden – exploring the potential and feasibility in comparison to alternative meassures

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KEY WORDS
MAR, Groundwater, Mapping, Sweden, Decision-Support

ABSTRACT
The Island of Gotland, situated in the Baltic Sea 100 km from the mainland of Sweden, suffers from insufficient water availability to supply the ever-increasing demand from society. Thin soil layers and lack of coherent reservoirs in the sedimentary bedrock leads to precipitation run-off resulting in limited reservoir capacity. To enhance water resource security, several potential demand and supply management measures are investigated. The aim of this paper is to explore the feasibility of MAR at the island of Gotland by (1) identifying potential areas for MAR, and (2) compare the MAR alternatives on a like-for-like basis to other alternative measures in terms of costs, water-availability potential and uncertainties. Mapping of potential locations for different kind of MAR alternatives are made based on results from five earlier investigations: (a) Intensive hydrogeological investigations, including two campaigns of airborne transient electromagnetic surveys (SkyTEM) covering 30% of the island; (b) Investigations of groundwater catchments currently used by the municipality, which show that geology and hydrology is favorable for MAR at ca 30% of the groundwater catchments; (c) 3D geological and hydrogeological model of the entire island based on resistivity models from the SkyTEM survey, existing geological information such as bedrock and soil maps, seismic profiles and information from water wells; (d) Regional maps for groundwater recharge and storage capacity for the entire island; and (e) Investigation of possible wetland locations (aim to reduce eutrophication) . The proposed comparative method is based on cost-benefit and cost-efficiency analyses for assessing and comparing the sustainability and economic viability of identified alternative measures. The method is based on a probabilistic approach where uncertainties of the measures' potentials and societal effects are considered, and calculations made using Monte Carlo simulation. It provides a novel approach that enables a holistic comparison of MAR to other alternative measures and thus provides important decision support to properly prioritize actions necessary to enhance water security.

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Antibiotic Degradation during Riverbank Infiltration of Reclaimed Water at Beiyun River in the North China Plain

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KEY WORDS
Groundwater contamination; Microbial processes; Water quality improvements

ABSTRACT
Urbanization results in an increasing amount of wastewater treated through industrial or domestic wastewater treatment plants (WWTPs). The treated wastewater (reclaimed water) can be reused. For instance, the environmental reuse is primarily to restore flow in dried river beds in the North China Plain (NCP), where groundwater overexploitation has caused significant declines in water tables (Cao et al., 2013). However, there is a potential for groundwater contamination when reclaimed water recharges aquifers either unintentionally or in a managed way through Riverbank Filtration (RBF). Reclaimed water contains antibiotics, which cannot be eliminated easily in conventional WWTPs. Antibiotics can perturb microbial ecology, increase antibiotic resistance in microorganisms, and threaten human health, despite of the low concentrations in aquatic environments (ng/L ~ μg/L). While improvements of water quality have been observed during RBF with decreasing organic matters, nitrogen and pathogens, antibiotic removal efficacy is not well constrained. Processes governing the degradation and transport of antibiotics are not yet well understood (Bertelkamp et al., 2016; Lim et al., 2008).

This study investigates the microbial processes that affect antibiotic transformation during and after reclaimed water infiltration at two sites in the NCP. Both sites are potential RBF sites in Beiyun river basin (4293 km^2, the NCP), where reclaimed water is discharged into dried river beds year-round. Monitoring wells (n=12, n=7) are installed with depths covering both the unconfined (depth 10-25 m, 10-30 m) and confined (depth 30-60 m, 50-60m) aquifers along a transect perpendicular to the riverbank at different distances (20-80 m, 30-75m). The hydraulic conductivity of sandy aquifer sediments was estimated to be 1.61×10^{-5} m/s. Samples of river water (n=21) and groundwater (n=15) were collected in August 2018. Measurements include 10 antibiotics (sulfamethoxazole, sulfamethazine, sulfathiazole, ofloxacin, lomefloxacin, ciprofloxacin, tetracycline, oxytetracycline, erythromycin and azithromycin), nitrogen species (ammonia, nitrite and nitrate), total organic carbon, and other hydrochemistry parameters. Initial results suggest that both the hyporheic zone and aquifer sediments are hot-spots to remove antibiotics. But contributions of different microbial processes (heterotrophic or autotrophic activities) to the removal is not clear solely based on field-site measurements. Hence, sediments will be incubated in lab-scale columns fed with selected antibiotics. Redox conditions and influent substrates will be controlled to assess degradation rates related to various microbial processes. Column results can be further compared with field measurements.

Re-engineering soil aquifer treatment (SAT) to enhance wastewater recharge flux without compromising water quality

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KEY WORDS
Soil aquifer treatment, Enhance biodegradation, Wastewater reclamation.

ABSTRACT
Soil aquifer treatment (SAT) was proven to be very useful for reclaiming high quality fresh water from large-scale wastewater (WW) treatment facilities. The Shafdan-SAT in Israel is treating ~140 MCM of municipal WW per year which is then used for agriculture. WW is pumped into infiltration basins and percolates through a vadose zone (25-35m) comprised mainly of sand and gravel. The WW undergoes various chemical, physical and biological processes mainly in the top meter of the soil profile. Increasing volumes of domestic WW, high demand for land and escalating real-estate prices around urban areas highlight the urgent need in re-engineering SAT to maximize recharge of WW without sacrificing water quality. In this study we developed a new approach to increase recharge-flux of WW into the aquifer while maintaining high water quality. We tested the new approach in novel column-microcosm (30 cm in depth) experiments that simulated the main filtration processes that take place in the Shafdan-SAT top-soil. In these experiments we compared the filtration efficiency of sand samples taken from the Shafdan-SAT infiltration basins to material with high internal porosity. Our results indicate that bacterial activity were fivefold higher in the material with high internal porosity compared to the natural SAT sand. Biodegradation rates were also found to be significantly higher (~130%) as well as water quality (~60% less bacterial abundance) in the material with high internal porosity We surmise that by re-engineering the SAT infiltration basins using materials with high internal porosity, bacterial biodegradation rates can be expedited without physically changing the size of the given area of land. It is also possible to pretreat the same volume of WW with a smaller footprint, making the process more cost efficient.

Title – Managed Aquifer Recharge at Local Level: Evaluating the Performance of Direct Well Recharge Structures

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KEY WORDS
Groundwater recharge; Water quality; Water level monitoring; Recharge performance; and Rainwater harvesting

ABSTRACT

A field study was carried out in the Dharta watershed, situated in semi-arid hardrock region of Udaipur district, Rajasthan, India during 2016 to 2018. In this study, we evaluated the performance of a new MAR approach that involves the use of direct well recharge structures (DWRS) to achieve local groundwater recharge. Basically, DWRS involves directing runoff from field to a nearby dug well, filtering it for suspended sediments and then discharging it directly into a well. A total of 11 DWRSs were constructed at farmers' field and in each well the discharge volume from DWRS, depth to well water level in and water quality (viz. pH, EC, TDS, Turbidity, Fluoride and, E. coli) were monitored during the monsoon season. For each well in which rainwater was discharged from DWRS, two nearby dug wells, called control wells, were also monitored for the depth to well water level and water quality.

The study shows that the turbidity of runoff was quite high for first two rain events but decreased significantly for the subsequent rain events after the establishment of vegetation. The volume of water recharged through DWRS into individual wells during the monsoon season varied with rainfall amount and intensity and ranged between 6 kL to 177 kL per well. The rise in well water levels at the end of monsoon season were higher in wells with DWRS when compared nearby control wells. The water quality analysis results showed that due to the direct and natural recharge the values of pH, EC, and TDS decreased as monsoon progressed in DWRS and control wells while the turbidity of well with DWRS slightly increased. The values of E. coli of water for well with DWRS were higher compared with control wells but the values were the under permissible limit. Overall, the DWRS were found to be beneficial in augmenting local groundwater supplies and can be used by small farmers with investment in the range of Rs 3500 – Rs 7000 (US$ 50 to US$ 100).

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Optimization of monitoring-management systems of anthropogenic micropollutants at MAR sites

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KEY WORDS
Risk-based monitoring, micropollutants, data management, assessment

ABSTRACT
Due to the impact of climate change, demographic and industrial development, the concentration of anthropogenic micropollutants identified in surface and groundwater is anticipated to increase (Huckerle and Track, 2013). Some of these substances are outlined as emerging pollutants, which are potentially hazardous substances with limited information about its possible effects on humans and aquatic organisms. With regard to their classification and chemical properties not all micropollutants can be removed during drinking water treatment using common techniques such as flocculation, filtration or activated carbon filtration (e.g. Kim and Zoh, 2016).

Water companies operating MAR systems, e.g. artificial recharge basins or bank filtration systems, have to deal with risks related to an increasing number of relevant micropollutants and continuously adjust their water quality monitoring programmes. A risk-based monitoring concept is useful to limit the number of required (costly) water analyses. The water company FWV Elbaue-Ostharz has been developing such concept for its RBF systems at the Elbe River in Germany to ensure both optimal water quality and cost efficiency.

Based on literature survey, official reports and regulation requirements, a database including 558 micropollutants has been set-up providing general information such as product applications, chemical abstract service (CAS) numbers, approval periods or heath related indication values for each compound. Monitoring data of 220 organic micropollutants (sampling campaigns 2010-2017) are sorted into positive and negative results according to defined limits of quantification and detection. Additionally, results for micropollutants of concern listed in environmental regulations (e.g. Water Framework Directive 2000/60/EC) were assessed. Using the given information a decision tree has been prepared taken into account recent and previous sampling campaigns, new environmental regulations and ecotoxicological relevance of the micropollutants. The concept allows to assess actual results and to adjust future monitoring (number of compounds, frequency of analysis). Examples will be discussed to show the application of the concept.

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

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KEY WORDS
Coastal zones, salt water intrusion, mathematical models, GALDIT, GABA-IFI

ABSTRACT
To counteract harmful, eventually with catastrophic consequences, today and future groundwater quality degradation due to saltwater intrusion into coastal aquifers, MAR is considered the best solution, a sound, safe and sustainable solution. MAR, in coastal areas, depends on the availability of water including waste water appropriately treated. How to control saltwater intrusion in coastal zones implementing a MAR facility? The parameters required to answer that question, include the selection of the most appropriate MAR technology and the best location for MAR. The appropriate location must have good infiltration rates; enough space to store underground the recharged water; guarantee that the travel time of the recharged water in the aquifer is long enough, compatible with the expected frequency of drought periods; economic efficiency maximization; availability of areas for MAR; and, positive impacts on the society. GABA-IFI model addresses those parameters allowing the selection of the most appropriate area for the location of MAR. Complementary, mathematical models are available to quantify MAR water injection rates required to recover groundwater depleted levels. But, GABA-IFI is not enough as an answer regarding coastal zones and the expected increase in sea levels worldwide. In those cases, we have to assess the most vulnerable zones to control groundwater quality degradation assessing vulnerability to saltwater intrusion. GALDIT is probably, today, the most used model worldwide towards that aim. GALDIT uses hydrogeological parameters such as aquifer properties, hydraulic conductivity, groundwater level, distance from the coastline, current severity of saltwater intrusion, and aquifer thickness to make saltwater intrusion vulnerability indices. GALDIT gives a weight to each of the indices, and prioritize the indices through a decision-making process, and then assess the possibility of saltwater intrusion by a numerical calculation. Examples will be presented.

Hydrogeochemical and clogging issues with ASR of reclaimed water in the brackish Werribee aquifer near Melbourne, Australia

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KEY WORDS
ASR, recycled water, water quality, clogging, prediction.

ABSTRACT
As part of an Integrated Water Cycle Management Strategy for the fast growing city of Melbourne, City West Water is conducting research to apply Aquifer Storage Recovery (ASR) utilizing recycled water. This non-potable water is injected and stored during winter in a brackish, anoxic sand aquifer at 220-240 m BGL, and recovered during peak demands in summer.

Hydrogeochemical issues consist of: (i) mobilization of trace metals and arsenic by pyrite oxidation; (ii) eutrophication due to high concentrations of NO_3 and PO_4, (iii) the formation of trihalomethanes and haloacetic acids by chlorination; (iv) the behavior of organic micropollutants in the aquifer; and (v) the undesired admixing of ambient groundwater (TDS, H_2S, natural radionuclides). In this contribution, we address the measured and predicted water quality changes of recycled water, during storage and recovery in the ASR well, and when passing a monitor well at 40 m distance.
Geochemical inspection of aquifer cores reveals that the main reactivity of the rather pure quartz sand consists of pyrite and organic material (partly as coal). Their slow reactivity is confirmed by the observed minor water quality changes during relatively short ASR cycles (6-50 days), comprising some O_2, NO_3, PO_4, Zn and TCA reduction and little SO_4, As and TIC production. Reactive transport modeling of the quality changes during future longer ASR cycles showed significantly more water-sediment interaction.

The ASR well showed cumbersome clogging because of a high injection rate, a high clogging potential of recycled water, and a small diameter injection borehole. Clogging predictors such as MFI, the ratio of the summed Total Suspended Solids input after a given infiltration time to the open area of the external borehole wall, and the build-up rate of bacterial biomass, indicate a high physical and biological clogging rate, and how to diminish the clogging propensity.

Microscopic and geochemical analysis of suspended solids in the input and in turbid, backpumped water (after mechanical well regeneration), demonstrate a significant contribution of diatoms, algae and colloidal $Fe(OH)_3$. CWW is therefore currently testing an additional prefiltration step composed of a compact 20 µm and 1 µm filter, in series.

Impact of geological heterogeneity on water quality at a decolmated river bank filtration site: A case study in Potsdam, Germany

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KEY WORDS

Riverbank filtration, Streambed changes, Redox zone, Geological heterogeneity, Stable isotopes

ABSTRACT

Riverbank filtration (RBF) is widely applied water treatment technology in Germany, and some of them are located on the glacial tills deposits with highly heterogeneous hydrogeological conditions, resulting in differences in redox zonation distribution along flow paths. Besides, the occurrence of colmation layers plays a critical role for RBF purification capacity at the riverbed is inevitable during long-term RBF operation. Although impacts of flood events on recovering of riverbed permeability have been studied in recent years, the artificial or hydro-mechanic removal of decolmation in RBF sites are still rarely studied.

This study mainly focused on the temporal and spatial change of the water quality along the flow path of a hydrogeological heterogeneous BF site, adjacent to a canal with the reconstruction of banks and streambed in Potsdam, Germany. Samples from river water and 12 groundwater observation wells were taken, with stable isotopes (δ18O and δ2H) and hydrochemical parameters measured. The infiltrated river water could be differentiated from the landside groundwater by scatter plot of δ18O and δ2H, while the decolmation-caused increase of river water contribution in deep wells could be shown by piper plots. Geological heterogeneity caused a substantial spatial difference in redox zonation among different flow paths, both horizontally and vertically. The consumption of electron acceptors along the flow paths could not be fully explained by the decrease of DOC, which suggested that particulate organic carbon (POC) is involved in the redox reaction. The well with larger electron consumption did not show lower DOC concentration, which indicates a higher level of POC involvement. The study suggests that with the sampling frequency in this reconstructed BF site, the artificial decolmation does not pose a substantial risk to the water quality, while the hydrogeological heterogeneity plays a key role on the spatial distribution of the redox zonation.

Combined removal of organic micropollutants and ammonium in a column study with reactive barriers simulating MAR

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KEY WORDS
Emerging organic contaminants, degradation, sorption, nitrification, 16S rDNA

ABSTRACT
Due to challenges of ground- and drinking water deficits in many countries, development of sustainable methods ensuring safe drinking water are urgent. Managed aquifer recharge (MAR) holds the potential to be an attractive solution to this problem, yet, despite being a decades-old technology, it is often operated as a black box. Our major focus was on removal of organic micropollutants, classified as emerging organic contaminants (EOCs). Although occurring at very low concentrations (ng-µg/L), presence of such chemicals in groundwater and subsequently drinking water is undesirable.

Using laboratory columns, we simulated operation of reactive MAR barriers. The columns were packed with different ratios of sand and compost, and selectively supplemented with microbial seeding from activated sludge. The columns were equipped with sampling ports that allowed sampling of water and sediments at different depths. During 16 weeks of operation, the columns were fed with synthetic wastewater containing emerging organic contaminants (1 µg/L each) and ammonium (2 mg/L). The EOCs included antibiotics and other pharmaceuticals, UV-filter, anti-corrosive agents and pesticides. The (bio)degradation and sorption of the EOCs was quantified by SPE-LC-MS/MS.
Both compost and microbial seeding generally enhanced removal of the EOCs. Paracetamol and BP-3 (oxybenzone) were effectively removed in virtually all columns. Sulfamethoxazole showed significant removal only in columns with 50% compost. Carbamazepine and diuron, known for persistence, displayed retarded transport due to sorption, but without pronounced degradation. Despite low C and N influx, oxygen was completely depleted within the top few cm of the column where also complete nitrification occurred. In columns with compost, nitrification was followed by denitrification at lower depths. The development in microbial community structure, responsible for nitrogen transformations and degradation of EOCs, is currently being elucidated by 16S rDNA sequencing and qPCR.

Overall, the reactive barriers stimulated removal of certain EOCs and nitrogen species from synthetic wastewater, supported by compost and microbial seeding applications. Likely, expanding aerobic conditions might further enhance degradation of several EOCs.

The characteristics of clogging issues at the riverbank filtration site with long-distance infiltration pathway to the Lalin River, NE, China

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KEY WORDS
Riverbank filtration; Clogging; Column experiment; Long-distance infiltration

ABSTRACT
Riverbank filtration (RBF) technology is a promising water resource development mode by conjunctive use of surface water and groundwater. Although the advantages of RBF in the quantity of groundwater withdrawal and quality of contaminants remove are prominent, the inevitable clogging issues during continuous RBF operation have been paid much attention and studied in recent years. However, the relevant studies are focusing on clogging at riverbed or short range of infiltration pathway and ignoring the characteristics of clogging during the whole infiltration procedure from the riverbed to pumping wells. It is therefore critical to explore the characteristics of clogging in long-distance infiltration process.

The RBF site is 2,000-3,000m far from the Lalin River, Wuchang City, northeast China. According to the field hydrogeochemical analysis and isotope analysis (^{2}H and ^{18}O) results, there were 61.69%-82.84% infiltrated river-water at 560m; 18.25%-24.09% infiltrated river-water due to groundwater withdrawal at the RBF site (2000-3000 m from the river). Thus, the infiltration system was divided into two regions: (1) infiltration dominated zone (0-560m), and (2) in-situ groundwater-dominated zone (2000-3000m).

Moreover, two sets of column experiments with river-water (infiltration dominated zone) and groundwater (in-situ groundwater-dominated zone), respectively, were used to study the clogging issues at the RBF site. The results demonstrated that physical clogging is dominating in both two infiltration system. Whereas, chemical clogging in the in-situ groundwater-dominated zone was more significant than in the infiltration dominated zone. For the long-distance RBF site, the clogging issues was induced by suspended particles of the river water in the short-distance of infiltration process, resulting in permeability decrease at riverbed and infiltration path; in the long-distance from the river, the clogging issues was caused by both suspended particles of the groundwater and precipitation of redox reaction, resulting in the filter pipe clogging.

MAR suitability mapping: why and how? Lessons from a case-study in Southern France

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KEY WORDS
MAR suitability mapping, GIS, awareness raising, Southern France

ABSTRACT
MAR suitability mapping is a GIS-based multiple-criteria decision analysis (MCDA) aiming at identifying the suitable locations for implementing MAR over a given region. The term “suitability” (or “potential”) is vague: MAR suitability mapping studies can follow different objectives and use different methods and criteria. It is however acknowledged that MAR suitability mapping is only a first step toward implementing MAR: the zones identified as “suitable” should be investigated in more details during a subsequent feasibility assessment phase. Recently, a simplified method has been proposed as a standard for MAR spreading methods suitability maps (MARSI), which needs to be cross-checked.

The Occitanie region in Southern France was used as a case-study to test different methods of MAR suitability mapping: MARSI, another method for spreading methods only and one innovative method considering all MAR techniques. The region was chosen because reliable datasets are available, and several MAR sites are active. MAR could be further implemented in Occitanie to address floods and droughts issues. The outcomes of the three methods were compared between themselves and confronted with the distribution of MAR sites in the region.

It results from this study that the intrinsic suitability to MAR can be evaluated with few invariable, environmental criteria. More criteria can be included if more information is provided as of the scope of MAR, the constraints (e.g. budget), the source of water, etc. MARSI can be used to evaluate the intrinsic suitability to spreading methods. However, this method is likely to overestimate the intrinsic suitability. MAR (intrinsic) suitability maps can help raising awareness among decision-makers on the applicability of MAR in their region and favor a top-down implementation of MAR. With this regard, it is more appropriate to create MAR suitability maps that consider all MAR methods. Therefore, a new simple method was developed to evaluate the intrinsic suitability to the main MAR methods. It was applied to the Occitanie region. The maps and graphs produced with this method are easily read and provide effective visual tools to promote MAR among regional decision-makers and funding agencies.

Scaling-up UTFI in the Watershed and Beyond: Mainstreaming in Programs and Policies of the Government

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KEY WORDS
UTFI, floods, droughts, policies, upscaling

ABSTRACT
Underground Taming of Floods for Irrigation (UTFI) involves strategically recharging aquifers with latent or depleted groundwater storage using wet-season high flows, thus mitigating flooding in downstream rural or urban areas and adding to groundwater storage and water availability locally. Following UTFI regional suitability assessment carried out for the Ganges basin, piloting of the concept was initiated in Jiwai Jadid village, district Rampur of Uttar Pradesh (part of Ramganga basin), India in 2015. Initial results has been promising with additional annual recharge of ~ 60,000 m3 of water, enough to irrigate 8 hectares of summer rice or 11 hectares of maize. To reap the full benefits and realise larger objective, it is necessary to upscale UTFI across watershed scale. This would involve building hundreds of UTFI structures requiring significant financial and human capital investments. This requires sensitization and capacity building of local officials and convergence of UTFI concept with government policies and programmes to mobilize resources.

Here, we present a framework and progress made to converge UTFI with ongoing government schemes and programmes. Various government programs have provisions for components that fit very well with UTFI but those are mostly working in silos, thus providing opportunity for convergence and integrating resources to harvest full benefits of UTFI. Given the nature of community owned and maintained concept of individual UTFI structures, local farming community, district level government officials and local Krishi Vigyan Kendra (Farm Science Centre) have been involved through the various stages of the project to bring in the sense of ownership. Overall efforts has also led to convergence of National Flagship Scheme, Mahatma Gandhi Rural Employment Scheme (MGNREGA), for site renovation and maintenance of recharge system. This also demonstrated buying in from the community as well as development agencies. Constant engagement with senior district officials has also resulted in mainstreaming of UTFI concept in the National Flagship Program, Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), which aims at providing access of water to each farm and has been included it he District irrigation Plan (DIP). This could serve as learnings to upscale MAR in India and other countries.

The MAR portal: A web-based tool for sharing MAR-related information

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KEY WORDS
MAR Global Inventory, GIS, web-based portal

ABSTRACT
The MAR Portal is a web-based platform launched in 2016, available at http://marportal.un-igrac.org. It contains information of about 1200 MAR case-studies, from 62 countries. These case-studies have been collected and analyzed with respect to historical development, site characterization, operational scheme, objectives and methods used, as well as quantitative and qualitative characterization of in- and outflow of water. The data harvested were compiled into a global inventory of MAR schemes, whose main goal is to provide access to existing MAR projects and techniques and demonstrate their benefits. The MAR Portal increases the availability and facilitates the continuous update of the MAR global inventory. The platform contains a “data layer catalog” containing the data arranged in a systematic way, a “map viewer” to visualize the selected data on a geographic location, and a “features panel” providing tabular output of the selected data. It also proposes a submission form for users to upload new data. In addition to the global inventory, the MAR Portal shows a selection of MAR suitability maps, in different parts of the world. The maps are based on different mapping methods and criteria. Like the global inventory, these maps are meant to show the applicability of MAR in a wide range of contexts and promote the implementation of new MAR sites.

Over the last few years, the MAR Portal has proven to be a powerful tool for sharing MAR-related information, connecting water managers, experts and non-experts, and promoting new MAR applications. It increases awareness of MAR as a viable solution for sustainable groundwater resources development and management and provides information for better planning of MAR at regional and global scale. To further develop this tool, MAR practitioners are encouraged to submit information about MAR sites that are not yet in the global inventory. They are also invited to communicate with the MAR Portal maintainers if they have new regional MAR suitability maps to share that can provide guidance for implementing new MAR sites. In addition, other information could be shared via the MAR Portal, like for example a selection of MAR success stories.

Mixing of Waters and Water-Rock Interaction Processes during Managed Aquifer Recharge

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KEY WORDS
Groundwater recharge; water mixing; water-rock interaction

ABSTRACT
This study focuses on water mixing and water-rock interaction processes in the course of groundwater artificial recharge along the eastern side of the Jordan Valley. Hydrogeological, geological and geophysical studies indicate that the impacts of artificially storing the water in aquifers are positive. Both flood water and treated wastewater are the potential sources for the recharge process and hence the mixing process of these two water types with the existing groundwater is of utmost importance due to the potential of aquifer matrix dissolution processes or precipitation of chemicals in the aquifer voids.

The groundwater in the aquifers to be recharged is shallow and the aquifer matrices are well washed of salts since they consist of coarse clastic sediments percolated by fresh water, therefore, water rock matrix interactions can be ignored. Reactions with the rock matrix start after the recharge water starts mixing with the existing groundwater. The results of the study show that mixing of flood and base flow water with the groundwater will not bring about any negative changes to the groundwater of dissolution/ precipitation of rock-forming minerals and will produce water which is less under saturated on gypsum and halite. Recharge with treated wastewater produces mixtures with the groundwater that are, in general more or less aggressive and can cause dissolution of rock matrix.

It is concluded that groundwater artificial recharge by utilizing flood and base flows, in order to alleviate the water shortages is recommended. From a quantitative point of view treated wastewater can be used in artificial recharge, but its qualitative impacts on the aquifer matrix and existing groundwater bodies have to be studied for each case individually, because treated effluents differ in the chemical composition from one area to another and from one treatment process to another.

An integrated system based on MAR and reclaimed water reuse for sustainable agriculture irrigation under climate change conditions in Mediterranean countries.

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KEY WORDS
MAR, ASR, SAT, agriculture, governance, monitoring system, ICT

ABSTRACT
The paper describes the conceptual scheme of an integrated system for sustainable management of non-conventional water resources through the smart integration of direct and indirect reuse practices, for increasing water availability via managed aquifer recharge & soil and aquifer treatment (SAT-MAR), using both treated waste water (TWW) and rainwater harvesting techniques (such as capturing excess winter flows).

The system aims to recognize, characterize, and offer solutions for overcoming the persisting barriers to the large scale implementation of SAT-MAR techniques in the Mediterranean region. The conceptual scheme will analyse relevant barriers such as regulatory frameworks, safety risks, economic concerns and social acceptance by adopting an innovative multi-actor, cross-border and multi-disciplinary approach involving local communities and experts from both EU and Mediterranean Partner Countries. Different capacities (isotopy, chemistry, microbiology, etc.) will be pooled together to develop knowledge and common innovative solutions to effectively integrate SAT-MAR techniques with reuse of TWW. Besides increasing the quantity and quality of non-conventional water resources for agriculture, innovation outcomes will support the achievement of sustainable and integrated water management strategies in the Mediterranean area, formulating practical and pragmatic solutions for making existing water infrastructure more climate resilient, efficient, cost-effective, environmentally beneficial, socially acceptable and sustainable. The system will contribute towards addressing water scarcity, environmental status, food security, nutrition, health, well-being and migration problems in the entire area, by supporting Mediterranean countries in a comprehensive capacity building process in the field of water resources management. This key transversal objective of this system will also be achieved through capitalisation activities for young and mid-career water researchers and practitioners. We envisage having the conceptual scheme tested in selected EU and Northern Africa Mediterranean countries, hopefully starting 2019.

Matching agricultural water supply using industrial and domestic treated wastewater via Controlled Drainage Systems

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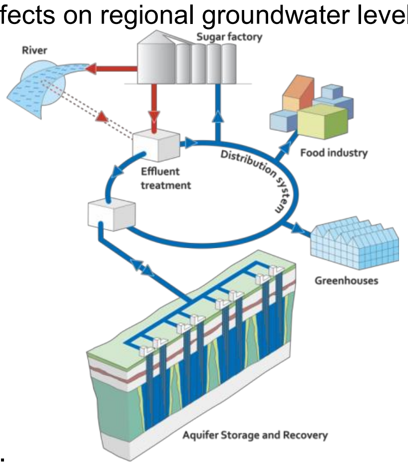
ABSTRACT
Available groundwater sources for irrigation purposes are increasingly under pressure due to the regional coexistence of land use functions that are critical to groundwater levels or compete for available water. At the same time, treated wastewater from industries and domestic wastewater treatment plants are quickly discharged via surface waters towards sea. Exploitation of these freshwater sources may be an effective strategy to balance regional water supply and agricultural water demand. We present results of two pilot studies in drought sensitive regions in the Netherlands, concerning agricultural water supply through reuse of industrial and domestic treated wastewater. In these pilots, excess wastewater is delivered to the soil-water system through sub-irrigation by controlled drainage systems.

Domestic wastewater treatment plants in the Netherlands produce annually 40-50mm freshwater. In a pilot project in the eastern part of the Netherlands, treated domestic wastewater is applied to a corn field by sub-irrigation, using a controlled drainage system. The chemical composition of treated domestic wastewater is different from infiltrating excess rainfall water and natural groundwater. The bromide-chloride ratio and traces of pharmaceuticals in the treated wastewater are used as a tracer to describe water and solute transport in the soil-water system. A field monitoring network was installed at several locations in the vadose zone and the local groundwater system, which enables measurement of vertical solute profiles. Based on field data obtained during the experiments, combined with SWAP (1D) and Hydrus (2D) model simulations, flow and transport of the sub-irrigated treated wastewater to the root zone and the groundwater are quantified.

In the south of the Netherlands, the Bavaria Beer Brewery abstracts a large volume of groundwater and discharges treated wastewater to local surface water. At the same time, neighbouring farmers invest in sprinkler irrigation systems. Within a pilot study, a sub-irrigation system has been installed, with an inlet control basin for the treated wastewater to enter the drainage system. We combine field experiments, process-based modelling of the soil-plant-atmosphere system and of the groundwater system to investigate the amount of water that needs to be and that can be sub-irrigated, to quantify the effect on soil moisture availability, and to quality effects on regional groundwater levels and (enhanced) groundwater recharge.



Atlas of infiltration ponds for treated wastewater disposal in the Apulia region: suitable indicators of potential environmental threats and benefits

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KEY WORDS
Wastewater infiltration ponds, indirect wastewater reuse, groundwater recovery, water reuse index, pollution vulnerability index

ABSTRACT
The lack of rivers and lakes in most of the Apulia region, a karst region of southern Italy, and the banned discharge of treated wastewater into aquifers in 1999, challenged the local government to find solutions for wastewater disposal for 92 out of 180 treatment plants. For these reasons, a plant upgrade programme was launched, while injection wells and sinkholes, previously adopted as final receptors, were replaced by surface infiltration ponds and trenches mostly dug into limestone and sandstone formations, with unsaturated zone permeability varying from minimal (massive carbonates) to high values. Nowadays 32 surface infiltration facilities are operated with an average discharge per plant of 3000 m^3/d and infiltration volume of more than 30Mm^3/yr. Furthermore, effluents from 60 treatment plants, currently disposed into karst ephemeral streams, mostly infiltrate (with average discharge per plant of 4000 m^3/d and infiltration volume of more than 85 Mm^3/yr).

In such context, a rationale is proposed for data collection and analysis for the environmental assessment of wastewater land disposal. Water quality and quantity data from treatment plants were analysed in combination with groundwater vulnerability setting. Potential benefits and threats of wastewater infiltration were summarized by defining two specific indices: the water reuse index, WRI, and the pollution vulnerability index, PVI. In particular, the WRI compares the annual irrigation demand around the infiltration facility with the infiltration volume, while the PVI uses the pollution dose concept (using basic chemical indicators), where the yearly dose is given multiplying pollutant concentrations by the yearly volumes of infiltrated water. Setting aside possible attenuation processes due to groundwater dilution; each dose provides an evaluation of the maximum amount of pollutants that should be diluted by the volumetric flow rate of groundwater at the local scale. A first vulnerability scenario was built by mapping the values of the ratio between the yearly pollutant doses and the depth to water (i.e. thickness of the unsaturated zone).
Though very simple, the two indices allowed mapping the most critical conditions in the study region in terms of opportunities and potential risks connected to the existing infiltration facilities.

Dynamic water balance modelling for risk assessment and decission support on MAR potential in Botswana

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KEY WORDS
risk assessment, decision support, drought, managed aquifer recharge, integrated water resource management

ABSTRACT
Water scarcity is a major challenge for sustainable development in many regions and calls for integrated water resource management and other measures. Furthermore, when assessing risks and evaluating potential measures the entire water supply system must be considered to identify interactions between subsystems and avoid sub-optimisation. The arid and semi-arid climate of Botswana provides a situation with low rainfall and high rates of potential evapotranspiration, which results in low rates of surface runoff and low rates of natural groundwater recharge. The hydrological conditions and a continuously increasing water demand result in a water stressed situation. To cope with this situation Managed Aquifer Recharge (MAR) is considered, among other measures, to increase available water quantities for water supply and to improve water quality. To evaluate the possibility for increased water supply safety a probabilistic and dynamic water supply safety model was developed. The model uses statistically generated time series of source water availability, together with dynamic storages in dams and aquifers and water demands, to simulate the magnitude and probability of water supply shortages. The model is capable of modelling future water supply scenarios, taking into account the dynamic variations over time of water availability and demand in the supply system along the nearly 400 km long North-South Carrier system in eastern Botswana, including surface water dams, groundwater well-fields, treatment plants and distribution network for 18 demand centres. The model simulates the system and its connected components from 2013 to 2035 (23 years), using one-month time steps. The model results show the need for increased water supply safety and to what extent large-scale MAR can provide the desired increase in water supply safety. Furthermore, the results illustrate the importance and benefit of using an integrated approach, including time-dependence and future scenarios, when evaluating the need and potential of MAR solutions.

Title - The role of Aquifer Storage and Recovery in securing resilient long-term water supplies in the East of England

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KEY WORDS
Water resources; aquifer storage and recovery

ABSTRACT

The East of England is the driest part of the UK, and classified as an area of water stress. The amount of water available for public water supply, agriculture and energy needs is under significant pressure from the impacts of climate change and the needs of the environment. Analysis undertaken by the Water Resources East (WRE) regional multi-sector planning initiative forecasts that that even in a sustainable growth scenario, the scale of the challenge will be equivalent to at least 750 Ml/d by 2060. Anglian Water, in partnership with the WRE initiative, has been assessing ASR options, as part of the overall strategy for addressing these challenges.

ASR schemes have been assessed in parallel with other water resource options such winter storage reservoirs, desalination and water reuse. Suitable ASR locations have been identified through the assessment of hydrogeological conditions and proximity of injection source water (including reclaimed final effluent). Schemes have been assessed for their yield benefits, risks and associated capital and operating expenditure.

Ten schemes were appraised alongside the alternative options in the region long term multi-sector regional strategy for the East of England, using Multi Criteria Analysis (MCA), to develop a long term multi-sector regional water resources strategy. The schemes have been modelled as yielding between 10 Ml/d and 50 Ml/d, so have the potential to contribute towards the long term challenge in the region. Two schemes have been subjected to further feasibility analysis, including groundwater modelling and pilot testing.

The work has also highlighted some of the barriers to developing ASR schemes, including environmental constraints and operating costs. Anglian Water are now planning further pilot testing of a scheme in the Sherwood Sandstone aquifer as the next phase of this work and will continue to work with the WRE initiative to assess ASR, along with other water resources options, using multi-sector, multi-criteria approaches.

Mitigating the impact of a future high-capacity ship canal on the nearby wetlands of the Seine estuary nature reserve: an on-site pilot to demonstrate the efficiency of a managed aquifer recharge solution to preserve wetland integrity

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KEY WORDS
Managed aquifer recharge, geotechnical impacts, mitigation, on-site pilot

ABSTRACT
To improve inland waterway transport from the Port of Le Havre (north-western France) to the River Seine, Le Havre port authority (GPMH) plans to connect two existing ship canals: the Tancarville Canal and the Le Havre Grand Canal.
The planned connecting canal is located near the Seine estuary nature reserve and could impact the surrounding wetlands by lowering the water table level in the area.
In a preliminary study, a modelling approach was used to assess the potential impacts of this project. This indicated that the drawdown zone could locally span a distance of several hundred metres from the envisaged connecting canal route, thus jeopardising wetland functions and ecosystems. A managed aquifer recharge (MAR) solution was proposed to reduce or even eliminate this impact. Calculations showed that a ditch supplied with water running along the connecting canal could maintain the water table at a high level within the wetland area. These results were presented at public consultation meetings. In view of the scepticism of some of the participants and in order to fine-tune the potential implementation of this solution, GPMH decided to launch an on-site pilot project.
A one hundred metre-long prototype ditch was hence dug in a zone close to the Tancarville Canal. The initial ditch depth (3.5 metres) was increased to 5 metres after the first tests, to go beyond a clayey sand lens and improve the hydraulic connection between the ditch and the groundwater. An automated pumping system was installed to regulate the water level in the ditch. A piezometric network was developed to monitor the influence of the recharge ditch on the water table. Groundwater and ditch water level and conductivity were recorded continuously for more than a year to assess the efficiency of the prototype in various hydrological conditions.
The pilot provided a means of capitalizing on the experience gained for potentially implementing this solution on a larger scale (pumping and regulation system, warning system, use of geotextile for stabilizing slopes and preventing clogging). Charts that could be used as a water level management tool during connecting canal construction and operation were also developed. In conclusion, the tests carried out over a complete hydrological cycle have demonstrated the ability of this MAR solution to preserve wetland integrity.

Case studies of manganese release during riverbank filtration

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KEY WORDS
River bank filtration, manganese release, climate change, water temperature, infiltration rate

ABSTRACT
Riverbank filtration (RBF) is a proven technology for the natural subsurface pre-treatment of water. Often increased manganese (Mn) concentrations in the pumped water can be observed and depend on the source water quality as well as on the geochemical properties of the aquifer. Mn release is usually attributed to redox reactions, sorption and dissolution or unfavorable well management. Increased Mn concentrations often cause filter screen clogging of the well or deposits in pumps and standpipes and can finally lead to erroneous well operation. Thus, knowledge about the source and the behavior of Mn is essential for an optimal operation of wells and waterworks.

The presentation focuses on two RBF sites, where increased Mn concentrations have been observed in the raw water. Processes in the riverbed were identified to be responsible for Mn release. To evaluate a potential RBF site at Cairo, Egypt, depth-dependent sampling was carried out and sediment samples from the Nile riverbed were taken. Results from sequential extraction of sediments indicated that riverbed material is a source for increased iron, manganese and ammonium concentrations in the bank filtrate (Paufler et al, 2018a).

For a RBF site in Dresden, Germany, the impact of temperature and infiltration rate on Mn release from the Elbe riverbed sediments was investigated. Here, Mn release was primarily controlled by temperature, the infiltration rate was less important. With increasing temperature, the infiltration rate became even less critical. Infiltration rates 0.3 $m^3/(m^2 \cdot d)$ required water temperatures above 20°C to trigger Mn release and at 30°C, infiltration rates of ≈0.6 $m^3/(m^2 \cdot d)$ already caused an extensive Mn release from the riverbed (Paufler et al, 2018b).

Tile-drain effluent and ASR as irrigation source for agricultural self-reliance and protection of ground and surface water quality

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KEY WORDS
Agriculture, MAR, water quality, nutrients, pesticides, efficiency

ABSTRACT
Groundwater in the coastal zone of the Netherlands is brackish due to past transgressions of the sea. Therefore no fresh groundwater is available, depending agriculture thus on precipitation and, during dry periods, on irrigation water extracted from the surface water system that is continuously flushed by the Water Boards with fresh water stored in the IJsselmeer Lake to maintain low salinity levels. Climate change is likely to reduce fresh surface water resources for agriculture, and there is a need for farmers to become less dependent on surface water for irrigation. Agriculture also impacts the water quality of the surface water system through leaching of nutrients and pesticides, which is of concern to the Water Boards in view of their needs to adhere to water quality standards posed by the EU Water Framework Directive. To promote farmer's independence and improve surface water quality a self-support fresh water circulation system was designed, consisting of a fresh tile-drain effluent collector unit feeding into a managed aquifer recharge system in the winter period in a brackish aquifer, which in turn feed a drip irrigation system during the growing season. Pilot studies were executed between 2014 and 2018 at two locations with sandy and silty clay soils, and flower bulb and potato crops, to assess the performance of the system in terms of water savings and water quality improvements. Tile-drain effluent proved to be a good source of fresh water for infiltration into the MAR system, with a realised annual storage of about 5000 m^3 ha^{-1}. With an efficiency of the MAR system of over 50%, sufficient water could be extracted to feed the drip irrigation system during dry periods in the growing season. The capture of tile-drain water also reduced nutrient and pesticide loads to the surface water by more than 70%, and concentrations of NO_3, PO_4 and of some pesticides were much reduced after infiltration into the aquifer due to denitrification, reduction, absorption and degradation. This suggests that such systems could be used on a larger scale as an adaptation to increase water use efficiency and water quality.

Push-Pull test – Reactive transport modelling: A new approach to study water quality changes

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KEY WORDS
Agricultural Managed Aquifer Recharge, Nutrients, Pesticides, Push-Pull Test, Reactive transport model

ABSTRACT
Groundwater technologies, such as Managed Aquifer Recharge, Aquifer Thermal Energy Storage and Subsurface Iron Removal, often result in desired or unwanted groundwater quality changes. For the first time, field Push-Pull Tests (PPTs) were combined with multi-component geochemical reactive transport modelling (RTM) to assess aquifer reactivity. This method, an alternative to column studies or field pilots, was applied to 2 groundwater wells at an agricultural Aquifer Storage and Recovery (ASR) site (Breezand, the Netherlands). The injected water at this ASR system has relatively high concentrations of nutrients (average: NO3 ~ 20 mg/L; PO4 ~ 15 mg/L). The fate processes, recycling of nutrients and other reactions were studied. The water quality changes observed during these PPTs were modelled with RTM. Equilibrium processes were used to simulate cation exchange, precipitation of Fe-(hydr)oxides and surface complexation on fresh Fe-(hydr)oxides and initial goethite minerals. The oxidation of pyrite and soil organic matter with O_2 and NO_3, and dissolved ferrous iron with O_2, were simulated as kinetic rate expressions. This approach provided not only information about the rates, but also about reaction networks and the factors that control these rates. Oxygen and nitrate were consumed by ferrous iron, organic matter and pyrite oxidation in both PPTs and were depleted in maximum 2 and 7 days, respectively. In the shallow well (24 m-b.g.l.), organic matter was the largest consumer of oxygen and nitrate, whereas in the deeper well (35 m-b.g.l) this was pyrite. In both wells the precipitation of Fe-hydroxyphosphates seems the main process related to the decreased phosphate concentration in the abstracted water. Transformation and precipitation showed to be the most important processes concerning nutrient fate. The PPT-RTM method results in a better fundamental understanding of governing processes. It could be used as a relatively cheap and simple tool in exploratory studies for groundwater technologies. Therefore, the method will be used in further research on several multi-level wells at different locations, to get insights in the reactivity of shallow aquifers in the Northern part of the Netherlands. This data will be used to determine the feasibility of ASR systems in this region, related to water quality.

Monitoring and understanding water quality changes during agricultural aquifer storage transfer and recovery: a field-study

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KEY WORDS
Agricultural Managed Aquifer Recharge, Nutrients, Pesticides, Push-Pull Test, Water quality, Field-study

ABSTRACT
Early 2019 an agricultural aquifer storage transfer and recovery (ASTR) system will be constructed to provide a farmer of fresh water in Breezand, the Netherlands. Fresh water availability is scarce during the growing season, due to droughts, brackish/saline groundwater and deteriorating surface water quality. This system will be the first of its kind built on company-scale (10 ha). Fresh tile drainage water (TDW) is collected from the 10 ha plot, stored in a shallow aquifer below a 8m thick clay layer and retrieved in summer for irrigation of flower bulbs. The system has two major advantages: 1) the farmer is self-sufficient for his freshwater needs, 2) TDW is not discharged to the surface water anymore, consequently decreasing nutrient and pesticide loads to the surface water system.

Previous pilots showed that agricultural ASTR is an efficient solution to make farmers self-sufficient for their fresh water needs. The water quality aspects are understood to a lesser extent. The collected TDW contains agrochemicals (e.g., nitrate, phosphate, and pesticides), which are therefore, also infiltrated in the subsurface. The objective of this research is to understand the fate of agrochemicals during agricultural ASTR. This includes processes as transformation, precipitation and sorption. Furthermore, these processes can contribute to other effects on water quality such as acidification, (im)mobilization of trace metals and metabolite formation. Understanding water quality changes is required to provide the farmer with water of sufficient quality and to prevent contamination of groundwater.

The system will be monitored for 2 years. The initial hydrogeochemical conditions of the aquifer will be determined, by analysing ambient groundwater and core samples of the aquifer. Water quality data from infiltrated and abstracted water will be obtained by analysis of weekly sampled water and continuous real-time monitoring of temperature, pH, EC, O_2, NO_3 and turbidity. Additionally, two multi-level wells with 6 screens each will be monthly sampled and real-time monitored with the same set of sensors in an automated system, which pumps up groundwater and automatically switches between the different filters. Finally, the reactivity of the aquifer will be studied with push-pull tests before and during operation of the system.

Soil Aquifer Treatment in Glacial Fluvial Deposits – Analogous to Managed Aquifer Recharge Alluvial Systems

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KEY WORDS
Glacial Fluvial Deposits, Alluvial, Reclaimed Water.

ABSTRACT
Reclaimed water aquifer recharge (RWAR) is becoming an integral part of more water supplies as the water quality improvement mechanisms behind the technology have become more clearly understood. During groundwater recharge, natural processes are driven by microbial transformations that remove the majority of organics. In addition, the natural processes decrease the dissolved organic concentrations to acceptable levels and transform the organic carbon such that it cannot be distinguished from natural organic matter in terms of structure and function.

As the implementation of RWAR expands, research and demonstration projects continue to be necessary before full-scale implementation. When RWAR is being considered in a new region with soils that are not alluvial, there is often a dearth of information on RWAR in the region. One example is the LOTT Clean Water Alliance which is located near Seattle, Washington where the soils are composed of glacial fluvial deposits The study includes 28 monitoring wells along with three sets of nested lysimeters. The LOTT Clean Water Alliance considers the extensive study necessary to demonstrate the technology before expansion of the project. Results have been promising with performance comparable to other indirect potable reuse systems that have been studied extensively. One unique aspect of the study is that the recharge basins are covered with fine to medium coarse sand that has a uniform hydraulic conductivity as compared to the naturally present soils below the sand. This allows the system to behave as a functional biological filter with residence times and surface areas similar to indirect potable reuse systems located in alluvial soils. The issue of uncertainty regarding soil aquifer treatment in different types of porous media was theoretically addressed in a research study that investigated the relationship between travel time and surface area (Fox and Makam, 2009). The on-going study of soil aquifer treatment in glacial fluvial deposits will confirm that flow through porous media with sufficient travel time are some of the most important criteria for successful soil aquifer treatment.

Environmental impact and mitigation of intake interruptions for Basin Aquifer Transfer Recovery systems

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KEY WORDS
Bridging period, salt water intrusion, oxidation, water quality, entrapped air.

ABSTRACT
The frequency and duration of intake interruptions for managed aquifer recharge (MAR) systems are on the rise due to climate change (more droughts and higher peak flows) and unrelenting environmental pollution. Interruptions form a normal problem and even a motivation to apply MAR. They put, however, exorbitant stress on Aquifer Transfer and Recovery (ATR) systems, which need to continuously deliver water by recovery after aquifer passage.

In the coastal dunes of the Netherlands, where large-scale Basin ATR is applied for drinking water supply since 1940-1957, intake interruptions are problematic, not only because of the necessity to supply nonstop drinking water to the Western Netherlands. There are also high risks of (i) salt water intrusion or upconing when drawing upon the stored volumes, (ii) undesired water quality changes due to oxidation processes when water tables decline or due to pumping more ambient groundwater, (iii) entrapped air hampering a rapid refill of the groundwater reservoir, and (iv) ecological damage of nearby wet dune slacks with an EU Natura 2000 status, which cannot survive without the artificially maintained high water levels. Examples are presented of the environmental impact of these risks, based on historical records.

An overview is given of the various reasons of intake stops, together with their score on a new Magnitude scale for Intake Stops (MIS). MIS is based on the duration of the intake stop and its impact (max if second intake also closed, and dynamic reservoir not available due to radioactive fall-out).

Simple closed form analytical solutions are presented to estimate the bridging period of 3 reservoir types: the dynamic reservoir (composed of recharge basins, shallow recovery and surrounding upper aquifer mainly filled with (infiltrated) surface water), the phreatic dune and deep dune reservoir.

Important mitigation and preventive measures have been taken to raise the security of water delivery by 8 Dutch dune infiltration systems. They consist of an international fluvial alarm system, solid pre-treatment near the intake, diffuse network of wells to pump from the deep reservoir if needed, a second intake of other source water, ASR wells along transport mains to create reserves outside the dune area, and internationally coordinated sanitation measures in the catchment areas of the Rhine River and Meuse River.

Implementing an energy-neutral Aquifer Storage and Recovery (ASR) system in a complex geological context in Lebanon

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KEY WORDS
Agricultural ASR, MAR siting, pilot system, Bekaa Valley, Lebanon

ABSTRACT
Plans to apply MAR have been discussed in Lebanon since the late 1960s, but have remained mainly academic. Putting ideas into practice, Acacia Water is showcasing the potential of MAR in counteracting Lebanon's decreasing groundwater levels with a recently constructed ASR scheme. The system will provide 5 $l\ s^{-1}$ irrigation water for grapevines in the Bekaa Valley, Lebanon's bread basket and refuge to 100,000s of people displaced by the war in Syria.

Selecting a suitable ASR site in a region of complex geology is a challenge – most of Lebanon is underlain by karst, for which little data is available. The project also needed to take into account practical criteria from the end-user perspective. For this, a multi-criteria funneling approach was employed to first identify areas with geological potential, and then refine the selection of potential sites based on criteria such as source water availability, groundwater quality, infrastructure, and stakeholder engagement. The site selection was completed after geophysical measurements (CVES) and water quality sampling was done.

A second issue was the technical set-up of the ASR scheme. An innovative site layout and state-of-the-art technology have been adopted to enable an energy-neutral operation-implementation of the system. Using elevation differences in the landscape, the source water is pressed through a filtration system without any additional energy input. A solar-powered pump recovers stored water during the growing season and feeds it into the irrigation network. Telemetric monitoring allows the off-grid operation of the system and provides easy access to real-time water level data, flow rates, and water quality parameters.

Great effort was put into building a strong knowledge base on MAR in Lebanon and to disseminate lessons learned in the project. For this, monitoring and evaluation of the system's performance were done in close collaboration with Lebanon's leading American University Beirut. Furthermore, expert workshops were organized to engage local water authorities, and the construction of the system was done in partnership with a Lebanese engineering firm. Most importantly, the project has been much appreciated by the agronomist who will play a significant role in upscaling the use of MAR schemes in Lebanon by demonstrating the pilot system to stakeholders in his network.

Site selection of underground dams using spatial multi-criteria evaluation in the Semi-Arid region of the State of Alagoas, Brazil

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KEY-WORDS
Underground Dams, Site Selection, Semi-Arid, Geographic Information System, Edaphic-water

ABSTRACT
The Semi-Arid covers 45% of the Alagoas territory (12.580 km²) and encompasses 30% of the state's population. Identifying suitable locations for Underground Dams - UD is essential and requires a multi-criteria evaluation, including pedological, geological, climatic, hydrographic and geophysical data. Due to there is a robust number of geospatial data from Alagoas available on the 1:100000 scale, Embrapa Soils and the Government of Alagoas have joined efforts to identify areas with the required characteristics. Topography (slope) and hydrography line vectors have been extracted using a hydrologically consistent digital elevation model (HCDEM) from a mosaic dataset created from 30-meter SRTM elevation raster images. Spring points received circular buffers, following the premises of the Brazilian Environmental Laws. Pedological data have been classified using soil attributes (effective depth, lithic contact, presence of stony, rocky, erosive and texture). Drainage system received a buffer containing the salinity and sodicity attributes from soil layer. Both layers (soil and water) were merged and this process was nominated as Edaphic-water Evaluation for UD Construction. Geological data have been classified according their structural / tectonic factors. Pluviometry data from 78 stations were classified and interpolated in three different seasons (dry, rainy and regular). All rasters produced were submitted to a basic math operation in GIS using the raster calculation tool. The numerical grids of each matrix file have been multiplied between them and classified in 3 categories – "excellent", "fair", and "restrict". The "excellent" category (3.6%) is dedicated for those areas that contain ideal natural conditions for UD; "fair" category (16.4%) is suitable, but may requires further analysis on variables which low evaluation rates were recognized, and; "restrict" category (78.5%) is not recommended but are not prohibited once environmental studies proved no other water technology can be successful. The site selection methodology adopted was effective, due to resulting areas presented high homogeneity. Furthermore, it was possible to validate the methodology as the most successful UDs in operation in Alagoas are located inside or close to the "excellent" and "fair" sites identified in the map.

Ozonation of Reclaimed Water to Enhance Soil Aquifer Treatment for Indirect Potable Reuse

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KEY WORDS
Ozonation, Indirect Potable Reuse, trace organics, pilot study.

ABSTRACT
The presence of persistent trace organic compounds has led to the consideration of alternative treatment processes prior to groundwater recharge. Reverse osmosis will remove almost all trace organics, but brine disposal is often a limiting factor. One promising alternative is ozonation prior to groundwater recharge. Ozonation is known to increase the biodegradability of organic matter and oxidize trace organic compounds. Ozonation was originally evaluated as a method to reduce dissolved organic carbon (DOC) concentrations. It was found that ozonation would increase the kinetics of DOC transformation during SAT. A more recent study evaluated the efficacy of ozonation prior to groundwater recharge on the removal of trace organics. Ozonation was effective at removing carbamezapine and primodone which are well known to be persistent in indirect potable reuse systems. However, ozone was not effective at reducing the concentrations of sucralose and the fire retardant TCEP. The results of this ozonation study were promising as other benefits included a reduction in DOC concentrations in the product water and the ozonation by-product bromate was removed during simulated groundwater recharge. Indirect potable reuse is becoming a necessity in Florida, USA where flow through porous media is often limited to the vadose zone. Therefore, soil aquifer treatment is limited to the vadose zone where residence times can be less than a day. Consequently, several communities in Florida are piloting the use of ozonation prior to rapid infiltration basins and applications for permitted indirect potable reuse systems in Florida are on the rise. Preliminary results from pilot studies look promising, but ozonation alone might not be sufficient to meet regulatory requirements for indirect potable reuse. Future pilot studies will include modification of surface sands to create a schmutzdecke and increase the residence time in the vadose zone. This could be necessary as rapid infiltration basins are designed to recharge groundwater without consideration of potential water quality improvements. The results of current pilot studies in Florida will be presented in the context of indirect potable reuse systems.

150 years old IBF systems in Budapest, Hungary – focusing on their sustainability and costs

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KEY WORDS
bank filtration, infiltration pond, river water, drinking water supply.

ABSTRACT
Managed Aquifer Recharge is an evolving technique worldwide to sustain groundwater level and preserve groundwater resources in the long term between changing climatic conditions. The web-based global inventory of managed aquifer recharge is a remarkable initiation (Stefan & Ansems, 2017) and it displays more than 1200 MAR sites from all over the world. However, IAH-MAR and INOWAS has only limited information about Hungarian MAR sites (eg. Homonnay, 2002). In addition, there are two fundamental questions about the already functioning MAR sites: their sustainability and their related costs. The bank filtration as a technique is handled as a MAR, and it has been long-term tradition in Hungary since 1868. Although there are 4 induced bank filtration (IBF) sites along the Danube River related to Hungary in the international database but there are several more represented only in the Hungarian literature. The oldest IBF sites are more than 100 years old and they are still working and ensure the drinking water supply of Budapest, the capital of Hungary. The Hungarian IBF sites are providing almost the longest operational experiences, therefore their sustainability and costs can be a good and traceable example for other countries. We present a review of the short history, sustainability and related costs of these larger MAR sites and also of others not yet represented in the database.

Recent applications and future prospects for MAR techniques in Hungary

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KEY WORDS
infiltration pond, MAR potential evaluation, drinking water supply, agriculture, water supply

ABSTRACT
The hydrogeological conditions of Hungary would be suitable for the more enhanced application of MAR systems for water management purposes. Recently there are two classical examples (aside from frequent IBF sites) of infiltration ponds for drinking water supply in Borsodszirák (Mikita and Kovács 2014) and in the area of Bátonyterenye Waterwork. The groundwater model of the Borsodszirák area could prove that 2–3 meters increase in water level can be achieved for the center and 0.2–1 m for a wider area in the gravel aquifers. The MAR concept was used for theoretical simulations in the area of Debrecen Great Forest. The study deals with the potential remediation of an overproduced area here. The potential technical solutions can be infiltration drains and an infiltration pond with different recharge capacities (Szűcs et al, 2007). The MAR concept also can be used in local discharge areas to flood the area and keep up water levels at the surface or in the soil layer to store the water for the purposes of agriculture and for natural vegetation. The artificial recharge of cleaned wastewater can be also an option but it is not favoured by Hungarian experts yet due to the restrictions in the legislation. In addition, future prospects along with a MAR potential of an area which is constantly fighting against water shortage will be discussed. We will present MAR potential maps for an area where water supply is planned in a natural conservation area.

Artificial recharge mechanisms via a leaky river bed – a case study in the outskirts of London, UK

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KEY WORDS
Artificial recharge, leaky river bed, drought resilience, leakage assessment, water resources management

ABSTRACT

The Chalk (a biogenic limestone) is the most important aquifer in the Southeast of the UK as it supports flows in the ecologically important chalk streams as well as significant groundwater abstractions for public water supply purposes. Based on the Water Framework Directive (EU directive) objectives, all rivers need to be in good ecological status or support good ecological potential by 2027. As such, understanding the surface – groundwater interactions is of paramount importance in order to quantify the groundwater abstraction impacts on river flows and the ecology, and implement an appropriate water resources management strategy. Managed Aquifer Recharge (MAR) schemes have been explored in the Southeast of the UK for water resources management, but depending on the local geology and the local water availability, it is not always possible to follow the conventional methods for MAR.

An alternative approach is presented in this study near London, in an unconfined chalk aquifer setting, supporting a number of groundwater abstractions, as well as providing baseflow to a river which is also supported by an effluent discharge. In this case study, the groundwater abstractions were found to be supported by river flows during drought conditions, which were in turn supported by effluent discharge directly into the river, upstream of the abstractions. During average flow conditions, treated effluent that is discharged to the river via the sewage treatment works, supports river flows at up to 5:1 dilution with the river baseflow, while under low flow conditions this dilution ratio can change. However, based on the river bed leakage assessment undertaken under different climatic conditions, it was found that a certain proportion of the total river flow can recharge the unconfined chalk aquifer via the leaky river bed in a 2-3 km stretch of river downstream of the discharge. This results in the discharge supporting higher pumping water levels in the nearby groundwater abstractions under low background groundwater level conditions and also heavily supporting river flows during such conditions. The effluent discharge contributes to the above groundwater sources which are considered drought resilient, however they are dependent on the operation and the effluent discharge from the sewage works.

The leaky nature of the river bed in this particular stretch of the river, has also been studied for other potential uses. For instance, the idea of capturing winter river flows above a certain trigger (i.e. Q10 or Q20) at a downstream location through the urban areas where the river is in a concrete channel and refilling currently disused reservoir storage is explored. Instead of then having to treat this water as surface water directly before using it for public water supply, releasing it back into the river at the head of the catchment during times of low flows to support both river flows and also the output of the groundwater sources via artificial leakage, could negate the need for additional treatment prior to use for public water supply. This can be classified as a type of MAR which albeit unconventional, has been proven to work under various climatic conditions. It can also prove a very cost effective scheme due to the lack of treatment needed for the surface-derived water. As such, there are wider water resources management options that can benefit from such MAR applications that can be more cost effective than conventional methods and should be explored further.

Potential for managed aquifer recharge to mitigate climate-change effects on fish and wildlife in the Snake River Basin, USA

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KEY WORDS
Climate change, Streamflow, Reservoir management, Fisheries, Snake River

ABSTRACT
Managed aquifer recharge (MAR) is currently being used in the Snake River basin, USA to stabilize and enhance water supply for agriculture, municipal use, and hydropower. In part because of favorable hydrogeology, MAR also provides a promising tool for mitigating effects of climate change on the basin's valuable fish and wildlife resources. MAR can act as an environmentally sustainable storage mechanism, diverting runoff from rain-on-snow and early snowmelt events to recharge local and regional aquifers. Resulting aquifer discharge can decrease summertime water temperatures and increase stream baseflow, mitigating regional climatic trends, which include decreased snow accumulation, early snowmelt, warmer temperatures, and increased interannual variability in water supply. MAR also has the potential to provide a market-based mechanism that can be used to incentivize decreased mid-summer irrigation diversion on key stream reaches, effectively moving withdrawal of that water to times and places that are less critical to fish and wildlife. However, the ecological benefits of MAR at target locations and times must be carefully weighed against potential environmental degradation at the times and places at which surface water is withdrawn for MAR. In the Snake River basin, one of the most important criteria from a fisheries standpoint is that withdrawal of surface water for MAR not place additional burden on reservoir storage. High-resolution modeling, ecological inventory, and monitoring will be necessary to design MAR projects that benefit multiple resources. Furthermore, realizing the full potential of MAR to benefit fish and wildlife will require modifications to current infrastructure and administrative rules. We provide examples of how fisheries conservation organizations in the upper Snake River basin are developing science-based strategies to use MAR as a conservation tool.

A Conceptual Framework for Managed Aquifer Recharge as a Strategy to Mitigate Drought Effects in Irrigated Agriculture: The Role of Institutions and Conservation

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KEY WORDS
Institutions, Managed Aquifer Recharge, Game Theory Application, Groundwater Banking

ABSTRACT
Increased water scarcity is a global problem. Groundwater aquifers, supplying 30 percent of water use, which are supposed to be managed as long-term storages for times of emergency, are gradually being depleted to a level that situates countries on the verge of water bankruptcy. Managed Aquifer Recharge (MAR) is a mitigation strategy against future uncertainty in water availability and receives growing attention, both in academia and in policy making arenas. Institutions, the governing rules that impact decision making on various levels associated with MAR, have mostly been overlooked, or at least were not explicitly incorporated in analyses conducted to evaluate MAR sustainability. In this paper we develop a conceptual framework, in a dynamic setting, to combine the effects of institutions, agricultural activity decision-making and uncertain water availability on the efficiency and sustainability of MAR projects. We discuss possible equilibrium states with respect to strategic behaviour on the part of economic agents, and given potential institutions governing the extraction of groundwater and the use of different water sources for recharge via MAR projects. We derive general results to be investigated empirically in the future in California. We also construct an illustrative example and examine how different solution concepts borrowed from cooperative and non-cooperative branches of game theory can achieve stable MAR arrangements. We also couple the different institutional arrangements with possible recharge methods (such as recharge basins, field-level flooding or well injection) and rank them based on their net gains to society.

Using machine learning to incorporate potential water quality improvements for mapping MAR suitability

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KEYWORDS
Mapping, water quality, machine learning, denitrification, recharge suitability

ABSTRACT
The generation of suitability maps for managed aquifer recharge (MAR) is a key step in identifying potentially promising locations for new recharge projects. These maps often incorporate soil characteristics, subsurface geology, climate, land use, runoff generation and other data to classify and rank potentially suitable areas for recharge. Less often considered is the potential for biogeochemical processing, such as the removal nitrate (NO_3), to improve water quality during infiltration. Many potential MAR source waters and groundwater supplies are impaired by elevated NO_3 concentrations and its removal during infiltration could provide a key benefit in impacted areas. Nitrate removal is most often carried out through the microbially mediated process of denitrification, which is most favorable under low oxygen and high carbon conditions. We have collected >150 individual measurements of denitrification during infiltration from four different operational or potential MAR sites at three different spatial scales within the Pajaro Valley, in central coastal California, USA. Using these measurements, we develop a statistical framework that leverages machine learning techniques such as regression trees and artificial neural networks to predict the potential of a soil unit to promote denitrification during infiltration. Maps of "denitrification potential" are then coupled with land use and modeled runoff maps of the area to identify locations where recharge projects could be located to maximize potential water quality benefit via nitrate removal during infiltration.

Producing more interpretable maps of managed aquifer recharge suitability by visualizing sensitivity to subjective choices during mapmaking

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KEYWORDS
Recharge suitability, mapping, open source software

ABSTRACT
Various input datasets used for aquifer recharge suitability mapping are generally classified, weighted and aggregated based on expert opinion, local conditions and/or project goals. As such, there is no standardized method for creating recharge suitability maps. Each step in the process requires subjective decisions that may significantly affect the final map of recharge suitability in ways that are difficult to discern without a formal sensitivity analysis. This can result in suitability maps of unknown or limited use to decision makers trying to effectively site new projects. We present an open source interactive web application that allows users to classify, weigh, and combine spatial layers to produce suitability maps easily. This is a general tool composed of a graphical user interface and underlying code that allows the user to quickly visualize spatial data and quantitatively explore the effect that different classification schemes, weights and aggregation methods have on the composite landscape suitability. Maps update in real time in response to changes in input values, resulting in better process understanding and allowing the user to develop intuition about the effects of the subjective decisions made during the map making process. Intermediate and final maps, as well as metadata documenting workflow and user input, can all be downloaded and used in other mapping software for subsequent analysis. The product is aimed at decision makers and stakeholders with limited experience in more sophisticated data analysis techniques such as scripting or other more powerful mapping software and it is geared towards more transparent interpretability of composite suitability.

Emerging organic contaminants in managed aquifer recharge: investigating their removal to ensure a sustained, safe, high quality water resource

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KEY WORDS
Water, Health, Environment, Groundwater, Hydrochemistry

ABSTRACT
Increasingly, the potential risks that water recovered from managed aquifer recharge (MAR) schemes could pose to public health and the environment are being recognised. A number of emerging organic contaminants are becoming ubiquitous in the environment, resulting in frequent detections in the stormwater and wastewater used in MAR.

In MAR, water that is potentially nutrient rich is injected into nutrient starved groundwater environments, meaning microbial growth is common, sometimes leading to the 'clogging' of pore spaces proximal to the injection site. Although a potential nuisance due to clogging, the biofilms which form in aquifers used for MAR could play an important role in the fate and transport of contaminants in these environments. Few studies have investigated their role in organic chemical removal.

This new study aims to improve understanding of how organic contaminants behave in managed groundwater environments. To achieve this a combination of batch and column studies in the presence and absence of biofilm are being conducted. These experiments integrate physical, chemical and biological processes which have potential to influence the removal of organic chemicals in MAR environments. Uniquely, authentic and unmodified aquifer materials, sourced from a representative tertiary aquifer in South Australia are used in these experiments. The effect of water composition was investigated.

Preliminary results from four-day time series experiments have shown how the investigated compounds are removed from solution under mixing conditions.

Ongoing batch studies aim to determine how the investigated compounds interact with aquifer substrates and, most importantly, how removal is affected by the presence and absence of biofilm.

Uniquely for column studies simulating MAR conditions, a discontinuous flow regime is being used in experiments. Such a flow regime enables distinction to be made between removal under static and continuous flow conditions, as would be encountered in a MAR scheme.

By better understanding the fate and transport of organic contaminants in MAR schemes, better informed management decisions can be made. This in turn assists in ensuring MAR can be implemented in a safe and sustainable manner.

This presentation will outline the most up to date results emanating from this ongoing work.

Laboratory and field experiments on the significance of the screen lengths for maximum well injection rates in an unconfined aquifer

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KEY WORDS
Managed aquifer recharge, water scarcity, well injection, well screen,

ABSTRACT
Beside spreading methods, such as basin infiltration, direct well methods, like aquifer storage and recovery (ASR) and aquifer storage transfer and recovery (ASTR) can be a viable technique for the managed recharge of aquifers (MAR), especially in case of need of avoidance of open water areas or more complex hydrogeological conditions. For ASR, the same well is used to inject and recover the recharge water while in for ASTR, one well or a set of wells is used for injection and another well or set of wells is used to recover it. In both cases, the injection or infiltration efficiency depends on various parameters from screen clogging, well diameter and depth of injection to recharged water quality and rate. In this work, the efficiency of the well recharge system under different screen lengths has been tested in a laboratory scale and following the results obtained have been upscaled to field experiments at the Pirna site (Germany). Both the laboratory and field results show that the screen length has a non-proportional effect on the infiltration rate, which is almost negligible for open screen length above 40% of the saturated aquifer thickness, but a high effect in the dynamic pressure level in the well. Three regions can be recognized on the effect of the screen length on the injection rate: 1) a non-significant effect on the relative recharge for open screen length above 80% of the saturated thickness, 2) an effect on the relative recharge for 80-40% of the saturated thickness, and 3) a significant effect on the relative recharge for 40-15% of the saturated thickness. For field conditions, aquifer heterogeneities may play an important role the effect of the open screen length on the injection rate. Based on this results and literature findings, too recommendations are done for the dimensioning of the open screen length for injection wells: 1) ASR well should be screened up to 40% of the total saturated aquifer thickness and 2) pure injections well should be screened up to 80% of the total saturated aquifer thickness in unconfined aquifers. Furthermore, the heterogeneity effects should be further studied with the aid of numerical simulations. Both the experimental and field experiments have brought light into the dimensioning of injection wells.

MAR as an adaptation meassure for saline water intrusion and water scarcity in the Guanacaste Region of Costa Rica

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KEY WORDS
Managed aquifer recharge, saline water intrusion, water scarcity, Guanacaste

ABSTRACT
Saline water intrusion in coastal aquifers and water scarcity, specially at the end of the dry season, affect water resources in Costa Rica, particularly in coastal aquifers located in the Northern Pacific peninsula, in the region known as Guanacaste. To address these issues, a research-cooperation project between the Technische Universität Dresden and the Universidad Nacional de Costa Rica is being implemented since late 2018. Managed aquifer recharge (MAR) is being evaluated as one of the potential adaptation measures for both the saline water intrusion and water scarcity in the Huacas-Tamarindo coastal aquifer.

This paper presents the results of the feasibility assessment for the identified projects based on the Australian MAR guidelines. The first stage of the feasibility assessment consists of a checklist of five critical elements: i) sufficient demand, ii) adequate recharge source, iii) suitable aquifer, iv) space to treat, and v) human capability, which constitute the base for the assessment of a MAR project. According to the Australian Guideline a MAR project is feasible in the Huacas-Tamarindo aquifer. Upcoming research will focus on the next stage in the Australian MAR Guideline, which implies a detailed investigation, followed by a pilot and the commissioning and operating of a MAR scheme in coastal aquifers. Our results suggest that MAR could be implemented in salinized coastal aquifers as part of an integrated water management approach to recuperate overexploited aquifers.

Modelling Long-Term Behaviour of 38 Trace Organic Compounds during Bank Filtration (Lake Tegel, Berlin)

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KEY WORDS
Bank filtrate, trace organic compounds, metabolites, reactive transport modelling, biodegradation rate constant, sorption isotherm

ABSTRACT
Though bank filtration diminishes the loads of many trace organic compounds present in source water, there is still a wide uncertainty on the influence of scale factors and local environmental conditions on soil-water interactions and biodegradation processes, as well as on the probability to obtain undesirable transformation products into the aquifer and eventually in drinking water wells. This research addresses the numerical characterization of the fate and behaviour of 38 trace organic compounds intensively monitored for the last six years at the shore of Lake Tegel in Berlin. The study area embraces an aquifer length of circa 100 meters from the lake bank to the proximity of a production well gallery. We compare the observed and estimated concentrations at 3 intermediate monitoring wells that are not affected by mixing processes with old bank filtrate observed in deeper parts of the aquifer. The outcome of a two-dimensional FEFLOW conservative and reactive transport model attains the identification of 12 persistent trace organic compounds and 5 metabolites formed into the aquifer, including 9-acridine carboxylic acid, which appeared in high concentration in other sites (Kaiser et al., 2014). Furthermore, first-order biodegradation rates and sorption isotherm coefficients are derived from the model for 12 reactive compounds. We approximate maximum half-life values for 9 chemical compounds only present in lake water. These results highlight the efficiency of the sub-surface to improve the water quality during bank filtration, yet at the same time prove the persistence of some compounds in the aquifer. These compounds may be used as surrogates/indicators of wastewater influence on groundwater quality. In the next step, we will consider the seasonal dynamics of temperature and redox conditions temporally establishing separate zones along the soil passage. Within these zones, certain compounds modify their reactivity, their capacity to produce metabolites, and/or their redox behaviour. For that purpose, the model will account for electron-acceptor availability and sorption/desorption approaches. Moreover, it will test the most likely reactive pathways and the relationships between trace organic compound occurrence and environmental parameters that may apply beyond site-specific conditions.

Key hydrogeochemical processes (im)mobilizing trace metals (arsenic, iron, manganese) in MAR for drinking water provision in Bangladesh

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KEY WORDS
SW Bangladesh, Managed Aquifer Recharge, Push Pull Test, Arsenic

ABSTRACT
The southwestern coastal part of Bangladesh suffers from lack of both safe and fresh drinking water due to shallow saline-brackish groundwater, elevated arsenic levels, and scarce surface water resources during the dry season with risk of pathogen contamination. To combat against this, Managed Aquifer Recharge (MAR) has been introduced in this part of the country where aerobic fresh surface water is injected and stored in the subsurface; and the resulted freshwater 'bubble' is recovered using a hand operated tube well for drinking water purposes. By injecting fresh (aerobic) surface water with possible presence of organic matter into brackish (anaerobic) aquifers, there is a chance of (im)mobilization of trace metals like As, Fe, and Mn that could possibly alter the quality of recovered water. As, Fe, and Mn could be mobilized as consequence of pyrite (if present) oxidation or iron oxy-hydroxide reduction. However, trace metals could also be immobilized due to adsorption of As, Mn, and Fe on newly formed iron-oxides. Both (cyclic) aerobic and anaerobic (sucrose amended) Push Pull Tests (PPTs) were conducted at selected MAR sites to observe aquifer reactivity in response to fresh water injections focusing on trace metals (im)mobilizations. In cyclic PPTs, oxygen saturated water seems to lead to oxidation of mostly dissolved and by cation-exchange processes desorbed ferrous iron in groundwater, while potential oxidation of pyrite seems a minor process. Accordingly, formation of iron-oxides and potentially also Mn-oxides have led to removal of trace metals including As, Fe, and Mn during abstraction. In anaerobic and sucrose amended PPTs, strongly increased concentrations of Fe, Mn, and As were observed after 12-15 hours since injection. Reductive dissolution of Fe(III)-oxides under anoxic conditions seems the key process for trace metals mobilization in MAR sites, while pyrite oxidation seems at most minor. Oxygen stimulated formation of Fe(III)-oxides may lower levels of Fe, As, and Mn in drinking water. The findings suggest that keeping the fresh water bubble oxic is essential to keep metal concentrations below drinking water limits.

Understanding hydrogeochemical processes governing MAR water quality by applying weekly monitoring and mass balance modelling in Bangladesh

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KEY WORDS
SW Bangladesh, Managed Aquifer Recharge, Water quality monitoring, Mass balance modelling, Trace metals

ABSTRACT
Aiming to address available fresh and safe drinking water options, a consortium of UNICEF, Department of Public Health Engineering (DPHE), Dhaka University, and Dutch consultant Acacia Water with the help of local NGOs have installed and monitored 99 Managed Aquifer Recharge (MAR) sites in the SW part of Bangladesh at different stages from 2009-2017. MAR has been introduced as a promising technology in this part of the country where aerobic fresh surface water is injected and stored in the subsurface; and the resulted freshwater 'bubble' is recovered using a conventional hand operated tube well for drinking water purposes. During regular monitoring these sites, it has been observed that MAR performance varies in degree of salinity reduction and occasionally shows elevated concentrations of trace metals like As and Fe. On this ground, knowledge and guidelines are urged for optimal MAR performance with reference to drinking water quality. Therefore, it is of utmost importance to study a typical MAR scheme in detail. High frequency monitoring was applied at two selected MAR sites with variation in arsenic concentration. Water samples from the pond, pre-filter, native groundwater, and recovered water were collected on weekly basis and onsite parameters like conductivity, temperature, pH, redox and dissolved oxygen were measured. Water samples were later analyzed for major ions and trace metals in the lab. For observing hydrogeochemical processes like extent of mineral dissolution/precipitation, cation-exchange, and redox processes starting from injection to recovery, an inverse mass balance model on median values of major ions and trace metals was developed. In this mass balance approach, mixing of infiltration water and native groundwater plus additional hydrogeochemical processes were calculated to produce the recovered water quality. At both sites, cation exchange (freshening), sulphate reduction, and consumption of dissolved oxygen is observed with increased bicarbonate concentrations. In addition to this, mobilization of trace metals like As and Mn is observed presumably due to organic matter degradation coupled to iron-reduction. However, immobilization of trace metals As and Mn is observed at one site due to sorption on newly formed Fe oxides minerals.

Identification of MAR archetypes through statistical and time trend analysis on basis of hydrochemical data from 99 UNICEF MAR sites, SE Bangladesh

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KEY WORDS
SW Bangladesh, Managed Aquifer Recharge, Python-pandas programming, Principal Component and Cluster analysis

ABSTRACT
Aiming to address available fresh and safe drinking water options, a consortium of UNICEF, Department of Public Health Engineering (DPHE), Dhaka University and Dutch consultant Acacia Water with the help of local NGO's have been installed and monitored 99 Managed Aquifer Recharge (MAR) sites in the SW part of Bangladesh (Khulna-Satkhira-Bagerhat) at different stages from 2009-2017. MAR has been introduced as a promising technology in this part of the country where aerobic fresh surface water (both pond and rain water) is injected and stored in the subsurface; and the resulted freshwater 'bubble' is recovered using a conventional hand operated tube well for drinking water purposes. Regular monitoring has been done (2009-2017) by field supervisors measuring parameters like water level, infiltration/abstraction water volume, turbidity, electrical conductivity, pH, temperature, and concentration of arsenic and iron. During regular monitoring of those sites, it has been observed that MAR performance varies in salinity reduction and elevated concentrations of trace metals like As and Fe are occasionally observed. Therefore, it is of utmost importance to identify and group similar MAR sites based on physical and hydrochemical processes like salinity reduction and concentration of As, Fe, etc. to potentially identify factors that cause these differences. Python-pandas scripting was developed to read and plot results of the 99 MAR sites dataset (data stored in excel). Linear trend analysis was applied to assess temporal patterns in As and Fe concentrations. Scatter plots (correlation between As/Fe), principal component analysis, and cluster analysis were done to find groups of similarly performing sites. Descriptive statistical analysis was performed to calculate mean and median values and then spatial maps with those values were prepared using ArcGIS® software. Sites with (i) decreasing As and Fe concentrations with high starting values, (ii) increasing As and Fe concentration with low starting values, and (iii) increasing As and Fe concentrations with high starting values were identified from above mentioned analyses. Based on these results, sites for further detailed study were selected.

Flood-protection of riverbank filtration wells

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KEY WORDS
River bank filtration, flood, protection, design, sealing, tracer

ABSTRACT
Riverbank filtration (RBF) for drinking water production plays a vital role as an ecosystem service in many countries including India, especially to remove pathogens. Commonly, RBF wells are located at a distance of 10 – 300 m from the river bank and prone to flooding. Not only RBF wells but also groundwater wells risk contamination from the direct entry of flood water and extreme rainfall events. The contamination pathways are attributed to non-watertight well heads and well chamber covers, cracks and fissures in well chambers and caissons, insufficient sealing of the well at ground level and below in the annular space of the well bore that result in preferential flow paths and eventually “short circuiting”. Based on long-term construction and operational experience of wells, recommendations and guidelines to waterproof and protect them against the direct surface water entry have been published (Rambags et al., 2011), actualized (Treskatis, 2017) and partly implemented in Europe. Not only in developing countries, practical implementation of flood proof measures during well construction is a major challenge comprising technical, institutional and industrial aspects.

Besides the conceptual design of a pilot flood-proof well constructed in Srinagar, India (Musche et al., 2018), field test methods to check the watertightness of different well elements will be presented. Tracer tests were conducted at RBF wells in Germany and India 2015-2018 to investigate the presence of short circuiting flow paths and to determine the travel time of the surface water in case of a flood. Inundation experiments were performed to proof the watertightness of commercial flood proof manhole covers and a custom made well head.

Conjunctive Surface Water and Groundwater Management in the Baoding Plain, China: Opportunities to Restore Overexploited Aquifers through in lieu Managed Aquifer Recharge

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KEY WORDS
Hydrological model; North China Plain; Managed Aquifer Recharge; regional scale

ABSTRACT
Over the past half century, water consumption has increased drastically in the North China Plain (NCP) due to the intensive agricultural and industrial activities. Groundwater depletion from 1960s to 2008 averaged ~4 km^3/yr (~2.5 km^3/yr in the 1970s, ~4.0 km^3/yr in the 1980s, ~2.0 km^3/yr in 1990-1996; ~7.0 km^3/yr in 1997-2001, and ~4.0 km^3/yr in 2002-2008.) (*Cao et al.,2013*), which resulted in a water table decline with 11 cones of depression in the shallow unconfined aquifer, totaling 11,000 km^2 in 2009 (*Fei et al.; Yang et al., 2013*). As early as 2002, the South to North Water Diversion Project (SNWD) was initiated to alleviate the water scarcity of the NCP. The central route of SNWD, which is built across the NCP, was completed in 2014, providing 9.5 km^3 of water annually. By 2030, water transfer is expected to increase to 12 to 13 km^3 annually. Increasing availability of water from SNWD means that there can be less pumping, representing in-lieu managed aquifer recharge (MAR), or a form of MAR through conjunctive surface water and groundwater management albeit in this case, cross basin transfer of surface water.
A multilayer, heterogeneous and anisotropic groundwater flow model was constructed for the Baoding Plain area of the NCP to evaluate recovery of groundwater aquifer with anticipated reduced pumping rates due to the newly available SNWD water. The Quaternary aquifers in the Baoding Plain were divided into four major aquifer units I, II, III, and IV (*Regional Hydrogeological Survey, 1970, Hebei Bureau of Geology and Mineral*). The three-dimensional regional groundwater model has two heterogeneous layers where the aquifers I and II are generalised into the first layer due to their likely hydraulic connection, and the aquifer III is set as the second layer. The boundary condition is set for specific flow based on specific inflow and outflow data. The first layer has 17 lateral inflow boundaries and 6 outflow lateral boundaries according to different lithology, while the second layer has 17 lateral inflow boundaries and 8 lateral outflow boundaries. The initial hydraulic heads of this model are from distribution of measured heads in Baoding Plain on June, 2010. This transient model was divided into 84 stress periods, i.e. per month from 2010 July to 2017 June. The simulated groundwater level contours are similar to regional flow pattern in groundwater level contour maps. And the simulated groundwater level time-series data are consistent with observed data with a maximum error of 4 m. The calibrated model is applied to predict the spatiotemporal variability in groundwater levels under the scenarios of 0.55 km^3 and 1.05 km^3 water supply from SNWD in 2020 and 2030 respectively. The results show that by the end of 2030, in spite of water supply from SNWD, water levels in ~40% of the first layer will still decline 15~20 m due to continued pumping demand of 2.05km^3 (*Institute of Hydrogeology and Environmental Geology, China Geological Survey, 2018)*, while the water levels in ~50% of the second layer will increase 0~5m and previous depression cones will disappear, since the pumping from this layer has been replaced by the water supply of SNWD. Thus, conjunctive management of surface water and groundwater in the NCP requires a more calibrated and quantitative management of pumping for different aquifer systems.

Assessment of bank filtration in arid climate, case study: El-Minya, Egypt

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KEY WORDS
Bank filtration, Egypt, ammonia, dissolved organic matter, the share of bank filtrate

ABSTRACT
Bank filtration (BF) is a cost-effective technique that has been used widely in many developed countries for providing drinking water with high quality. Recently, this technique is applied in developing countries (e.g., Egypt) under different environmental and climatic conditions. The main objective of this research is to assess the capabilities of BF to remove specific pollutants under Egyptian conditions. The field study has been conducted in Upper Egypt, (El-Minya) along the River Nile and its distributaries. The investigations have included drilling test boreholes, recognition of both the subsurface profile and hydraulic parameters of the productive layer. Moreover, continuous monitoring of water quality has been done during the period of Jan. 2016 to Dec. 2016 on a monthly basis. Water samples were collected from both the surface water and bank filtration wells.

The Nile valley aquifer has the high potentiality to produce a high quantity of subsurface water. The thickness is more than 40 meters and means hydraulic conductivity is 0.0006 m/s. Nevertheless, the hydraulic connection is not clearly recognized and if the River Nile and its distributaries are fully or partly cutting the top layer (silt and clay). This has entailed using major tracers as EC and Chlorides. The bank filtration share range from 60 to 90%. The chemical analyses results refer to the high capability of this technique to remove organic pollutants, the DOC removal was ranged between 62 and 81%. The high removal of organic matter during the filtration process is mainly attributed to the high concentration of labile matter in the raw water that efficiently removed by biodegradation. The concentration of ammonia was decreased by more than 90% during the BF process. Please write about other results in terms of range during the monitoring periods (positive or even negative) (turbidity, TDS, pathogens, protozoa, iron, manganese and ammonia, etc). These results refer that there is potentiality to apply BF under the Egyptian environmental conditions. BF techniques deserve detail investigation under the Egyptian conditions in order to support the current conventional techniques infeasible localities along the River Nile and its distributaries in Egypt.

Modeling the influence of temperature in the infiltration rates and redox reactions of an infiltration pond located in the Llobregat River Basin

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KEY WORDS
Flow and heat transport model; Hydrus-HP1; bioclogging

ABSTRACT

The recharge efficiency of an infiltration pond in terms of water storage can be diminished by the generation of bioclogging during warm periods (spring and summer). On the other hand, during these periods the water viscosity is highly affected by temperature – increasing the effective hydraulic conductivity. Furthermore, in terms of water quality, the presence of bioclogging due to the growth of photosynthetic organisms in the infiltration pond could imply the incorporation into the recharge system of an electron donor (in form of organic carbon), potentially enhancing the redox reactivity and favouring the attenuation of emerging organic compounds and nutrients.

In this work we aim at answering what are the effects of temperature in the infiltration rates and in the redox reactivity. For that, we developed an integrated model of flow, heat transport and hydrochemistry in an infiltration pond considering the different management conditions of the recharge facilities during a full year. The model was fitted with high resolution (in space and time) data of hydraulic levels, temperature and *in situ* redox potential, plus data from four hydrochemical sampling campaigns at the infiltration pond, unsaturated zone, and groundwater from an aquifer recharge facility located in the Llobregat River Basin in Castellbisbal (Spain). The model considered the different recharge management particularities along the whole year 1) incorporating a soil layer to simulate clogging in the shallow soil depths (physical and bioclogging) and its hydraulic conductivity changes during scraping and 2) incorporating a carbon source to simulate accumulation of photosynthetic organisms and how it releases organic carbon into the system. We found that the effective hydraulic conductivity was highly influenced by temperature, increasing the infiltration rates in warm periods. Although this phenomenon sometimes occurs simultaneously to at the same time of bioclogging, the infiltration rates are larger better than in colder periods. Besides, the release of organic carbon implies an extra input of organic carbon into the system and the enhancement of redox conditions. This would imply a quality improvement of recharged water during infiltration in terms of the presence of nutrients like nitrate and the emerging organic compounds.

Regulation of Managed Aquifer Recharge schemes under the EU's Water Framework Directive

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KEY WORDS
Governance, Water Framework Directive, Groundwater Directive, Environmental Impact Assessment, Prevent and Limit

ABSTRACT
The EU Water Framework Directive (WFD) considers Managed Aquifer Recharge (MAR) as one of the groundwater management tools which EU Member States can consider for the achievement of the environmental objective of good groundwater status. The application of MAR is however regulated under the Water Framework and the Groundwater Directives, as well as associated Directives such as the Environmental Impact Assessment Directive to ensure that the application of MAR to support the achievement of good quantitative status takes full consideration of the protection of groundwater qualitative status.

The review undertaken under this study identifies the main regulatory requirements for the management of MAR schemes under the EU Water Acquis. These include aspects such as the legal conditions required for the issuance of a permit, the context of resource and environmental protection, the development of monitoring frameworks and the enforcement of permit conditions. Furthermore the application of the regulatory requirements to direct and indirect MAR schemes is also considered, with particular reference to the important role of the unsaturated zone in enhancing groundwater protection.

Based on this comprehensive review the study proposes a compliance scheme to guide the application of the provisions of the EU regulatory framework to the development of different MAR techniques. This scheme clearly identifies the roles and responsibilities of policy, regulatory and implementing agencies, hence also supporting the actual implementation and enforcement of the legislative provisions under the EU Water Acquis. This whilst ensuring a sufficient level of flexibility to allow its adoption in the different institutional context in the various EU Member States.

Furthermore, a comparative assessment of the legal and institutional framework developed in regions outside the EU was undertaken with the aim of identifying the different approaches which have been developed for the optimised implementation of MAR techniques. This assessment contributes to the identification of practical approaches which can facilitate the application of MAR as a safe technique for the optimal management of groundwater resources.

This study was part financed by the European Union's 7th Framework Programme under the MARSOL Project.

A Socio-Economic Impact Assessment of Managed Aquifer Recharge in the Pwales Groundwater Body - Malta

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KEY WORDS
Socio-economic, environmental benefits, cost effectiveness,

ABSTRACT
The Pwales Coastal Aquifer is a small groundwater body in the northern region of Malta, which sustains an important local agricultural community. The groundwater body, due its hydrogeological isolation and anthropogenically highly impacted nature, has been identified, during the formulation of Malta's 2nd River Basin Management Plan, as one of the ideal sites for the undertaking of an initial application of Managed Aquifer Recharge (MAR) at the groundwater body scale. The scope of this study is focused on the application of highly polished treated water (New Water) in periods of low agricultural demand, hence enabling the application of water reuse for groundwater body restoration. The application of MAR with New Water is hence considered as a tool which can potentially enable the Pwales Groundwater Body to attain the good quantitative and qualitative status objectives under the EU's Water Framework Directive.

This study undertakes a comprehensive socio-economic assessment of the application of MAR to the Pwales groundwater body and determines the expected positive contribution that the implementation of the MAR project will have on the economy at the local, regional and national levels. The estimation of the socio-economic impact of the application of MAR on the groundwater body is undertaken through a comparative evaluation of the total projected cost of the project with the impact of the project output, hence allowing for the establishment of a cost effectiveness ratio. In order to highlight the multiple economic benefits of the project, the study undertakes a comparative assessment with the baseline scenario, hence providing an opportunity for the comparison of project benefits and costs to determine the incremental effect of the project.

The costs considered under the study include the investment costs, operating costs such as maintenance costs, project management costs and labour costs. The direct benefits generated by the project mainly relate to the improvement of the ecosystem services whilst the economic benefits relate to employment and income generated by the project. The study thus adopts a comprehensive assessment of the application of MAR through a broad assessment of both direct and indirect socio-economic impacts.

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Infiltration in Sustainable Urban Drainage Systems: are we doing it right?

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KEY WORDS
Infiltration, MAR, pollution, stormwater, SUDS

ABSTRACT
Sustainable urban drainage systems (SUDS) are an alternative approach to conventional urban stormwater management. SUDS are part of the urban green infrastructure which promote natural processes to mimic predevelopment hydrology in cities. One of the main mechanisms enhanced by SUDS is infiltration into the ground. Thus, infiltration reduces runoff volumes during rainfall events, delivering interception for the contributing area and reducing the attenuation storage volumes required for achieving the design goals. The benefits of infiltrating water are multiple: from increasing aquifer recharge till supporting soil moisture and local vegetation. Nevertheless there are also risks and constraints when promoting infiltration in urban areas: risk of subsidence, slope instability, pollution into the ground, among others.

In Spain, despite some examples, there is a lack of guidance and regulations for SUDS design, construction and operation. As a consequence, international manuals are generally used and adapted to local conditions. Focusing on the water quality requirements, a common methodology for designing the SUDS treatment train is the simple index approach: the catchment is characterised by a pollution hazard index depending of its land uses and the SUDS treatment train is characterised by a pollution mitigation index. The last depends on the specific SUDS typologies but also on whether runoff excesses are spilled into surface waters or into the ground. When the infiltration component itself does not provide enough pollution mitigation, the treatment train must include other SUDS techniques upstream to ensure a sufficient mitigation index. Since the last decade, a significant number of SUDS promoting infiltration have been built or retrofitted in Spain.

This paper presents some examples in Valencia, Madrid and Barcelona (Spain), where annual infiltration volumes have been estimated and the former preventive measures where adopted when designing for infiltration. Nevertheless, are we doing it right regarding water quality of infiltrated water? Despite the current SUDS monitoring efforts, are we paying the same attention to characterising impacts into the ground than to surface water? Are we considering managed aquifer recharge (MAR) for climate change adaptation? The main conclusion is that more efforts are needed to improve mitigation indexes for infiltration SUDS techniques to reduce their uncertainty, while MAR benefits need to be considered in the urban agendas.

Smart framework for real-time monitoring and control of subsurface processes in Managed Aquifer Recharge applications

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KEY WORDS
Managed aquifer recharge, web-based tools, real-time monitoring and control, risk assessment and management

ABSTRACT
Despite its financial and ecological benefits, the contribution of MAR to safe water supply at global scale is still limited due to various reasons. Especially the lack of data on associated risks and the absence of proper monitoring at some MAR facilities reduces the level of public trust, raises questions about the impact of MAR on the affected ecosystem and hinders the optimal operational management. An efficient control of the recharge and recovery processes through simulation-based optimization and control incorporating real-time data would allow water operators to optimize the performance of MAR systems while satisfying economic and environmental constraints.

The main objective of the EU-funded project SMART-Control is to reduce the risks in the application of sustainable groundwater management techniques through the development and implementation of an innovative web-based, real-time monitoring and control system in combination with risk assessment and management tools which will allow to improve the implementation, management and operational capabilities of MAR facilities.

The SMART-Control approach encompasses research, piloting, demonstration, training and technology transfer in one framework where tools developed in previous and ongoing European projects will be enhanced. The core of the project consists of the web-based INOWAS platform, where various analytical and numerical tools for MAR assessment are compiled and which will be enhanced with additional features to assess, monitor and control the occurring processes at MAR facilities. The approach will be tested at six pilot and full-scale MAR schemes in Germany, France, Cyprus and Brazil which ensures that the framework can be applied to various environmental and operational conditions to improve integrated water resources management techniques

SMART-Control will prove that despite MAR is a nature-based solution, risks associated with the implementation and operation can be managed and controlled and demonstrates that it is a safe and reliable technique for integrated water resources management. The web-based platform offers a new scientific approach to analyse the relevant processes in real-time which enables the up-to-date diagnostic for operators, regulators and water managers.

Delimitation and categorization of potential recharge zones in a multi-layered aquifer

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KEY WORDS
Recharge zones, multi-layered aquifer, management measures, groundwater.

ABSTRACT
The recharge of an aquifer system is generally conditioned by the spatial distribution of the hydrogeological units, the geomorphological characteristics of the landscape, the characteristics of the rocks that surround and support the aquifers, the type of coverage and the hydraulic characteristics of the soils, the hydrography and the hydrometeorological conditions. Additionally, anthropic factors such as the return from irrigation and leaks in the aqueduct and sewerage networks can be constituted as sources of recharge. The delimitation of the recharge zones constitutes a fundamental element in the conceptual hydrogeological model, which provides tools for the implementation of management measures of a technical, administrative and normative nature, whose purpose is to carry out an adequate management of the underground water resource.

In the Gulf of Urabá, in Antioquia-Colombia, groundwater is the main source of supply for some communities and the banana industry, this area has a conceptual hydrogeological model, which recognizes a multi-layered aquifer system. Through the research agreement between the University of Antioquia and the environmental corporation CORPOURABA, the identification and delimitation of the potential recharge zones was made, both for the shallow aquifer levels and the deep levels. To this end, a methodology was implemented that considers parameters such as: topography, geological structures, textural characteristics, infiltration capacity, and location of springs. This methodology performs a weighting of the parameters considered and is assigned a weight of 1 to 5, with 1 being the least important zones and 5 the most important ones, with these weights a qualification is obtained that allows the delimitation and categorization of these zones. Finally, maps are obtained with the distribution of the potential recharge zones for the aquifer of the shallow and deep levels, which are validated from hydrogeochemical and isotopic analyzes. Based on these results, management measures will be derived considering that it’s an agricultural area that depends on groundwater, and over-exploitation or mining of groundwater should be prevented.

Combined natural and engineered systems (cNES) for Managed aquifer recharge (MAR) & soil aquifer treatment (SAT) system with water storage and quality improvement

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KEY WORDS
Natural and engineered water treatment, reuse, SAT, MAR

ABSTRACT
MAR systems have numerous functions and advantages in water management. They are used to mitigate floodwater, control saltwater intrusion, store water to reduce pumping and piping costs, temporarily regulate groundwater abstraction or treat wastewater for water reuse. To maintain system performance and to enhance its efficiency, pre-treatment of the source water before infiltration or injection is necessary. This may encompasses the removal of critical contaminants (pathogens, ammonia, trace metals…) and a variety of chemical compounds, both endogenous and anthropogenic. Depending of the uses and in view of new target uses such as indirect potable reuse (InPR), sustained long term operation and compliance with regulatory requirements are key.

The H2020 project AquaNES demonstrates combinations of natural and engineered treatment systems (cNES) in 14 sites in Europe, India and Israel to cope with issues such as water scarcity, excess water in cities and micro-pollutants in the water cycle. Four of these sites investigate MAR applications and aim to:

- Investigate the effect of UV/H2O2 pre-treatment before SAT to remove recalcitrant micropollutants and enhance the overall biodegradability of organics in a drinking water production site based on surface water infiltration (Site Lange Erlen, CH);
- demonstrate the benefits and optimised operation of an alternating ozonation-biofiltration-oxidation treatment of secondary effluent before SAT for ultimate use of reclaimed water in agricultural irrigation or even InPR (Site Shafdan, IL);
- develop site specific ICT tool to assess and control the long-term performance of combined engineered-MAR solutions assisted by advanced monitoring and modelling (Site Agon-Coutainville, FR);
- test and optimise a mobile high-rate filtration system combined to Aquifer Storage and Recovery (ASR) to better cope with and utilise storm water (Site in the Netherlands Ovezand).

Results from demonstrating these innovations will highlight the benefits of combinations of natural and engineered components for improved or adapted design, operation and management of MAR systems.

Groundwater-based natural infrastructure: a critical piece in supporting water security and resilience

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KEY WORDS
Groundwater-based natural infrastructure, groundwater-based ecosystems and services, managed aquifer recharge, integrated water and sub-surface management, water security, resilience

ABSTRACT

Groundwater and the subsurface environment provide significant ecosystems services, in terms of 1) storage and protection of water, 2) mitigation of floods and droughts, 3) purification of water and biodegradation and attenuation of anthropogenic contaminants, and 4) support to in-situ and ex-situ environmental functions. It is increasingly acknowledged that these natural processes and supportive services depending on groundwater are critical in addressing multiple challenges of expanded pressure on water and environmental resources and climate change; e.g., increased storage of water underground in arid and semi-arid areas enhances water security and resilience. In order to enhance the long-term benefits from these groundwater-based ecosystem services, we need to pro-actively manage these natural assets, and in many cases combine them with engineering or human-built infrastructure. We call these solutions groundwater-based natural infrastructure (GBNI) solutions.

The paper provides a definition and typology framework for GBNI solutions, which broaden the portfolio of nature-based solutions that presently focus on surface water and on-the-ground solutions. The framework does not focus on provisioning services from groundwater *per se*, but rather the supporting processes required to sustain them such as water storage and purification. Benefits are often multiple from a single system (e.g. increased storage and environmental flows), less land footprint, and less water loss from evaporation. When managing recharge, subsurface storage and flow pathways through the landscape, the tradeoffs and short- and long-term impacts need to be understood. Equitability in benefit accrual and financing as well as integrated hydrogeological/geochemical impacts are aspects requiring further attention. A spectrum from simple and local GBNI enhancing water storage, to hi-tech solutions, which optimize water quality and supply for large populations, is presented through cases from around the world.

GRIPP (Groundwater Solutions Initiative for Policy and Practice), a global initiative of 30 international partners with an interdisciplinary mix of groundwater expertise, is co-developing integrated and sustainable solutions that rely on GBNI in support of the 2030 Agenda for Sustainable Development.

Regional impact of MAR in Southern Central Valley

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KEY WORDS
Hydrological droughts, Sustainable groundwater management, Drought-MAR, Banking water, Drought alleviation

ABSTRACT
Groundwater resources are under stress by increased frequency of climate extremes and rising water demands. Dependence on groundwater is increasing and abstracted volumes exceed natural recharge, resulting in depleted aquifers. The Central Valley (CV) in California is well-known for partially over-drafted groundwater basins in a highly productive agricultural area. Managed Aquifer Recharge (MAR) projects have been implemented since 1967 to enhance groundwater storage. Storing and banking of flood or imported water has replenished groundwater reserves locally. Banked water is used during dry periods, reducing dependency on imported water during climate extremes.
Implementation of the Sustainable Groundwater Management Act emphasises the potential for MAR to enhance climate resilience during droughts and to compensate for overuse. The impact of MAR projects and relative contribution to sustainable management remains unknown. Hence, this study investigates regional impacts of MAR on hydrological droughts in the Central Valley.

Groundwater data were obtained from the California Department of Water Resources and the US Geological Survey. The long-term groundwater level observation wells defined the temporal variability in groundwater. These time series were standardized and indices were clustered hierarchically. The spatially coherent clusters described the main variability in groundwater hydrographs across the CV. The relative contribution of MAR was established using the relation between groundwater and precipitation. The strength and coherence of groundwater and precipitation time series was assessed for all observation wells. Time series of recharged MAR volumes were used to establish the relative contribution during droughts.

Results show that observation wells located close to MAR basins have a distinct recharge pattern. All clustering methods identify this distinct pattern. Altered recharge processes cause changes to droughts (defined by the 20th percentile of time series). On regional scales, MAR has contributed to altered drought duration and timing. The relative contribution of MAR to groundwater recharge patterns marks the influence and importance of enhanced infiltration. It highlights key role for MAR projects to contribute to sustainable groundwater management.

Influence of temporal discretization of rainfall data on efficiency of an injection well

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KEY WORDS
Managed Aquifer Recharge, Drainage system, Water Balance, Urban Floods

ABSTRACT
Rainfall harvesting is one possible source of water for Managed Aquifer Recharge (MAR). The efficiency of injection rate is highly dependent of rainfall properties (depth, duration and intensity). In Brazil, there are several rainfall regimes with different rainfall properties. In its Northeastern coastal region, the average yearly rainfall is 1.700 mm and up to 70% rains from March to June. This natural condition combined with high impervious surfaces are responsible for urban floods. Few studies deal with MAR as a management tool for flood mitigation in this country, and most of water balances studies are carried out on daily or monthly scale. This paper presents an in-situ case study simulation based on monitored rainfall and on in-situ injection test. The aim is to quantify the efficiency of injection based on different temporal discretization of rainfall data: 10, 30, 60, 120, 360, 720 and 1440 minutes. The rainfall is monitored every minute and during the simulation it was aggregated at these time steps mentioned. The rainiest year (2011) from 2004 to 2017 was used. The rainfall harvesting system was made up of one rooftop (with area ranging from 106 to 1,350 m²), one storage tank (with volume ranging from 310 to 3,000 Liters), an injection well (diameter: 100 mm and 42 meters depth) and an unconfined aquifer (Barreiras system), whose water level was equal to 31 meters. An artificial injection test was carried out to understand the behaviour of the well, in order to find the relationship between the hydraulic head and the injection rate for this aquifer. These results were used to set up the mathematical model. The water balance was carried out in the storage tank and in the injection well, for the seven time steps. Results showed that temporal discretization of rainfall data plays an important role to define the volume of rainfall that can be injected in a well. For the smaller area (106 m²), the efficiency of the system decreased in average from 96% (10 min) to 47% (24 hours). On the other hand, for the largest area (1,350 m²), the efficiency decreased in average from 33% (10 min) to 8% (24 hours), for the simulation considering different storage tanks (310 – 3,000 Liters). The paper concludes that the larger the area the smaller the efficiency of the system, and that the time step has a high influence on the results.

Managed aquifer recharge in Brazil: current state of the legal framework

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KEY WORDS
Laws, Regulation, Federal, State, MAR

ABSTRACT
Managed Aquifer Recharge (MAR) can be defined as any process that employs engineering principles to introduce surface water into aquifers in an intentional and planned manner. Currently, some experimental studies and projects using MAR techniques have been discussed in Brazil to overcome different water management challenges. However, Federal and State legal framework in Brazil regarding MAR are still scarce and non-well defined. Therefore, the aim of this study is to present a survey and diagnosis of legal framework, in both State and Federal levels regarding MAR in Brazil. In addition, some Council resolutions are also presented and discussed. An extensive collection and analysis were carried out to assess: 1) how detailed MAR is dealt, 2) what kind of support is given to MAR implementation and 3) the legal challenges. Collected information shows that there are 26 legal provisions regarding MAR at both Federal and State levels. The first law that mentioned the term MAR dates from early 1990s. Sixteen Federal States, which include the Federal District (DF, acronym in Portuguese), mention some MAR aspects in its legal framework. Only the laws and regulations of four Federal States (DF, Espírito Santo, Pernambuco and Maranhão) present some mention regarding MAR methodologies and sources to be adopted. Overall, DF has more significant advances in comparison to others Brazilian States because it also considers – without specific parameters – the necessity of a post-recovery treatment process to assure the water quality required for final consumption. However, even considering a significant number of legal provisions that mention MAR aspects, none of them encourages its implementation in Brazil as a feasible project. Moreover, specifications about quantitative and qualitative parameters regarding MAR implementation are not covered at both Federal and State levels. In conclusion, this study highlights the need to create a more detailed legal framework regarding Managed Aquifer Recharge to induce its use in Brazil.

Geophysical investigation in the high infiltration basin for groundwater recharge project in Pingtung Plain, Taiwan

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KEY WORDS
Artificial recharge of groundwater, Benefited water reuse from storm water, groundwater flow, resistivity image profiling method

ABSTRACT
The Pingtung Plain, Taiwan is formed by Quaternary alluvial fan material from the three main rivers. The aquifers comprise very coarse permeable sands and gravels under phreatic conditions in the north and less permeable sands under confined or even artesian conditions in the southern part of Pingtung Plain. The natural groundwater source is mainly from direct rainfall percolation and infiltration from the three main rivers, with their catchments lying partly outside the plain. The uncontrolled development of groundwater resources has led to undesirable effects, especially in the south where aquaculture is concentrated. These effects are land subsidence, saline water intrusion, lowering of water tables. Benefited water reuse from storm water becomes very importance issue for re-think of Taiwan water policy. Artificial recharge of groundwater has been developed into a major strategy in Taiwan's integral water resource exploitation policy since two big disasters of Earthquake 921, 1999 and Typhoon Morakot 8th August 2009. The Implemented project of the Great Chaochou Artificial Recharge of Groundwater in Pingtung Plain, Taiwan has been completed for the first stage with 50 ha in total 300 ha in September 2018. Much work remains to be done in developing effective means of transferring excess surface water, which can be conserved for use in the dry season. However, how to understand the groundwater flow after artificial recharge is the critical issue. Therefore, this study aims to assess the feasibility of groundwater recharge and groundwater flow direction in small scale and using the Resistivity Image Profiling method.

The results of the average infiltration rate is approximate 16 m/day by recharge test from the pilot site located near the Linpien River where has high infiltration and natural recharge zone. The pilot site reflects the groundwater fluctuates within 5~40 m during dry and rainy seasons. The geophysical result obtains the groundwater flow mainly toward the west; southwest and some part go back the river after recharge. Therefore, even the site has a great hydrogeological condition, the suggestion can be established an optimal pump system for the multiple purposes water use in downstream when the groundwater recharge implemented entirely in future.

Metals content, occurrence and distribution in soil of Al-Qilt catchment

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KEY WORDS
Al-Qilt catchment, heavy metals, pollution, groundwater, analysis.

ABSTRACT
A good quality of soil and groundwater is essential for drinking water and water used for domestic and agricultural purposes. The objective of this research was to make an elemental background for soil's analysis in Palestine because there is no elemental background for soil's analysis in Palestine or the Arab world, and there is dependence on the world reference, but there is different of the soil nature in Palestine or Arab world with other soils, and to study the pollution origin in soil of Al-Qilt catchment. soil samples from pristine areas of Al-Qilt catchments were analyzed and assessed with regards to their content for heavy and trace metals. The sources and impact of anthropogenic pollution in the Al-Qilt catchment soils were also discussed. Samples along the Al-Qilt catchment were collected, then digested and analyzed by using BCR fractionation method.

Data were analyzed by computing the correlation coefficient of heavy and trace metals, and graphed against Al and Fe as reference elements to facilitate the comparison between different Al-Qilt sites. Fe was chosen as elemental normalizer, based on the higher values of correlation factor (R^2) compared to Al. This allows identifying the trace metal as a man-made pollutant, then the Enrichment Factor (EF) was calculated, this led to identification of anomalous metal concentrations that have an anthropogenic source.

The elemental background concentrations of anthropogenic pollution in the soil of Al-Qilt catchment were determined and compared to the continental crust values. Results showed that metal/Al and metal/Fe normalization for Ti, V, Mn, Co, Rb, Ag, Li, B and Be were used as anthropogenic pollutants for most of Al-Qilt sites, As comparison the Fe was found to be the best elemental normalizer, The EF calculation showed that Pb had the highest value of trace metals in Ramallah and Stone cut areas, and there was a moderate values for Sn and Ag in Sweanit and Sultan respectively.These values are below/above international standards for drinking water. Sources for pollution in Al-Qilt catchment, from heavy metals concentration in the soils of Al-Qilt catchment are higher than the average values of continental earth crust, and thus such heavy metals are considered as soils' contaminants and they affect the surface and groundwater, and ultimately the people in the surround.

Laboratory experiments for the assessment of the impact of solar irradiance on clogging of MAR basins

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KEY WORDS
Surface spreading methods, river water, sunlight irradiance, clogging

ABSTRACT

The clogging of the infiltration bed surface is an unavoidable process when aquifers are recharged with water rich in suspended solids such as river water. The reduction of the effective volume of the voids in the soil boosts the impedance of water to flow through and reduces the recharge rates. Different factors are associated with the clogging of the basins such as the content of suspended solids, organic matter, temperature, presence of air bubbles, etc. This investigation addresses the role of daylight and its components in the clogging development during infiltration through surface spreading.

An array of Plexiglas columns (diameter: 4,0 cm and length: 49,5 cm) were filled with sandy soil (k_s:10^{-5} m/s) and in each column tap water (control columns) and river water (active columns) was infiltrated continuously under different light incidence: 1. complete darkness; 2. 450nm blue light; 3. 750nm red light and 4. sunlight (UV, visible range & IR). All the columns were run with a constant head and tracer experiments were performed to track the impedance growth of the media. Simultaneously, the outflow flow rate was monitored to relate it to the Darcy hydraulic conductivity.

The results give a hint that during darkness there is a lower growth of medium impedance. This would suggest an alternative operating condition with the infiltration cycle during the night only, which is expected to maximise the recharge volume and minimise the evaporation losses. Additionally, the higher range of the visible light (higher spectral power during sunny days) incites a higher growth of biomass in comparison to the lower range of visible light (spectral power is almost independent of weather condition).

Groundwater recharge estimation for sustainable development of groundwater in Kandi Belt of Jammu, India

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KEY WORDS
Groundwater Recharge, Sustainable development, Kandi belt, Plant water uptake, Soil moisture modelling.

ABSTRACT

In this paper, groundwater recharge is estimated using soil moisture modelling of unsaturated zone in Kandi belt of Jammu, India. The Kandi (Bhabhar) is steep sloping and flattens downstream, imperceptibly merging with the Tarai tract lying in the outer Himalayas of Jammu division of Jammu and Kashmir, India.

Entire Kandi belt suffers from water scarcity and ground water table is deep. This model considers the subsurface flow component along with the evapotranspiration from the crop or actual evaporation from soil and vegetative covers. The subsurface flow component is represented using one-dimensional Richards equation with root water uptake as the evapotranspiration from crop. The root water uptake is calculated considering the crop coefficient, potential evaporation, and soil moisture available at different depth and the distribution of the root density along the root zone depth. Conceptualizing the unsaturated zone depth as a vertical soil column comprised of number of cells, in which flow calculated using Darcy's law for the unsaturated flow from one cell to another takes place in accordance with the gradient of the suction head. The unsaturated hydraulic conductivity in such case is computed at the cell face. A strongly implicit finite-difference procedure is used to solve the subsurface flow equation with the suitable initial and boundary conditions.

The model is used to simulate a single soil column having different soils (sandy loam, Silty loam and loam) in Kandi belt of Jammu (J & K). Groundwater recharge is estimated for one complete crop year with daily rainfall and pan evaporation data of Jammu. The results show a considerable improvement over the existing method of estimation of groundwater recharge.

Reduction of the environmental impact of managed aquifer recharge

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KEY WORDS
Environmental impact, Drinking water, Managed aquifer recharge, Mitigation

ABSTRACT

Managed aquifer recharge (MAR) can be used for drinking water treatment as a means to remove natural organic matter from surface waters. A typical drinking water MAR plant includes infiltration of lake or river water and withdrawal of water from wells a few hundred meters downgradient.

MAR is applied at specific geological sites which can attract also other interests or activities: the sites can be centres of population, recreational areas or nature conservation sites. A potential conflict of interest can arise from the European Union regulations for “Natura 2000” nature conservation network with strict limitations on environmental impacts (EI). Operations in, or in the neighbourhood of, these areas are subject to scrutiny and official approval. Minimization of the EI is a condition for granting a license to operate a MAR plant there.

The aim of this paper is to show measures how to plan, construct and operate MAR plants to minimize EI. EI and risk assessments were carried out first. Experience from assessments and their interpretations are reported in the paper. The main focus is at measures, both theoretical and practical, to reduce EI, including:

- choice of infiltration methods (basin, well, sprinkling)
- seasonal variations of infiltration, clogging prevention
- process control to maintain water balance of the saturated groundwater zone (infiltration and withdrawal adjustment coupled with observation of groundwater levels in monitoring wells)
- spreading of infiltration and withdrawal sites in a production area
- excess infiltration to provide sensitive areas with sufficient groundwater supply
- construction of additional infiltration sites for protection of moisture sensitive sites
- planning and construction: pipelines can be built under existing roads to minimize EI, during construction ditches can be kept narrow with the help of support structures, etc.

Data were gathered from three separate impact assessments conducted for the Tavase MAR project. Benchmarking from other Finnish MAR plants was also used. Tavase Ltd. is owned by municipalities and it aims to construct and operate a MAR plant (capacity 70,000 m^3/d) to provide drinking water. The location and design have been under extensive research including groundwater modeling, sedimentological analyses, drilling, and infiltration and tracer tests.

Implementing Incentivized Managed Aquifer Recharge on a Basin Scale

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KEY WORDS
Managed aquifer recharge, incentivized, implementing, basin scale, aquifer recharge units

ABSTRACT
Managed Aquifer Recharge (MAR) may be defined as processes designed to move water from land surface to aquifer storage. MAR has been conducted in various locations throughout the world since ancient times. But virtually all of these efforts have been undertaken by or through a governmental entity (state or municipal), or by a private entity at a local scale involving one or just a few wells.

Recharge Development Corporation (RDC) incentivizes entities to be involved in MAR through a patent-pending solution which includes the following eight elements:

1. Incentivized ownership of Aquifer Recharge Units (ARUs) that are fungible, have value, can be bought and sold and are directly analogous to the space acquired in a surface reservoir.
2. MAR volumes are measured allocated to ARUs which each represent one acre-foot of virtual space in an aquifer, and are fully tracked.
3. Real-time measurements of MAR volumes are surface water flow measurements.
4. Water allocated to owned ARUs becomes available to enable pumping.
5. Canal companies are commonly non-profit corporations created to distribute allocated water supplies to the stockholders of the company. Similarly, a local non-profit organization that is owned and operated by ARU owners is established under law.
6. The ARUs are associated on a one-to-one basis with the shares of stock in the local non-profit corporation.
7. Specific MAR allocation protocols that are similar to an allocation priority have been applied to certain ARUs based on the date of acquisition of the shares.
8. The local aquifer is treated as an additional reservoir that is fully integrated with the surface reservoirs in a basin.

This paper provides an overview of a unique Incentivized Managed Aquifer Recharge (IMAR) process. The paper discusses ARUs, municipal applications, ground water district applications, tribal opportunities, and costs. The existing implementation in the Eastern Snake Plain Aquifer in Idaho is described. Criteria for other eligible basins are listed. The result is a case for application of these concepts in other basins throughout the western United States and internationally.

Evaluating the multi-scalar impact of widespread MAR implementation on groundwater storage: A critical review and case study of Gujarat

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KEY WORDS
Managed aquifer recharge (MAR), multi-scale impact, Gujarat, India

ABSTRACT
The state of Gujarat, located in semi-arid to arid western-most part of India relies heavily on groundwater for irrigation and has witnessed widespread groundwater depletion. However, in recent years, there has been signs of recovery with a number of studies corroborating the increase in groundwater storage or reversal from earlier declining trends. However, the verdict on primary cause for the reversal remains unclear with a number of drivers being proposed, including increasing rainfall, positive effects of energy policies, implementation of decentralized rainwater harvesting (RWH) for aquifer recharge, and large scale transfer of water from the Sardar Sarovar Dam and related diversion schemes.

An estimated 500,000 or more decentralized RWH structures built across state over the last couple of decades has received its share of attention and accolade for stabilizing and increasing groundwater tables. However, a closer inspection shows that supporting evidence is mostly based on local or anecdotal accounts, very large and poorly resolved assessments, or semi-quantitative correlations. Further critical and integrated evaluation of coupled drivers and factors and their relative contribution is lacking.

Against this background, we propose to assess the efficacy of MAR in Gujarat by applying a multi-scalar analysis framework linking Individual MAR structure performance with observed catchment scale impact, and isolating various possible drivers and effects. We segregate regions where impact of MAR on groundwater storage is supposed to be more pronounced, e.g. Saurahstra. Here, catchment scale impact analysis is analysed in one of its major basins, Bhadar, with a drainage area of around 7100 km^2. We employ dynamic hydrogeological modelling using groundwater table monitoring data and rainfall data, cropping pattern and area, irrigation demand and observed flows for the last 15-40 years, including a baseline before the practice of widespread MAR. With the case of Gujarat indicating positive outcomes, and a recent ambitious national-scale artificial recharge master plan with 11 million structures planned, the work will support the larger policy landscape and guidance on MAR.

Taiwan's water policy needs re-think to adapt climate change. The artificial recharge of groundwater project in Pingtung Plain, Taiwan

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KEY WORDS
Pingtung Plain, Taiwan, Benefited Water Reuse from Storm Water, artificial recharge of groundwater, simulation model

ABSTRACT
Taiwan is an oceanic nation with an area of approximately 36,000 km^2. The Central Mountain Range where formed by Eurasian and Philippine Plates and stretches along the entire island from north to south, along the entire island, thus forming a natural line of demarcation for rivers on the eastern and western sides of the island. The Pingtung Plain is formed by Quaternary alluvial fan material from the three main rivers. The aquifers comprise very coarse permeable sands and gravels under phreatic conditions in the north and less permeable sands under confined or even artesian conditions in the southern part of Pingtung Plain. The natural groundwater source is mainly from direct rainfall percolation and infiltration from the three main rivers, with their catchments lying partly outside the plain. The uncontrolled development of groundwater resources has led to undesirable effects, especially in the south where aquaculture is concentrated. These effects are land subsidence, saline water intrusion, lowering of water tables.

It is thus one of important key strategies on the solution of water resources development and flood control for sustainable development and management named as Benefited Water Reuse from Storm Water in Pingtung, Taiwan. A serious of studies for this issue has been carried out. The feasibility study phase of the Artificial Recharge of Groundwater Project (ARGP) for Pingtung, Taiwan has then been implemented in 1997 using MODFLOW simulation and optimal model. Through the managed aquifer recharge model, the aquifer storage increase and inundation scale reduce at land subsidence of coastal area as aimed at the purpose of controlled groundwater level. Infiltration mechanism simulation of artificial groundwater recharge, TOUGH2 model, was used to simulate the high infiltration behavior in sequence in 2010. Both the publications have been confirmed and approved by the Central Government and then approved by the environmental impact assessment. The ARGP has now been implemented in May, 2018 and operated one wet season for the first phase with 50 ha in total 300 ha from May to Oct., 2018. The sedimentation over the top of the recharge basin forms the clogging mechanism which has been analyzed. The operation experience can be further provided the mechanism process for research reference and improved suggestions.

Managed Aquifer Recharge as a bridge between water demand and supply – cases in Chile, Vietnam and Malasya

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KEY WORDS
Subsurface water solutions, Managed Aquifer Recharge, drought, salinization, water scarcity, agriculture

ABSTRACT
Currently, a large part of the global population experiences water scarcity. Fresh groundwater resources are deteriorating in an ever more populated world, while increased groundwater extraction rates and climate change stresses are expected to increase the shortage of enough high quality water at the right place and on the right moment. We present three cases in which initial assessments have been done towards managed aquifer recharge (MAR) solutions to serve as a bridge between water demand and supply as regards to space and time. The three projects have in common the need to maximise the potential of the subsurface to attain a robust and sustainable fresh water supply and to combat droughts and salinization.

The Valley of Pan de Azucar and the Elqui Basin, in Chile, is a region with high freshwater demand for agriculture (large, medium and small scale), mining, potable water (both urban and rural) and industry. Extreme events are frequent in the region, with prolonged droughts that cause severe water scarcity issues and water conflicts. In this project we make an initial estimation of potential sources of water, surface water surplus, desalinated water or treated waste water, and we improve the aquifer knowledge to identify the storage capacity and the potential to bridge the gap of water surplus and water scarcity. The outputs are potential measurements that can increase freshwater availability for the Valley.

In the Mekong Delta, Vietnam, drought and salinization of coastal aquifers, threatens the availability of fresh water resources. The provinces of Ben Tre and Tra Vinh harbour extensive areas of vegetable gardens, fruit trees and rice, and food production is highly dependent on fresh (ground)water availability. In this project we provide an overview of the potential of different techniques of aquifer storage and recovery (ASR), such as restoring phreatic fresh groundwater, deep well infiltration, and the construction of fresh (ground)water reservoirs; in different locations of the provinces.

Finally, in the Kelantan province in Malaysia we map potential areas for different MAR techniques to increase the availability of water resources during drought periods. A surface water analysis was conducted to determine the time and volumes of water surplus that could effectively be used as artificial recharge.

Hydrogeological characterization of a meso-scale managed aquifer recharge experiment focusing on the fate of nanocontaminants carried by reclaimed water (Palamós site, ACWAPUR project)

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KEY WORDS
MAR systems, degradation, basin, aquifer, tracer test

ABSTRACT
Water is essential for life, for industry, agricultural and supply purposes.Waste water treatment plants (WWTP) treat huge volumes of waste water which are directly discharged into water bodies or unintentionally infiltrated through the river beds into underlying aquifers. The development and standardization of efficient, sustainable and cost-effective techniques for water treatment is imperative to deal with the scarcity of quality water. Managed aquifer recharge (MAR) is a very useful option to improve quality groundwater resources and to reduce direct discharges. The use of reactive barriers or layers in MAR facilities has proved to be an efficient tool to enhance the degradation of nanocontaminants. Previous experiences at Sant Vicenç dels Horts water river recharge basins, located 15km NW from Barcelona (Valhondo et al, 2014, 2015) have served as a starting point to test the effect of different actions in the waste water purification process at another site, within the Palamós WWTP (150 km NE from Barcelona, in Costa Brava region).

An experimental MAR system using reactive barriers has been constructed in Palamós to study the degradation of potential nanocontaminants that may be commonly present in WWTP effluents. This experiment consists of 6 independent scaled MAR boxes made of concrete (15 x 15m total extension, including a 2.4 x 1.5 x 1m recharge area and a 14 x 1.5 x 1 m aquifer), where multiple monitoring points have been implemented to control water flow and quality evolution.

The first phase of the project has consisted of the physical site construction and subsequent characterization tests, since assessing the hydrogeological behavior of the system is crucial to understand the fate of contaminants and residence time distributions. With this objective, a conservative tracer test was designed and performed during one of the recharge periods. A pulse of tracer was added at the infiltration basin, maintaining flow in steady state condition and measuring its concentration at the effluent point. The interpretation of measured data has been done with a numerical model representing the geometry of the site, including both reactive barrier and aquifer. These results will be applied to evaluate the degradation processes affecting nanocontaminants in MAR systems.

Modeling suspended solid clogging of saturated porous media in managed aquifer recharge

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KEY WORDS
Managed aquifer recharge, clogging, suspended solid, physical clogging

ABSTRACT
Based on a series of laboratory column experiments of suspended solid clogging during managed aquifer recharge, the suspended solid clogging was divided into three types of superficial clogging, internal clogging and mixed clogging. Each suspended solid clogging type has the different clogging mechanism which led to the different position, different changing laws of hydraulic conductivity and the different deposition profile of suspended solids. According to the particle size, the suspended solids were also divided into three types of large particles, intermediate particles and fine particles.

The clogging which caused by different size of suspended solids also has its own mechanisms and characteristics. A complex conceptual model and a numerical model were developed that accounts for different suspended solid types by considering both particle size of suspended solid and types of suspended solid clogging. Based on the particle size of suspended solid and the size ratio of suspended solid to saturated porous media, the potential specific clogging type was determined and the related mathematical model was assigned to simulate the changing laws of hydraulic conductivity.

The modeling method could help people to recognize the potential suspended solid clogging types and its developing law if they can get the characteristics of recharge water quality, infiltration media and its geological structure, etc.

A GIS approach to evaluating bank-filtration occurence and potential in the province of Quebec, Canada

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KEY WORDS
Bank Filtration, Typology, Geographic Information Systems (GIS), Province of Quebec, Canada

ABSTRACT
Canada is often overlooked in current estimates of global use of managed aquifer recharge (MAR) and in bank filtration (BF) in particular. This is likely due to the large amount of surface water bodies present in Canada, and the widespread use of surface water as the principal source of potable water in the country's largest metropolitan areas. In addition, a Canadian inventory of MAR and BF has never been completed, and no regulations specific to these types of exploitations exist.

Nevertheless, groundwater is an important resource for many individuals and smaller municipalities throughout the country. A rapid overview of the location of any subset of municipal wells in the province of Quebec reveals that many of these are located in close proximity to surface water. It is thus highly probable that a significant number of wells are taking advantage of BF as a means of improving water quality (compared to surface water). These sites are treated and regulated as standard groundwater exploitations and the interactions between surface water and the nearby well are not considered. Due to this oversimplification, the risk of contamination may be underestimated.

The primary objective of this study is to identify and locate, through a geographic information system (GIS) approach, all pumping wells that use BF in Quebec. We use a variety of data, including distance from surface water bodies, type of water body, and surficial geology, as indicators of bank filtration potential at existing municipal well sites. Using the results, based on the aforementioned method, the specific municipalities can be targeted for acquisition of more detailed data related to their site including geomorphology, geochemical results, well depth, drill logs and historical data related to quality problems. A typology of BF sites regarding their resilience as drinking water resources can then be proposed.

This study is the first to attempt to quantify the contribution of MAR in the form of BF within the province of Quebec and will provide an opportunity to propose guidelines that serve to promote and improve upon BF techniques, not only in the province of Quebec, but also throughout Canada and globally. Indeed, the Canadian situation offers a rare opportunity to study the behaviour of BF with varying scales, climatic conditions, and hydrogeologic contexts.

A preliminary study of artificial recharge of groundwater using existing agricultural ponds

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KEY WORDS
Artificial recharge of groundwater, constructed wet land, MODFLOW model

ABSTRACT
Taiwan is an oceanic nation with a combined area of approximately 36,000 km^2. The Central Mountain Range where formed by Eurasian and Philippine Plates and stretches along the entire island from north to south, along the entire island, thus forming a natural line of demarcation for rivers on the eastern and western sides of the island. The uncontrolled development of groundwater resources has led to undesirable effects, especially in the coastal area where aquaculture is concentrated. These effects are land subsidence, saline water intrusion, lowering of water tables. The purpose of this preliminary study is to evaluate the reclaimed water reuse via aquifers. The sewage waste water discharged from the surrounding settlements closed to the pathway of the High Speed Railway located at the land subsidence area. Purification technology using existing agricultural ponds as constructed wet land is to recharge aquifer and then to mitigate the land subsidence for railway safe. After the assessment of the purification method, the estimated amount of reclaimed water is 220 CMD and 590 CMD as selected sites Tinlan and Xinji respectively. The waste water purification facility is connected to the Free Water Surface system (FWS) with Vegetated Submerged Bed (VSB). From the data collection, the evaluation and analysis was simulated by MODFLOW model.

The constructed wetland system can be achieved the required quality for recharge from the reclaimed water reuse. Based on the well results from preliminary study of artificial recharge of groundwater using existing agricultural ponds to alleviate the land subsidence, the planned projects will be promoted by the Council of Agriculture along the pathway of the High Speed Railway located at the land subsidence area in the future.

Seeking Simplicity, Reliability and Sustainability in Drinking Water Purification for Future: the River Bank Filtration Based One Step Reverse Osmosis Process: from Concept to Practice

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KEY WORDS

River Bank Filtration, One Step Reverse Osmosis, Drinking Water Purification, Sustainbility, Simplicity

ABSTRACT

The combination of RBF and RO combines a relatively low-cost natural pre-treatment of river water with an advanced purification technique. The benefits of RBF are well known. It provides a continuous natural source of water with a stable water quality, including a robust barrier for microbiological risks. In combination with the removal of particles, DOC and a large percentage of organic micro-pollutants, it becomes an ideal source for a purification system based on R.O. membranes, this is especially true when compared to a direct intake of surface water. A stabile high quality source implicates both better performance of the membrane system and a higher quality of the drinking water permeate and the concentrate. The treatment with R.O. will not only remove almost 99,9 % of the remaining known micro-pollutants, including the frequently discovered unknown emerging compounds, but will also remove the vast majority of the nutrients, adding to the goals of a chlorine free delivery of drinking water with a high bio stability as measured by the indictor parameters TCC, BPP and AOC. Moreover, the concept is very robust and prepared for hydrological system changes like upcoming of brackish water or seawater intrusion as a result of climate change. The complete concept has a competitive cost level when compared to the standard conventional series of purification steps with sprinkling filters, softening and activated carbon.

Influence of aquifer recharge structures and surface water bodies on geogenic fluoride contamination

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KEY WORDS
Sub-surface dams; village ponds; numerical modelling; Pambar River basin; India

ABSTRACT
In order to dilute the fluoride concentration in groundwater, managed aquifer recharge (MAR) can be adopted as a suitable method. This study aimed to assess the impact of induced recharge through check dams and rejuvenated surface water bodies in diluting fluoride contamination in an endemic area in southern India. The gneisses and charnockite rocks of this area have fluoride-bearing minerals like fluorite, fluorapatite, biotite and hornblende. Dissolution of these minerals has resulted in >1.5 mg/l of fluoride in about 40% of the study area. The impact of a check dam located on a river in this area in reducing the fluoride concentration was assessed by monitoring the groundwater level and fluoride concentration in an open well near the check dam. Groundwater level was always shallow (4 m bgl) and fluoride content did not exceed the maximum permissible limit (>1.5 mg/l). Though the geology of the area had fluoride-rich minerals, the fluoride content in the open well was low compared to the wells located farther away due to the recharge from the check dam. These check dams are specially constructed MAR structures along the rivers to induce recharge. Construction of such structures is cost-intensive and may not be a suitable option in all places. Hence, the performance of surface water bodies as a MAR option was determined. This area has many ponds, but are not maintained. It was found from the surface water bodies map prepared for the years 1973 and 2008 that many ponds have disappeared due to negligence. A shallow well located near two ponds, that were silted due to lack of maintenance was modelled using FEFLOW to understand the MAR effect. Fluctuation in the groundwater level of the well was up to 2.5 m and the average fluoride concentration was 3 mg/l. Geochemical studies indicated that a rise in groundwater level by 2.5 m would result in a reduction of about 1 mg/l of fluoride. The groundwater model was used to simulate the groundwater head assuming that these two surface water bodies are rejuvenated. Simulation was carried assuming 1 m of water depth in the ponds throughout the year except during the summer months. The model predicted that the groundwater level increased by about 5 m in the well and the fluoride concentration is reduced by 2 mg/l, thus bringing the fluoride concentration in groundwater below 1.5 mg/l. Thus, the effect of increased groundwater recharge will make the groundwater in the open well suitable for drinking purposes with respect to fluoride.

MAR Perspectives in Brazil

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KEY WORDS
Water security, urban water management, semiarid, Social Technology, Nature based solutions, Developing Countries

ABSTRACT
Although its worldwide water resource wealth reputation, Brazil has been suffering from droughts at least since the beginning of the 16th Century, when the first big drought was recorded. In order to face the severity of the climate in the Semiarid Region, many artificial aquifer recharge schemes based on social technologies were implemented, mostly in-channel modifications and infiltration ponds, basins, and trenches. Governmental Programs such as "One Million Cisterns" - P1MC and "One Piece of Land and Two Types of Water" - P1+2 have helped to widespread the concept of artificial aquifer recharge, especially in semiarid rural areas. The P1+2 Program has implemented 25,917 boardwalk cisterns , 8,736 runoff cisterns , 6,560 clay pit trenches, 1,053 subsurface dams, 827 stone tanks, 1,813 infiltration dams, and 503 popular water pumps, between 2007 and 2014. Barraginhas Project, which has started in North Minas Gerais, was widespread to Semiarid Region where more than 150.000 infiltration ponds were constructed. In urban areas, almost all MAR initiatives aim to reduce runoff peak flows. Permeable pavement, rain gardens, infiltration trenches are among the main techniques applied in urban areas, in some cases stimulated by urban drainage public policies, and in the context of sustainable urban water management Bank filtration study cases are also examples of nature based solutions for water management that are pursued in few places in the country. However, the lack of sanitation and pollution could probably negatively affect water quality, causing thus public health and environmental problems, especially in densely populated and poor areas. In recent times, some pilot scales projects have been carried out as academic studies in Managed Aquifer Recharge, for example in Paraíba, Pernambuco, Brasilia, and São Paulo states. Some are focused on helping to prevent seawater intrusion in coastal aquifers, and also on investigating the possibility of using wastewater as source of water for MAR. A cooperation between Brazil and Germany - BraMAR is a recent example of research initiative. Brazil is still incipient in MAR initiatives and needs to overcome technical, legal and socio-cultural challenges to adopt MAR approaches in order to help facing water security challenges in a climate change scenario.

Multidisciplinary subsurface monitoring for a better understanding of Soil Aquifer Treatment capacity applied on coastal operational wastewater treatment plant (Agon-Coutainville, France)

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KEY WORDS : SAT, MAR, coastal aquifer, natural/engineered water treatment, reuse

ABSTRACT
Unconfined coastal aquifers are potentially subject to both saline intrusion near the seashore and over discharge of treated wastewater in the surficial environment during the tourist season. In Agon-Coutainville (Normandy, France), managed aquifer recharge (MAR) system, combined with Soil Aquifer Treatment (SAT), was integrated as part of the full-scale operational wastewater treatment plant. Such integrated natural/engineered water treatment system ensure the sustainability of the seaside activities (seafood production, beach) and locally supply freshwater for the irrigational needs of the golf course.

Concerning the MAR system, the secondary treated wastewater is infiltrated alternatively into three natural reed bed areas before reaching the sand dune aquifer and thus to enhance the quantity of freshwater in the aquifer. Treated wastewater potentially contains various compounds (chemical, virus, pathogen) which can, however, affect the groundwater quality. Nevertheless, some of these compounds are partly removed, during the SAT. To assess performance and efficiency of the integrated system in the natural environment, we have designed and performed an innovating and multidisciplinary monitoring dedicated to 1) spatial evolution of the freshwater generating by the MAR system, 2) mean residence time of water during SAT and 3) potential reactivity occurring during SAT. Spatial field campaigns and tracer tests were conducted by associating classical and innovative approaches including physico-chemical measurements and quantitative analyses, non target analysis for screening organic compounds, ecotoxicological bioassays, online biomonitoring BACTcontrol® system to detect fecal contamination and online system monitoring device dedicated to saline intrusion. Results show that the MAR system provides a freshwater barrier in the aquifer which is seasonally affected by saline intrusion. A part of the aquifer is assessed for freshwater potential production regardless of the natural and anthropogenic recharge. SAT mean residence time is around two weeks that allows SAT reactivity and thus increases quality of the pumped groundwater. This novel subsurface monitoring provides a better understanding of the SAT capacity to enhance the quantity of freshwater and improve its quality.

Agriculture as a System for Managed Aquifer Recharge for Drylands by Restoring Hydrologic Connectivity to Floodplains and Aquifers in Watersheds

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KEY WORDS
Floodplain reconnection, watershed restoration, Stormwater harvesting, drought and flooding

ABSTRACT

In the American Southwest, what underlies both drought and increased flooding as social crises is a water storage problem. Less winter precipitation has diminished snowpacks and the resulting spring runoff. Reduced soil infiltration capacity coupled with increased precipitation intensity has increased runoff energies and the resulting catastrophic flooding. Alternative water management strategies that replenish groundwater and soil storage systems have increasingly become critical. Maximizing available water storage will require land managers to develop innovative solutions to handle stormwater supplies that arrive in fewer and increasingly intense monsoonal bursts. Historically, floods along the Rio Grande River network in New Mexico were more connected to more richly vegetated floodplains, which resulted in watersheds retaining more their water and soil resources. Agriculture supported that natural dynamic through systems of stormwater harvesting and by spreading flood flow onto floodplains (floodplain connectivity) which resulted in infiltration into shallow (aquifer connectivity). Today management has lost many of these system functions, and communities are seeking solutions to watersheds “leaking” their resources of water and soil. A broad group of stakeholders in Southern New Mexico are collaboratively facing the related challenges of severe water scarcity and erosion from drying uplands in watershed clogging valley irrigation systems and riparian areas. To predict how much ecological restoration it would take to turn degradation trends around, we developed a remote sensing and system dynamics modeling approach to identify and predict high priority areas for restoring an optimum level of floodplain and aquifer connectivity. We synthesized hydrologic flow data, satellite images, spatially explicit models, and generalized linear models into a system dynamics model to predict landscape behavior responses. The evaluation resulted in identification of interventions with the potential to achieve a target level of ecosystem service benefits. Nearly forty percent of the global land surface is managed in agriculture, and with potential innovative adaptation, agriculture can once again become a system for recharging our aquifers and restoring our watersheds.

Feasibility of enhanced infiltration basins in Harris County, Texas

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KEY WORDS
Infiltration basin, infiltration rate, storage, storm water, groundwater

ABSTRACT
Surface spreading or infiltration through excavated recharge basins, surface ponds, and impoundments in stream channel, have been used to recharge an unconfined aquifer with storm water and treated wastewater for both long-term storage or short-term augment of water demands. In this study we evaluated the feasibility of enhanced infiltration of infiltration basins in Harris County by considering following hydrological factors, available storage space, infiltration rate, current groundwater level, and others.

First, we evaluate storage space and infiltration rates based on existing detention and retention ponds data. Then we developed two conceptual models to demonstrate the infiltration processes using the HYDUS2D, a computer program that simulate water follow and solute transport in variably saturated porous media. One case is an off-channel square basin with a width of 550 meters, while another is an in-channel strip basin (100 m x 1000m). In addition, a perched layer was added to evaluate potential impacts of groundwater mounding.

The results show that large infiltration capacity and favorable hydrological conditions at some sites demonstrate a great potential for implementing MAR program and some sites were selected for further consideration based on high storage capacity. The results showed different responses of those two types of infiltration basins as well as effects of the perched layer, providing additional insights of performance of infiltration basins as well as their impacts on groundwater system and guidelines for selecting design parameters.

Coupling bank filtration to pond infiltration – a useful option in terms of quality improvement?

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KEY WORDS
Bank filtration, pond, trace organic compounds, aeration

ABSTRACT
Managed Aquifer Recharge (MAR) techniques, such as aquifer recharge via infiltration ponds or induced bank filtration are often applied to disburden stressed groundwater bodies, especially in densely populated areas. Typically, surface water is used for the infiltration and its quality becomes considerably improved during subsurface passage towards the (drinking water) extraction wells. However, in many cases emerging organic contaminants, such as pharmaceutical residues or personal care products, which are introduced into the surface water by upstream wastewater treatment plants, cannot be fully removed during the underground passage. Previous studies showed that the removal efficiency of many compounds depends on the redox conditions prevalent on the flow path, and that most organic compounds are more efficiently removed under oxic and carbon-limited conditions. As the residences time in the oxic zone is typically short, removal of these compounds stagnates at some point on the flow path. Thus, re-aeration of bank filtrate and subsequent re-infiltration, which was introduced as sequential managed aquifer recharge technology (SMART), may lead to further removal. The aim of the present study was to test whether the removal of trace organic compounds can be improved by coupling river bank filtration and ponded infiltration, where the water is passively aerated to prolong the residence time of the compounds within the oxic zone.

The study was carried out at a bank filtration site in Berlin (Germany). Over a period of several weeks, bank filtrate containing a set of 19 trace organic compounds was abstracted, re-aerated and transferred to a nearby infiltration pond. Monitoring wells below the pond and in groundwater flow direction were previously installed and periodically sampled. A tracer test conducted in parallel yielded groundwater residence times between four hours and 13 days along the investigated transect. Although the residence times were relatively short, for some of the 19 investigated compounds (e.g. gabapentin lactam, valsartan acid, gabapentin) decreasing concentrations were observed. Others (e.g. acesulfame, candesartan, oxypurinol) remained stable. Thus, the results showed that coupling of both MAR techniques may lead to an enhanced removal of some trace organic compounds.

The costs and benefits of managed aquifer recharge

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KEY WORDS
recharge, costs, benefits, natural infrastructure

ABSTRACT
Groundwater use increased by 300% between 1960 and 2010 and over 20% of the world's aquifers are overexploited. Managed aquifer recharge (MAR) is an important groundwater based natural infrastructure approach for improving groundwater recharge, maintaining aquifer levels and enhancing water security. Despite the numerous benefits and demonstrated advantages of MAR, uptake has been lower than expected.

The financial and economic performance of MAR is a key determinant of its global uptake but there are very few studies that demonstrate the financial performance or economic advantages of MAR. The economics working group of IAH MAR is carrying out a two-stage research program to address this deficit; to document the financial costs and economics of MAR, and to provide information on situations where MAR may produce the least cost water supply.

The first publication from this program included the development of a methodology for assessing the financial costs of MAR schemes, and a comparative analysis of recharge costs in 21 schemes from five countries. The costs of recharge vary substantially, with schemes using infiltration basins and untreated water having lower recharge costs than schemes using water that requires expensive water treatment infrastructure. Other factors that affect recharge costs include the range of scheme objectives, scale, operating periods and frequency of use, infiltration rates, recovery efficiency and well yields.

This presentation includes the results of a comparative analysis of costs of recharge and recovery for a wider range of 30-40 MAR schemes including from developing countries. The presentation also discusses methodology for the classification and assessment of the economic costs and benefits of MAR and provides examples of economic assessment of MAR and groundwater based natural infrastructure.

Reconstruction of Damascus City including the use of Barada River and its attributes as infiltration facilities during the flood season

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KEY WORDS
Alfigeh Spring, Damascus, artificial recharge, waterworks, Barada River

ABSTRACT

Artificial recharge of groundwater has been started in Damascus since 1997. The first field investigation was carried out in a waterworks Almazraa where two shaft wells were drilled to inject water into the confined aquifer. The injected water originates from the karst spring Alfigeh (7.7 m3/s) which supplies Damascus and suburbs. This experiment was applied afterwards in the rest of the waterworks in the city and the water was transported through the supply network.

The waterworks abstract groundwater from the recent quaternary aquifer which occupies an area of around 550 km2 and partially recharged by Barada River.

The water surplus has an average amount of 50 million m3/a only available during the flood period (February-May). The maximum injected amount of water does not exceed 14% of the water surplus which is available for artificial recharge. The modelling of the artificial recharge process shows that a maximum amount of two million m3 can be injected in the biggest waterworks considering the natural recharge of groundwater.

The injection process leads additionally in some places to flood in the rainy years and this reflects the need of infrastructure to take up the surplus water and distribute it in a larger area. The possibility for a proper infiltration system can be investigated through the use of the bed of river Barada. The river course has a length of 44.5 km and an average slope of 0.002.

The reconstruction of the city can be used as a chance to change the concept of injection through the wells into converting certain parts of the river bed to infiltration basins. The infiltration basins should be chosen in the areas where the river has high influent conditions into the aquifer. The challenge remains with the question of transporting the water from Alfigeh Spring into the infiltration basins. This question still represents a limiting factor for the artificial recharge process in this area. One of the possibilities is to construct infiltration basins with a layer of gravels and sand in the upper part of Damascus City. In the center of these basins wells will be constructed to recharge the aquifer artificially.

Flash floods – possibilities of artifical recharge, example Egypt

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KEY WORDS
Flash flood, artificial recharge in Wadis, subsurface dams, gabions for flow decrrase

ABSTRACT
Flash floods occur mainly in arid and hyperarid regions. In average more than 20 mm of rainfall are registered in hours. There is no periodical repeat of this events. The drainage pattern shows dry flow systems (Wadis). The transported boulders indicate the high destructive energy of flash floods.

In a catchment area of approximately 850 km^2 north of Hurghada (Egypt) in one event in 2014 in four hours 38 mm of rainfall accumulated to 34 Million m^3. The huge amount of water can't infiltrate in the dry sandy soil and is lost to the Red Sea or remains in ponds where clay remained in depressions from the last flash flood. Hadidi (2016) measured an underestimated loss of fresh water to the sea of 9 Million m^3. During those events millions of m^3 of fresh water are lost to the sea in an area where fresh water is almost not abundant.

Artificial recharge of flash flood water is a challenge. First steps were made in the last two years. Gabions perpendicular were built to slow down the speed of the flood and enable infiltration of the water. In the next steps subsurface dams should be constructed to hinder the water to flow in the permeable aquifer consisting of gravel and sand layers to the sea. At the end of the flow channels in the coastal plain the transport energy is low and silt and clay is settled. Infiltration basins or trenches could be installed and used as a filter. The first basin was built in El Gouna at the Red Sea but the leak of maintenance made it serving only once.

The capacity of the aquifers in the Wadis is very high. Infiltration tests in various depth have shown a moderate to high permeability. A few existing dug wells equipped with powerful pumps don't show a significant draw down. Two problems still have to be overcome. The turbidity of flash floods and the increasing salinity of the groundwater due to high evaporation in the infiltration areas in front of the gabions. The water supply of Port Sudan from Wadi Arbaat resolved the problem with a reservoir where silt and clay can settle and the clear water flows in the Wadi. However, this may entail the increase in mineralization. The flash flood water in general is not enough to supply the demand and desalinization plants are necessary. Sea water mixed with the artificial recharged groundwater guaranties a longer life of membranes in the desalinization plants and need much less energy.

Measuring and Monitor MAR in a Channel in Idaho, USA

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KEY WORDS
Station construction, monitoring, data analysis

ABSTRACT
Since 2013, Recharge Development Corporation (RDC), has been developing a process for conducting managed aquifer recharge (MAR) and using recharge credits to mitigate for existing and future groundwater diversions from the Eastern Snake Plain Aquifer in Idaho, a state in the northwestern United States.

One of RDC's long term MAR projects that presented some unique challenges involves a 5.6 km (3.5 miles) long channel through a lava field. Field reconnaissance revealed gauge stations were needed at both ends of the channel. Neither location selected for a gauge station had an existing power source, but both had cell phone reception. Geology and access, particularly at the lower end, complicated the structural design and construction of the gauge station. To facilitate obtaining a continual record of water levels year-round with real time monitoring and reporting on the internet meant instrumentation at each station would include a datalogger, cell modem, a solar power supply, a vented pressure transducer and a staff gauge. The staff gauge is secured to a vertical support anchored in the channel and the transducer is housed in 2-inch diameter steel pipe anchored to the bottom of the channel. The other electronic components are housed in an instrument enclosure designed by a colleague in RDC. Periodically, open channel discharge measurements are conducted at both gauge stations to obtain real time flow rates and an observed gage height. Analysis of the measured flows and the electronic stage data from both gauge stations revealed an atypical flow pattern for a regulated channel. The fluctuating flows coupled with the time required for water to reach the lower gauge meant MAR wasn't simply the difference between the flow rates at the two stations. RDC decided to determine the MAR based on the difference in daily volume flowing past the two stations.

This paper presents details about this MAR project that will be of interest to those involved with gauge station construction, real time monitoring, data collection and analysis, and reporting on the internet. It shows the state of the art achieved in Idaho and provides recommendations and lessons learned.

Anticipating pathways and timing for cyanobacteria breakthrough at a 2-lake bank filtration site via environmental tracers

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KEY WORDS
Lake bank filtration; lake stratification; mixing ratios; pumping schemes; cyanobacteria

ABSTRACT
The drinking water supply of a town near Montreal (Canada) relies on a bank filtration system consisting of 8 pumping wells lying in a 20 m deep, 500 m long and 90 m wide sandy bank between two artificial lakes. As these lakes fully penetrate the aquifer, the pumping wells are solely supplied by infiltrating surface waters. Monthly-based analysis showed cyclic presence of different types of algae, including cyanobacteria, in the lakes at various depths and eventually at some wells. Due to their potentially high toxicity, understanding the origin and pathways of cyanobacteria is crucial to maintain the security of the drinking water supply. Studies concerning stratified lakes have showed that various bacterial assemblages can develop in different water layers and evolve over the seasons. Typically, thermal stratification in shallow lakes inhibits exchanges between different layers and turnovers allow for mixing of the entire water column. This highlights the need to better depict the contributions from the different parts of the lakes to the pumping wells.

Coupling in-situ measurements with isotopic analyses, we developed an approach using environmental tracers to identify the mixing ratios between the upper- and bottom most layers of the lakes. Continuous measurements of temperature and discrete monitoring of EC, pH and redox potential were carried out at the pumping wells over a 2-year period. During the same period, water was sampled for major ions, alkalinity and $\delta^{18}O$-$\delta^{2}H$ analysis on a monthly-basis. Depth-dependent measurements were conducted seasonally at both lakes and included all the parameters listed above. Our findings indicate that using d-excess is relevant to characterise the timing of the turnovers and anticipate signature changes of the bank filtrate. In addition, temperature and $\delta^{18}O$-$\delta^{2}H$ time series reveal that continuous pumping leads to more contribution from the uppermost layers to the pumping wells, in comparison to the less actively pumped wells. The results of this study will help select a pumping scheme that minimizes migration of algae towards the pumping wells. This work will provide an important contribution to better understanding of the sensibility of a 2-lake bank filtration system to contamination by cyanobacteria and securing water quality by optimizing pumping schemes.

Aquifer Recharge Management in a Metropolitan Area with high population density

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KEY WORDS
Urban hydrogeology, land management, recharge management technologies, sustainable drainage systems.

ABSTRACT
In metropolitan areas, as the Aburrá valley (Colombia), the natural resources are under pressure due to the urban developing. This situation is particularly important for environmental sustain of the basins. Aburrá valley, with an area of 1.206 km^2 and approximately 4 million inhabitants, it is a narrow alluvial plain between mountains which configure the central mountain range of the Andes. Such characteristics confer to the basin steep slopes and a small flat areas associated to the Aburrá river, where is located the urban core of cities as Medellín, with high population density. These areas as well are known for his capacity of allow the aquifer recharge, with a highest potential for the ground water sustainability.

Although water access is currently supplied by surface water sources located outside of the territory and in different basins, in this area there is an aquifer system that is generally used only for industrial commercial and services purposes. Base flow sustains the function of wetlands as well as other ecosystems. Additionally, the confined aquifer in the valley could constitute a complement or even an alternative water supply to satisfy future demands under urban expansion or climate variability. To ensure groundwater sustainability and renewability in the Aburrá valley aquifer, the permanence of direct recharge as well as regional fluxes leading to recharge are required. This requires rethinking and redefining land occupation and land management models as well as to implement measures such as urban drainage systems that favour surface-to-subsurface fluxes of water, especially when urbanization precludes deep infiltration and water movement towards the aquifer. Joint efforts between academia and land managers have explored MAR and sustainable drainage systems that, if successful, would allow the permanence of aquifers and their potential to provide services that derive in benefits to the population.

Deciphering the long-term evolution of groundwater mixings at a multi-aquifer river bank filtration site

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KEY WORDS
RBF, multi-aquifer, Long-term evolution, complex mixing, geochemical tracers

ABSTRACT

Most river bank filtration (RBF) systems are in alluvial aquifers. The extracted water is generally considered as a mixture of two sources: river and regional groundwater. However, groundwater sourced from complex geological environments can consist of multiple types of water. During exploitation, the water types get mixed, and the blend can control long-term quality of the RBF.

This case study consists of a well field located in a meander with a lake at its center. The alluvial superficial aquifer is connected to and limited by an underlying sandstone aquifer. The morphology and position of the river is controlled by a regional fault that separates the sandstone and granite/gneiss formations.

The aim of the study is to describe the long-term evolution of mixing of waters originating from these different sources with distinct chemistry. Every month, all 10 wells are sampled to analyze chemistry, dissolved radon and δ18O-δD in addition to physico-chemical parameters. Each groundwater end-member and their contribution to the mix is revealed by these multiple tracers. Recent data as well as data collected over 10 years allow us to evaluate the contribution of each groundwater source since the installation of RBF system.

Indeed, long-term results reveal a complex evolution of groundwater at the pumping site, from an initial scattered geochemistry towards an overall river-water influenced water type. However, there are still significant differences between wells highlighting complex mixing between the different water sources. Prior to the start of pumping, each side of the river had distinct chemical signatures. The opposite bank was sodic due to the influence of crystalline rocks being transmitted through the fault. The well field was overall calcic however, one well at the extremity of the system is more mineralized probably due to mixing with groundwater from the sandstone aquifer. The other end is characterized by pronounced differences in geochemistry related to de-icing salts from a former snow dump. To conclude, this RBF well-field supplied by up to 4 distinct water types creates a unique multi end-member mixing model that evolves through both time and space. Defining complex groundwater flow patterns is a crucial step to develop strategic pumping schemes for a sustainable long-term exploitation.

Amsterdam Water Supply Dunes: Unclogging of horizontal abstraction galleries built in the 1950's and -60's, to restore the original capacity.

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KEY WORDS
Horizontal abstraction galleries, pumping and flushing, sludge, ironoxides.

ABSTRACT
Since 1957 artificial infiltration is in operation in the Amsterdam Water Supply Dunes. Pre-treated water from the river Rhine is artificially infiltrated in 40 infiltration ponds and recaptured both by abstraction canals (75 %) and horizontal abstraction galleries, also called 'drains' (25 %). Between 1955 and 1967 9 km of drains were laid out in dug trenches. The drains are made of concrete elements, surrounded by a gravel pack and covered again with the original eolian dune sand. The design capacity is 92500 m³/d and the flow towards the drains is driven by gravity. The discharge can be managed from no water to the full capacity by adjusting the weir levels at the end of the 12 drain systems. This is an important feature, to steer exactly the discharge from the dunes to the post-treatment, to meet the demand of drinking water. Since the start, very slowly but certainly the drains clogged by precipitation of ironoxides. A stress test revealed that the original capacity was lowered with 25 % and that only the last sections of the drains were attracting water. This meant that the residence time during the groundwater passage was not optimal.

Measurements of the levels in piezometers in and around the drains showed that the clogging proces continued. Several attempts were made to remove the sludge. Due to the design of the drains this was difficult and not successful. Already sketches were made to drill new horizontal wells, but that would be very expensive. A final, innovative attempt was made to try to pump and flush out the sludge. The pumping was done halfway the drains, sectionwise and intermittently with different directions. This attempt succeeded and after more than 50 years of operation, the original capacity was restored.

The ways of pumping and flushing will be presented, combined with the measurements that show the positive effect. This practical information can help to monitor, clean and maintain other horizontal abstraction galleries. It can also help in the design of new systems. The cleaning of the first part of the drains suddenly resulted in completely draining an area above the drains that was wet before.

For drinking water production this is positive, but it threatened several ecological important species. The operation of the drains were adjusted for some months, and the endangered plants have successfully been moved.

The Legal Basis Under Idaho, USA, Law for Private Managed Aquifer Recharge and the Subsequent Rediversion and Use of Such Recharged Groundwater

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KEY WORDS
Legal basis, managed aquifer recharge, groundwater, storage water, aquifer recharge units

ABSTRACT
The State of Idaho, USA, has abundant and extensive natural water resources, including the Snake River and its numerous tributaries which overlie the Eastern Snake Plain Aquifer, a very large broken basalt aquifer containing in excess of 600 billion cubic meters (500 million acre-feet) of groundwater.

Uses of the surface water resources in Idaho began with the arrival of the pioneers in the mid nineteenth century and the irrigation by them of agricultural crops and their uses of such water for domestic purposes and stock water. By the time Idaho became a state in 1890, major canal systems had been constructed.

Idaho became an "appropriation doctrine" state with the adoption of the State Constitution, whereby "first in time is first in right." The State owns all the waters within its boundaries, whether flowing in a surface stream, standing in a lake or other body of water or standing or moving within an underground aquifer. Originally all that was required to legally appropriate a water right was to divert it from the public source of supply and apply it to a beneficial use; called the "constitutional method of appropriation."

Recharge Development Corporation (RDC) has endeavored to conduct private incentivized MAR to enable a continuation of groundwater pumping for beneficial purposes. Water for MAR can be appropriated from natural flow (such as high flows during spring freshets) and surface storage water before it leaves the basin. Such water, when actually recharged remains in the aquifer for substantial periods of time and the aquifer can essentially serve the same functions as a storage reservoir. RDC can measure the water into the aquifer and then out again and has developed a sophisticated accounting system to keep track of all such water. RDC has entitled the space within the aquifer in which such water is so recharged and stored "Aquifer Recharge Units" or ARUs, each one representing one acre-foot of space. To fill the ARUs and make the water available for rediversion and use, water must be so recharged.

This paper considers legal aspects of whether water stored in the aquifer via private recharge in ARUs can be sold, rented or leased to be subsequently diverted from the aquifer and applied to beneficial uses by those who own or hold such ARUs. The paper also considers whether an aquifer legally be treated the same as any other reservoir.

Beyond demand-driven adaptation: A governance perspective for MAR implementation in Guanacaste, Costa Rica

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ABSTRACT
Water scarcity is a recurrent issue in communities located in the Mesoamerican dry-corridor. In Costa Rica, water scarcity is especially relevant in the Guanacaste province, where ENSO related droughts, seasonal aridity, knowledge and technical limitations, and weak governance exacerbate water issues. More specifically, the development of the tourism industry in burgeoning coastal communities is threatened by the lack of sustainable fresh water availability. This is the case of the Huacas-Tamarindo and Brasilito-Potrero aquifers, whom in 2014 were reported with salt intrusion issues. This paper assesses governance framework conditions for the implementation of green adaptation options, including MAR for enhancing water security in coastal aquifers with salt intrusion issues. For this we surveyed technical and scientific literature available and performed a water security assessment in 22 communities from the Huacas-Tamarindo and Brasilito-Potrero aquifers. Our results represent one of the few systematic efforts for addressing water security issues in coastal areas from Latin America. We found that academic organizations, NGOs and Costa Rican institutions have been working to increase the technical information available for decision making related to water resources. Relevant examples include the organization of a participatory process for the sustainable use of coastal aquifer led by SENARA. This process increased the institutional presence in coastal areas and the understanding of the technical and biophysical challenges for addressing water issues. Moreover, our results indicate that current adaptation options are based on hard alternatives, e.g. building aqueducts from neighbouring areas which include the Nimboyores aquifer; or building PACUME, a large infrastructure project conducting water from the Arenal -Tempisque irrigation district. Soft adaptation options are less evident and often implemented at smaller scales with a notable exception: the organization of a regional water governance platform named CONIMBOCO which integrates representatives from the private sector, water related institutions, local governments and community-based drinking water organizations. More importantly, water security and the sustainable development of coastal communities is threatened by water scarcity as climate change impacts will enhance negative effects on water availability and quality. We conclude highlighting the great potential from academic institutions to collaborate with institutions, private sector, and NGO's for implementing green adaptation measures such MAR.

Using free web-based tools for strenghtening capacities and promotion of MAR

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KEY WORDS
capacity development, training, INOWAS, summer school, workshop, training course

ABSTRACT
Successful implementation of technical solutions for water resources management is not possible without adequate development of institutional and human capacities. In case of managed aquifer recharge (MAR), despite its apparent simplicity, the uptake of subsurface water storage is still rather low at international scale, much lower than other conventional storage solutions such as surface reservoirs. The reasons include insufficient data on MAR technological costs, site-specific hydrogeological characterisation, lack of regulations and, most important, weak institutional and human capacity. To address these challenges, the research group INOWAS at Technical University of Dresden, Germany, developed over the past four years a set of tools and instruments for planning, assessment and optimisation of MAR schemes. For the maximisation of their outreach and simplicity of use, the entire collection of 22 tools of different complexities was compiled on a free, web-based platform available at: https://inowas.hydro.tu-dresden.de).

The platform enabled the INOWAS group to engage in two types of capacity development activities: 1) general promotion of MAR through the development of an integrated knowledge base with detailed descriptions and best-practice examples of most common MAR techniques; and 2) demonstration of MAR benefits through the simulation of multiple management scenarios using empirical, analytical and numerical modeling tools. The general objectives of the training activities address the following challenges: i) how to design nature-inspired water management solutions in order to promote sustainable urbanisation; ii) how to restore degraded ecosystems due to groundwater overexploitation and how to increase water availability in times of high demand; and iii) how to use smart water management strategies for the development of climate change adaptation and mitigation.

The present paper brings evidence on how internet and computer technology (ICT) can contribute to MAR promotion and summarises the experiences collected from capacity developing activities implemented by the INOWAS group in a series of international summer schools, interactive workshops and short training courses covering the main aspects of MAR planning and operation.

Overexploitation of aquifers in the industrial corridor of Bajio Guanajuatense, Mexico

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KEY WORDS
Acuifers and piezometric levels

ABSTRACT
The Bajío Guanajuatense, in the central zone of Mexico, has traditionally constituted a region of great national economic and social relevance, with a strategic geographical situation, in a high plateau with extensive valleys of fertile soil and temperate climate, which constitutes a zone of union and obliged way to communicate the different zones of the country, and exchange of diverse products. This region, which since the colonial period has highly contributed to the agricultural and mining development of the nation, is currently experiencing great industrial and population growth, with a consequent and constant increase in the demand for all kind of services and water.

Every four years or so, the National Water Commission (CONAGUA, for its acronym in Spanish), publishes the average annual availability of groundwater for the 653 aquifers of Mexico. In January 2018, 16 of the 20 aquifers that belong to the state of Guanajuato, two of them partially shared with San Luis Potosí, were reported in a significant state of overexploitation. This condition is particularly pronounced in the Valle de Celaya, Irapuato-Valle de Santiago, Silao-Romita, Pénjamo-Abasolo and Valle de León aquifers, which have a total area of 10,846 km2, with around 11,253 underground water wells and other discharge authorizations, and present a deficit of between 160 and 550 million cubic meters of water per year. The piezometric levels range from 50 m to 160 m deep, with abatement ranging from 0.5 m to 4 m in recent years.

The region constitutes an important industrial corridor, with more than 20 parks and industrial zones installed, and with nine more parks in project, where the automobile sector is has particular importance. The population increased from 3,272,124 to 3,940,158 inhabitants in the period 2000 - 2010, according to figures from the last census. Many cultural manifestations and tourism are also relevant. Given the current conditions, the managed recharge of the aquifers stands as an alternative that must be seriously considered and studied within any strategy, to address the great challenge of ensuring the viability and sustainability of development in the region, as well as environmental responsibility and social in a context of climate change.

Developing a strategy to recover condensated water from air conditioners in Palestine and reuse for MAR

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KEY WORDS
Condensate water recovery; air conditioner; water quality; water quantity, Palestine.

ABSTRACT
As the need for water is increasing in Palestine, and the available water resources are barely meeting the current quality of life and economy, air conditioner condensate water could be explored as an alternative water source. The objective of this study is to better understand the potential for recovery of condensate water from air conditioning systems in two Palestinian cities. In addition, this study is to evaluate this water source in terms of quality and quantity. Generally, it was found that the condensate water is at good water quality, which conforms to the Palestinian standards for reused water for irrigation, except for turbidity, BOD and COD measurements. Reflecting the heavy metals occurrence in the collected condensate water, no particular risk was recognized for drinking water or reused irrigation standards, except for Manganese occurrence in one sample. From a single unit capacity, high quantities of water were observed at approximately 259 L and 453 L per one-ton unit per month in Ramallah and Jericho cities, respectively.

These figures should draw the attention to decision and policy makers to put in place strict technical guidelines to be followed for potential reuse of condensate water at the local level, and their integration into MAR and SUDS.

The VietMAR project: first results from the hydrogeochemical characterization of the Bin Dinh province (Vietnam)

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KEY WORDS
Vietnam; dune filtration; river-bank filtration; tourism; stormwater filtration

ABSTRACT
Vietnam is undergoing a rapid socio-economic development. Along the Vietnamese coastline, in particular, groundwater demand is expected to increase dramatically in the next years because of flourishing tourism and pressing industrial needs. Unfortunately, the current groundwater consumption rates can exceed the natural recharge rates, while there is a severe risk associated to climate change (increasingly more frequent and severe droughts are expected in addition to sea water rise). The quality of groundwater resources may be affected by salt-water intrusion, potential contamination due to emerging industrial sites and unmanaged urban pollution. Managed aquifer recharge (MAR) can mitigate the groundwater stress and reduce freshwater-related risks in the next decades.

The Geological Survey of Finland (GTK) is currently involved in a project called "VietMAR", supported by the Finnish Ministry of Foreign Affairs and in cooperation with local partner organizations, CEFAWO (Hanoi) and SIHYMETE (Ho Chi Minh city). VietMAR aims at studying the feasibility of MAR in a selected coastal area of the country, near Quy Nhon in the Binh Din province.

This contribution presents the first results of the hydrological, climatological and hydrogeochemical characterization of two potential MAR sites, the Tan An well sites and the Dunes area in the Phuong Mai peninsula, are presented and described. The results emphasize the types of MAR applications that are most suitable for the artificial recharge of aquifers under hydrogeological (permeability-limited recharge) and surface-water quality constrains. The results seem to suggest that riverbank filtration is not an optimal solution at the Tan An well site, in spite of the presence of multiple pumping wells. In the still-unspoiled Dunes area, the conditions is almost ideal for MAR applications.

The project now tackles other aspects of MAR, including cost-benefit analysis, water needs mapping, land use, evaluation of water infrastructures, and quality of water at the end users. These steps lead to a comprehensive design and feasibility study of MAR, which will determine, among other aspects, which sources of raw water can be used for MAR in the sites. These sources may include currently-unmanaged stormwater collection, large-scale rainfall harvesting or delivering river water to the Dunes area.

the effect of the artificial recharge pulse from streambed on karst system

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KEY WORDS
Artificial recharge pulse; streambed; karst system

ABSTRACT
The Jinan karst system is a typical karst system in northern China, with a group of karst springs occurring in the city center of Jinan as the dominant discharge. However, the lowing regional groundwater level threats the outflowing of these karst springs. In the past decades, several measures were conducted including shutting down the municipal water supply well and using surface water as replacement in order to increase groundwater level and protect karst springs. The Yufu River with watershed of approximately 1510 km^2 in western Jinan is dry for most time. The surface water can be transported into the streambed of Yufu River in dry season (May), and infiltrate into the karst aquifer, and forms an important recharge source for Jinan karst system.

Hydrochemistry and isotope methods were investigated to study the influence of the recharge pulse from river water infiltration on Jinan karst system. Results show that: 1) The water type of karst groundwater (including the karst springs) was predominantly Ca-HCO_3-SO_4 in May and October, while the water type of river water was Ca-Mg-SO_4. 2) The δ^2H and $\delta^{18}O$ in river water were average -51.2‰ and -6.6‰. The groundwater samples can be divided into two parts by δ^2H and $\delta^{18}O$ characteristics both in May and October. Some samples located around the Global Meteoric Water Line (GMWL) with depleted $\delta^{18}O$ of -9.04 to -8.6‰ in May and -9.01 to -8.11‰ in October. Other samples located below GMWL with enriched $\delta^{18}O$ of -7.91 to -6.89‰ in May and -7.59 to -6.01‰ in October. 3) Based on the hierarchical cluster analysis, the groundwater samples showed partition according to chemical and isotopic components. The samples close to the bank of Yufu River had the highest SO_4, least NO_3, most enriches δ^2H and $\delta^{18}O$ values, indicating the recharge from river water. 4) A simple two components mixing model is developed to estimate the fractions of the river water in groundwater based on $\delta^{18}O$ values in groundwater and river water.

The flow path of infiltrated river water is obtained from the spatial distribution of the river water fractions in groundwater samples, which is from streambed through Dongkema to Manzizhuang. 5) On the basis of mass balance modeling, the dominant processes is the dissolution of dolomite along the recharge flow path.

This study will provide a framework for a better understanding of the interaction between groundwater and river water and the processes controlling the groundwater evolution in Jinan karst aquifer.

Biological and Physical Clogging in Infiltration Wells – The Effect of Well Diameter and Gravel Pack

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KEY WORDS
Well diameter, gravel pack, infiltration, clogging

ABSTRACT

In the recent past, gravity-driven infiltration via small-diameter wells (wells with an inner diameter smaller than 2 inch) into the shallow subsurface has been proven to be a cost-efficient and flexible tool for Managed Aquifer Recharge using clean water, as it provides relatively high recharge rates with minimal construction effort. Nevertheless, when using low quality waters, clogging has always been expected to be more critical compared to wells with larger diameters. One of the main reasons for this is the system's active filter area (AFA), i.e. the open screen area, which is significantly smaller. This holds especially true, when larger wells are equipped with a gravel pack, as the porosity of a gravel pack is mostly larger than the open filter area of a well screen, which is in direct contact with the aquifer. Therefore, different processes of clogging in laboratory aquifer-well models were studied within this study to investigate their susceptibility to physical and biological clogging. To analyze the respective processes separately under controlled conditions, either clean but turbid water or synthetic treated waste water (by adding nutrients) has been applied for infiltration.

The studies showed that smaller diameters and a direct contact between the well screen and the aquifer increase the well's susceptibility to clogging of any kind. However, it became also clear that this effect is much stronger, when it comes to physical clogging than for biological clogging.

Our conclusion is that small-diameter wells are not suitable for the infiltration of highly turbid waters, but can be a suitable tool for the infiltration of nutrient-rich waters, when infiltration operation is properly managed.

Fate of plant pathogenic bacteria in drainage water during managed aquifer recharge for agricultural irrigation

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KEY WORDS
plant pathogens, irrigation, water quality

ABSTRACT

Agricultural production in coastal areas is often impaired by freshwater availability. Additionally, the presence of bacterial plant pathogens in waterways and their dissemination through irrigation water pose a threat to crop production. A natural solution to provide safe irrigation water is managed aquifer recharge (MAR) for agriculture where tile drainage water (TDW) is stored in the subsurface. This results in a fresh water 'bubble' giving farmers access to sufficient irrigation water even in times of drought. The TDW may contain plant pathogens which could be present in the recycled water. To prevent the occurrence of crop diseases the removal of selected plant pathogens during aquifer soil passage will be analysed. We focused on three plant pathogenic bacteria, namely *Ralstonia solanacearum, Dickeya solani* and *Pectobacterium carotovorum sp. carotovorum* that are all worldwide present causing high crop losses associated with immense economical costs. First, their die-off in natural TDW is studied in water microcosms at a starting concentration of 10^4 CFU/mL. Second, to predict their fate during soil passage the transport in saturated porous media is analysed with column experiments. Both experimental setups are conducted under representative aquifer conditions. Results of microcosm experiments under aerobic conditions in natural TDW show that all bacteria were not detected anymore in 0.1-mL samples within 14 days at 10 ^{0}C using viable cell counting, corresponding to 3 $\log_{10}$ reduction by die-off. *D. solani* and *P. carotovorum* were no longer detected within 6 days at 25 ^{0}C, but *R. solanacearum* was more persistent at 25 ^{0}C and was detectable up to 25 days. In autoclaved TDW at 10 ^{0}C and 25 ^{0}C, the persistence of the bacteria is increased to more than 112 days illustrating the effect of natural microbiota on the bacterial survival. Only *R. solanacearum* is no more detectable after 41 days in autoclaved TDW at 10 ^{0}C confirming its inability to persist at low temperatures. Next to results of anoxic microcosms, the first outcomes of soil column experiments will be presented.

Based on results from lab and field experiments guidelines will be developed using quantitative microbial risk assessment to demonstrate the feasibility of MAR in agriculture to deliver safe irrigation water, thereby fighting water scarcity and food losses.

Tunisian experience in managed aquifer recharge by hill dam water release: case of some groundwater flow systems in North of Tunisia

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KEY WORDS
MAR, hill dam, release, semi arid, Tunisia

ABSTRACT
As the water demand is continuously increasing with increased population, water availability is becoming a crucial concern. Thus, understanding the complex interactions between the different components of the water cycle is necessary in order to regulate and control their flux exchange, to cope with their rarity and to ultimately insure their sustainability.

In arid and semi-arid regions, surface water bodies and groundwater are interacting in a variety of geographic landscapes. In addition to their agricultural role, hill dams provide in Tunisia an important water volumes for Managed Aquifer Recharge (MAR) through water release in wadis such as the cases of Wadi Saadine in Zaghouan prefecture and Wadi Khairat in Sousse prefecture. The aim of this study is to evaluate the Tunisian experience in MAR throughout assessing the efficiency of water release from hill dams for the artificial recharge of the shallow aquifers and to propose some decision-support tools for sustainable water resource management.

Frequent field observations were conducted in 2015 and 2016, and during them, physical and geochemical parameters of stream, dam and well waters were measured. Time series of the released volumes with aquifer reaction (groundwater level) were examined to assess the impact of MAR. Furthermore, based on the geochemical and isotopic data, a statistical analysis (PCA) and an End Member Mixing Analysis model were used in the studied groundwater flow systems in order to calculate the flux exchange between the streams and the aquifers.

Water release from the hill dams in Sousse and Zaghouan regions are playing important roles in aquifer recharge and the dam water contribution exceeds 70% in some locations. Recharge amount is clearly depending on the released volume, climatic conditions and wadi lithology and morphology. The managed release of dam water is contributing to the rise of the groundwater near the Wadis. This concept is strongly encouraged to be applied in the stressed aquifers where an excess of surface water might exist in order to guarantee the sustainability of these resources.

MAR Revolution in California – Policy and Regulatory Change to Increase Groundwater Recharge Statewide

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KEY WORDS
MAR Policy Regulatory Flooding Geophysics

ABSTRACT
California has undergone significant challenges over the past two decades. Realization that the massive statewide water project delivery system that San Joaquin Valley farms and southern Californian communities rely on has caused fisheries declines due to cross estuary flows into massive pumps, water quality impacts from multiple sources including wastewater, and invasive species that thrive in the engineered environment crested. Actions have been taken to cut through-estuary flows, and setting instream flow requirements for estuary watershed contributing rivers, and water quality and invasive species are being further examined. The California Sustainable Groundwater Management Act took effect in 2015, requiring for the first time that groundwater basins be managed sustainably, emphasizing the need to increase groundwater recharge where possible to achieve sustainability in many overdrafted basins. A significant drought was capped by the second wettest year on record in 2017 marked by extreme weather events, and the near catastrophic failure of the state's Oroville dam, the highest earthfill dam in the country and primary supplier to the state water project. As most of the flood waters departed the state, with SGMA as a driver, the water industry came together with a unified message emphasizing the need to increase groundwater recharge statewide. The result has been more flexibility on the process of being built into state permitting requirements, further refinement of how to consider peak flows and surface water availability from a water rights perspective, increased research on reservoir reoperation and extreme weather events, and greater initiatives for MAR including a rapid growth of on-farm field flooding with stormwater in areas where overdraft and subsidence have been occurring. A number of studies and evaluations have been conducted to assess areas most suitable for MAR statewide. The state has also partnered with the Kingdom of Denmark to evaluate aerial electromagnetics as a means to improve hydrogeologic characterization through pilot demonstrations and development of a standardized workflow to go from data compilation and collection to creation of 3D hydrogeologic conceptual models using geostatistical methods and uncertainty analysis. Increasing the use of sophisticated geophysical methods in groundwater management is a key theme of the project, led by Stanford University. A compilation of on farm field flooding projects, including the characterization and methods to assess success and potential impacts on crops, is examined and summarized. Policy and regulatory permitting advances are evaluated with discussion of options that can be further considered. Research and investment in additional tools is also examined through compilation of state agency and organization efforts to improve MAR successful application and practices.

Indirect Assessment of Aquifer Recharge from Electrical Resistivity Measurements through Estimation of Hydraulic Properties

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KEY WORDS
Aquifer, Recharge potential, Resistivity measurements, Hydraulic properties

ABSTRACT

Globally, groundwater resources have unique qualities for maintaining metabolic processes and the sustainability of life. However, this vital resource is prone to anthropogenic contamination from untreated waste and flood waters, especially in developing nations. Thus, this study is aimed at assessing the recharge / filtration potential vis-a-vis aquifer protective capacity of a quartz-schist weathered basement aquifer setting in Ibadan metropolis, SW-Nigeria through indirect estimation of aquifer hydraulic characteristics from electrical resistivity measurements.

Sixty-two (62) vertical electrical soundings (VES) were carried out along eleven (11) profiles, established in an E-W direction across the regional structural trends, in the study area. The acquired resistivity data were interpreted in using both manual curve matching and computer software-based iteration and evaluations of the associated layered parameters. Furthermore, Dar-Zarrouk parameters (longitudinal conductance, LC and transverse resistance, TR) were evaluated and alongside with the hydraulic conductivity (K) value estimated from pumping test were employed to estimate the aquifers transmissivity and indirectly the aquifer recharge potentials.

The results revealed mostly three to four subsurface layer systems which include top soil, weathered saprolite unit, fractured bedrock unit and the underlying fresh (unfractured) basement rock unit. The overall weathered saprolite aquiferous unit ranges from 5–22m while the transverse resistance ranges from 14.23 – 1882.04 Ωm (av. 119.60 Ωm). The estimated longitudinal conductance range from 0.014 – 0.714 Ω^{-1} (av. 0.23 Ω^{-1}) indication of a good infiltration capacity while the Hydraulic conductivity and Transmissivity vary as $1.24 \times 10^{-2} – 5.2 \times 10^{-1}$ (m/day) and 6.4–0.2 (m^2/day).

In summary, the estimated hydraulic parameters based on the resistivity measurements are comparable with K= 1.13 m^2/day and T= 1.48 m^2/day estimated from the pumping test data. Therefore, this study revealed the applicability of resistivity measurements as a rapid, non-invasive indirect assessment of aquifer of recharge / infiltration potentials with reliable results in place of conventional pumping and permeability tests.

Participatory Aquifer Management an Alternative Approach to Sustain Urban Water Supply – a case study of Bhuj City – Gujarat, India

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KEY WORDS
Participatory, Institution, Aquifer, Urban Watershed, *Bhujal Jankars*

ABSTRACT

The present abstract is a case study of Bhuj city of Gujarat state, explains how urban water management planning to be adopted against dynamic urbanization development. The paper is a classic example of advance growth of urban area based on centralized water supply facilities gradually de-linked local, traditional and decentralize in nature water management practices. Beginning of paper explains stages of development of Bhuj city and associated process of water supply management through distance sources, followed by geo-hydrological characteristics and capacity to supply water through local water resource. Present status of city of Bhuj has evolved through three stages with and the same stages are evidences of ignorance of traditional water management systems.

In this scenario Arid Communities and Technologies – A Bhuj Based not for profit organization, has demonstrated Participatory aquifer management activities in Bhuj city to make a self-reliance city that gradually secures groundwater resources in peri urban areas by adopting multiple tasks such as (01) Decentralized people centric watershed management plans for urban – peri urban areas; (02) preparing integrated groundwater recharge plan to create interface between groundwater and surface water within urban land scape by using storm water construction and revival of water harvesting structure in watershed inflow areas; (03) development of land use specific techniques for recharge and water harvesting and most importantly (04) attempt to constitute recognized and knowledge equipped "Urban *Bhujal Jankars*" – (UBJs) and citizen's institution "*Jal Srot Sneh Samvardhan Samiti"* (JSSS) for management of watershed, aquifer and decentralized water supply.

Sharing and dissemination of this whole experience has helped to build faith in such decentralized process among local municipality and state level urban departments. Incorporation of successful technique of common plot recharge in storm water management plans of AMRUT – Scheme, and strategies for groundwater recharge in town planning made by urban development authority are some of the positive way forwards. Additionally citizen institutions like JSSS and BJs have strongly proven that an empowered citizen institution is must to resolving urban water issues.

Managed aquifer recharge (MAR) in coastal aquifers, in brackish and saline groundwater – Cooperation between partners from European and GCC countries

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KEY WORDS
Managed aquifer recharge, Water management, Coastal aquifers, Brackish and saline groundwater, Subsurface water solutions

ABSTRACT
Managed aquifer recharge (MAR), the intentional recharge of water into an aquifer, has been generally shown to work in different geological settings. The origin of the source water for MAR applications depends on local water availability. Many successful MAR schemes apply water from alternative sources, e.g. desalinated seawater or treated sewage effluent. An adequate treatment prior to recharge, hydrochemical mixing reactions and water-rock interactions within the aquifer after recharge have to be considered. The application of MAR for water storage in coastal aquifers in saline or brackish groundwater poses additional challenges: Mixing of recharge water with native brackish and saline groundwater, either in the aquifer or during abstraction may render the abstracted water unfit for intended purposes. It is therefore important to recover recharged water with minimal mixing.

Members of the SUBSOL project – bringing subsurface water solutions to the market –, financed by the European Commission, have modified conventional MAR techniques to make them more efficient in saline or brackish groundwater settings. Subsurface water solutions (SWS) provide different building blocks to minimize mixing of freshwater with native groundwater: Multiple partially penetrating wells can be used to control upward movement of freshwater bubbles caused by buoyancy, smart configurations of interception wells can be applied to prevent upconing of saltwater during freshwater abstraction, and automated control units are utilized to optimize pumping schemes.

In the framework of the SUBSOL project, GCC countries have been visited with the aim to conduct so-called "regional assessments" to evaluate the potential of SWS. Besides hydrogeological and technical matters, other issues were addressed in these studies. One aspect is the regional perspective, whether subsurface solutions are considered suitable tools in the repertoire of the water management options. Another aspect is the regulatory framework, especially the legislation on water – e.g. regulations on injection, abstraction and quality of water. Based on preliminary assessments, first positive results give way to the hope that regional cooperation between European and GCC countries can establish a solid base for common future projects.

Application and evaluation of an advanced aquifer storage and recovery pilot system in Recife, Brazil

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KEY WORDS
Groundwater static level, Coastal aquifer, Artificial recharge, Brazil

ABSTRACT
The rapid growth of the world's population has been increasing the demand for water. Especially in coastal cities where many of the world's most productive and economic centres are located, groundwater resources are suffering from increasing exploitation. Consequences such as sinking groundwater levels, soil subsidence, and possibly saltwater intrusion have been increasingly gaining significance in many debates.

To meet these growing challenges, Managed Aquifer Recharge (MAR) emerges as a nature based solution for improved water management by protecting, enlarging, and utilizing subsurface freshwater resources. Despite the great success of MAR in water storage and treatment, traditional MAR and ASR concepts face several challenges in salt-water impacted aquifers such as buoyancy effects and up-coning, which often make them inefficient. Therefore, a number of eco-innovative technology concepts (named Subsurface Water Solutions (SWS)) improving the application of MAR and ASR in aquifers prone to salinization have been developed in the last years (Zuurbier et al., 2016). In Recife, Brazil, where still few pilot projects are located but increasingly needed, one of these SWS concepts, an ASR-Coastal, is currently under construction.

The ASR-Coastal concept combines innovations in well design by using Multiple Partially Penetrating Wells and configuration for a more robust, sustainable, and cost-efficient freshwater management in coastal areas. The recharge pilot plant, located at a public school in Pina neighbourhood and less than 500 m from the coast, includes a rain water harvesting system using the school roof as a catchment area. The rainwater will be injected into the confined aquifer through the MPPW during the wet season and recovered in times of water scarcity to cover the school's water demand. Recharge tests will begin in early 2019.

Qualitative and quantitative analysis will be carried out. It is expected that this pilot plant and the project results will contribute to the sustainability of the water supply system and promote, as a good example, further similar and upscaled implementations. In Brazil, regulations for MAR are still in its very beginning.

The project includes a close collaboration with local authorities to foster the development of an appropriate legal framework.

Conjunctive Use of Managed Aquifer Recharge to Improve Water Resources and Riparian Habitat Quality

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KEY WORDS
MAR, Streamflow, Riparian Habitat, Endangered Species, Recharge

ABSTRACT
Throughout the western USA and many arid regions throughout the world, construction and operation of flood retention and water-supply dams and/or excessive groundwater extraction have greatly altered river hydrologic flow regimes and measurably damaged riparian ecosystems. Within the USA, there is increasing conflict between water users and the environmental needs of affected river systems. Managed Aquifer Recharge (MAR) is a well-recognized tool to recharge and store surface water in aquifers. However, MAR sites are typically designed to maximize aquifer storage and minimize losses from evaporation and off-site migration or discharge to surface water bodies. For these reasons, shallow aquifers or those adjacent to rivers are usually not considered suitable for MAR. Strategic placement and operation of MAR sites, however, has the potential to improve riparian habitats and increase river flows during low-flow periods with relatively low losses due to evapotranspiration.

Three case studies will be presented as examples of conjunctive use of MAR to increase water storage and improve or support riparian system habitat. Case Study 1 is located in an area with threatened fish populations that are exposed to conditions of low flow and high water temperature during late summer periods. MAR is being used to store excess surface water during the winter and early spring in the shallow alluvial aquifer. The MAR increases groundwater storage and return flow of cooler temperature groundwater to streams during the summer. Case Study 2 is in an area where a cone of depression from groundwater pumping is reducing baseflows in an ecologically sensitive river. Existing and proposed MAR facilities are/will be used to raise groundwater levels near the river and thus maintain baseflows. Case Study 3 proposes to convert existing high water use agriculture into a mix of low-water-use crops, surface water retention and storage, groundwater recharge sites and habitat restoration areas. Estimated water losses due to habitat improvement and methods for controlling the water budget for each of the examples will be discussed.

The artificial recharge as a tool for water resources management, application to the hight mountain aquifers (Peru)

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KEY WORDS
Artificial recharge, recharging methods, karst, hydraulic connection, High Mountain.

ABSTRACT

The area is located in a high mountain area, in the central and southern part of Peru, with a predominance of fractured and karst hydrogeological resources, being the main aquifers that supply the high Andean populations, in which there is a need to improve the underground reserve and / or maintain the download of their sources.

The classification of recharge methods based on the current ones is proposed, differentiating recharge systems on the surface (inside and outside the channel), and at depth (in the saturated and unsaturated zone), to which a series of devices are attributed, that develop in different parts of the world. It summarizes the progress made with artificial recharge experiences in countries with high mountain geography and similar aquifers.

A case study was made in a pilot basin with aquifers; karstic and fractured, in a high mountain context, applying techniques to determine the natural recharge and its hydraulic, hydrodynamic and hydrochemical functioning, with attention to the mining drainage and its associated problems.

The annual rainfall reaches 1,500 mm/year, the area has mountains with deep valleys, supported by calcareous rocks of the Upper Cretaceous, with developed epikarst. The hydraulic conductivity of the soils is 1.5 m/d, limestones 2.0 m/d at 10 m/d, (matrix), in the ducts it reaches 71 m/d. The injection of tracers in sinkholes and piezometers, indicated transit speeds of 328 m/d, the highest 487 m/d at 528 m/d, which is why the mine flow increases 1 to 2 days, being dependent on the duration and intensity of rain.

The recharge in calcareous rocks obtained with the numerical model is from 250 to 350 mm/year, and in dolines it reaches 500 to 600 mm/year. Its phreatic level is fluctuating, especially in areas with conduit karsticity, and less variation in a less fractured matrix. The drainage of the underground mine in dry season extracts permanent reserves of the aquifer between 300 l/s, at 350 l/s, and in wet months it reaches 1,600 l/s.

Four experiences of artificial recharge of high mountain in Peru have been collected, those that were developed in the central and southern part of Peru, these have been systematized and put in value, some collect old technologies of artificial recharge, called "amunas or mamanteos" dating from the Inka culture, similar to the facets of the Alpujarra of Granada.

Statistical impact assessment of ASR and ASTR schemes on hydrogeochemical and hydrodynamic functioning of two Mediterranean coastal aquifers

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KEY WORDS
Recharge, multivariate statistical analysis, correlation and spectral analysis, detritic aquifer.

ABSTRACT
The coastal aquifers of the Mediterranean area, characterized by a semi-arid climate, are especially vulnerable to pollution and overexploitation. In this sense, the increase of population pressure in touristic areas where the occupation can be doubled or even tripled in summer, intensifying pumping-induced seawater intrusion. This may be the case of Aloha aquifer in Marbella and Lower Llobregat Valley aquifer in Barcelona (Spain). Pliocene Aloha aquifer is formed by conglomerates, sands and sandy loams, constituting a multi-layer aquifer with frequent intercalations of low permeable levels. With respect to Lower Llobregat Valley aquifer, it contains highly permeable alluvial sediments resting on and bounded by low permeability Paleozoic shales and Miocene and Pleistocene. As a measure to face the vulnerability of these formations, managed aquifer recharge experiences (Aquifer Storage, Transfer and Recovery –ASTR– and Aquifer Storage and Recovery –ASR–) were carried out by using water surpluses from Verde River alluvial aquifer and Llobregat River water (after conventional treatment) in Aloha and Lower Llobregat Valley aquifers, respectively. The total recharged volumes have been 32.870 m^3 (2017-2018) in Aloha aquifer and 600.000 m^3 in Llobregat aquifer (2015-2016).

The hydrogeological response to managed aquifer recharge has been assessed by monitoring daily control variables (water levels, electrical conductivity, rainfall, and temperature) and scheduling water sampling campaigns. Multivariate statistical techniques have been applied to the previous information, allowing the determination of MAR impact in hydrogeochemical and hydrodynamic functioning. Moreover, time series analysis (autocorrelation, cross-correlation and spectral density functions) has been used to identify patterns, trends, and relationships between the analyzed variables. The obtained results have contributed to better understand the positive impact of MAR schemes in coastal Mediterranean aquifers.

Recharge technologies applied to the Llobregat aquifers

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KEY WORDS
Llobregat aquifers, Multirecharge strategy, scarification, ASR, recharge ponds, Hydraulique barrier

ABSTRACT
The Llobregat aquifers, close to Barcelona, is a key element for the urban (2 Million population) and industrial water supply of Barcelona Metropolitan Area. The water demand of the area is historically very high relative to the small and highly variable water resources under the Mediterranean climate conditions. Since 1955, the joint use of surface- and groundwater has improved the guaranty of availability. In 1966 started a water transfer to Barcelona from the river Ter. Later, in 2008 a waste water reclamation plant and in 2009 a seawater desalinization plant were incorporated to the water system. In addition, the relation between the different water sources has been favoured by means of artificial recharge, which is also relevant to prevent groundwater quality degradation.

Since 1950 the scarification of a stretch of the river bed to reduce siltation allows increasing water river infiltration into the Low Valley aquifer. But after 60 years the stretch has less capacity to infiltrate and a new study was realized to decide a new zone.

Since 1969 a storage and recovery (ASR) well system is used to recharge treated water river from a DWTP. The treatment was improved along the time with an advanced treatment and the approach of the facility has to be redefined (DESSIN LIFE project). A new project to change the facility to ASTR is doing now.

Since 1985 to compensate the overexploitation of Sant Andreu de la Barca aquifer a recharge pond was constructed. This facility lived several stages because the river was caused damages and it was necessary to rebuild several times.
Since 2007, to compensate for infiltration area loss due to new civil works, a recharge pond infiltrates river water or reclaimed water in the low Valley aquifer. The behaviour of an organic layer bed in the infiltration pond has been studied (Life ENSAT).

Finally, in 2007 a hydraulic barrier was constructed to inject advanced treated reclaimed water to halt seawater penetration into the deep delta aquifer. Since 2011 to now this facility was stopped for economic problems but next month will be reactivated.

In all cases, an additional goal is to achieve the environmental objectives derived from the European Water Framework Directive because the groundwater body is in bad state. A protocol defines how and when these techniques of recharge are applied. Normally the decision depends on water availability and the threshold values of quality of the water source and on the piezometric level. The cooperation between different partners has been and is the key for the multi-recharge strategy approach and the water cycle management.

Managed Aquifer Recharge Solutions (MARSOL). Final statements

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KEY WORDS
Managed Aquifer Recharge, Technical Solutions, Water Scarcity, Drought, MARSOL

ABSTRACT
MARSOL project (Demonstrating Managed Aquifer Recharge as a Solution to Water Scarcity and Drought) has taken place since 2014 to 2017 within EC FP7 call with GA 619120. In the final part of the project, first row members put together the conclusions from their personal point of view and after three years of intense research. All these statements have been put together in a **seven minute video**, where authors expose their final statements.

As an example are included three of the whole set of summaries:

-Christoph Schüth (TUDA; GE): During the MARSOL project there are many experiences of the operation of the MAR sites most effectively to infiltrate different water qualities. However there are certain basins that we have to look into for the future, one is related to water quality of, for example, infiltration of emergent pollutants as pharmaceuticals, not so easy to predict; and the second one related objection is the regulatory framework that has to be implemented to ensure MAR safe and sustainable.

-Annette Wefer-Roehl (TUDA; GE): MAR is a sound, safe, and sustainable strategy for climate variability preparedness that can be used with great confidence, and through MARSOL and its demonstration sites the awareness and the acceptance among stakeholders for MAR solutions has been greatly increased.

-Jon San Sebastián (TRAGSATEC, SP): In the future the demand for water gained by MAR will be higher due to climate change, energy issues, increase of population etc. In general, economics is also an issue. Does MAR present a cost benefit? For the EU we have to present suggestions for the future. We have to link people and economy to MAR.

The first author collected and produced a video, concluding the following outcomes:

- MAR works, but needs experts to do it
- MAR is now a proven technology
- MAR is key solution to ecosystems depending on groundwater
- MAR is a sound, safe, and sustainable strategy that can be used with great confidence
- MARSOL has created a new generation of water managers that have an additional option now
- The awareness and the acceptance among stakeholders for MAR solutions is greatly increased
- MAR as one of the best techniques to face frontally climate change adverse impacts.

Authors request a 7 minute slot to display publicly this final video (subtitled). The paper will include two additional statements.

Note: 7 minute slot (Flash presentation) is requested for ISMAR 10 second Flash session.

Managed Aquifer recharge in Mexico

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KEY WORDS
MAR, Mexico, Inventory of structures, Intensive Exploitation

ABSTRACT
A Managed Aquifer Recharge (MAR) analysis of Mexico is carried out. Environmental (geological, hydrological and climatic), economic and social conditions prevailing in Mexico's different regions are analyzed, from water shortage in the industrialized and arid north, to flooding in the tropical rural south.

Various terminologies related to the MAR concept, as well as its objectives and legislation for Mexico, are analyzed throughout this paper. MAR works inventory in Mexico is updated increasing it from 11 to 60 structures, and key information such as location, status, type of structure, water origins, historical background, focus, objective and modality of the techniques employed are obtained. Eighty percent of works are located in the center and northern parts of the country, with 70% of the works using torrential runoff, while 80% are pilot projects without continuity.

The importance of updating the MAR inventory in arid and semi-arid countries such as Mexico should be highlighted, because 40% of the water resource comes from groundwater. It is also important the diffusion of MAR techniques within the non-specialized public, and a greater understanding by the water management institutions for its dissemination, implementation and continuation must be done. In addition, the most successful MAR structures in Mexico are studied as well as the knowledge and experiences they left behind, plus opportunities for improvement and implementation of new projects.

The role played by Mexican society in the MAR processes it is revised, emphasizing urban and agricultural uses, analyzing pipeline losses and the importance of increasing the improvement of irrigation systems. In both cases incidental aquifer's water recharge is generated in those aquifers which are in intensive exploitation status. Very complex conditions, such as environmental (hydrological and ecological), social (poverty in areas of low water stress), economic (high demand in regions of high water stress), as well as future challenges due to population growth and climate change, prevail nowadays in Mexico. As a conclusion, the role that society and civil organizations must play in making decisions regarding water resources in general and MAR works in particular must be greater, avoiding misunderstandings by delegating responsibilities only to the government.

Water Farmers – An Aquifer Recharge Case Study in Caparaó, Brazil.

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KEY WORDS
Managed Aquifer Recharge, Unmanaged Aquifer Recharge, Plantadores de Água, Social Technology

ABSTRACT
In a Climate Change scenario, agriculture almost entirely dependent on rainfed irrigation is under threat. Thus, the trend is to depend on irrigation for food production. That's the case of Brazilians Agriculture, especially small farmers in Serra do Caparaó, Espírito Santo. Although, Brazil has lots of MAR cases, most of them are Unmanaged Aquifer Recharge, mainly small infiltration dams (known as "barraginhas") and infiltration ponds and trenches. Almost all are located in the Northeastern of the country, in the semiarid region.

In 2012, in order to face the drought and the depletion of water resources in a degraded region mostly dominated by coffee-growing and livestock, a group of small farmers of the Municipality of Alegre (Espírito Santo) joined with several local organizations to apply a project to Petrobras funding. The project called "Water Farmers" was based on a set of techniques used to slowing down the runoff and its consequent loss of soil, providing the aquifer recharge. The "water farming" approach includes among others social technologies, the spring isolation, the construction of small infiltration ponds and infiltration trenches in terraces.

The project was carried out in eight proprieties, involving among family farmers, students, researchers, teachers and civil society representatives interested in the subject, more than 5.000 people in the region. The Water Farmers Project could be highlighted by its different approach not focused only in the techniques, but mostly in exchange of experience, raising the awareness and changing behavior patterns related to land use and water resources management. This approach was adopted aiming to overcome the farmers' lack of knowledge in these areas. The water table recovering has ensured the water security, allowing family farmers to produce food for their own subsistence and, in some cases, selling the surplus in local markets, enhancing thus their incomes. The project was so successful that those who were involved are now organized in a cooperative called PLANT'ÁGUA in order to continue the work.

Use of Managed Aquifer Recharge to improve Water Management in Arid and Semi-Arid Regions of Mexico

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KEYWORDS
MAR, Mexico, arid regions, soft-path, policies

ABSTRACT
In Northern Mexico, expansion of irrigated agriculture, changes in consumption habits and urbanization, and other factors have increased groundwater pumping, which is becoming a threat to sustainable development. In addition, according to scientific models, climate change will affect hydro-meteorological events. Severe drought and warmer temperatures are projected to affect arid northern México, with impacts on agricultural and drinking water. To face new hydrological scenarios, it is imperative to develop a portfolio of alternatives for groundwater management, such as improving water efficiency in agriculture, matching water quality with use, and increasing Managed Aquifer Recharge (MAR). For water-stressed countries like Mexico, MAR can be an option to improve water management, including mitigation of droughts and water scarcity. Throughout the world, policies implemented to address water scarcity have largely been grounded in hard-path strategies. Mexico has not been the exception; its policies have been focused on creating new infrastructure to deliver water (hard-path strategies) and finding new water sources. Projects to manage water demand, recycle water, build small-scale decentralized infrastructure (soft-path strategies) have been little explored in Mexico. Particularly in water-stressed regions, hard and soft-path strategies coexist, and their conjunctive implementation can help to increase water resilience in arid regions. In the first section of this paper, we describe MAR projects developed in Mexico, their geographical distribution and the method used for recharge. In the second part, we explore how small MAR projects in Mexico can be part of the soft-path solutions and the role that MAR can play to increase water reuse. In the last section of the paper, the regulatory framework for MAR is examined and some suggestions for improving it are offered. The perspective proposed in this paper, which includes the joint implementation of soft and hard-path strategies, is innovative regarding MAR and it will fill a gap in the literature. Overall, it is feasible for water-stressed countries like Mexico to contemplate MAR as an option to increase water resilience.

Monitoring of Eh, DOM and water quality in a MAR surface pond: understanding changes in the infiltration rate

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KEY WORDS
Redox processes; Dissolved Organic Matter; vadose zone, wetland, carbon cycle

ABSTRACT
Understanding redox processes and the origin and the fate of dissolved organic matter (DOM) in artificial recharge ponds is key to understanding water quality improvement due to biodegradation processes. In this study, we present a MAR site where redox processes have been monitored with high resolution both temporal (every 12 minutes) and spatial (every few decimeters) in the topsoil below an infiltration pond during one year. Furthermore, the characterization of DOM by fluorescence (in protein-like and humic-like fractions) and the hydrochemical signature have been mapped in four field surveys in different seasons.

The Castellbisbal Recharge system is a recharge facility located in the Llobregat pre-delta aquifer (Spain), which itself sustains mainly industrial and agricultural uses but also urban water supply. The system is fed by the Llobregat River consisting of two ponds: 1) a sedimentation one (15,000 m^2) that acts as a natural impermeable wetland during a retention time of a few days; and 2) a recharge pond (1,400 m^2) where water infiltrates down to the aquifer through a 4-6 m thick vadose zone. The system is monitored with piezometers upstream, downstream and in the middle of the infiltration pond. A small area of the infiltration pond (2 X 4 m^2) is densely monitored in the first meter of the vadose zone with 3 manual piezometers to allow sampling at 30, 60 and 90 cm depth, and a monitoring network of temperature and redox sensors.

The evolution of Eh in the infiltration pond is linked to the variations in river quality parameters, infiltration rate and hydrochemical signature along the year (either measured continuously or from field surveys data). Results elucidate how these variations are produced by physical clogging, biological clogging and management operations (e.g., scrapping). At the same time, results of DOM characterization indicate that: 1) the sedimentation pond/wetland can act as a source of organic matter, and 2) the proportion of recalcitrant organic matter entering from the river changes along the year, with significant implications for pollutant degradation. These results allow defining MAR management measures in order to increase water quality while keeping a reasonable infiltration rate.

ASR for Water Management in the Everglades Restoration, Florida: Status, Progress, and Challenges

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KEY WORDS
Everglades, water management, groundwater quality

ABSTRACT
Aquifer storage and recovery (ASR) was proposed as the greatest component (by volume) of new water storage in support of Everglades restoration. Lightly treated surface water is stored during the wet season, and recovered during the dry season to supplement surface water flows in the Everglades. Water storage in permeable zones of the Floridan Aquifer System supplements above-ground storage in reservoirs, and provides an additional tool for water managers to replicate natural wet-dry flows. Subsurface storage also will reduce the frequency and duration of excessive freshwater flows into estuarine environments.

ASR implementation proceeds at a modest pace in Everglades Restoration projects. Two pilot sites were constructed on the Kissimmee River and Hillsboro Canal in south Florida. These ASR systems were tested successfully between 2009 and 2013. An intensive groundwater data collection effort at the Kissimmee River ASR system showed that ASR is feasible for ecosystem restoration purposes. Water-quality changes that occurred during cycle testing were compliant with state and Federal standards. Arsenic and phosphorus concentrations declined during storage. There was no disruption to aquifer integrity during operation of single 5-million gallons per day recharge and recovery. At present, ASR is incorporated into two new projects (Lake Okeechobee Watershed Restoration and Loxahatchee River Watershed Restoration projects) to develop conjunctive use of ASR and reservoirs in south Florida.

Characterization of the behaviour of dissolved organic matter during bank filtration using PARAFAC-EEM and LC-OCD techniques

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KEY WORDS
Dissolved organic matter, bank filtration, temperature, redox conditions, PARAFAC-EEM

ABSTRACT
Dissolved organic matter (DOM) is a paramount parameter that controls the biochemical and redox processes taking place during the bank filtration (BF). A better understanding of the behaviour of DOM during BF processes will help to increase contaminant removal efficiencies and optimise the performance of BF systems. Laboratory–scale batch and column studies were performed under different environmental conditions of redox and temperature (20-30°C) using different water types with different organic composition. The DOM components during the experiments were tracked using different analytical techniques: fluorescence excitation-emission matrix spectroscopy in combination with parallel factor analysis (PARAFAC-EEM), and size exclusion liquid chromatography with organic carbon detection (LC-OCD). The results demonstrated that DOM removal is significantly dependent on the temperature and redox conditions. Terrestrial humic was the most fraction impacted by the temperature alteration during the filtration process, with preferential removal at lower temperature (20°C). PARAFAC-EEM results revealed that the adsorption of these hydrophobic compounds reduced by 22-46% when the temperature decreased by 10°C. In contrast, microbial humic and protein-like components exhibited temperature-independent behaviour during the filtration process. LC-OCD results revealed that labile compounds (i.e., biopolymers) are effectively removed (>80%) by biodegradation under oxic condition. However, this removal decreased by 20-24% under sub-oxic conditions. Thus, it can be concluded that BF is optimized to remove non-refractory compounds under oxic conditions regardless of the feed water temperature and organic composition, however, its effectiveness is less toward condensed-structure and hydrophobic compounds at high temperature (25-30°C).

Technical and legal experiences of the artificial recharge works of the Morroa aquifer, Sucre – Colombia

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KEY WORDS
Aquifer Morroa, Artificial Recharge, Groundwater Management, CARSUCRE.

ABSTRACT
The Morroa aquifer is located in the Northwest of Colombia, is constituted by layers of sandstones and conglomerates interbeded with arcillolites. This aquifer is the only source of water supply for urban and rural populations in the central area of the department of Sucre, who use it for both human consumption and for agricultural and livestock use. As the natural recharge is much lower than the current extraction, the intense exploitation of this aquifer is evident, which has led to continuous piezometric decreases (between 1 and 4 m/year). This limits their use and puts at risk the supply of the population and the sustainability of the resource.

To ensure the sustainable management of this water resource, it was considered as an alternative to reduce the rate of descent of the levels and maintain the reserves of the aquifer, the management of aquifer recharge. For this, initially, the following artificial recharge pilot works for the Morroa Aquifer were designed and built: an infiltration trench, an infiltration pond and a large diameter well, designed to allow the infiltration of rainwater that circulates through streams of sporadic streams. Every time there is rain in the area, the water levels are continuously monitored in each of these pilot recharge projects. The average infiltration rate in the trench and in the large diameter well is 0.58 m/day, while in the infiltration pond it is 0.13 m/day. The average flow infiltrated in the pond is 19 m3/day, in the trench of 2.9 m3/day and in the large diameter well is 1.8 m3/day. It is proposed to build on a large scale and in large quantity, artificial recharge works of these types, to increase the recharge of the aquifer and contribute to the decrease of fall progresive of water level in to aquifer.

Regarding the legal aspects, CARSUCRE structured the administrative acts of the concessions of groundwater granted to the users that are supplied with the aquifer Morroa, with the imposition of the obligation to carry out artificial recharge on the aquifer, which must be designed under supervision of the environmental authority The foregoing has been supported by judicial decisions in favor of the environmental entity CARSUCRE, which obliges the large aqueduct companies to implement artificial recharge mechanisms, as compensation for the intensive use of this water resource.

Natural-Engineered System (NES) for the Improvement of Conventional Soil Aquifer Treatment (cSAT) in Shafdan

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KEY WORDS
Soil Aquifer Treatment; Ozonation, CECs

ABSTRACT
Soil Aquifer Treatment (SAT) has been known as a natural, low cost, effective tertiary treatment for wastewater reuse. This treatment has been applied by Mekorot at the Dan Region Effluent Treatment Facility (SHAFDAN) in Israel for four decades, where secondary effluents infiltrated through natural sand dunes are extracted and delivered to farmers in the south of the country (Negev). The high quality reclaimed water is then used for unrestricted irrigation.

Several obstacles must be averted for a successful application at the SHAFDAN: 1) The quality of the secondary effluents effects the quality of the reclaimed water. Specifically, total nitrogen values greater than 10 mg/L in the infiltrated effluents were shown to allow both ammonium and organic nitrogen to reach the aquifer and the reclaimed water; 2) The residence time of treated water in the aquifer is long, typically between 6-12 months; and 3) The reclaimed water is of great quality, but still contain trace amounts of Contaminants of Emerging Concern (CECs).

In the work presented here, our goal was to demonstrate improvements to the SAT application at the SHAFDAN by combining it with an engineered pre-treatment that includes bio-filtration and ozonation.

Preliminary results show potential for improvement on all three fronts. First, water obtained from the observation well (OW) after pre-treatment had significantly lower levels of CECs (975 and 185 ng/L at cSAT and OW, respectively) indicating the pre-treatment significantly improves the quality of the reclaimed water. Second, the OW selected for this work, with a residence time of 22 days, displays similar or better water quality compared to typical cSAT values, suggesting a shorter residence time can be applied without negatively effecting the reclaimed water quality. Last, water infiltrated after the pre-treatment contained nondetectable concentrations of NH4 and NO2, thus minimizing oxygen consumption in the unsaturated zone, allowing more oxygen to reach the aquifer, and preventing the release of metals to the reclaimed water.

Our initial observations suggest that the proposed pre-treatment can not only improve the quality of the reclaimed water supplied to farmers, but do so using a shorter residence time, less land resources, and while maintaining the aquifer at better operating conditions.

Evolutionary multi-objective optimization of managed aquifer recharge locations in the Central Valley (US)

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KEY WORDS
Managed Aquifer Recharge, Optimization, Central Valley, Genetic Algorithm

ABSTRACT
In 2014, California passed legislation requiring the sustainable management of critically overdrafted groundwater basins, located primarily in the Central Valley agricultural region (US). Managed Aquifer Recharge (MAR) has shown good promise to mitigate groundwater depletion, though the numerical simulation of MAR and its impact on the groundwater – surface water system at the regional scale still poses a significant scientific challenge. In order to improve or optimize management of water resources, decision makers increasingly rely on integrated studies that consider both the groundwater hydrology and the behavioral economic use of groundwater. Using advanced numerical optimization strategies, such as genetic algorithm, increase further the overall modeling flexibility and allows obtaining and testing multiple suboptimal management solutions for decision makers to consider.

In this study, we explore the use of the California Central Valley Groundwater-Surface Water Simulation Model C2VSim coupled with an evolutionary multi-objective optimization algorithm to identify optimal MAR locations. The modeling framework is used to calculate multiple optimal locations for a set of recharge basins across the Central Valley that use streamflow excess to recharge groundwater. Hydrological (e.g. maximization of groundwater storage) and economic (e.g. cost of surface water delivery for MAR) objective functions are used to obtain a two-dimensional Pareto front. Results demonstrate that a more integrated use of water resources coupled with an optimal distribution of recharge basins can significantly improve long-term groundwater storage in the Central Valley. Furthermore, results confirm the usefulness of the proposed modeling framework, which identifies compromise MAR locations able to minimize economic costs and maximize hydrological benefits.

First results on the assessment of the impact of artificial recharge on the unsaturated zone: Medina del Campo groundwater body (Duero, España)

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KEY WORDS
Artificial recharge, Medina del Campo, NAIAD, numerical models, unsaturated zone.

ABSTRACT
Medina del Campo groundwater body (GWB) is located in a semiarid area with intensive groundwater use mainly for agriculture since the 1970’s. This exploitation regime has caused important water depletion of the aquifer that has derived in associated problems of water quality and quantity and in no less important damages to associated groundwater-dependent ecosystems. The Duero Basin Authority projects four artificial recharge performances in two sections of the Zapardiel and Trabancos rivers within the border of this GWB. The IGME, in the framework of the European project "NAture Insurance Value: Assessment and demonstration-NAIAD" (Id: H2020-SC5-2016-2017) modeled the unsaturated zone to assess the impact of future artificial recharge on the river banks of Trabancos river and Arroyo de la Vega in the basin of Zapardiel river. The models are of local scale and aimed to evaluate the time in which the saturation front reaches the water table and the extension of the saturation bulb. The models are two-dimensional and developed with the VS2DI Code of the US Geological Survey. Infiltration tests in situ carried out in the river channels, where the refill will be made by flow discharges, confirm the project viability.

Increasing groundwater resilience through managed aquifer recharge in the Central Highlands of Vietnam

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KEY WORDS
Managed aquifer recharge (MAR), agriculture, livelihoods, Vietnam

ABSTRACT

Vietnam's booming coffee industry is underpinned by unsustainable levels of dry season irrigation that is derived mostly from groundwater. Groundwater resource overexploitation leads to seasonal water scarcity and diminishes resilience to droughts, thereby threatening the nation's coffee sector with potentially adverse impacts for consumers more broadly. High monsoonal rainfall creates opportunities to store local surface runoff through MAR; however, this form of intervention has not yet become established practice in Vietnam, unlike most other countries with high dependence on groundwater resources.

To address these challenges, MAR is being trialed in Krong Buk district, situated in Dak Lak province, one of the major coffee producing areas of Vietnam. Since early 2017, five participatory, farm-scale pilots have been set up to harvest local runoff from fields, roofs and other paved surfaces and stored in the shallow weathered basaltic aquifer ubiquitous to the area. The MAR pilots are compared against nearby control sites to establish technical and socio-economic performance.

The initial results indicate that whilst there is high degree of variability across the sites, in general, the volumes of water recharged make an important contribution to the final and most critical round of irrigation just prior to the monsoon. The results also highlight the inherent challenges in this setting, particularly in relation to the rate of downstream migration of recharge water and the mixed perceptions of the farmers of the benefits.

The design and operating parameters of the pilots have been improved in year two and are currently being monitored. The results to date are promising and offer enormous potential for farmers and rural communities more generally to gain benefits if the MAR approach can be proven so that appropriate policies and plans can be developed to bring this into practice more widely.

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The impact of MAR suitability mapping and maps as a tool in the science-policy interface

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KEY WORDS
Suitability, mapping, methods, policy, recharge

ABSTRACT
Countries in temperate climates have used and developed aquifer recharge schemes for over half a century to sustainably provide clean drinking water to major cities such as Amsterdam. More recently, under pressure of increased population growth and future scenarios for climate change, countries in the Middle East are increasingly considering to resort to artificial aquifer recharge as an alternative to the current more conventional ways of water supply for human and agricultural use.

The increased attention paid to artificial aquifer recharge (also known as managed aquifer recharge (MAR) or aquifer storage and recovery (ASR)) leads to new related questions such as the costs and benefits related to (al)location and techniques used for groundwater recharge. This has opened up new grounds for scientists to study the alternatives for groundwater recharge as part of, for example, environmental impact assessments and spatial queries supporting cost-benefit analyses.

Mapping of terrain or location suitability for MAR is one of the tools often referred to as part of the process on the way to implementation of a MAR project.

MAR suitability mapping could involve the production of an optimization algorithm that uses physical geographical, hydrological and geological parameters in order to define a range of locations or regions that are more or less suitable for human-induced aquifer recharge. Sometimes human factors – including roads, built area, population, land use, socio-economics – are included in the mapping exercise as well.

Many governments have used and are using suitability mapping in projects; at least 1,200 cases in 62 countries are known (2017). The production of a suitability map assumes that the map will be used along the process of site selection, and assumes that there are alternatives to consider. Often the mapping process merely aims to produce maps. Another way of looking at it is to see the mapping as a thinking and internalization process for those involved. It is unclear in how many of the 1,200 cases the maps have actually been used by decision-makers to decide on the location of real-world MAR projects. Have the maps been used as input for a decision-making process, or was the mapping process itself part of the decision-making process?

If acceleration of the use of MAR is an aim – for example in arid and developing countries – how does suitability mapping help?

Ancient techniques of Managed Aquifer Recharge: Spanish Careos and Peruvian Amunas as an Adaptive Complex System. Breakdown, pathology and comparative analysis

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KEY WORDS
Managed Aquifer Recharge, Amunas, Careos, artificial recharge, ancestral water management techniques.

ABSTRACT

The most ancient written references for MAR Recharge are the Careos, in the South of Spain, and the Peruvian Amunas. Both high mountain systems are complex and present extraordinary analogies and differences, despite being chronologically Pre-Columbian structures in the case of Amunas. From both there are written chronicles since the XII Century and both evolved in parallel, although disconnected, with amazing similarity.

After studying in detail 10 Careos and 6 Amunas from a construction techniques perspective, they have been decomposed in 24 different components. All these units have been compared, studying their analogies and differences according to the employed materials, hydraulic masonry, mortar types, carved stones, layout, profiles, relationships between the different elements, water origin and treatment, and water recharge. Units' pathology and recovery measures have also being studied by means of polygonal, linear or punctual structures.

Some common points are the low rainfall conditions, temporal water availability from snow smelt and runoff, induced recharge by means of infiltration fields, canals, ditches and simas, subsurface and deep groundwater transit and recovery from springs or irrigation ponds.

Some of the differences are based on the form of carving the stone and masonry, maximum flowrate capacity from 200 l/s to 800 l/s, distance between consecutive canals, time of transit (15 days to 7 months), recovery flow rate from 1 to 5 l/s (respectively for Amunas and Careos), etc.

In both MAR cases, ancient structures work as a hydrogeological and socio-cultural complex system, with values, norms and traditions scarcely evolved in 8 centuries. Water management is accompanied by land and crops management too, to the extent that both can be considered a cultural met in the distance or "cosmovision of water", as there are certain evidence of synchrony in their temporary development.

Both systems fit the definition for Adaptive Complex System (Murray, 2010) as a articulated group of subsystems with self-similarity, complexity, and self-organization, rather than a Multi-Agent or system, defined as a composed system with multiple agent in permanent interaction (Wooldridge, 2002, for artificial intelligence).

Finally, the article recommends some improvement advices, based on their cross-comparison. It also studies the possibilities of replicability for other ridges of mountains in the world and suitability to face climate change adverse impacts.


The MAR system in Ica, Peru. Technical and social lessons learned from a Mega-scale MAR system and improvement possibilities

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KEY WORDS
Ica, MAR, pozas, IWRM, Peru

ABSTRACT
Ica is located on the South Coast of Peru and counts on the most advanced agro-industrial development of the country. Agricultural production depends on groundwater availability, and since 2012 JUASVI and ANA have implemented more than 700 infiltration ponds for intermittent use. So, it has become one of the largest scale MAR systems in America, and it is providing lessons beyond those from pilot-size sites.

Water is taken from Ica River during the rainy season, stopped by specific constructions, retained in decantation ponds and later directed at infiltration ponds (*pozas*) interspersed along the aquifer.

Some specific lines of action to improve the system already applied are:
- Structures to retain water from Ica river minimizing the volume finishing in the Ocean
- Over-floods management with a certain predictive component
- Aquifer knowledge and its behavior improvements, so as to set new infiltration ponds in the most suitable sites
- Creation of an integrated and interconnected water management system
- Monitoring network in real time
- Clogging fight and high efficiency maintenance operations
- Search for alternative sources of water such as WWTP, transferences, irrigation return, etc.
- Coordination and communication improvement

Some alternative lines of action are based on the use of gravity dikes, underground dykes, river basin´s slopes treatment and SUDS.

Most of the technical and social lessons are about the integration of the different elements in a multicomponent scheme. It is also worth to mention the support of local authorities and difficulties to reach agreements between the different agents within the basin (from the mountain to the sea) which have different interests leading to eventual water conflicts. Apart from the technical and social barriers, the total dependence of rainfall is forcing to seek new sources of water and alternative mechanisms, from WWTP to SUDS implementation.

MAR is in the Peruvians idiosyncrasy (Incans recharged intentionally from at least the XII Century), so, by means of single surveys, it is possible to find out new susceptible areas to build new “*pozas*”. In seven years of operation it is worth to mention that clogging damage is not remarkable yet, infiltration rates have barely changed and cleaning and maintenance activity is inviting to new owners to provisionally loan their terrains for new infiltration ponds.


El Carracillo. An example of rural development and positive impact on the agroindustry thanks to MAR technique. Los Arenales Aquifer, Castilla y León, Spain

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KEY WORDS
Managed Aquifer Recharge, indicators, economic assessment, rural development, El Carracillo, agroindustry.

ABSTRACT
Since 2003, MAR has been used in the El Carracillo District, Castilla y León, Spain. This district is supported by important agro-industrial activities reliant on MAR and groundwater exploitation.

The increasing aquifer storage is having a direct impact on the economy of the area. Some specific indicators, especially related to rural development and economic improvement, have been designed and tracked by the association of farmers for more than 10 years.

The indicator database has provided important information. A specific benchmarking approach was applied, measured, tracked and charted so as to evaluate the difference between areas with and without MAR activities integrated into their water management approaches.

Economic indicators have permitted the assessment of economic trends over a decade in time, demonstrating that MAR is contributing to several key economic factors including: the stability and even rise of the rural employment rate, a reduction in emigration from rural areas, greater crop production, energy savings due to the rise of the water table, guaranteed water supply for short drought periods, etc. El Carracillo has 4,000 new hectares under irrigation, an 80% of increase in vegetable production of the whole province, 3,700 MAR related employment, 6% population increase, etc. and 23.8% of water used for irrigation comes from MAR.

The article also describes several constraints: how MAR is affecting the agroindustry agents, the sustainability of the aquifer and the agricultural activity or the relationships among farmers, authorities and some ecological groups who are against MAR activities in this area.

In short, the El Carracillo area has successfully employed MAR techniques with positive results compared to other nearby areas without groundwater resources and rain-fed crops.

Reclaimed water quality improvement by means of MAR and nature based solutions from local industrial reuse. The Alcazarén-Pedrajas, system, Valladolid (Spain)

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KEY WORDS
Managed Aquifer Recharge, reclaimed water, industrial wastes, water treatment plant, pine bark

ABSTRACT

Alcazarén is the Northernmost MAR site in Los Arenales Aquifer (Castilla y León, Spain). Three types of water sources are used for recharge: a transport pipe with surface water diverted from Pirón River dam through a River Bank Filtration System (RBF), run-off water from a canal collecting occasional drainage from Pedrajas Village streets and recycled water from Pedrajas WWTP. Surface water from the dam has been unavailable for the last years due to legal issues about water rights, so the percentage of recycled water has been higher than originally designed, and consequently, dilution rate of reclaimed water with freshwater has decreased.

All available sources (river, WWTP and run-off) are mixed within a chamber, where different types of organic filters have been tested (post-treatment) previous to MAR occurs through three infiltration canals in an irrigation area. Selection of materials for filtering was based on low cost inversion and the availability in the area (pinewood industry).

Tests have successfully validated the use of both, inorganic (siliceous and calcareous gravel, grit and sand) and reactive organic (pine bark and pine rachis into geotextile sacks) filters, removing certain pollutants from reclaimed water. 17 parameters were observed and 16 had a clear improvement. It is also worth mentioning that after several weeks of continuous post-treatment and recharge, the reactive layer was still active. Therefore, this technology is likely to be useful for longer-term applications, despite the small scale of the experiment and the short time of interaction.

The project demonstrated that physical, chemical and biochemical post-processes associated with MAR plants represent a passive and affordable way to reduce the presence of certain contaminants, with economic and environmental benefits, complemented by further aquifer filtering after MAR. No negative effects have been observed in the infiltration rate as indicated by minimal variation in water levels in 6 piezometers.

Finally a set of artificial wetlands using recycled abandoned sand pits completes the water quality improvement.

Book: MAR - a focus towards Latin America

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KEY WORDS
MAR, aquifer, recharge, book, Latin America

ABSTRACT
Managed aquifer recharge (MAR) consists of a set of actions and technologies aiming to store water in the subsoil for later use, or to remedy the aquifer condition such as to reduce or prevent land subsidence or seawater intrusion. The book *Manejo de la recarga: un enfoque hacia Latinoamérica*, describes several MAR projects implemented in Mexico and the world. The 25 Mexican and International collaborations include site characterization, basic concepts, used materials, the costs and benefits, the technical complexity, the management policies employed, as well as good practices recommended in the planning, design, construction, monitoring and evaluation phases. The book was intended to disseminate knowledge on MAR technologies to professionals and technical personnel who need to apply and implement MAR technologies to better manage scarce water resources. The book is in digital format which facilitates its distribution with access and free distribution on the internet.

Acequias de careo (Sierra Nevada, Southern Spain). One thousand years of MAR & IWRM operation

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KEY WORDS
Recharge, rural ancestral water management, hard rock.

ABSTRACT
Ancestral MAR and IWRM techniques have been successfully and continuously applyied in Sierra Nevada (Southern Spain) for more than one thousand years. The irrigation communities, which are comprised of local people, capture melting water flowing from the headwaters of the mountain streams for recharge in the upper part of the valleys, through long and narrow unlined channels that are locally known as *acequias de careo*. The aquifer is formed by (1) glacial and periglacial materials exposed by the deglaciation of the mountain, and also (2) by the weathered zone of schists from the Nevado-Filábride Complex that extensively outcrop in the axial zone of Sierra Nevada. The aquifer recharge increases the river base flows and groundwater discharge to springs located at the mid-point of the mountain in summer. This is a crucial resource for supplying drinking water to people and livestock during the driest season in the lower zones. Crop production in the area greatly depends on the MAR operations. The increase on water availability also benefits the ecosystems located downgradient from the *acequias de careo* by enhancing their ecological diversity, which is consistent with the foundation principles of the IWRM. During the last four years, a multidisciplinary team led by the Geological Survey of Spain, has focused on estimating the history of this MAR system. To this end, archaeological, stratigraphic and geochronological studies have been conducted as well as hydrological, hydrogeological, hydrogeochemical and isotopic research regarding the behavior of this hydrological system. These studies reveal a surprisingly high efficiency MAR system which manages to transform highly variable flow of short high mountain rivers into stable flows with a high groundwater discharge component.

Sites and indicators of MAR as a successful tool to mitigate Climate Change effects in Spain

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KEY WORDS
Managed Aquifer Recharge, Climate Change, water management, mitigation measures, IWRM, indicators, Spain.

ABSTRACT
Managed Aquifer Recharge (MAR) has been considered for a long time as an important technology to combat the adverse effects of Climate Change (CC). This is not a gratuitous claim. In this article, the authors will support this statement on the basis of real sites, indicators and cases located Spain. MAR has been used in Spain in combination with other measures of Integrated Water Resources Management (IWRM) to mitigate and adapt to CC challenges.

The main effects of CC are to raise the average atmospheric temperature, decrease average annual precipitation, cause extreme weather, and induce sea level rise. These result in a series of negative impacts reflected in an increase in certain parameters or events, such as evaporation, evapotranspiration, water demand, fire risk, floods, droughts and saltwater intrusion, and a decrease of others, as in water resources availability, run-off, wetland area and hydro electrical power production.

MAR is a flexible tool with a wide array of techniques that can address not only different objectives but also a mix of goals. Examples taken from different MAR systems in Spain have been selected to show their effectiveness to mitigate the problems mentioned previously. Solutions include underground storage, temperature decrease, soil humidity increase, reclaimed water infiltration, punctual and directed infiltration, self-purification, off-river storage, wetland restoration and/or establishment, gravity flow water distribution, power saving, eventual recharge of extreme flows, multi-annual management and intrusion barrier wells.

But success must be measured, so indicators have been calculated to quantify the actual influence of these solutions. They have been expressed in the form of volumes, lengths, areas, percentages, grades, euros, CO_2 emissions or years. Therefore, MAR in Spain demonstrably supports its usefulness in battling CC impacts in a variety of environments and circumstances.

Using environmental isotopes and major ions to characterize recharge and mixing properties in the aquifer system along Fen River in Taiyuan basin, northern China

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KEY WORDS
Recharge, Mixing, Isotope, Major ions, Taiyuan Basin

ABSTRACT
Environmental tracers（^{18}O, ^{2}H, ^{3}H, CFCs, $^{34}S_{-SO4}$ and $^{18}O_{-SO4}$）and major ions were employed to study groundwater recharge and mixing properties in the aquifer system along the Fen River in Taiyuan basin, northern China. According to hydrogeological conditions and hydrochemical data, groundwater in the Quaternary aquifer can be classified into three types: the Holocene phreatic aquifer, the Middle and Upper Pleistocene confined aquifer and the Lower Pleistocene confined aquifer. Hydrochemical results from the study are as follows; Na^{+} and Cl^{-} increase from the upper to the lower aquifer, ^{18}O and ^{2}H are more depleted in the lower aquifer compared to the upper aquifer, groundwater age increases with depth, and groundwater within cones of depression are depleted in heavier isotopes with low ^{3}H concentrations. Hydrogeological conditions show that the lower aquifers are mainly recharged by precipitation and lateral inflows, with leakage from the Fen River occurring in the west piedmont area. Groundwater in some areas can be characterized by mixing type, especially within cones of depression. Characterizing recharge and mixing properties is essential for understanding groundwater systems and can help to promote the sustainable utilization of groundwater in the Taiyuan Basin.

Determining the Potential for Managed Aquifer Recharge (MAR) for the Bengal Basin, Bangladesh

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KEY WORDS
Managed aquifer and recharge, physical and demand potential, hydrogeological condition, artificial recharge, infiltration well

ABSTRACT
Artificial recharge, i.e. the augmentation of infiltration of treated, safe, and fresh surface water or harvested rain water into groundwater by different technologies, is an accepted and high potential solution for many of the overstressed aquifers worldwide. In Bangladesh, many communities depend on groundwater for drinking water and small scale irrigation. During the dry season when rains have ceased, safe and reliable groundwater supply is key to the livelihoods and socio-economic development of a large part of the rural population. The shallow and main aquifers in the country can yield large quantities of water but these aquifers are not all suitable for further development due to the already declining water tables and deteriorated water quality. Over exploitation has been the result of widespread and intensive irrigation abstraction in rural areas and huge domestic and industrial usage in cities. Further complications arise from arsenic contamination in shallow groundwater and saline water encroachment in the coastal belt which make many of the available groundwater resources unsuitable for human consumption and irrigation. Managed Aquifer Recharge (MAR) is a proven and high potential technology of artificial recharge and recovery that could help alleviate water scarcity during the dry season in Bangladesh.

This paper summarizes a method used to generate potentiality maps for artificial recharge techniques in Bangladesh. The method described in this paper consists of analysing key variables that contribute to the Physical Potential (PP) and the Demand Urgency (DU) for the aquifer systems in Bangladesh. The variables describing these two aspects are analysed and reclassified according to a set of criteria. Each criterion is then assigned a “suitability score” equal to 0, 0.5 or 1, depending on its correlation to the PP or DU. The final total potentiality is calculated by first normalizing the Total PP and the Total DU, and then adding the two together.

In this study, the potential of a number of MAR techniques that have a proven potential in Bangladesh are mapped using the method described above. According to the method used, the techniques “infiltration well” and “artificial reservoir” have the highest physical potential.

Check dams across non-perennial rivers for mitigation of seawater intrusion

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KEY WORDS
Check dams, Arani-Kortallaiyar River basin, Chennai, India

ABSTRACT
Managed aquifer recharge (MAR) methods are used to augment groundwater resources in many regions. Among several methods of MAR, the check dams are more efficient methods in regions with non-perennial rivers. The objective of the present study is to access the impact of check dams on the spatiotemporal dynamics of groundwater quality through an integrated modelling approach. This study was carried out in the Arani-Kortallaiyar River basin, located north of Chennai, Tamil Nadu state, India where several check dams are being constructed since the year 2004. Simulated results indicated that the extent of seawater intrusion is up to 10 km in the upper aquifer and up to 14 km in the lower aquifer during 2012. The lower aquifer has a higher extent of seawater intrusion than the upper aquifer due to the high groundwater pumping rate from the lower aquifer for irrigation and public water supply. The model indicated that by renovating the existing surface water bodies that are not well-maintained such as the ponds, lakes etc., increasing the recharge through the check dams along the rivers and termination of pumping of water from five well fields located in the area will slowly revive the aquifer. The seawater-freshwater interface which is currently at a distance of 14 km will decrease to about 8 km by the year 2030. Thus, with time these check dams will help to mitigate the seawater intrusion and improve the groundwater quality.

Water quality changes during river bank filtration at Budapest, Hungary

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KEY WORDS
River bank filtration, water quality, organic carbon, nitrate, heavy metals,

ABSTRACT
Drinking water supply is based 100% on river bank filtration (RBF) in Budapest, Hungary. As of today 760 production wells are in operation by Budapest Waterworks. Their monitoring and sampling is determined by legislative and operational needs. Results of parameters sampled from the Danube raw water and from river bank filtrate of the operation wells have been considered and evaluated in the study in the period of 2006-2017.

Wells have been grouped according to travel times (t) previously determined by MODFLOW modeling. Therefore three different groups have been examined with t < 10 days, t = 10-25 days and t > 50 days respectively. Over sixty parameters have been analysed separately, where minimum, maximum and median values had been determined. The obtained dataset served as the basis to give an overview on water quality changes during river bank filtration. According to the findings it can be concluded that as the Danube River water is of high quality, no problems occur during regular operation of RBF systems.

For a broader overview of the RBF process, more specific conclusions are also highlighted. River water temperature is not only affecting denitrification but also the removal of total organic carbon. Algae counts are used to identify input of surface water into wells to decide about shutdown during floods. RBF systems have a strong buffering capacity against spills of contaminants in the river, which has been proven during the red mud spill in October 2010. The removal of microorganisms was found between 1.5 log and 3.5 log removal and is in the same order as for other RBF sites worldwide.

Operational strategies and adaptation of RBF well construction to cope with climate change effects at Budapest, Hungary

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KEY WORDS
River bank filtration; hydrological trends; sustainable water production; well structure remodeling

ABSTRACT
The objective of this study is to provide an overview of the Hungarian experience of river bank filtration (RBF) systems in Budapest. The study addresses the conflict that arises between the stochastic character of river water quantity and quality and the required standard of drinking water supply. Water level trends, surface water discharge, and water quality are discussed along with technical measures and operational rules that were developed for implementation of RBF systems.

It is essential that large-scale infrastructural elements such as the Danube based RBF systems adapt to a changing environment. Increased frequency of floods and droughts stresses the need to implement climate adapted RBF systems and related operation strategies. Operational strategies developed by the Budapest Waterworks to deal with extreme hydrological scenarios are presented. This work also provides an overview on the average lifespan of the wells and operational strategies. The emerging reconditioning and reconstruction needs are highlighted and existing alternatives are presented.

Large-scale infrastructural elements such as the Danube based RBF systems have to be adapted to a changing environment. Increasing frequency of floods and droughts stresses the need to implement climate adapted RBF systems and related operation strategies. Operational strategies developed by the Budapest Waterworks to deal with extreme hydrological scenarios are presented.

Riverbank filtration in a narrow river valley of the Barranca river, Costa Rica

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KEY WORDS
Water resources management, riverbank filtration, hydrogeological analysis, infiltration modelling, water production

ABSTRACT
Costa Rica, due to its geographical location has abundant water resources. The use of surface and groundwater technologies have been and continue to be researched. Nevertheless, little is known about the potential for the application of bank filtration (BF) in the country. This research seeks to move from the empirical implementation of riverbank filtration (RBF) to solid scientific based RBF in Costa Rica. In Barranca, Puntarenas, located in the central pacific region of Costa Rica, a study is being carried out to evaluate the efficacy of RBF. The site consists of 4 wells of which 2 are operating and provide water for the town of Barranca. The wells are located on an alluvial deposit on the inner side of a meander along the bank of the Barranca river, approximately 75 meters from the river. The alluvial sand and gravel aquifer has a thickness of up to 25 m. The recent deposits overlay the hardrock in a narrow river valley. Pumping test data suggest a K-value of 1.5x10-4 m/s which is in a favorable range for RBF.

Water level measurements indicate a partly parallel flow of bank filtrate along the river due to the meander and a weir. Thus, the travel time of the bank filtrate is much longer than expected. A groundwater flow model (PMWin) has been created to determine travel times and portions of bank filtrate. Data of the water budget calculated show potential to implement more wells due to a water input of 82 m3/day from the river and an extraction from the wells of 78 m3/day. Multiple operation scenarios and a site investigation concept for narrow river valleys will be presented including technical and operational recommendations for a sustainable improvement of the water production at the study site.

Risk reduction of water resource crisis using the managed recharge of coastal pliocenes aquifers in Marbella (Málaga, Spain)

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KEY WORDS
Costa del Sol, Managed Aquifer Recharge, ASTR, soft path for water, water bank, GWD

ABSTRACT
This paper presents the experiences of Aquifer Storage Transfer and Recovery (ASTR) in coastal pliocenes aquifers, called Señorio and Aloha, which are subjected to seawater intrusion. Hidralia, the company in charge of the water supply and waste water in Marbella, strives to improve the productivity and efficiency of water use from the conceptual point of view of 'soft path for water'. Outcomes show not only the positive impact on groundwater protection and public health, but also allow the risk reduction of a drought, and develop a sustainable water ecosystem management according to the European Groundwater Directive (GWD) on the protection of groundwater against pollution and deterioration.

The intention is to launch ideas in order to contribute to new approaches of water management resources on the Costa del Sol, supporting MAR techniques and other methodologies associated with monitoring indicators of the impact of the recharge. This area has a Groundwater Mass 060.038 - Sierra de Mijas, with greater storage capacity and slower reaction to the recharge than the Pliocene aquifers, making it suitable natural water storage for some of the surplus surface water and, even, opening the door to the implementation of a water bank.

Design of an ASTR installation in a deep aquifer destined to supply the Community of Madrid

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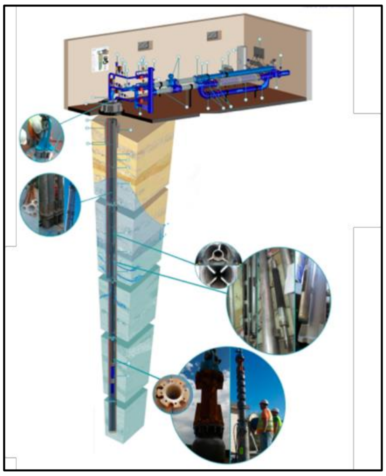
KEY WORDS
Canal de Isabel II, Madrid Tertiary Detrital Aquifer (ATDM), Aquifer Storage Transit & Recovery (ASTR), deep recharge boreholes.

ABSTRACT
The main aquifer of the Community of Madrid and its integrated system of supply have ideal characteristics for the improvement of the supply guarantee through the application of recharge techniques. The conditions that favor this situation contemplate both aspects of management and structural, likewise operational and hydrogeological aspects.

The recurrent droughts have given the ATDM a smoothing role in the hydrological variability and as a guarantor of the availability of resources to cope with these scenarios. This compensation capacity allows the availability of groundwater on the periods when it is necessary, even when the dry periods last more than one year. The occasional long run aquifer extraction impact temporally on its quantitative, but the artificial recharge helps the recovery and guarantee the water availability in key areas of the supply system.

In this work is presented the constructive design of an experimental installation of ASTR constructed in the year 2010 by Canal de Isabel II, which is the company that manages the integral water cycle in the Community of Madrid (Spain), with more than six million inhabitants supplied. The aim of this installation was the realization of some studies that allowed to evaluate the suitability of the application of the technique of deep recharge in the aquifer of Madrid and to advance in its knowledge and further extrapolation. Additionally, the project searched the viability of use existent groundwater extraction facilities. To carry out this search was needed the construction of elements and facilities for the introduction of water into the aquifer (recharge well) and control and monitoring of the system.



The recharge well has a depth of more than 500 meters and a diameter of 500 mm of intubation. The percentage of filtering piping is around 26% and is irregularly distributed along the entire casing column from 96 m depth. The static level is about 150 meters deep, conditioning the depth of water entering the aquifer. This is built by three pipes of 80 mm of diameter, located at 195 meters deep and equipped with three packers that allow the closure of these pipes as a step prior to the process of water entry into the aquifer. The system completes two grooved extraction wells around 400 meters depth each and located at 60 and 600 meters, respectively, of the recharge well, as well as seven piezometers of different depths located between 25 and 80 meters through the recharge well. Finally, the installation has a complete instrumentation system to control the operation.

The main conclusion obtained from this experimental installation is the confirmation of its feasibility, although its extreme complexity could condition the operation. This research opens the door to assessing a design to be generalized in the entire field of operation of the ATDM that improves the efficiency in its execution and management.

Design and operation of the MAR infiltration scheme in Suvereto (Italy)

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KEY WORDS
Managed Aquifer Recharge, Groundwater management, Rainwater harvesting, Sensors, Groundwater monitoring

ABSTRACT
The water demand in the Cornia valley (central Italy) strongly depends on groundwater stored in a multi-layer alluvial aquifer, widely exploited for industrial, irrigation and drinking purposes. This led to large lowering of the hydraulic head and a deficit in the water balance, causing subsidence, groundwater salinization and reduction of groundwater-dependant ecosystems. Within the LIFE REWAT project (sustainable WATer management in the lower Cornia valley through demand REduction, aquifer Recharge and river REstoration; http://www.liferewat.eu) a pilot Managed Aquifer Recharge infiltration basin for harvesting flood-water was designed and set in operation testing the new-issued Italian regulation on artificial recharge of aquifers (DM 100/2016).

The river provides water during high flow periods, including floods, and when discharge is above the minimum ecological flow. The infiltration basin is set in a groundwater recharge area constituted by gravel and sands.

A preliminary project and an executive one (supported by a groundwater flow modelling-based approach using the FREEWAT platform, www.freewat.eu) were prepared, discussed and approved by the relevant authorities, following one-year long monthly monitoring of surface- and ground-water.

The facility consists of the following elements: i) intake work on the River Cornia; ii) the inlet structure control system, managed by quality (mass spectrometer defining surface water spectral signature, along with TOC, DOC) and level probes, and allowing pumping into the facility at predefined head and chemical quality thresholds; iii) a sedimentation basin; iv) the infiltration area; v) the operational monitoring system, based on a network of piezometers where both continuous data (head, T, EC, DO) are gathered and discrete measurements/sampling performed. Depending on the climatic conditions, the volume of diverted surface water may vary between 300,000 m^3/year and 2 Mm^3/year. The cost of construction of the plant is about 300000 €, well below the cost of a surface water reservoir for a similar storage. Minimal site development was required, resulting in a no-impact water-work, while providing ecosystem benefits. The effectiveness of such pilot may demonstrate the potential for Flood-MAR schemes to increase water availability in scarcity prone areas.

Managed Aquifer Recharge in Italy: an overview

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KEY WORDS
Managed Aquifer Recharge, Groundwater management, Italy, Regulation, Water scarcity

ABSTRACT
In Italy man-made aquifer recharge is traditionally applied unintentionally, via riverbank filtration or excess irrigation. The aim of this contribution is to give an overview of the relevant experiences on managed aquifer recharge in Italy since the last century. While artificial recharge of aquifers is cited in one of the first Italian book on engineering geology (Canavari, 1927), interest for this technique arose between the '70s and the beginning of the '80s, when tests have been carried out in Tuscany, Veneto and Friuli Venezia Giulia. During the last decade, some projects on aquifer recharge were co-financed by the European Commission mainly through the LIFE program (TRUST, AQUOR, WARBO). Nearly all of them still deal with artificial recharge rather than MAR. Recently, within the EU FP7 MARSOL project (Demonstrating Managed Aquifer Recharge as a Solution to Water Scarcity and Drought), further sites were set in place or switched from unmanaged to managed recharge. Aquifer recharge is allowed by law in Italy only since September 2013, but a regulatory framework was issued only in June 2016 with DM 100/2016 describing procedures for permitting such plants.

In 2014, the Regional Authority of Emilia Romagna started a pilot on the Marecchia River fan using a recharge basin to alleviate water scarcity in the Rimini area as results of drought periods; this plant is now in operation after passing the permitting procedure including Environmental Impact Assessment procedure. Since December 2018, another authorised infiltration basin is in operation in Tuscany within the LIFE REWAT project (www. liferewat.eu) harvesting the high flows of the Cornia River.

Although interest for MAR is increasing, dissemination of MAR scientific findings and technical know-how among governing authorities and the general public is crucial for the application of MAR techniques. Fundings for setting up new MAR plants may be available at national level. At the same time, lack of knowledge at intermediate governing bodies level is preventing the application of these techniques (i.e. building of small dams is still favored).

Finally, it is of outmost importance to define which are the financial instruments to sustain these water infrastructures, so as to guarantee not only their set up, but also routinely operations, opening a new market in the water sector.

MARSOL Policy Brief. Essentials on Managed Aquifer Recharge for policy makers and water managers

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KEY WORDS
MAR, regulations, MARSOL, policy

ABSTRACT
The European Water Framework Directive (2000/60/EC) considers 'artificial recharge' of groundwater as one of the water management tools that can be used by EU Member States to achieve a good groundwater status. It has to be ensured, however, that the necessary regulatory controls are in place to warrant that such practices do not compromise quality objectives established for the recharged or augmented groundwater body. It is also acknowledged by the Groundwater Directive (2006/118/EC) that it is not technically feasible to prevent all input of hazardous substances into groundwater, in particular minor amounts which are considered to be environmentally insignificant and thus do not present a risk to groundwater quality. For such cases the Groundwater Directive, under Article 6(3)(d), introduces a series of exemptions. Artificial recharge is considered as one of these exemptions. MARSOL suggests a Regulatory Framework based on risk assessment, control mechanisms and monitoring as a tool which can facilitate the application of the Water Framework and Groundwater Directives on MAR. It is the intention of such a regulatory framework to provide clear guidelines to Member States on the application of MAR techniques.

What are the costs?
MAR operations have to be economically feasible and apply simple engineered solutions that are easy to maintain, otherwise it will not be implemented. The financial feasibility of MAR projects depends on a number of parameters affecting their costs, such as capital expenses and operating costs, and the revenues potentially derived from the sales of the water for a variety of uses. However, water has also social and environmental values that are difficult to quantify. The benefit of a MAR project should not be solely based on market revenues. MAR projects can improve the quality of lives of the people benefiting from an increased availability of water, and recharged water can contribute to sustained ecosystem services. A thorough cost-benefit analysis is required to justify a MAR installation. However, MARSOL could prove that MAR can be a cost effective tool.

MARSOL Policy Brief

Essentials on Managed Aquifer Recharge for policy makers and water managers

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Water scarcity is one of the key issues our society faces today. Although there is enough freshwater on our planet, it is unevenly distributed and often not properly managed. Despite uncertainties in global climate projections, the anticipated reduction of renewable freshwater resources can be as high as 50% within the next 100 years hitting regions that already suffer from water scarcity and droughts. At the same time, large water quantities are lost to the sea as surface run-off and river discharge, discharge of treated and untreated wastewater, or discharge of excess water from various sources during periods of low demand. These alternative water resources in principal can be used to increase water availability in general, in periods of high demand, or as a strategic reserve.

What is Managed Aquifer Recharge?

Managed Aquifer Recharge (MAR) refers to the intentional infiltration of excess water into the subsurface through engineered systems for temporal storage or to influence gradients. Water can be recovered in times of high demand. In principal, large storage capacity is available in shallow aquifers, either due to thick unsaturated zones or due to already depleted water resources in extensively exploited aquifers. In addition, water quality can be improved due to chemical and biological reactions during flow of the infiltrated water through the unsaturated and saturated zone. MAR can be a key Water Resources Management tool for tackling water scarcity in Europe, and in water scarce regions worldwide by linking water reclamation, water reuse and integrated water resources management in a long-term strategy.

ICT solutions for monitoring and operation of Managed Aquifer Recharge schemes

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KEY WORDS
Information and Communication Technology, Sensors, Managed Aquifer Recharge, Groundwater monitoring, Groundwater modelling

ABSTRACT

Managed Aquifer Recharge has been allowed by law in Italy since 2016, and the licencing of the MAR plants is regulated by the DM 100/2016. One of the key points of the authorization procedure is the setting up of a monitoring system for defining the reference hydrodynamic and hydrochemical framework, for evaluating the effectiveness of the operation/ the potential deterioration of the groundwater, and for a rapid stop of the recharge. The monitoring system must be at high frequency (i.e. using multi-parametric probes) thus foreseeing a relevant role of ICT applications in this sector.

Within the LIFE REWAT project (sustainable WATer management in the lower Cornia valley through demand REduction, aquifer Recharge and river REstoration; http://www.liferewat.eu) a pilot Managed Aquifer Recharge infiltration basin for harvesting flood-water from the Cornia River was designed and set in operation in Suvereto (Italy).

The MAR scheme is controlled through a monitoring system based on the use of a dedicated hardware and software infrastructure. The hardware architecture consists of a control unit and a series of sensors for hydrodynamic and hydrochemical monitoring of surface and ground water.

The monitoring system is divided into two parts. The first part controls the diversion and the recharge process through: i) the data acquired by a level sensor at a Cornia River hydrometer - this to avoid that diversion takes place at flow conditions lower than the minimum ecological flow; ii) the data acquired from a S::CAN Spectrolyser providing the spectral signature of the surface water and parameters of interest, such as turbidity, nitrates, TOC, DOC, UV254 and color.

The recharge process is controlled: iii) by a head sensor in the infiltration basin to avoid overflow; iv) by a multi-parameter probe placed in a piezometer downstream - whose role is to highlight any negative changes in the aquifer system. A further series of sensors gathering temperature, level and electrical conductivity are positioned downstream the MAR scheme for recording the variations induced in the aquifer by the recharge process.

The system implemented is a classic example of Smart Infrastructure for the management of water resources. The lack of such infrastructure can convert MAR from an opportunity to a threat to the safety of aquifers.

MARSI: a proposal for an common suitability mapping approach for managed aquifer recharge using surface spreading

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KEY WORDS

MAR suitability mapping, GIS, Multi-criteria decision analysis (MCDA), standardized

ABSTRACT

The creation of maps for ranking, identification and selection of sites for the implementation of managed aquifer recharge (MAR) schemes increased significantly in the last years. Most of these studies are based on GIS—multi-criteria decision analysis (GIS-MCDA) methods and use different criteria (and number of criteria), as well as different criteria values, weights and integration methods. For this reason, it is almost impossible to compare the results from different GIS-MCDA studies for MAR suitability mapping.

To analogize the diverse studies, we propose the MAR site selection standardization index (MARSI), which is intended to be applied in parallel to the actual suitability map. It is a simplified index inheriting the criteria chosen the most often for MAR mapping of spreading methods: terrain slope, hydrogeology and top soil texture along with given weights and standardization methods. Using GIS maps that are easily available and a mapping procedure that is clearly defined, MARSI maps can give a first tendency of how MAR potential maps of different regions and origin compare to each other.

Managed aquifer recharge as an integrated water resource management tool: a case study in semi-arid Sudan

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KEY WORDS
Managed aquifer recharge, IWRM, Sahel, semi-arid, Sudan.

ABSTRACT
The stress on groundwater in semi-arid Sahel region is derived, mainly, by population growth and migration coupled with fluctuating spatial and temporal rainfall patterns. This has resulted in reduced natural recharge and, consequently, a significant decline in groundwater tables over the last three decades.

Rural areas with depleted aquifers in Sudan have received many humanitarian interventions which focused on increasing boreholes as a solution for water shortages while neglecting the implications of over-abstraction on groundwater depletion.

This paper documents a case study where rural communities have applied catchment scale integrated water resource management with a focus on Managed Aquifer Recharge (MAR) as a sustainable alternative for commonly applied supply based approaches. A water supply gap caused by reduced water points yields was identified in Darrasta catchment, east Sudan. To meet this gap, local communities designed and co-implemented low-cost MAR interventions, based on a pre-conducted hydro-geological assessment.

The construction of five subsurface dams has significantly enhanced recharge in the underlying shallow aquifer and, hence, water points yields have increased to fill 51% of catchment water supply gap adding 50,040 m3 of water annually.

This shows MAR potential, at local catchment level, to solve water shortage in comparison to the short-term approach of increasing boreholes.

Artificial recharge techniques in dry area. Case study of Triassic sandstone aquifer in South of Tunisia

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KEY WORDS
Recharge well, arid region, artificial recharge aquifer, ground water resources, Triassic sandstone aquifer

ABSTRACT
Arid region of Tunisia, suffer scarce water conditions. Erratic behavior of rainfall events over brief intervals often produce short and intense floods events which converge into ephemeral wadi beds. Most part of the available superficial waters is thus lost, providing scarce benefits for households living in villages of such semi-desert areas. With an arid climate, the rainfall is ranging between 150 and 220 mm. Around 25000 people are living in this site. The farming system is mainly based on rainfed agriculture and livestock. Various traditional/indigenous (jessour, tabia, cisterns, terraces, etc.) and newly introduced (gabion check dams, recharge wells, etc.) are encountered. They allow mainly olive and other fruit copping as well as occasional legumes and wheat. The main objective of any recharge scheme in a dry environment is to harvest as much as possible of water (rain, flood, etc) to be stored for future use while reducing all possible losses especially by evaporation. Natural recharge to an aquifer in an arid region may occur by various mechanisms.
The implementation of the national strategy for water resources mobilization and soil conservation (Min. Agr., 1990,a, b) and in order to ensure the replenishment of the main groundwater aquifers in Tunisia, a strategic program has been implemented since 1990. In the main hydrographic networks, it consists of the installation of gabion check dams, releases from dams, drilling of recharge wells aiming at mobilizing additional resources for the aquifer through recharge with floodwater. Other procedures have been used too such as injection wells, treated waste water, quarries, ... (DGRE, 2008; Louati and Bucknall, 2010; Chaieb et al.,). It was estimated that between 1992 and 2007, the average annual rate of artificial recharge is around 35 Mm^3.
The water harvesting projects in the province of Médenine. Watershed treatments concerned the construction of jessour (657 ha), tabias (5725 ha) and contour stone ridges (1014 ha) totaling 7406 ha. There has been also the installation of 177 groundwater recharge gabion check dams and 21 flood spreading gabion check dams besides the drilling of 10 recharge wells. Recharge wells are used in combination with gabion check dams to enhance the infiltration of floodwater into the aquifer. In areas where the permeability of the underlying bedrock in front of a gabion is judged too low, recharge wells could be installed in the wadi beds. Water is retained by the gabion check dam and it flows through the recharge well allowing accelerated percolation into the aquifer (Ouessar, 2007). The drilling of the recharge wells was halted since 2000 in order to have the opportunity to assess the pilot experience.
The Tunisian government has invested directly in increasing recharge to the aquifer through the construction and maintenance of artificial recharge structures in the upper part of the watershed (Hadded et al. 2013). Two years ago (2016-2017), three more recharge wells were constructed at Wadi Hjar to increase water recharge and two piezometers were installed to monitor ground water levels in the Grés de Trias aquifer with support from the European Commission through its Sustainable Water Integrated Management (SWIM) Programme project on Water harvesting and Agricultural techniques in Dry lands: an Integrated and Sustainable model in MAghreb Regions (WADIS-MAR). Data on water level fluctuations collected over the course of a year (September 2016 - September 2017) by pressure sensors in a data logger register a 50 cm variation of the water level in the aquifer compared to a reference level, and a negative overall annual balance. The situation is more pronounced at one of the sites (mgarine), where the variation in the water level reaches 70 cm and the annual balance is still negative.

Alternate Conjunctive Use and Artificial Recharge in Water Resources

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KEY WORDS
Conjunctive use, artificial recharge, alternate conjunctive use, droughts.

ABSTRACT
In most conferences and scientific literature on Integrated Management of Hydraulic Resources only Artificial Recharge (AR) appears as method for the Conjunctive Use of Surface and Groundwater, not considering Alternate Conjunctive Use (ACU). Both methods make use of the possibility of using the large storage of aquifers with relatively small oscillations of their piezometric heads. The storage function in AR is obvious. In ACU system target yield is obtained in dry years with increased pumping. When more than average water is available in rivers or surface storage, more surface water is used allowing more groundwater to remain in storage. In ACU storage is provided through differences between extremes in the aquifer water levels, which are high at the end of wet periods and low at the end of dry ones. This strategy allows water supply increase water supply without augment surface storage, nor resort to artificial recharge. In the Plana de Castellon in Spain the aquifer storage used reaches 700 hm3 / year, five times the capacity of the three existing dams in the Mijares River Basin. The ACU can contribute to mitigate the problems of drainage and salinization of soil and water typical of arid zones by lowering the phreatic levels of surface aquifers.

Conjunctive use management requires an adequate understanding of the relationship between surface and groundwater that have to be considered and modelled together. Most probably variability of river flows will increase in the coming decades because of global warming. This could cause more intense floods and droughts and it will be necessary to have a greater water storage capacity; then conjunctive use can be useful and it will be vital to carry out simulations of the behaviour of each system, with different operating rules, for dry and wet time series and droughts. The latter is especially true in the case of ACUs, since the consideration of different reservoir management alternatives is also crucial.

To evaluate conjunctive those systems the simplest are unicellular linear and pluricellular models. The eigenvalue method is an explicit and exact method appropriate for simulate large time periods and many alternatives.

Artificial recharge proposed for the Purapurani Aquifer System, Bolivia

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KEY WORDS
Urban aquifer, overexploitation, aquifer management

ABSTRACT
Of Bolivia's fifty most populated cities, thirty eight depend on groundwater for their water supply. Approximately a million people of the cities of El Alto, Viacha and La Paz depend on the Purapurani Aquifer System, which is emplaced in 300 Km^2 and 100 m deep fluvioglacial and alluvial sediments at the footslope of the Andes mountain range at an elevation of 4000 m.a.s.l.

The aquifer has been used as a source of domestic fresh water since 1990 and as of 2000 extensively used for domestic, agricultural and industrial purposes, where future tendency is to increase groundwater production. In 2018 it is estimated it has more than 400 legal wells and about the same quantity of illegal ones that produce between 10 L/s and 20 L/s for more than twelve hours a day. For the period 1990 to 2018 groundwater level monitoring has evidenced drawdowns of over 20 m in some areas of the aquifer implying its overexploitation.

Its natural recharge areas are five mountain catchment outlets located at the footslope where alluvial fans have been formed, where their main rivers have been channeled and where urbanization has covered practically 100% of the available natural recharge area. Illegal and low economy housing in the recharge area have no sewage systems and the use of permeable cesspits is common. The main rivers located near the central and upper part of the alluvial fans are losing rivers and are also locally the city's domestic and industrial sewage collecting system.

The proposed recharge method consists of collecting surface water upstream in the catchment, before it enters the urban area to avoid contamination, through small low cost infrastructure such as transversal river dikes and conducting it by gravity to reduce costs, through flexible tubes to prevent contamination, down to infiltration pools excavated in available terrains inside the urban area.

The five catchments can provide a considerable amount of water for recharge, which at present is not used at all, however the space available for the construction of infiltration pools is limited by houses and streets. Water quality would be the same, if not better, as that of natural recharge. Surface water collection, its conduction and infiltration pools operation methods consider silting and urban contamination prevention.

Managed Aquifer Recharge Plan based on a surface water-groundwater model for the Santo Domingo creek, Baja California Sur, Mexico.

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KEY WORDS
Recharge dams, Coastal areas, Modflow modeling, SWI2 package, Sea water intrusion.

ABSTRACT
The Santo Domingo aquifer represents the main source for the Irrigation District 066, but is overexploited due to the intense historical extractions that reached up to 230% above the annual average recharge. As cone of abatement of up to 35m under sea water level has caused the impoverishment of water quality, through saline intrusion. With the purpose to plan the artificial recharge of the aquifer with excess surface water through infiltration dams, a hydraulic model was developed, as a design tool to plan scenarios with artificial recharge in smaller dams that would receive surface Water from a retention dam located in the Sierra la Giganta Mountains.

For the groundwater model of the Santo Domingo creek, a mesh of 56 rows and 76 columns with a cell size of 2 X 2km was generated with a magnifying glass of 250m towards the mouth of the Santo Domingo creek, where there is evidence of progress of the intrusion saline. The extension of the model includes the area of the northern part of the porous Santo Domingo aquifer with an area of 2450km^2; the model has 3 layers.

The simulation of the saline intrusion was realized using Modflow with Model Muse as pre- and post-processor in combination with the SWI2 package. Stream runoff and riverbed infiltration were introduced, using the Stream Flow Routine (STR) package. The calibration based on 100 control points were used, reaching an average variation of 1.18m,

According to the model, the maximum capacity of natural alluvial infiltration is in the range of 4.3 to 4.7 million m^3, which would represent a percentage of infiltration of between 12.1 and 14.3% of the average volume of runoff for the watershed. Under actual conditions the amount of seawater intrusion from the Santo Domingo mouth will increase 3.6 times in 2050. The will lead to soil chemistry and permeability deterioration, with adverse consequences for the region’s environment, economy and population.

At least another 10 million m^3 could be artificially infiltrated, if the proposed dams would be constructed, stopping the sea water infiltration and partly recharging the aquifer. The groundwater model represents a useful tool to plan the position of recharge dams in order to reduce the effects of over exploitation of groundwater such as sea water introduction. This model forms an essential part of a managed aquifer recharge plan.

SUDS and resilience to climate change

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KEY WORDS
Sustainable Urban Drain Systems, water cycle, rain, climate change, global warming

ABSTRACT

The climate change means increase of temperature with consequences that are especially harmful to environmental conditions, and are revealed in:

- Heat-island effect: with greater affection in central urban areas.
- Worse air quality: situations of extended concentrations of contaminants.
- Warmer water masses, that origin more storm episodes and torrential rains, combined with prolonged droughts.

Reality and current urban design are not able to resist those affections, nor these new rules of precipitations, so an ongoing deterioration of life conditions is being caused, and even material or human losses in increasingly frequent extreme episodes.

These circumstances put cities in an emergency situation to become resilient. To face that challenge, a global strategy to confront an urban change is necessary, in particular in rain management in built environments, in addition to mobility and consumption changes.

The implantation of Sustainable Urban Drain Systems (SUDS) is an effective tool related with this objective of resilience. Its aim is to recover the natural water cycle and mitigate the climate change by links of dispersed systems, according to the principle of local action with global thought.

The advantages of these systems are the reduction of the rain overflow, the improvement of air quality, the decrease of "heat-island" effect by evapotranspiration, and the optimization of the water resource. Some examples are infiltration trenches, straining belts, infiltration stores, permeable pavements or vegetal building roofs.

The linked implantation of different typologies strengthens the effectiveness of the SUDS and mitigates the climate change effects in urban environments.

Proposed approach to extend managed aquifer recharge facilities with reclaimed wastewater in Catalonia in a context of tighter regulations and extreme climatic events (NE Spain)

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KEY WORDS
Managed aquifer recharge (MAR) in Catalonia, reclaimed wastewater, emerging contaminants, regulations, potable indirect reuse

ABSTRACT
Reclaimed water has proved the most suitable option to enhance aquifer recharge. Often this recharge takes place incidentally, since many wastewater treatment plants discharge to ephemeral or seasonal water bodies typical of Mediterranean countries, which implies that a significant amount of the effluents reaches groundwater in an unplanned way. But the need to achieve a further step in sanitation is becoming more and more evident because of the concern about emerging contaminants and the foreseen implementation of tighter regulations. This is why managed aquifer recharge must occupy a preferential place in the planning of water resources to achieve the good status of water bodies.

A real small-scale MAR site with reclaimed wastewater was developed within the frameword of European Union DEMOWARE project in a tiny coastal alluvial aquifer at Port de la Selva (Catalonia, NE Spain), where three basins were constructed to infiltrate part of the urban effluent subjected to an additional tertiary treatment with the aim of increasing the capacity of wells that are being exploited downstream for urban supply. Even though the contamination risk of pumped groundwater was evaluated as low and despite the fact that the target compounds are not specifically regulated in the drinking water Spanish Act, the Catalan Health authorities have required complementary studies to approve this potable indirect reuse scheme in a regular basis.

This experience, together with that acquired at other recharge sites in Catalonia, serves to identify the current limitations as for emerging contaminants and to propose an approach that may overcome the difficulties when both scarcity and health protection seem to be opposing forces in a context of extreme climatic events.

Numerical modeling of pumping test data at an artificial recharge site in Kuwait

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KEY WORDS
Aquifer Storage and Recovery (ASR), Pumping Test, Numerical Model Calibration, Fractured Rock

ABSTRACT
A pilot scale injection- recovery experiment in the Dammam Formation aquifer has been planned to be implemented at a site located in the Kabd area of Kuwait to assess the feasibility of artificial recharge of the aquifer at this site with partial funding from the Ministry of Electricity and Water (MEW), Kuwait. One injection-recovery well, also called an Aquifer Storage and Recovery (ASR) well, and six monitoring wells have been drilled at the site for this purpose. Prior to the start of the experiment, a 96-hour pumping test followed by 96 hours of recovery have been conducted in the ASR well. The water level data collected from the ASR well and the monitoring wells have been used for the calibration of a numerical model that has been set up for the simulation of the injection-recovery process. The calibration process has highlighted the fractured nature of the Dammam Formation aquifer at the selected site. A good match of the water level data could only be obtained when ASR well and five of the six monitoring wells are assumed to be located along or very near to a fracture zone with higher hydraulic conductivity than the surrounding areas. It is furthermore observed that more or less similar evolution of head in the pumping and the monitoring wells can be obtained from the modelling runs with different distribution of fractures within the aquifers. This, however, needs in most cases, adjustments of the hydraulic conductivity values, and in some cases, of the specific storage values of the aquifers and the fractures. Because of the expected spatial variations in the fracture density and fracture conductivity, the planning of the full-scale artificial recharge should be done in stages. The recharge field should be developed in steps through assessment of the hydraulic conditions (including locations, trends and density of fractures) and the extent of mixing of the injected and the native groundwater (that will depend on the local salinity of groundwater and dispersivity parameter) at every step of the expansion of the recharge field. The numerical model should be updated with the data from the previous cycles of injection and recovery through the existing ASR wells. The planning of the next series of step-off recharge-recovery wells around the existing ones should be done, based on this assessment and results of the model runs.

Competitiveness and sustainability in agricultural irrigation areas in the Irrigation District No. 041 at the Yaqui River (Sonora, Mexico)

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KEY WORDS
Competitiveness · Sustainability · Logical Framework · SWOT · Strategic Planning

ABSTRACT
The gradual complexity of the issues that affect the competitiveness and sustainability of irrigation District No 041 at the Yaqui River, located in the South of Sonora, Mexico, manifested by a lack of indicative strategies, contributing to develop a planning according to its needs. The research was carried out using the logical framework; which establishes actions and necessary projects for the good functioning of the district; using the methodology of strengths, opportunities, weaknesses, and threats (SWOT). The objective of the study was to determine the importance of the efficient use of irrigation water for competitiveness and sustainability, as a determinant indicator of permanence of the agricultural activity in the irrigated areas of the irrigation district. The results allowed corroborating the hypothesis raised of disengagement between actors (users – producers, and directors), establishing overall organization strategies, integral planning, competitiveness, and productivity, derived from main objectives, while the specific problems allowed to structure projects and actions referred to each of them. The logical framework allowed to identify that the most irrigation modules present a potential improvement; admitting the articulation of efforts of all actors in the different stages of the development of the strategic plan.

Artificial Recharge of a Karst Groundwater System in Developing Country

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KEY WORDS
Aquifer artificial recharge, karstic formation, groundwater, geophysics, hydrogeology

ABSTRACT
Water exploitation is increasing worldwide. Engineers can assist in the development and management of groundwater resources in order to assure safe and efficient use of these resources. It is possible, under suitable conditions, to supplement an aquifer's natural recharge thereby adding to its safe yield capacity, a process called artificial recharge. Artificial recharge requires knowledge of site specific geological and hydrogeological parameters including an aquifer's hydraulic conductivity. In this study managed aquifer recharge was tested for a Jurassic (karstic) aquifer, located in Douma-Lebanon [34°13'28.00" N and 35°51'4.00" E], using the hydrogeological aspects of the site and assessing source water availability as a requisite for groundwater recharge. In order to identify the subsurface hydro-lithologic environment including the aquifer units, their depth of occurrence, and hydraulic conductivity, knowledge from existing literature was coupled with the results of the audio magneto-telluric (AMT) study. Four subsurface layers were inferred from resistivity versus depth measurements at several locations in the study area and a J4 formation was identified as a potential aquifer in Douma. The site suitability for augmenting the groundwater reservoir was tested by modeling the aquifer using USGS MODFLOW Flex. Dual wells (water discharge and recharge) tapping the potential J4 aquifer were modeled. The models showed a significant decrease in the generated drawdown levels, from -19.16 m to 9 m in some zones. Artificial aquifer recharge can also be achieved by means of the river diversion method. A sample structural design showed the results of diverting a flow of 5.2 m^3/s from the Al Jaouz River into the aquifer from a diversion head work structure (weir) of 0.8 m height, 2.5 m top width and 3 m base width. The water ran through an alluvial channel (canal) of 2 m depth and 1.5 m width to injection wells situated in close proximity to the river channel. These wells pump the diverted river water into the aquifer, potentially at a deeper level than the access points for the pumping wells.

Monitoring of the Managed Aquifer Recharge (MAR) System by treated wastewater reuse in Akrotiri Limassol Cyprus

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KEY WORDS

Over- pumping, sea intrusion, quantitative and qualitative degradation, enrichment.

ABSTRACT

Managed Aquifer Recharge (MAR) is becoming an attractive water management option, with more than 230 sites operating in Europe. A main advantage of MAR technology is its flexibility and applicability to different scales and purposes. The quality of the produced water for irrigation processes is strongly depended on the aquifers hydrogeochemical characteristics and on the MAR design and operation. Two MAR systems in two different sites are currently in operation in Cyprus. The first one is in Paphos area and enriches the Ezousa aquifer with tertiary treatment water since February 2004, while and the other one is in Limassol area and enriches the Akrotiri aquifer with tertiary treatment water since February 2016. Specifically the second one recharges the Kouris Delta region of the Akrotiri aquifer, with tertiary treated water from the Sewerage Board of Limassol Amathus in order to improve both quantitative and qualitative parameters of the aquifer water. In this project, two sets/systems of 17 total enrichment ponds are used to store the recycled water that are located in the Kouris basin. Currently, Akrotiri Aquifer tertiary treated water, is recharged during the winter, through 4 of the 10 upstream enrichment ponds along the riverbed, while the other 7 enrichment ponds are located downstream. The quantities of recycled water discharged in the Akrotiri aquifer were 847,340 m^3 in 2016 and 1566,520 m^3 in 2017. However, during the irrigation period, groundwater is pumped for irrigation purposes from boreholes located nearby. Monitoring results of water levels data's from 2014 to February 2018 show than the enrichment inhibited the saltwater intrusion but there is still a quantitative degradation in the area, since three of five monitoring boreholes in Kouris Delta region were -1.39 m, -0.55 m, and -0.3 m below sea level. Also enrichment decreased the contaminant contents (e.g., Chlorides and other substances) of groundwater at some points in the aquifer. Nitrate content slightly increased in some specific boreholes, mainly due to the impact of the intensive farming in the region. Specifically the mean values of nitrate in the boreholes with hydrological numbers 1983/153, 1985/076 and 1997/047 was 11 mg/l, 5 mg/l and 7 mg/l in 2016 and 21 mg/l, 8mg/l and 11mg/l in 2017 respectively. A slight improvement on the quality and quantity of groundwater is observed but in the future we expect to have even better results.

Insights from groundwater level measurements over a managed aquifer recharge site in Central Morocco

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KEY WORDS
streamflow, irrigation, groundwater fluctuation, Haouz, Tensift

ABSTRACT
Northern Africa is one of the most sensitive regions of the world with respect to the likely climatic changes that are predicted as a result of human activities. Despite the uncertainties in projections, the anticipated reduction of renewable water resources can be as high as 50% within the next 100 years hitting regions that already suffer from water scarcity and droughts.
The Haouz plain (Tensift basin, Central Morocco), a highly populated area, is indeed already experiencing a severe depletion of groundwater resources. To enhance the groundwater recharge within the upstream area of the plain, concrete and masonry bunds were placed in 2012 across the streambed of Ourika wadi. The objective of these bunds is to spread the water in the streambed and to enlarge the infiltration surface during high-flow events generated within the overlooking mountains of High-Atlas. However, the overall hydrologic impact of this managed aquifer recharge (MAR) system was unknow. The main reason for this was the lack of adequate monitoring and the limited knowledge on surface water-groundwater interactions.
To have over that MAR site a first view of groundwater fluctuation during a hydrological cycle, 2 groundwater level measurement campaigns were held in September 2017 representing dry conditions and in March 2018 representing wet conditions. The drawn piezometric maps indicated groundwater flowing from south to north, towards the Haouz plain. A large groundwater mound was surrounding the Ourika wadi. From September 2017 to March 2018 the groundwater depth rose by 01 m to 3.5 m, resulting of groundwater recharge. The groundwater fluctuation showed clearly that recharge outside the streambed was higher than recharge beneath the streambed. This was explained by streamflow diversion for irrigation, as deduced from the analysis of the land cover of the area and from streamflow data. It seems therefore that in our system groundwater recharge by irrigation leakage along the hydrological cycle was more important than the one by streamflow infiltration even with the existence of MAR plants. These results along with a first analysis of the environmental impact of the bunds calls into question the pertinence and efficiency of such a MAR system in our context.

Application of MAR systems for sustainable water-curtain insulated greenhouse system

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KEY WORDS
Water-curtain insulated greenhouse, groundwater shortage, borehole injection, infiltration gallery, sustainability

ABSTRACT
Over 100 km^2 of rural area in South Korea is covered by water-curtain protected cultivation facilities, which use heat source in groundwater to keep warm inside of the greenhouse during winter night by splashing groundwater inner roof of the green house. Those cultivation methods can produce various vegetables and fruits in winter, but induce groundwater level decline over a large area because it discharge the used groundwater to nearby stream via drain ditch. To restore groundwater level, Aquifer-circulating Water-curtain Insulated Greenhouse System was facilitated at 9 greenhouses in Cheongju, Korea, which can reuse groundwater through dual purpose injection-pumping well and infiltration sand gallery. Groundwater usage was measured to be 739m3/d and injection rate through dual purpose well was measured to be 404m3/d on forced injection mode and 139m3/d on natural injection mode (Syphon). The averaged injection rate was calculated to be 162m3/d, which corresponds to about 22% of the groundwater usage. Infiltration sand galleries, located at the space between each greenhouse, can capture the used groundwater during flowing over those and recharge it before it discharge to ditch. The infiltration sand gallery is evaluated to recharge water more than 50% of the used groundwater. Radon (Rn-222) as a natural tracer was applied to evaluate recharge and recovery efficiency of the dual purpose well. A continuous radon monitoring system was used to measure radon activity continuously in pumped from the dual purpose well. A radon mass balance equation was derived from radon activity of intrinsic groundwater, injected used groundwater and mixed pumped groundwater. The recovery rate of the injection water was estimated to be 95.6% by a simple radon mass balance model. This system coupled with various MARs is evaluated to be energy saving, groundwater protecting and sustainable system for the protected cultivation facility during cold winter season.

Hydrogeologic characteristics of rivers alluvium at an artificial recharge site in Korea

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KEY WORDS
Alluvial aquifer, Hydrogeologic characteristics, Aartificial recharge, pumping test, Electical conductivity logging

ABSTRACT
This study aimed to examine the hydrogeological characteristics of an aquifer artificial recharge site in Daesan-myeon, Changweon city, Korea. For this purpose, a long-term pumping test and electrical conductivity (EC) logging were conducted on the pumping, injection, and observation wells in the alluvial aquifer.

The study area is being used as a playground and had been used for greenhouse agriculture until 2010. The alluvium in the floodplain along the Nakdong River mostly consists of alternating layers of sand, gravel, silt, and clay that have been produced by numerous meandering activities of the Nakdong River. Site geology by geological log showed four layers (gravel/sand, silty sand, silty clay, and sand layers of 15 m thickness) from depth to surface. The gravel/sand layer serves as the main aquifer from 33 m below the land surface, the silty sand and silty clay layer as an aquitard, and the sand layer as an unconfined aquifer. In detail, each layer partially contains a small-scale portion of silt and clay.

Geological and electrical conductivity logging, a long-term pumping test, and multi-depth water quality measurements were conducted at pumping, injection, and observational wells to evaluate the hydrogeologic properties, identify the optimal recharge rate, and assess artificial recharge. Using a hydraulic test, a large difference in drawdown and salinity appeared at the radially located observational wells because of the difference in hydraulic connectivity between the wells in the small study area.

As a result of the study, the aquifer in the study area was proven to be highly anisotropic and heterogeneous while the pumping test analysis assumes the aquifer’s isotropy and homogeneity. The varying EC values as well as irregular groundwater heads in both the vertical and lateral directions also indicated the anisotropic and heterogeneous properties of the studied aquifer system.

It was concluded that the hydraulic anisotropy and heterogeneity of the alluvial aquifer should be carefully examined when locating an injection well and considering the efficient design of artificial recharge.

Strategies for an effective managed aquifer recharge in a water-curtain cultivation area using a hydro-thermal model

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KEY WORDS
Managed aquifer recharge, Water-curtain cultivation, Seasonal pumping, Stream-aquifer interaction, FEFLOW

ABSTRACT
In South Korea, large agricultural fields are located mostly in alluvial aquifer, and groundwater is used for cultivation. In particular, a significant amount of groundwater is used for the heating of water-curtain insulated greenhouses during the winter dry season, which causes groundwater depletion. FEFLOW, a three-dimensional finite element model, was used to evaluate the strategies for managed aquifer recharge of the cultivation areas having local groundwater depletion by excessive seasonal pumping. A conceptual model was developed to analyze the effects of managed aquifer recharge on the groundwater level and temperature in the greenhouse cultivation area near the Nam River. For effective managed aquifer recharge, the groundwater depleted area was evaluated by considering the minimum pumping available thickness (PAT). The optimal rates and duration of managed aquifer recharge were assessed by analyzing the recovery of the groundwater levels and the change in the groundwater temperature. The results show that more than 8,000 m3/d of groundwater is required to prevent groundwater depletion when the injection wells are located inside the groundwater depletion area. It is also demonstrated that starting the injection prior to the pumping season is more effective at reducing the depleted area. Especially, year-round injection is the optimal strategy in terms of equipment management and groundwater use efficiency for water-curtain greenhouses. Riverbank filtration is an effective means of securing the water to be injected due to plentiful source of induced recharge from the river.

Assessment of MAR efficiency to increase groundwater sustainability with different climate change scenarios

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KEY WORDS
MAR, climate change, Jeju, groundwater sustainability, numerical model

ABSTRACT
Change in climate system has introduced increasing uncertainty to the water supply and disaster managements. In groundwater systems, changes in surface temperature and rainfall due to climate change could result in the modification of the groundwater volume and groundwater recharge. In the areas where groundwater challenges are observed in relation to climate change, it is critical to predict the impact climate change on the available groundwater resources and develop mitigation measures for increasing groundwater sustainability. In this study, we assessed the change of groundwater recharge rates under different climate change scenario in order to predict the future groundwater sustainability in the Pyoseon watershed, Jeju Island. SWB (A Modified Thornthwaite-Mather Soil-water-Balance Code for Estimation Groundwater Recharge; Westenbroek et al, 2010) was used to simulate the changes in groundwater recharge rate, runoff and evapotranspiration. The calculated groundwater recharge rate was used for groundwater flow simulation (FEFLOW 6.0; Diersch, 2010). Lastly, we introduced different MAR (Managed Aquifer Recharge) schemes to the modal area and evaluated the efficiency of MAR in terms of the capacity of groundwater supply. The results showed change in climate pattern in the study area would lead to substantial groundwater level drawdown in some monitoring wells. The model also predicted increased seasonal and annual fluctuation of groundwater recharge, making the sustainable management of water resource more challenging in the future. Introducing MAR to the subsurface system could mitigate climate change impact, and different schemes (well location, injection rate, and injection period) would modify the system efficiency. Our study results demonstrates that MAR can serve as an effective groundwater mitigation actions, thus more active implementation of MAR systems is recommended to secure groundwater resources and future availability.

PVC-O pipes and fittings, the most environmentally friendly solution for water transportation

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KEY WORDS
Groundwater recharge; piping, conductions, PVC casing

ABSTRACT
The installed pipe is one of the most important elements of the network, therefore, the importance in the choice of the material to be used. At this point it is very important to take into account the quality of the material, its durability and of course, its contribution to the environment.

The environmental impact of a pipe system depends on its composition and on the application to which it is intended, being the type of raw material used, the production process, the finish of the product, and its useful life the main factors that determine the efficiency and sustainability throughout its life cycle.

Analyzed different products (cast iron, steel, Oriented PVC, reinforced concrete) for the execution of various projects, Oriented PVC pipes and fittings present the highest installation performance and the lowest cost in the use of machinery and construction workforce which allows to undertake the project in a time and at a much lower cost than if it were carried out with traditional materials.

Additionally, they guarantee efficient energy consumption thanks to their extremely smooth inner surface that minimizes load losses while becoming, at the same time, the most environmentally friendly solution since they present a significantly lower environmental footprint than other products. This is due both to the energy efficiency achieved during their manufacture and use, as well as to the lower CO_2 emission into the atmosphere throughout their life cycle. In this way, they present a lower contribution to the greenhouse effect and to the climate change of the planet.

Improving SAT underground oxygen conditions by air bio-sparging

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KEYWORDS
SAT, wastewater treatment, Soil-column experiment, bio-sparging.

ABSTRACT
Soil aquifer treatment (SAT) is a managed aquifer recharge technique that allows for tertiary treatment of wastewater. Under this scheme, ponds are used to infiltrate pre-treated wastewater into the soil. During the passage through the vadose zone, contaminants are removed from water through biochemical, physical and chemical processes.

The current research aims to improve the wastewater treatment capacity of SAT projects by enhancing the available oxygen in the soil profile using bio-sparging. Bio-sparging is a remediation technique, at which decontamination of aquifers and groundwater is the result of enhancing the biological biodegradation activity through the injection of air.

For this purpose, a 90 cm long soil column was set up with oxygen saturation sensors and air feeding systems. The air feeding systems were located at the lower half of the column, where the exchange of air with the atmosphere is limited. Artificial wastewater consisting of a solution with glucose (1.2 mM) and ammonium chloride (300 µM), was infiltrated into the column. Infiltration occurred in cycles of 1 hour followed by 2 hours of drying.

Two types of scenarios were run: Scenarios without bio-sparging and scenarios with bio-sparging. The bio-sparging took place during the drying period.

The duration of the drying periods was short, lowering down the overall oxygen saturation in the column over time. This resulted in stressed conditions at which DOC and ammonium removal, as well as the infiltration capacity, decreased continuously. However, while using air sparging this conditions where improved. DOC- and ammonium-removal kept constant, and the infiltration capacity did not change compared to the scenarios with no bio-sparging.

These results suggest that coupling bio-sparging to SAT projects could potentially help to improve DOC and ammonium removal without compromising the infiltration capacity. Furthermore, due to the stressed conditions of the experiment and the observed removal, this combination of techniques could potentially allow for shortening the drying periods and increasing the treatment capacity of SAT projects.

Chlorine isotope fractionation during catalytic reductive dechlorination of trichloromethane ($CHCl_3$) over palladium-on-alumina in hydrogen-saturated water: implication to managed aquifer recharge as sustainable storage solution for desalinated water (MAR-DSW) in Menashe recharge basin, Israel

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KEY WORDS: Cl-CSIA, $CHCl_3$, DBPs, THM, MAR-DSW

ABSTRACT
During the storage of excess desalinated water in a managed coastal aquifer in Israel, chlorine in desalinated water may react with natural organic matter, forming toxic disinfection by-products (DBPs), like trihalomethanes (THMs). In order to facilitate managed aquifer recharge as storage solution for desalinated water (MAR-DSW), it is important to understand the mechanisms of the formation and degradation of such DBPs.

In this work, degradation of chloroform ($CHCl_3$), a main pollutant of interest at the Menashe recharge basin in Israel, was investigated to derive chlorine isotope enrichment factors for the educt and degradation products as a part of the Israel-German joint research “aquifer recharge as sustainable storage solution for desalinated water (MAR-DSW)”.

100ml of deionized water spiked with 30mg/l chloroform was saturated with hydrogen, which serves as an electron donor. Then, 0.25g/l palladium was added as palladium-on-alumina (10% wt.) to catalyze the reaction. Samples were taken at specified intervals from a sampling port designed at the bottom of the reactor, which is closed with a plunger from the top so that no headspace was created as samples were taken out or during the entire experimental period.

During degradation of chloroform, the change in chlorine isotope ratios of $CHCl_3$ as well as its chlorinated degradation products was determined using a gas-chromatograph-mass spectrometer online connected to a purge and trap system (P&T-GC/MS). This simple online method was developed and optimized at TU Darmstadt. In addition to the reaction kinetics, isotope fractionation of $CHCl_3$ and its degradation products dichloromethane (CH_2Cl_2) as well as methyl chloride (CH_3Cl) were investigated. A chlorine isotope enrichment factor (ε) of -2.7‰ was derived for chloroform using the Rayleigh equation.

The investigation of isotope fractionation during the reductive dechlorination of chloroform i.e the Cl-CSIA can potentially be used as a tool to discriminate the source, pathway and fate of these compounds so as to foresee the feasibility of medium and long term use of managed aquifer recharge as a storage solution.

Introducing economy into suitability mapping of MAR scheme

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KEY WORDS
Infiltration basin, cost function, capital cost, operational cost, spatial analysis

ABSTRACT

During phase 1 (desktop study based on available information and data collection) of the course of a MAR project, an analysis of suitability maps is generally done in order to identify the most suitable location for a given MAR scheme. Most of the approaches found in the literature rely on the construction of suitability maps using spatial multi-criteria analysis (SMCA) and focus on the aptitude of the aquifer to store water, the infiltration capacity of soils, the distance from the targeted surface resource or the available space (derived from land-use) necessary for building such a MAR scheme. At this stage of the project, only physical parameters are considered and no economic analysis is ever carried out.

The objective of this study is to introduce economy in this first phase by producing a distributed map of total costs of an infiltration basin scheme. Both capital costs (water abstraction, transfer, land acquisition, basin construction) and operational costs (energy, maintenance, monitoring, water pre-treatment) are taken into account.

In a first step, an objective of volume to be recharged is defined. A cells grid is applied on the study area and, using a GIS tool the following distributed data are extracted for each cell: (i) Distance D between cell and the nearest surface water point; (ii) Head change H between cell and the nearest surface water point (using DEM); (iii) the soil infiltration rate on the cell (value obtained from permeability maps) and (iv) Land value. Other parameters are not distributed and are then fixed. In a second step, from these parameters and data, a distributed cost function is developed to map the levelised costs of recharged water for a given operating life duration of MAR scheme and discount rate. The cost function is applied for all the surface streams that can be used for recharge purpose. Afterwards, the minimum cost is kept in order to build a map of levelised costs (in €/m^3 recharged).

The methodology has been applied to a case study (500 km^2 area). The cost function can be used in order to illustrate how the various parameters (distance from the surface stream, head difference, pre-treatment cost…) impact the levelised costs. The costs map can be mixed with other types of suitability maps in order to identify the most suitable location for a MAR scheme taking into account economic and financial aspects.

Comparative Analysis of the Implementation of the Underground Flow Model to Two Geographically Distant Sub-Basins

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KEY WORDS
Flow, underground; aquifer; model; pollution

ABSTRACT

There are no comparative studies of aquifers behaviour, such as their over-exploitation due to agricultural frontier expansion and natural effects in distant but geologically similar areas. Thus, this work contributes with a comparative analysis applied to two distant zones, in Ecuador and Argentina. Modflow software was used for the underground flow modeling in Milagro's Sub-basin. The modeled area covers 25 Km². The input data was 10 m/day, initial level 2,9msnm, recharge 743 mm/year. Data calibration and validation was done with hydraulic conductivity parameters and recharge. The model used is quantitative based on comparing measured and simulated values. The predominant characteristic of Milagro's (Ecuador) soil is silty-sandy. The studied soil in Cordoba is silty-sandy interspersed with silty-sand. The base scenario consists of 2 wells designed for exploitation, irrigation of green areas and Supply of Buildings in Milagro. The suggested change scenario 1 will have 2 more exploitation wells for irrigation, in total 4 wells. The proposed change scenario 2 will have 3 more wells than the base scenario, i.e. 5 wells. Table 1 shows the results of the modeling, where Milagro's Sub-basin, scenario 1 and scenario 2 have a level variation of 17% and 38%, respectively, in relation to the base scenario. In the Suquia sub-basin, scenario 1 and scenario 2 has a level variation of 2% and 4%, respectively, in relation to the base scenario. The variability is higher in the results of Milagro's sub-basin, than in Suquia's sub-basin. Figure 1 shows descent vs. time curve, when the well is in production. The static level passes to the dynamic level in 2 min, it is with stationary regime. These results indicate that the physical characteristics and the average annual rainfall influence the sub-basin of the Milagro sub-basin of the Suquia sub-basin in the modeled scenarios. The former is located in a tropical region and the latter in a semi-arid region. However, the aquifer of the Milagro Sub-basin has a decrease in its levels with greater differences than Suquia Sub-basin. It is an indicator that has a better storage capacity than the first. The results observed show that the study was successful, as it allows to conclude that aquifer recharge and exploitation are variables that are not similar, as the volume of groundwater exploitation is increasing, while natural recharge is increasingly affected and reduced by anthropogenic action. According to results, the modeled scenarios where the exploitation of groundwater was increased, lower the levels, in the case of Milagro's sub-basin with greater differences than Suquia sub-basin. The comparison of both sub-basins has been successful, because it has allowed to determine how differ water levels, according to the rainfall in each region, as exploitation increases. In view of this, it is recommended to evaluate the water cycle by means of current environmental policies, taking into consideration the attempt not to affect or alter the mentioned cycle, since with the anthropogenic action the waterproof areas in the water basins increase every time, causing that there is less infiltration towards the aquifers recharge, consequently the levels in the wells descend with greater frequency.

Effect of green biofilters and artificial wetlands to improve water quality in canals for MAR. Observations in Los Arenales Aquifer (Spain)

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KEYWORDS
Managed Aquifer Recharge, MAR, artificial recharge, groundwater quality, triplet scheme, SAT-MAR, TDO reduction, green-biofilter, artificial wetlands, NBS, Nature Based Solutions.

ABSTRACT

Los Arenales aquifer is a broad groundwater body that occupies 2,400 km^2 and lodges 96 villages with 46,000 inhabitants in Castilla y León, Spain. Managed Aquifer Recharge (MAR) activities began in 2002 in Santiuste area (12.2 hm^3 per year). Later, two more areas on the same aquifer developed their own recharging facilities: El Carracillo (5.61 hm^3/year) from 2003 and Alcazarén (3.0 hm^3/year) from 2011. Core water usage is irrigation. Within Santiuste and Carracillo, two stretches of their canal networks have been designed to perform three functions in a row: decantation, biofiltration and restoration.

In 2005 a WWTP by lagooning began to spill its effluent into the junction with the near East infiltration canal of Santiuste. Therefore, the recharging volume from Voltoya River, with a high water quality (95%), began to be mixed up with the sewage (5%) into the immediate ditch. Hydrophilic plants in the canal bed help micronutrients absorption from water flow and also their roots prevent clogging and increase infiltration. At the same time, the green cover is used as a fauna shelter. In a branch parallel to the canal the water may enter a three-pond-group artificial wetland, where purification, infiltration and environmental functions follow.

In El Carracillo the second triplet consists in a 42 m^2 stagnation strainer-infiltration pond, a 125 m-long-green-filter canal and a 4,170 m^2 artificial wetland. Complementarily, a near sandy meadow receiving occasional spillway flow from the last marsh acts as a spreading field for recharge. The water source is Cega River.

Water quality analysis and groundwater level monitoring have been carried out in a series of sample points at both sites so as to test processes in these canals. According to the datasets obtained by now, some chemical measurements show dissimilar behaviour in canals and in ponds, indicating a general water improvement for MAR efficiency. The checked balance between water infiltrated and used by the plants in the ditches is still positive for the aquifer. The presence of artificial wetlands in MAR facilities plays a very complementary role as nature based solutions for post-purification processes and enhancing general biodiversity.

Clogging map for Santiuste basin MAR site, Los Arenales Aquifer, Spain. Multivariable analysis to correlate types of clogging and groundwater quality

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KEYWORDS
Managed Aquifer Recharge, MAR, artificial recharge, clogging, groundwater quality, multivariable geo-statistical analyses; Los Arenales.

ABSTRACT

Clogging is considered one of the major negative environmental impacts caused and affecting the 'artificial recharge' devices. Consequently, several experiments aimed at the study of clogging have been accomplished in managed aquifer recharge (formerly known as artificial recharge) facilities within the framework of the EU founded DINA-MAR and MARSOL R&D Projects. Since 2010 research is specially being conducted on the detection and distribution of physical, chemical and biological clogging processes and their combinations by means of sampling in 34 stations, visual inspection using magnifier and/or microscope, reaction to acid tests, biochemical analyses, radiometric images, photographs in the field and physical parameters determinations.

These activities have led to a classification of these complex clogging processes, by binocular microscope, serial radiometric images taken at the infiltration ponds and canals of the main site used as an experimental laboratory where the project is developed: Santiuste basin, Los Arenales aquifer (Segovia, Spain), locations before studied and well known through other methods, such as chemical analysis, interaction models, sequential gauging tests, infiltration tests, etc.

The article aims a new characterization of clogging processes in the area, developing distribution cartographies for the different clogging processes and combinations. Later correlations with groundwater quality are performed by means of multivariable geostatistical analyses and comparisons with groundwater quality isoline cartographies. Finally, the different clogging processes are mapped and related to the distribution of the major components of groundwater.

The findings propose a methodological approach to correlate clogging-groundwater quality and the specific geological conditions for each area. It is especially remarkable the bi-directional influence of MAR water in the groundwater and the opposite, thus, groundwater has a direct action on clogging processes generated on the surface, at least for the environmental conditions of this aquifer.

Using Managed Aquifer Recharge of Surplus Mine Dewater to Protect a Sensitive Environmental Receptor in the Pilbara, Western Australia

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KEY WORDS
MAR to manage surplus dewater

ABSTRACT

BHP Western Australia Iron Ore (WAIO) has five major mining operations in the Pilbara region of Western Australia. The volume of below water table ore mined by WAIO has increased and is projected to do so over the next 5 years. The volume of water required to dewater the below water table pits exceeds the local mine site demand for processing and operational water supply, resulting in a surplus. Additionally, this surplus volume is projected to increase over the next 5 years.

The region is semi-arid and rivers and pools generally dry up between wet seasons. Periodic flooding and groundwater aquifers sustain a range of sensitive and often unique ecosystems. These hold great cultural value to the indigenous communities in the regions. The aquifers are also a key water supply for the current and future communities and industries of the Pilbara.

BHP predominantly uses Managed Aquifer Recharge (MAR) as the first surplus management option to preserve the water resource for future beneficial use. Future beneficial use includes the mitigation of drawdown impact to sensitive and groundwater dependent receptors, accelerated recovery in mine closure and providing a future water supply for BHP or other users.

At one of the WAIO mines, numerical modelling has predicted dewatering-induced drawdown extending to a sensitive receptor (Coondewanna Flats). A MAR scheme (Juna Downs) is planned for management of surplus mine dewater. A key objective of the planned MAR scheme is to mitigate potential drawdown at the receptor. The MAR scheme will enable injection of up to 20 ML/d into a shallow karstic dolomite aquifer up-gradient from the sensitive receptor. The MAR scheme will be managed to mitigate potential hydrogeological change (e.g., groundwater levels) associated with dewatering-induced drawdown at the receptor. A regional monitoring network is in place to assess hydrogeological response.

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