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ABSTRACTS BOOK

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ISMAR SPEAKER PRESENTATIONS

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2· ASR in suboptimal conditions: freshwater self-sufficiency of the Dutch island Texel
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Corné Engelbrecht, Institute for Groundwater Studies (IGS), Natural and Agricultural Sciences, University of the Free State, South Africa & GEOSS South Africa, Stellenbosch, Western Cape, South Africa

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https://recharge.iah.org/files/2021/02/ismar10_book_abstracts.pdf

Aquifer Storage and Recovery Development in Northern California – Considerations and Lessons Learned

Christian Petersen[1], Rodney Fricke[2] and Trevor Kent[3]

Aquifer Storage and Recovery of treated drinking water, that is using a well for both injection into and extraction from aquifer storage, has been under development in Northern California for nearly 2 decades. However, within the past 2-3 years, a surge of development activity has occurred in response to unusually dry conditions and as a mitigation strategy for compliance with the Sustainable Groundwater Management Act (SGMA) of 2014. In developing ASR, consideration must be given to technical, Institutional, environmental, and financial factors in evaluating the feasibility of ASR for a given community or region. This presentation addresses specific items to be evaluated in each of these four (4) topic areas and then provides five (5) Northern California case studies involving the development of ASR by local and regional scale water agencies including:

- City of Roseville
- Sonoma Water
- City of Woodland
- City of Davis, and
- Sacramento County Water Agency

These cases have been selected because they span the continuum of ASR development from initial feasibility level studies to full scale operation and optimization of injection. The presentation will provide a brief overview of the groundwater conditions, source water project need, stakeholder involvement, and project costs and benefits realized through implementation of each of these projects.

1. Christian Petersen, Groundwater Group Leader, GEI Consultants Inc., cpetersen@geiconsultants.com
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ASR in suboptimal conditions: freshwater self-sufficiency of the Dutch island Texel

Abstract ISMAR11

Author: Beatriz de la Loma Gonzalez – Acacia Water

The Dutch Island of Texel in the Wadden Sea is completely dependent for its freshwater supply on rainwater and a pipeline to provide domestic water from the mainland. The objective of the project *Zoete Toekomst Texel* (Fresh Future Texel) is to make the island self-sufficient in terms of its fresh water supply for agriculture and possibly nature reserves. With increasing drought periods and brackish to saline groundwater, access to fresh water for irrigation has become a challenge for the farmers. Aquifer Storage Recharge (ASR) systems could offer a solution to dry springs and summers by storing excess fresh water in winter in the underground to be used in summer. However, high salinity groundwater and thin aquifer layers with a low permeability pose a challenge to the application of this concept. An ASR system is developed using horizontal wells to optimize recovery efficiency in combination with rainwater harvesting from tile drainage en efficient water use by subirrigation using the same tile drainage.

Acacia Water Institute and LTO Noord (association of farmers of the North of the Netherlands) have started an initiative to test how two ASR-based fresh water supply systems combined with efficient drainage and irrigation systems could help Texel to become more self-sufficient.
The objective is to develop two ASR systems for at least 50 hectare each, linking these storages the tile drainage system for rainwater harvesting and to sub-irrigation smart systems to optimize water use, ensuring as well that the systems are energy neutral and financially optimal.

A hydrogeological study was performed using publicly available *REGIS* and *DINO Loket* data to characterise the geological conditions and two locations were selected for geophysical measurements and cone penetration tests. In addition, piezometers were installed, and water samples were taken for chemical analyses. Furthermore, a 3D groundwater flow model was developed that included density driven flow since some of the target aquifers proved to be brackish or saline. The results of the model were used to determine the type, location and depth of the pumping test to obtain more information on the aquifer characteristics. This information was used to further refine the model and to run different scenarios regarding optimal filter distribution and system efficiency.

In addition, financial aspects of application and economic benefits were studied. The cost-benefit analysis indicated how ASR systems could be financed and what kind of ownership infrastructure could result in optimal exploitation and future use.

The hydrogeological study showed that the thickness of the aquifers was limiting the amount of water that could be infiltrated. A high number of vertical wells would be needed for infiltration of the target volume, which would increase the costs of the system. As a solution, horizontal wells were constructed.

The 3D groundwater flow models showed that by using a horizontal well the upward drifting effect of the injected fresh water, as would occur in in vertical wells, would be strongly reduced and the recovery efficiency therefore increased. Models also proved that in order to reach the target abstraction volumes, recovery efficiencies of around 30% could be enough to satisfy the irrigation requirements. This indicates that lower recovery efficiencies do not necessarily need to be an impediment for ASR applications in sub-optimal locations since they might still provide enough water for irrigation.

Finally, the study proved that larger ASR systems are more cost-effective. To ensure a sustainable application and future use the best ownership structure would be by grouping interested farmers in cooperatives of fresh water supply, of which the farmers would be the owners.

The project *Zoete Toekomst Texel* provides the baseline data needed for upscaling small-scale ASR systems (50 ha) such that Texel can become fresh-water sufficient in the coming years. The project will share the knowledge acquired with other national programs, like the Dutch Delta Programme, to promote further the implementation of this type of systems that can help climate adaptation.

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2D AND 3D SEISMIC REFLECTION SURVEYS TO IMPROVE THE EFFICIENCY OF ASR SYSTEM

John Jansen, Sr. Hydrogeologist/Geophysicist, Finn B. Michelsen*, Sr. Geophysicist, Timothy K. Parker**, Sr. Hydrogeologist/Sustainability Expert, Max Halkjaer**, Sr. Geophysicist, Ahmad Ali Behroozmand**, Sr. Geophysicist, Don Zdeba***, General Manager*

Abstract

The hydrogeologic parameters and structure of an aquifer are the most critical elements that determine the success of an ASR system. Unfortunately, these parameters are largely unknown prior to committing to a site and drilling a well. Once a well has been drilled, it is usually impractical to move it and many clients are reluctant to abandon it unless the conditions encountered are unworkable. It is also difficult to predict how far the conditions encountered in a well can be extrapolated and predict if any significant changes are present within the ASR storage volume. As a result, many ASR Wells have failed due to unexpected or poorly understood stratigraphic or structural complexities. Methods that can find sites with suitable aquifer thickness and porosity and identify faults, fracture zones, and discontinuity in confining units prior to drilling can greatly improve the performance of the ASR well and avoid expensive failures.

Seismic reflection technology has been developed by the oil and gas industry to map subsurface reservoirs in detail. This technology is now economically feasible for use in the ASR industry. Seismic reflection surveys produce high resolution images of the subsurface and can be used to identify favorable permeable units to serve as ASR storage zones, map the presence and continuity of confining units, and identify faults or fracture zones that may cause excess mixing with formation water or allow the vertical migration of fluids into the storage zone. This presentation will demonstrate the use of seismic reflection methods to improve the performance of ASR systems. The presentation will also illustrate seismic attribute processing techniques that can be used to extract greater detail from the data than can be seen by the human eye. Case histories will be used to illustrate how existing seismic data can be reprocessed for ASR applications and how new data can be acquired for even higher resolution imaging of the subsurface.

New high-resolution seismic reflection surveys can be designed to image the zone of interest and provide far superior visualization of the subsurface than can be obtained by other methods. This presentation will demonstrate the use of high-resolution reflection data acquisition and processing through the discussion of four reflection surveys conducted in South Florida to map a carbonate aquifer. The survey was optimized to image faults and fracture zones within the storage zone and the adjacent confining units. The results of these surveys have been used to explain the rapid increase in salinity in several production wells and select more favorable ASR and production well locations in areas where the aquifer and confining units are more intact and less likely to facilitate mixing with formation or the vertical migration of saline water into the ASR zone.

In many areas seismic reflection data has been collected for oil and gas or other objectives. This data is often available for purchase at a nominal price, though the quality of the data is generally inferior to contemporary high-resolution surveys. The quality of vintage data can often be improved through reprocessing using contemporary techniques and by optimizing the choice of parameters to focus on the intervals of interest. The use of pre-existing vintage seismic reflection data will be demonstrated by a case history in central California where seismic data collected for geothermal studies in the 1990s has been reprocessed to map the structure and stratigraphy of shallower aquifer zones at depths of 400 to 2,000 feet. Attribute processing was used to map the net and gross sand of the major aquifer intervals, map the thickness and continuity of clay confining units, and map faults and fracture zones. The data will be used to calibrate the data from a regional airborne EM survey and improve the conceptual hydrogeologic framework, which will assist selecting potential future ASR and production well sites.

* *Collier Geophysics LLC, Texas, USA, ** Ramboll,* ***Indian Wells Valley Water District

Part 1: City of Phoenix, Aquifer Storage and Recovery (ASR) Well #302: Recharge, Well Rehabilitation, and Lessons Learned…

LRE Water
Gary M. Gin, R.G.
Vice President of AZ Operations
Jackie Tappan,
Hydrogeologist II
Water Systems Engineering
Michael Schnieders, PG, PH-GW
Principal Hydrogeologist

What happens when an ASR well is severely clogged and what approaches would you implement to reduce / limit clogging? This presentation will detail the recharge operations at ASR Well #302 that lead to well rehabilitation activities. Biofouling on the well screen was considered the main clogging constituent, however, during well rehabilitation efforts, the presence of residual drilling muds was identified as the main clogging constituent (97 cubic feet developed out of the ASR well). Recharge efficiency improved 134% from the clog event. Since this ASR well was impacted with a significant volume of residual drilling muds, the latter portion of this presentation will discuss construction mud management metrics and well development efforts and means of monitoring that should be considered when developing water supply and ASR wells. Participants in this session will be reminded that certain activities can be conducted during the well construction and development phases that will improve the operational efficiency of ASR wells.

Part 2: Bench Scale Testing: Reducing Impacts to Stainless Steel Casing While Targeting Legacy Drilling Fluids

LRE Water
Gary M. Gin, R.G.
Vice President of AZ Operations
Water Systems Engineering
Michael Schnieders, PG, PH-GW
Principal Hydrogeologist

The drilling business and the practices employed in drilling boreholes has evolved impacting conventional well development methods. A growing percent of amendments are being added to drilling fluids including natural and engineered materials. The presence and detection of these additives has led to the identification of residual drilling fluids in newly constructed potable water supply and Aquifer Storage and Recovery (ASR) wells. The presence of residual drilling fluids has a negative impact on well productivity and produced water quality, as well as the ability to recharge supplies into the aquifer (COP ASR Well #302). These remnant fluids can impact the well and its usefulness for years. The challenge then becomes effectively targeting these fluids while reducing the impact on the well structure, especially the stainless steel well screen 304 or 316L. We will summarize our testing protocols and provide insights on how oxidative chemistries impact the remnant fluids and the stainless (304 and 316L) steel well screen. Implementing new development methods will promote smarter/efficient development strategies that will result in improving operations for both pumping groundwater and recharging resources into aquifers.

Well Efficiency and Performance: Influencing Factors and Management Guidelines

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CONFERENCE TOPICS - MAR Engineering and Design, MAR Operations and Maintenance & MAR Students

KEY WORDS - Well efficiency, borehole design and construction, management guideline & Managed Aquifer Recharge (MAR)

ABSTRACT

The Western Cape Province located in South Africa is characterized as having a complex geological setting which consist of younger Cenozoic sediments, sedimentary, igneous and metamorphic rocks. These different geological host rocks result in different aquifer types and are classified as intergranular, fractured, karst and intergranular/fractured aquifers.

Groundwater play an important role as a water supply source for various sectors in the Western Cape. Groundwater is abstracted from the aquifer systems predominantly from boreholes. The heterogeneous nature of the geological host rocks and different aquifer types pose a technical challenge when it comes to groundwater development (specifically borehole drilling and construction).

Different drilling techniques and borehole construction are utilised for intergranular, fractured and intergranular/fractured aquifers. The region has been impacted by a severe drought during the past five years. The drought has led to a large number of new boreholes being drilled throughout the region with a large percentage of boreholes having issues due to incorrect drilling methods, inadequate borehole construction used and poor borehole management (highly fluctuating water levels during abstraction). Thus leading to issues relating to borehole well efficiency, which can have severe long term practical and financial implications. This highlighted the fact that there are currently no clear borehole management guidelines in South Africa.

The objective of the study is to investigate the factors influencing well efficiency and performance and the aim is to develop a practical management guideline. The Western Cape in South Africa will be used as a study area due to the complex geological setting, resulting in different aquifer types. The project will focus on both physical (borehole design and construction) and chemical factors (iron biofouling, carbonate precipitation etc.) that can influence well efficiency and performance. The results will be used to develop implementable best practise management guidelines. Well efficiency is not only relevant for groundwater abstraction boreholes but also play an important role in Managed Aquifer Recharge (MAR) injection boreholes.

2- Managed Aquifer Recharge and Integrated Water Management I

TECHNICAL PRESENTATION

1· Co-Managed Aquifer Recharge (Co-MAR). A bottom-up approach for Integrated Water Resources Management enhancement. Novel method employed at Los Arenales aquifer (Spain) and first results
Enrique Fernández-Escalante, Tragsa Group (Spain) & IAH MAR Commission

2· Evaluation of Managed Aquifer Recharge Using Municipal Residential Stormwater in the Pacific Northwest US
Jason Melady, Principal Hydrogeologist, Summit Water Resources

3· Groundwater recharge in India: the transition from water conservation to MAR
Himanshu Kulkarni, Executive Director, ACWADAM

4· Aquifer recharge and green stormwater infrastructure applied in urban regions
Hugo A. Loaiciga, Professor and Director, University of California, Santa Barbara

5· Managed Aquifer Recharge in the Los Angles Coastal Plain
Nathan Hatch, Hydrologist, Intera Incorporated, California

Co-Managed Aquifer Recharge (Co-MAR). A bottom-up approach for Integrated Water Resources Management enhancement.
Novel method employed at Los Arenales aquifer (Spain) and first results

Enrique Fernández-Escalante and Elena López-Gunn

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KEY WORDS
Co-Managed Aquifer Recharge (Co-MAR), multi-level governance, groundwater users association (CUA), space of collaboration, stakeholders, stakehomers, green solutions, Public-Private People Partnership (PPPP) and Decision Support Systems (DSS)

ABSTRACT

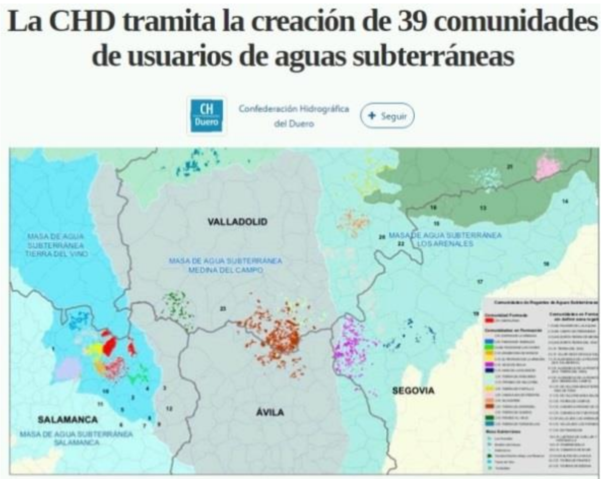
Co-Managed Aquifer Recharge (Co-MAR) is a novel concept in which the integrated water resources management techniques, including MAR, are organized with the contribution of water authorities, stakeholders/end-users, and related institutions with no direct interest in the subject (Stakehomers). This approach entails a greater contribution of groundwater users in the governance, relating MAR and multilevel governance in a participatory approach in which the whole society gets involved in water management issues by means of the creation of "spaces of collaboration". These spaces are created based on confidence for the fair use of (ground)water resources and in organizational measures with a direct influence on groundwater quality and therefore, on environmental issues and green practices. These spaces are becoming the basis for new governance schemes that are aimed to increase sensibility at the groundwater exploitation for the whole user´s collective interest, including ecosystem services and green solutions.

Spanish regulation requires that, for every over-exploited aquifer, responsible water authorities (CHD) must engage communities or groundwater users (CUAS), to be a unique counterpart to negotiate and reach agreements in the future management of the resources. This scheme has modified the traditional "top-down" scheme for integrated water resource management (IWRM) into a more collaborative space, in which members of the general public, in general, represented by CUAS´ Boards and external experts as stakehomers, have the possibility to propose inputs for water management regulations, assignment criteria seeking the collective benefit, controlling land-use practices, improving future water supply prospects and water quality standards for rural development, within an "environment of trust". In the case of Los Arenales aquifer, Co-MAR expects policy implications and includes a **certain control on the demand**, which is another novel issue in which end-users organize the groundwater exploitation taking into consideration not only the present but also the foreseen future resources.

The article demonstrates through real case studies at Los Arenales aquifer, with four regional-scale MAR systems and 39 CUAS how Public-Private Partnership (PPP) enhances governance and water security; and how the intervention of farmers (and the population in general) in the Decision Support Systems (DSS) are improving the application of hard and soft management measures for IWRM, taking into consideration a certain control on the demand and reserving a certain amount of the resources for green functions.

The four MAR systems closely studied are Carracillo, Cubeta de Santiuste de San Juan Bautista, Alcazarén and Medina del Campo. These locations count on Managed Aquifer Recharge (MAR) facilities, some since 2002, which provide between 22 and 25% of the total amount of water used for irrigation with quota systems for groundwater extractions. At the same time, the 39 CUAS explore MAR possibilities to be implemented in their respective areas and proposing recommendations to improve the water security, the fair distribution of the resource, and the current governance schemes.

The experience is having positive results, overall, for example with job creation and economic growth due to improved yields and productions. In addition, end-users have been able to save up to 36% in energy consumption thanks to the increase in piezometric levels. MAR is also reducing agricultural depopulation. From the experience gained, MAR has become a key element for agricultural development and water security. However, some pending issues remain and it is necessary a "shift in paradigm" in the water sector, from traditional patterns of water consumption to evolve to a circular economy approach in which wastewater resources are not considered unwanted, but rather an important asset in a context of water scarcity where MAR is an IWRM key technique.


La CHD tramita la creación de 39 comunidades de usuarios de aguas subterráneas
CH Duero
Confederación Hidrográfica del Duero
+ Seguir
VALLADOLID
MASA DE AGUA SUBTERRÁNEA TIERRA DEL VINO
MASA DE AGUA SUBTERRÁNEA MEDINA DEL CAMPO
MASA DE AGUA SUBTERRÁNEA LOS ARENALES
SALAMANCA
MASA DE AGUA SUBTERRÁNEA SALAMANCA
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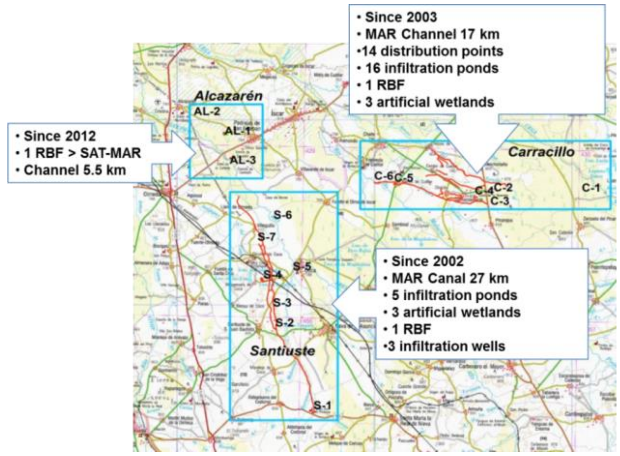
• Since 2003
• MAR Channel 17 km
•14 distribution points
• 16 infiltration ponds
• 1 RBF
• 3 artificial wetlands
• Since 2012
• 1 RBF > SAT-MAR
• Channel 5.5 km
Alcazarén
AL-2
AL-1
AL-3
Carracillo
C-6
C-5
C-4
C-2
C-3
C-1
S-6
S-7
S-4
S-5
S-3
S-2
Santiuste
S-1
• Since 2002
• MAR Canal 27 km
• 5 infiltration ponds
• 3 artificial wetlands
• 1 RBF
•3 infiltration wells

Presentation Title:
Evaluation of Managed Aquifer Recharge Using Municipal Residential Stormwater in the Pacific Northwest US

Presenter:
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Abstract:
In many parts of the Pacific Northwest, wintertime urban stormwater represents an ample, cool, and relatively clean source of water. In most locations, stormwater is discharged to surface water at rates that are far higher than the natural undeveloped hydrologic regime, which can be detrimental to stream channels and aquatic life. Runoff from impervious urban areas also reduces natural groundwater recharge and cool base flow, in turn impairing summertime instream flows. This project will utilize stormwater collected in a suburban residential neighborhood in Beaverton, Oregon, which will be treated to remove any potential contaminants and will then be used for aquifer storage and recovery (ASR) in a deep basalt aquifer during the winter. The stored stormwater will be recovered in the summer and used as the source of water for a “purple pipe” irrigation system currently being installed in adjacent residential and commercial developments and will also be used for streamflow and temperature enhancement in Summer Creek, a tributary to Fanno Creek and the Tualatin River. Following the completion of a positive feasibility evaluation in 2018 and a grant award from the Oregon Water Resources Department, the project moved into pilot-scale implementation of the water treatment elements of the project in the spring and fall of 2020. This presentation will describe the overall project concept and history, and discuss stormwater treatment pilot testing to meet water quality requirements for use as a groundwater recharge source.

Groundwater recharge in India: the transition from water conservation to MAR

Himanshu Kulkarni, Uma Aslekar and Siddharth Patil

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Abstract

India's groundwater footprint is the largest in the world. With an annual extraction exceeding 250 km^3, India's groundwater extraction has unfolded and boomed over a period of 60-70 years as a consequence of many different factors. Millions of groundwater users exist across India's rural and urban settings, users, who have invested their small earnings and developed groundwater resources in different ways over a period of time. In many areas, this very paradigm of decentralised, user-driven groundwater resources development has significantly contributed to the food-security of the nation. However, such a decentralised development has had its own pitfalls, resulting in myriad problems ranging from depleted and contaminated aquifers to the drying up of rivers; it has also resulted in a serious and complex decline in the basic water security of different populations, not to mention issues such as competition and conflict over groundwater resources.

Policy instruments have always fallen short of catching up with the galloping rate of groundwater resources development. Such development was propelled by factors such as rapid advancements in technology for sourcing, extraction and distribution of water. Hence, demand and usage of groundwater overtook the availability through formal supplies by governments, whether in provisioning drinking water, irrigation water or urban water supplies. Two glaring omissions during such development were (1) the reference to aquifers and (2) the trade-offs, mainly between anthropogenic uses of groundwater and the ecosystem services it provides. Although, aquifers have increasingly come into the focus in water policies and practices since 2010, the role of groundwater in the larger context of anthropogenic and ecosystem security still remains neglected.

At the same time, during the 1970s and subsequently in the 1980s and the 1990s, groundwater recharge was conceived as part of watershed development. Water resources development included soil conservation measures, plantations and structures such as small and large check dams to harvest and store stream flow with the intention of inducing recharge through spreading of water through the floors of such check dams. Subsequently, as groundwater levels continued to drop and the shallow unconfined aquifers got depleted in some regions of India, the concept of injection recharge, often in combination with watershed development measures was introduced, without much reference to aquifers systems.

Studies in the early 2000s across India, as a consequence of exposure to international concepts such as ASR and MAR, revealed just how gross the overall approach of claiming the impacts of groundwater recharge through mainstream watershed conservation was. Increasing inclusion of hydrogeology, particularly the study of aquifers at local scales has enabled both, the right questions and more systematic approaches to improved groundwater recharge through the concept of MAR. This paper tracks the course of an evolving paradigm of MAR in India, with a sprinkling of case studies that the authors were part of. Some of the questions that these case studies attempted to answer were:

1) Why does a percolation tank constructed in one village benefits wells in another village located in the adjoining watershed, with little benefit to the wells in the first village?
2) When aquifer information becomes available, how can MAR be optimised in terms of a cost – benefit scenario?
3) How can MAR be made part of the larger agenda of aquifer-based participatory groundwater management?
4) Is MAR a magic wand that can solve the myriad problems that are with diverse patterns of groundwater usage, a variable set of aquifer conditions and prevailing differences in the political economy of groundwater that often dominates policies and practices of water management in India?

Aquifer recharge and green stormwater infrastructure applied in urban regions

Hugo A. Loaiciga

Severe overdraft of groundwater has led to the continuous decline of groundwater levels and consequent drying of water wells and qanats in arid regions. Nonfunctional wells and qanats are considered a threat, yet, this study evaluates the use of nonfunctional wells and qanats as drywells to enhance stormwater management and increase aquifer recharge. A coupled simulation-optimization model (SOM) is developed in this work that links the US Environmental Protection Agency's Storm Water Management Model (SWMM) with a genetic algorithm. The SOM simulates rainfall-runoff processes in urban watersheds and optimizes the implementation of green stormwater infrastructure (GSI) in the form of drywells, bio-retention cells, and permeable pavement for stormwater control and aquifer recharge. Feasible drywells are selected through site inspection and considering stormwater quality criteria to prevent aquifer contamination. This paper compares the current rates of urban runoff and groundwater recharge (baseline scenario) with new stormwater management strategies, which were designed based on several levels of funding in a middle-eastern arid region. Results show the highest rate of runoff reduction and infiltration, as well as the most cost-effective options, would be achieved when drywells are added to the combination of bio-retention cells and permeable pavement for stormwater management. The runoff reduction rate in the presence of drywells would rise by 11.7, 7.0, and 6.1% in comparison to their absence for 12-, 17-, and 22-million-dollar budget levels, respectively. Implementation of bio-retention cells and permeable pavement would cause infiltration of about 235, 274, and 279 thousand cubic meters for the three cited budget levels, while combining drywells with bio-retention cells and permeable pavement would increase infiltration by 19, 15.6, and 14% for the three levels of investment, respectively. These results demonstrate the benefits of using local nonfunctional wells and qanats to reduce peak flows, replenish urban aquifers, and improve the economic efficiency of urban stormwater management.

MAR in the Los Angeles Coastal Plain

Author: Nathan Hatch – INTERA, Inc.

The Water Replenishment District (WRD) and the Los Angeles Department of Water and Power (LADWP) are currently developing a Joint Los Angeles Basin Replenishment and Extraction Master Plan (Master Plan). The Master Plan is aimed at maximizing use of the adjudicated Central and West Coast Basins, identifying opportunities for storage, replenishment with recycled water, and offsetting the need for purchased imported water. Currently, an average of 463,000 acre-feet-per year (AFY) of water is imported into the Central and West Coast Basins, and an average volume of approximately 200,000 AFY of recycled water is discharged to the Pacific Ocean through outflows. The Master Plan takes a regional approach for identifying and developing projects that integrate several components including replenishment of recycled water via existing and new locations, extraction at existing and new locations, and treatment facilities. For evaluating the hydrogeologic constraints of the projects and adhering to the storage rules under the adjudication, a MODFLOW model of the Los Angeles Coastal Plain (LACPGM) is being used. The LACPGM is an unstructured grid model and is based on a 13-layer sequence stratigraphy geologic model. We discuss an efficient methodology for simulating well networks and post-processing model results for evaluating storage constraints. We conclude the talk with a summary of the Master Plan evaluation results and the identified projects.

3- Multi-Benefits of Integrated Flood Managed Aquifer Recharge in California

TECHNICAL PRESENTATION

1· The Merced Flood-MAR Reconnaissance Study - Integrated Modeling
David Arrate, P.E., California Department of Water Resources

2· The Merced Flood-MAR Reconnaissance Study - Climate Change Vulnerability
Karandev Singh, P.E., California Department of Water Resources

3· The Flood Risk Sector of the Merced Flood-MAR Reconnaissance Study
Aleksander Vdovichenko, P.E., California Department of Water Resources

4· The Water Supply Sector of the Merced Flood-MAR Reconnaissance Study
Lisbeth (Liz) DaBramo, E.I.T., Woodard & Curran

5· Evaluation of Ecosystem Enhancements of the Merced Flood-MAR Reconnaissance Study
Taylor Spaulding, Fisheries Biologist Scientist, ESA Environmental

SESSION TITLE: ***Multi-Benefits of Integrated Flood Managed Aquifer Recharge in California***

PRESENTATION TITLE: ***The Flood Risk Sector of the Merced Flood-MAR Reconnaissance Study***

PRESENTER NAME: ***Aleksander Vdovichenko, P.E.***

AUTHORS: David Arrate[1], Francisco Flores-López[1], James Wieking[1], Jenny Marr[1], Aleksander Vdovichenko[1], Shem Stygar[1], Karandev Singh[1], Iman Mallakpour[1], Romain Maendly[1], Wyatt Arnold[1], Glen Low[2], Lee Bergfeld[3], Wesley Walker[3], Daniel Mounjoy[4], Taylor Broadhead[4], Ladi Asgill[4], Taylor Broadhead[4], Lisbeth DaBramo[5], Sercan Ceyhan[5], Ali Taghavi[5], Betty Andrews[6], John Pritchard[6], Travis Hinkelman[6], Paul Bergman[6].

AFFILIATIONS: [1]California Department of Water Resources, [2]Earth Genome, [3]MBK Engineers, [4]Sustainable Conservation, [5]Woodard & Curran,[6]ESA Environmental.

ABSTRACT:
Expanded integration of water management sectors and activities at the watershed-scale can help water managers enhance their water supply portfolio, increase resiliency, and support multiple benefits. The California Department of Water Resources (DWR) recognizes the need to rehabilitate and modernize water and flood infrastructure in California and promotes using flood water for managed aquifer recharge (Flood-MAR) to support sustainable water resources and achieve SGMA (Sustainable Groundwater Management Act) objectives.

DWR, in partnership with the Merced Irrigation District (MID), conducted a study in the Merced River watershed within the San Joaquin Valley. The study aims to quantify and describe the multi-benefits of planning and implementing Flood-MAR as part of a watershed scale water management strategy, evaluating flood risk reduction, groundwater sustainability, ecosystem enhancement, and water supply benefits of Flood-MAR projects. In addition, the study has assessed water sector vulnerabilities to climate change in the Merced River watershed and then assessed the potential resilience provided by these Flood-MAR strategies.

This is the third presentation of a five-part presentation-series describing the approach and results from the integrated analytical toolset used to assess the vulnerability of the Merced River watershed to climate change and potential resilience provided by Flood-MAR. The Merced River HEC-ResSim Model or reservoir operation model simulates flood control, water supply, ecosystem, and Flood-MAR operations over the multiple year period. The model is used in the Study in two ways. 1) To assess the vulnerability of reservoir operations due to changing hydrology by evaluating the effects of climate change on flood management, water supply reliability, and drought resiliency. 2) To estimate water available for Flood-MAR to be diverted off the Merced River. The model is used to explore multiple Flood-MAR operation scenarios, including modified reservoir operations.

The reservoir operation model quantifies the benefits from multiple levels of Flood-MAR implementation, which include reservoir reoperations (Forecast Informed Reservoir Operations and Recharge Pool) and infrastructure expansion. The study assesses results across Flood-MAR implementation levels under current and multiple future climate conditions.

This presentation will explore the results from modified reservoir operations scenarios with an emphasis on flood risk reduction under current and multiple future climate change conditions.

The 11th International Symposium on Managed Aquifer Recharge (ISMAR 11)
April 11-15, 2022 Long Beach, California

SESSION TITLE: ***Multi-Benefits of Integrated Flood Managed Aquifer Recharge in California***

PRESENTATION TITLE: T***he Merced Flood-MAR Reconnaissance Study - Climate Change Vulnerability***

PRESENTER NAME: ***Karandev Singh, MS, P.E.***

AUTHORS: David Arrate[1], Francisco Flores-López[1], James Wieking[1], Jenny Marr[1], Aleksander Vdovichenko[1], Shem Stygar[1], Karandev Singh[1], Iman Mallakpour[1], Romain Maendly[1], Wyatt Arnold[1], Glen Low[2], Lee Bergfeld[3], Wesley Walker[3], Daniel Mounjoy[4], Taylor Broadhead[4], Ladi Asgill[4], Taylor Broadhead[4], Lisbeth DaBramo[5], Sercan Ceyhan[5], Ali Taghavi[5], Betty Andrews[6], John Pritchard[6], Travis Hinkelman[6], Paul Bergman[6].

AFFILIATIONS: [1]California Department of Water Resources, [2]Earth Genome, [3]MBK Engineers, [4]Sustainable Conservation, [5]Woodard & Curran,[6]ESA Environmental

ABSTRACT:
Expanded integration of water management sectors and activities at the watershed-scale can help water managers enhance their water supply portfolio, increase resiliency, and support multiple benefits. The California Department of Water Resources (DWR) recognizes the need to rehabilitate and modernize water and flood infrastructure in California and promotes using flood water for managed aquifer recharge (Flood-MAR) to support sustainable water resources and achieve SGMA (Sustainable Groundwater Management Act) objectives.

DWR, in partnership with the Merced Irrigation District (MID), conducted a study in the Merced River watershed in the Central Valley of California. The study aims to quantify and describe the multi-benefits of planning and implementing Flood-MAR as part of a watershed scale water management strategy, evaluating flood risk reduction, groundwater sustainability, ecosystem enhancement, and water supply benefits of Flood-MAR projects. In addition, the study has assessed water sector vulnerabilities to climate change in the Merced River watershed and then assessed the potential resilience provided by these Flood-MAR strategies. The study is conducted using 30 potential climate change futures and three progressive levels of Flood-MAR implementation (Level 1 – existing infrastructure and operations, Level 2 – existing infrastructure and reservoir reoperations, and Level 3 – new/expanded infrastructure and reservoirs reoperations).

This is the second presentation of a five part presentation-series describing the approach and results from the integrated analytical toolset used to assess the vulnerability of the Merced River watershed to climate change and potential resilience provided by Flood-MAR. This presentation will provide an overview of multi-sector metrics used to track performance under the three primary water management sectors – flood risk, water supply and ecosystem – and present results assessing the vulnerability of the baseline, no project scenario to a range of potential climate change futures using decision scaling approach. The results will demonstrate that each sector is vulnerable to climate change and quantify the risk (or likelihood) associated with each vulnerability metric. The next series of presentations (parts 3, 4, and 5) will take a deeper dive into each of the three sectors and showcase the potential resilience provided by the three progressive levels of Flood-MAR implementation.

Although results are evaluated using a headwater-to-groundwater integrated watershed approach developed specifically for the Merced River watershed, the approach can be replicated in other watersheds. This offers a unique opportunity to assess a watershed's potential to capture and recharge water to meet groundwater sustainability goals over time as dictated by SGMA. This approach also provides water managers the ability to test different flood and recharge management alternatives and evaluate the multi-benefits of Flood-MAR.

The 11th International Symposium on Managed Aquifer Recharge (ISMAR 11)
April 11-15, 2022 Long Beach, California

SESSION TITLE: ***Multi-Benefits of Integrated Flood Managed Aquifer Recharge in California***

PRESENTATION TITLE: ***The Flood Risk Sector of the Merced Flood-MAR Reconnaissance Study***

PRESENTER NAME: ***Aleksander Vdovichenko, P.E.***

AUTHORS: David Arrate[1], Francisco Flores-López[1], James Wieking[1], Jenny Marr[1], Aleksander Vdovichenko[1], Shem Stygar[1], Karandev Singh[1], Iman Mallakpour[1], Romain Maendly[1], Wyatt Arnold[1], Glen Low[2], Lee Bergfeld[3], Wesley Walker[3], Daniel Mounjoy[4], Taylor Broadhead[4], Ladi Asgill[4], Taylor Broadhead[4], Lisbeth DaBramo[5], Sercan Ceyhan[5], Ali Taghavi[5], Betty Andrews[6], John Pritchard[6], Travis Hinkelman[6], Paul Bergman[6].

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This is the third presentation of a five-part presentation-series describing the approach and results from the integrated analytical toolset used to assess the vulnerability of the Merced River watershed to climate change and potential resilience provided by Flood-MAR. The Merced River HEC-ResSim Model or reservoir operation model simulates flood control, water supply, ecosystem, and Flood-MAR operations over the multiple year period. The model is used in the Study in two ways. 1) To assess the vulnerability of reservoir operations due to changing hydrology by evaluating the effects of climate change on flood management, water supply reliability, and drought resiliency. 2) To estimate water available for Flood-MAR to be diverted off the Merced River. The model is used to explore multiple Flood-MAR operation scenarios, including modified reservoir operations.

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This presentation will explore the results from modified reservoir operations scenarios with an emphasis on flood risk reduction under current and multiple future climate change conditions.

SESSION TITLE: ***Multi-Benefits of Integrated Flood Managed Aquifer Recharge in California***

PRESENTATION TITLE: ***The Water Supply Sector of the Merced Flood-MAR Reconnaissance Study***

PRESENTER NAME: ***Lisbeth (Liz) DaBramo, E.I.T.***

AUTHORS: David Arrate[1], Francisco Flores-López[1], James Wieking[1], Jenny Marr[1], Aleksander Vdovichenko[1], Shem Stygar[1], Karandev Singh[1], Iman Mallakpour[1], Romain Maendly[1], Wyatt Arnold[1], Glen Low[2], Lee Bergfeld[3], Wesley Walker[3], Daniel Mounjoy[4], Taylor Broadhead[4], Ladi Asgill[4], Taylor Broadhead[4], Lisbeth DaBramo[5], Sercan Ceyhan[5], Ali Taghavi[5], Betty Andrews[6], John Pritchard[6], Travis Hinkelman[6], Paul Bergman[6].

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This is the fourth presentation of a five-part presentation-series describing the approach and results from the integrated analytical toolset used to assess the vulnerability of the Merced River watershed to climate change and potential resilience provided by Flood-MAR. An especially attractive Flood-MAR benefit is supplemental water supply which can replenish depleting groundwater aquifers and mitigate the adverse impacts of groundwater level decline. To quantify the multi-benefits of MAR on the Merced River watershed's water supply sector, an integrated hydrologic model was developed and applied utilizing an Integrated Water Flow Model (IWFM) application, the Flood-MAR Merced Groundwater-Surface Water Simulation Model (FM2Sim). FM2Sim is integrated with eight other models, which forecast surface water operations and delivery and optimize recharge and economics to best represent future Flood-MAR operations. Focusing on the groundwater system, FM2Sim simulates the groundwater supply and flow, the interactions between surface water and groundwater, and replenishment of the aquifer. FM2Sim quantifies the benefits from multiple levels of MAR, from baseline current water available for replenishment, without (Level 1) and with (Level 2) reservoir reoperation, to infrastructure expansion and surface water reoperation (Level 3). The study assesses results tracking across Flood-MAR implementation levels under adaptations to current conditions and the benefits hold under climate change.

Demonstrating the benefits of MAR in the water supply sector and examining the fate of recharged flood water will be a key step in researching and implementing local and basin-wide Flood-MAR.

The 11th International Symposium on Managed Aquifer Recharge (ISMAR 11)
April 11-15, 2022 Long Beach, California

SESSION TITLE: ***Multi-Benefits of Integrated Flood Managed Aquifer Recharge in California***

PRESENTATION TITLE: ***Evaluation of Ecosystem Enhancements of the Merced Flood-MAR Reconnaissance Study***

PRESENTER NAME: ***Paul Bergman, Senior Fisheries Scientist***

AUTHORS: David Arrate[1], Francisco Flores-López[1], James Wieking[1], Jenny Marr[1], Aleksander Vdovichenko[1], Shem Stygar[1], Karandev Singh[1], Iman Mallakpour[1], Romain Maendly[1], Wyatt Arnold[1], Glen Low[2], Lee Bergfeld[3], Wesley Walker[3], Daniel Mounjoy[4], Taylor Broadhead[4], Ladi Asgill[4], Taylor Broadhead[4], Lisbeth DaBramo[5], Sercan Ceyhan[5], Ali Taghavi[5], Betty Andrews[6], John Pritchard[6], Travis Hinkelman[6], Paul Bergman[6].

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DWR, in partnership with the Merced Irrigation District (MID), conducted a study in the Merced River watershed within the San Joaquin Valley. The study aims to quantify and describe the multi-benefits of planning and implementing Flood-MAR as part of a watershed scale water management strategy, evaluating flood risk reduction, groundwater sustainability, ecosystem enhancement, and water supply benefits of Flood-MAR projects. In addition, the study has assessed water sector vulnerabilities to climate change in the Merced River watershed and then assessed the potential resilience provided by these Flood-MAR strategies.

This is the fifth presentation of a five-part presentation-series describing the approach and results from the integrated analytical toolset used to assess the vulnerability of the Merced River watershed to climate change and potential resilience provided by Flood-MAR. The implementation of managed aquifer recharge projects presents the opportunity to provide ecosystem enhancements by carefully coordinating the timing and location of water deliveries to minimize impacts and maximize benefits to aquatic and terrestrial species of concern. We define ecosystem indicators and associated metrics that were used to evaluate the environmental effects of Flood-MAR and also help refine water management actions to maximize project benefits to key indicator species. Ecosystem indicators were developed to capture effects to all key indicator species and cover the range of effects spatially across the Merced River Basin. Ecosystem indicators are described for the following species groups: groundwater-dependent vegetation, Chinook salmon and Steelhead, and shorebird species.

We present the findings of analyses evaluating the effects of each level of Merced Flood-MAR on each ecosystem indicator compared to baseline conditions, with Level 1 using existing conveyance infrastructure and existing reservoir operating rules, Level 2 including reoperation of reservoirs, and Level 3 including reoperation of reservoirs and modifications to water infrastructure. We also examine how effects change under future climate conditions. In addition to presenting results of the effects analysis, we describe how baseline analyses for each ecosystem indicator were used to refine reservoir reoperations (for Levels 2 and 3) and identify water infrastructure changes (Level 3) to minimize impacts and maximize benefits to key indicator species.

4- Managed Aquifer Recharge Engineering and Design I

TECHNICAL PRESENTATION

1· A proposed methodology for identifying the feasibility of Managed Aquifer Recharge
Anne Imig, Technical University of Munich

2· The effect of air injection on the biogeochemical efficiency of a soil aquifer treatment (SAT) system
Ido Arad, Civil & Environmental Engineering, Technion - Israel Institute of Technology

3· Cooperative project on feasibility of MAR in the MENA region
Thomas Grischek, Professor, Dresden University of Applied Sciences, Division of Water Sciences

4· Extraction of Brackish Water and Optimization of Injection at Seawater Intrusion Barriers and Inland Wells
Raghu Suribhatla, Senior Engineer, INTERA Incorporated

5· Injection and Extraction at Elandsfontein Mine to Protect Langebann Lagoon
Kes Murray, SeniorScientist/Hydrogeologist, GEOSS South Africa (Pty) Ltd – Groundwater and Earth Sciences

A proposed methodology for identifying the feasibility of Managed Aquifer Recharge

Anne Imig[1], Arno Rein[1], Sophia Klausner[1], Olha Halytsia[2], Maria Vrachioli[2]

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Managed aquifer recharge (MAR) is increasingly being used worldwide for drinking and irrigation water supply, aimed at a sustainable and resilient groundwater management. Excess water e.g. from rainfall/flooding, water treatment plants, rivers or desalinated seawater can be infiltrated into an aquifer to store and recharge groundwater. The potential for MAR, worldwide, is far from being exhausted and its demand is expected to increase further due to climate change effects on water supply. Within the DEPPWATER-CE Interreg project funded by the European Union, methodologies for investigating the feasibility of MAR implementation were developed. Potentially suited sites for MAR can be chosen based on geological and aquifer characteristics, as well as on hydrological settings. Feasibility studies for such sites comprise interdisciplinary activities: based on geological and hydrogeological criteria, adequate MAR scheme types have to be chosen. Regulatory frameworks need to be investigated in order to identify if MAR, under which requirements, is allowed, in the chosen investigation area. In a successive step, the need for MAR is identified (and quantified) with a water demand and inherent water supply investigation. If the two prior steps show the need and the regulatory possibility for a MAR scheme, an assessment of potential associated risks is considered to be the next crucial step. These can, e.g., include human health and environmental risks, technical risks related to the MAR scheme (operation, maintenance), or risks related to governance and legislation. For identified risks, adequate risk treatment options shall be identified and evaluated in their practicability. Further, a financial assessment is proposed with, e.g., Cost-Benefit-Analysis (CBA).
The proposed methodology was applied within four Central European countries and at a study site in Freeport, The Bahamas. Concerning the latter, a need for MAR was determined because of the salinization of groundwater resources on the island, due to impacts of hurricane Dorian in 2019. Before, major parts of these groundwater resources were used for drinking water supply. A suited investigation site for MAR has been identified, where water supply infrastructure does already exist. A freshwater lens is present at this site (recharged by precipitation), which however has been impacted by the hurricane. Risk assessment revealed low health risks, but it is suggested to carry out flood protection measures, to allow for resilience to future hurricane storm surges.

The effect of air injection on the biogeochemical efficiency of a soil aquifer treatment (SAT) system

Ido Arad[1], Shany Ben Moshe[1], Noam Weisbrod[2] and Alex Furman[1]

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With the growing global population and an increased need for potable and non-potable water, wastewater reuse has become more prevalent all over the world. Soil aquifer treatment (SAT) is a natural system for tertiary wastewater treatment and reuse in which secondary effluents are infiltrated through the vadose zone, into the aquifer, in cycles of flooding and drying. During infiltration, physical and biochemical processes (e.g., adsorption to the soil minerals, biodegradation) take place and water quality is enhanced.

Dissolved oxygen (DO) is necessary for aerobic microbial oxidation of carbon and nitrogen species in effluents, e.g., dissolved organic carbon (DOC) and $NH4^+$. Therefore, oxidizing conditions are important for maintaining an efficient process. Looking at the biogeochemical state of an SAT system, previous studies show that long drying periods (DPs) led to better oxidizing conditions in the soil profile and resulted in higher quality outflow. However, long DPs allow for the infiltration of smaller water volumes. As the population grows, the quantity of secondary effluents directed to SAT sites increases, and long DPs become less feasible.

In this study, we will explore the ability to actively inject air to the subsurface as an alternative for long DPs, that would allow higher reclaimed effluent quantities without compromising water quality. We will examine, at the laboratory scale, the effect of the air injection on the biogeochemical state of the soil, ultimate outflow quality and infiltrated amounts. Our experimental setup includes a ~1.40-meter sandy soil column connected to an air supply system (air pressure and flow rate will be controlled/measured continuously). Along the column, sensors will monitor pH, water content and oxidation-reduction potential. First, a set of experiments designed to determine the suitable wetting and drying periods will be conducted. Afterward, three sets of experiments will take place, each considering two scenarios (with and without air injection) and different wetting/drying ratios. DOC, Total Kjeldahl Nitrogen (TKN), $NH4^+$, NO_3^- and selected contaminants of emerging concern (CECs) will be tested at the outflow as well as along the profile through rhizons. In addition, the infiltrated amounts of secondary effluents will be measured and compared between the different experiments.

Preliminary results show that the air injection led to better oxidizing conditions in the soil and resulted in a higher quality outflow. It improved the DOC and total nitrogen (TN) removals by 66% and 30% respectively.

Cooperative project on feasibility of MAR in the MENA region

Thomas Grischek[1]; Thomas Reimann[2], Peter-Wolfgang Gräber[2], Catalin Stefan[2]; Prabhas Yadav[1], Gustavo Covatti[1]; Carsten Leibenath[3]; Abdulnaser Aldarir[4]; Mohsen Rezaei[5]; Mohammad Sedghi-Asl[6]; Joanna Doumar[7]; Othman Al-Mashaqbeh[8]

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[5] Shiraz University, Earth Sciences Department, IR Iran
[6] Yasouj University, Soil Science Department, IR Iran
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The 3-year project “Feasibility of MAR for safe and sustainable water supply (FEMAR)” started in July 2021. It is funded by the Federal Ministry of Education and Research (BMBF) and involves three partners from Germany, two from Iran, and one from Syria, Lebanon, and Jordan respectively.

The project aims to provide a model based framework for integrated water resources management (IWRM) to identify and propose suitable sites for managed aquifer recharge (MAR) and to predict their impact on the regional water balance. Well-established methods for MAR will be compared with respect to its feasibility in the target regions. Collaborative analysis and summary of regional knowledge will be accompanied by laboratory experiments and pilot experiments at selected sites.

The project approach is to establish model based tools for IWRM and to use these tools to identify and prioritize methods and sites for MAR. Suitable methods and techniques will be adapted and transferred to the target regions. An initial step is the collection of available data, information, and knowledge, which are transferred in an open source GIS data base. Data are further used to setup initial hydrogeological conceptual models that provide an overview about the respective water balances. Further activities are the assessment of water reuse, e.g. wastewater reuse for irrigation, and water quality investigations. The current process understanding of methods for MAR is critically assessed and enhanced.

The concept of the network project, its cooperation with the INOWAS group at TU Dresden and the IAH Commission on MAR will be presented together with a short description of the pilot sites and recent developments.

Extraction of Brackish Water and Optimization of Injection at Seawater Intrusion Barriers and Inland Wells

Raghu Suribhatla[1], Saman Tavakoli[1]

Presenter: Raghu Suribhatla

[1] INTERA Incorporated

The Water Replenishment District of Southern California (WRD) is responsible for managing and replenishing both the West Coast and Central Coast groundwater basins. In the West Coast Basin, a saline groundwater plume with elevated total dissolved solids (TDS) has been trapped in the Gage, Silverado, Lynwood, and Lower San Pedro aquifers due to historical seawater intrusion and the subsequent implementation of the West Coast and Dominguez Gap Barrier projects. The WRD has initiated the Regional Brackish Water Reclamation Program (RBWRP) to reclaim the impaired groundwater and replenish the West Coast Basin. As part of the RBWRP, several configurations of extraction wells are being evaluated along with potential options for replenishment at the Barrier projects and inland locations. We present results of numerical modeling conducted to evaluate the optimal volume and distribution of additional injection along the Barrier projects, and the inland injection location. The numerical modeling results include particle tracking to evaluate residence time requirements for the injected water as well as consideration of potential subsidence at the extraction locations.

Environmentally Managed Aquifer Recharge and Transfer at Elandsfontein Mine, South Africa

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Abstract:
The Elandsfontein Phosphate Mine is situated approximately 16 km inland from the West Coast of South Africa and 95 km north northwest of Cape Town. The open-pit mine targets phosphate deposits that are located below the natural groundwater level and therefore require dewatering to safely access the deposit. Concerns were raised about potential impacts on the fresh groundwater inflows which mix with saline seawater inflows at the Langebaan Lagoon, a 15 km long, 6000 ha Ramsar site supporting a diverse ecological setting. The area between the mine and the lagoon is also ecologically protected and is owned by SANParks. To address these concerns, all groundwater that has been abstracted since dewatering started in 2017 is transported via pipeline to 20 injection boreholes located 2 – 3 km southwest of the mining pit, in the direction of the lagoon. Dedicated groundwater monitoring positions chosen through a committee of independent hydrogeologists, mine representatives and SANParks representatives are located hydraulically up and downgradient from the mine, as well as between the mine and the lagoon. The effectiveness of the abstraction and re-injection of this water at 100 – 375 L/s on the surrounding aquifer is assessed through groundwater level and quality monitoring conducted at these 28 boreholes, supplemented by repeated multiparameter downhole profiling over time. This data is used to address whether the initial concerns of fresh groundwater flows to the lagoon is being adequately met through the implemented MAR injection scheme. Additionally, groundwater level monitoring and downhole camera logging of the injection boreholes are used to assess the efficiency and or potential clogging of the injection sites after 4 years of continuous abstraction and subsequent injection.

Keywords: Artificial recharge, Managed Aquifer Recharge, Mining, Environment, South Africa

5- Managed Aquifer Recharge Geophysics I

TECHNICAL PRESENTATION

1· A new high-resolution geophysical imaging method for advanced assessment of MAR sites
Ahmad-Ali Behroozmand, Senior Geophysicist, Ramboll

2· Efficient Hydrogeologic Characterization Using a Newly Developed Direct Push Magnetic Resonance System and Applications to Managed Aquifer Recharge
David Walsh, President, Vista Clara

3· Soil texture and seepage mapping beneath earth irrigation infrastructure using electrical conductivity imaging.
David Allen, Principal, Groundwater Imaging Pty. Ltd.

4· Identification of potential recharge pathways at the field scale using geophysical and CPT data: tools for recharge site assessment
Meredith Goebel, Post Doctoral Research Fellow, Stanford University

5· Integrated Geophysics for Managed Aquifer Recharge Infiltration, Injection and Conjunctive Surface/Groundwater Scheme Investigation
Geoff Pettifer, Technical Director, GHD, Australia

A new high-resolution geophysical imaging method for advanced assessment of MAR sites

Ahmad-Ali Behroozmand (Ramboll)
Max Halkjaer (Ramboll)
Tim Parker (Ramboll)
Peter Thomsen (Ramboll)

When planning a managed aquifer recharge (MAR) program, one of the main challenges is to assess the suitability of a site for water infiltration. In other words, it is crucial to know what portions of the subsurface materials are of high hydraulic conductivity, how good is the vertical hydraulic connectivity across the site, and whether the volume of recharge can be enhanced by focusing at specific parts of the site where the geology is dominated by coarser materials.

To address the above challenges, a cost-effective and detailed 3D characterization of the subsurface is needed in both shallow and intermediate depth intervals.

A new towed time-domain electromagnetic geophysical method, tTEM, has proven to be very valuable for the assessment of MAR sites. The tTEM system measures subsurface properties continuously while towed on the ground by an all-terrain vehicle (ATV), and provides high-resolution electrical resistivity models of the subsurface, which can then be interpreted as subsurface geology. The tTEM method enables fast and cost-effective mapping of potential and existing recharge basin sites at high vertical and lateral resolutions.

This presentation includes results from recent MAR case studies in California where the challenge has been to achieve information about the sediments to a depth of 60 meters (200 feet) at existing and new infiltration sites. The projects aimed at obtaining a solid understanding of the vertical hydraulic connectivity of the sediments, and to define new drilling locations. The high-density tTEM data have revealed several fluvial channels at different depths across the study areas. In each infiltration basin, the tTEM results provided a good understanding of where the water most likely infiltrates from the surface and how the vertical hydraulic connectivity varies across each study area. Moreover, the case study results revealed which areas will provide the highest infiltration rates when comparing basins.

EFFICENT HYDROGEOLOGIC CHARACTERIZATION USING A NEWLY DEVELOPED DIRECT PUSH MAGNETIC RESONANCE SYSTEM AND APPLICATIONS TO MANAGED AQUIFER RECHARGE

David Walsh, Vista Clara Inc., Mukilteo, WA, USA
Elliot Grunewald, Vista Clara Inc., Mukilteo, WA, USA
Thomas Christy, Geoprobe Systems, Salina, KS, USA
Wesley McCall, Geoprobe Systems, Salina, KS, USA
Rosemary Knight, Stanford University, Stanford, CA, USA
Gordon Osterman, Stanford University, Stanford, CA, USA

A new system of instrumentation and tooling is presented that enables magnetic resonance characterization of hydrogeologic properties using direct push profiling. Magnetic resonance measurements allow direct determination of water content or saturated porosity, as well as estimation of pore size distributions and hydraulic conductivity. Typically, magnetic resonance logging measurements would require installation or availability of an appropriate borehole or PVC-cased well. Through the design of new tooling and sensors, a new platform has been developed allowing magnetic resonance data to be acquired using direct push drilling, significantly reducing drilling/disposal costs, simplifying logistics, and expanding the range of projects where these data can be leveraged. The new magnetic resonance system is designed for use with 2.25" outer-diameter Geoprobe rod tooling, allowing drilling depth up of 50-100 ft under favorable conditions. The sensor is deployed through the bottom of the rods and data is acquired as the rods are retracted. Two sensor variants have been developed with vertical resolutions ranging from less than 10 cm to 25 cm, and an echo spacing less than 500 µs. An extensive validation dataset was acquired in Salina, Kansas to assess sensitivity, accuracy, and measurement variance. Direct push hydraulic profiling tool (HPT) measurements were also acquired at coincident locations for comparison. The validation field results show excellent repeatability and high correlation with both HPT data and known hydrogeology. Following validation, projects have been successfully executed in support of managed aquifer recharge. In one project, direct push magnetic resonance data were acquired along with cone penetration test (CPT) data to characterize vadose hydrogeology across an almond orchard in the California Central valley. Use of direct push drilling was key to project feasibility, as it mitigated permitting requirements and avoided casing installation and drill cuttings waste. The data was used to map water content and soil type and to identify optimal zones for managed aquifer recharge, where infiltration would be most efficient and cause minimal disruption to orchard health. Measurements in the saturated zone allow profiling of hydraulic conductivity, illuminating the potential for connection between surface water and ground water. For managed aquifer recharge investigations, this new system allows magnetic resonance data to be much more efficiently acquired and to improve subsurface characterization and predictive modeling of subsurface response.

Sediment texture and seepage mapping beneath earth irrigation infrastructure using electrical conductivity imaging.

By Dr David Allen, Principal, Groundwater Imaging Pty. Ltd.
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For MAR projects that use surface water infrastructure for infiltration, either intentionally or inadvertently, knowledge of seepage and infiltration pathways is of great importance. Alluvial geology is typically highly heterogeneous and complex, with coarser grained permeable deposits, left from river flood action, interconnecting each other and cross-cutting clays left by overbank flood deposition and volcanic ash falls. A common anecdotal rule cited is that 90% of seepage can disappear through 10% of ground covered. Whatever the percentages are, it is best to map the high seepage pathways to sort out how infrastructure can constructively contribute to MAR. For a large flood capture reservoir, there may be opportunity to partition a part and enhance infiltration into the right geology while sealing the remainder by clay reworking. Similarly, for irrigation canal networks, some parts may suit use as part of MAR schemes while other parts are best sealed or piped to avoid inappropriate waterlogging and salinization. The same mapping, monitoring and control used to manage recharge can be exactly what is needed to also manage crop waterlogging and salinization.

Electrical conductivity (EC) correlates excellently with ground moisture salinity. As MAR works with fresh water, which prefers to flow through permeable sediment, features of interest in EC maps are typically low conductivity anomalies in otherwise saturated clay substrate which retains old moisture with a build-up of salt from rock weathering and concentration by evapotranspiration. In coarser more glacial environments EC may distinguish seepage from otherwise dry coarse sediment of extremely high resistivity.

From earth irrigation infrastructure I have mapped substrate at depths from decimeters to 10m deep and more using towed submarine streamers of electrodes and am surprised at how each depth slice can tell a rather different story.

Across land I have mapped substrate at depths from 1m to 100m using electromagnetic induction from towed antennae. This is sufficient depth to span the water table and to image through stacks of crosscutting prior stream deposits. In some instances groundwater discharge through such deposits, from times of wetter climate, has potentially cleaned what are now seepage pathways so that very pronounced anomalies can be seen. Interpretation, on a pragmatic level, can be simple, but on a paleo-climatic and geomorphological level can be challenging.

Establishment of good MAR projects using direct infiltration requires an exploration process similar to oil/gas exploration but at a much shallower depth. Electrical conductivity imaging using towed streamers and electromagnetic sources is a most appropriate tool for establishing the detailed spatial information needed for such a task.

Identification of potential recharge pathways at the field scale using geophysical and CPT data: tools for recharge site assessment

Meredith Goebel, Karissa Pepin, Rosemary Knight
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In recent years there has been increasing interest in managed aquifer recharge (MAR) as a tool for balancing water budgets; storing water in times of excess for use in times of shortage. One critical consideration when selecting a site for MAR where the water will be applied at the ground surface is whether the water will be able to infiltrate rapidly and reach the underlying aquifer. Fast infiltration is important to minimize losses due to evaporation, maximize the amount of water that can be moved through the surface, and to minimize risks associated with damage to crops when MAR is conducted on planted agricultural fields. After initial wetting, coarse-grained materials are the key recharge pathways from the surface to an aquifer. Characterizing the quantity and spatial distribution of connected pathways of coarse-grained materials from the surface down to the water table is a key step in assessing the potential quality of a MAR site.

Traditionally, the subsurface has been characterized using measurements made in wells or with soil cores. In areas with spatial heterogeneity in sediment texture, traditional methods may be cost prohibitive or fail to sufficiently capture the complexity in the subsurface needed to locate recharge pathways. A number of geophysical methods have been applied to the problem of recharge site assessment in recent years, with the goal of capturing the spatial variation in sediment type. One of these methods is tTEM, a time domain electromagnetic method, which can be used to rapidly acquire measurements of subsurface electrical resistivity. Interpretation of resistivity models in terms of potential recharge pathways requires a transform between resistivity and sediment texture, creation of a full 3D model of sediment texture from the data acquired, and the mapping of connected pathways through the sediment texture model.

In this work we present a methodology for moving from tTEM-derived resistivity models to 3D subsurface models of sediment type, used to identify potential recharge pathways through the unsaturated zone. We demonstrate this workflow using data collected on an almond grove outside of Tulare California. At all points in our workflow, we seek to incorporate, and account for, the various sources of uncertainty that exist in our datasets and methodologies. Our workflow involves: 1) the development of a resistivity-to-sediment texture transform using collocated tTEM-derived resistivity and cone penetrometer testing data, 2) the use of geostatistical methods to generate numerous realizations of the subsurface representing the spatial distribution of sediments classified as either high or low hydraulic conductivity, and 3) quantitative assessment of the quality of preferential flow paths by locating those that provided the shortest connections of high-K units between the surface and the water table. Evaluation of the lengths and spatial distribution of these pathways is a way in which water managers can assess the quality of a MAR site (or part of a site), in regard to its potential for rapid and effective movement of water to the target aquifer.

INTEGRATED GEOPHYSICS FOR MAR INFILTRATION, INJECTION, AND CONJUNCTIVE SURFACE ⇔ GROUNDWATER SCHEME INVESTIGATIONS

Geoff Pettifer, GHD, Perth, Western Australia, Australia

Geophysics, whether for either irrigation, water supply, sea-water-intrusion management or mining MAR development schemes, involves single and integrated multi-method use of downhole, surface (land and water) and airborne geophysics (helicopter, fixed-wing and drone) and satellite remote sensing, for investigating, understanding, assisting and optimizing design, sustainable operation and monitoring of: -

- direct injection schemes,
- infiltration and flood recharge schemes,
- a total water system approach - turning surface (river and irrigation channel losses and surface-groundwater interaction to advantage (aquifer gain that can be conjunctively managed with the surface water), and
- investigating the extents and characteristics of aquifers and confining layers that are potential areas for MAR scheme development of either of these above three types of MAR scheme.

Supported by many case examples of hydrogeophysical investigations and methods, an overview and critical review is presented of the capabilities, limitations and potential for greater use, for the full range of existing and emerging hydrogeophysical methods applicable to the range of MAR schemes in salinized and fresh water aquifers in alluvium, basin sediments and fractured rock environments from regional, through site, to aquifer, down to permeability/pore/fracture level scales of required detail. Essentially MAR geophysics is customized and targeted hydrogeophysics. Each geophysical method can be used either in a mapping mode to locate drilling targets, to enhance development of the necessary conceptual and numerical models used to manage a naturally recharged and artificially recharged aquifer system or in a more quantitative sense, to empirically derive from modelled geophysical properties the necessary hydraulic parameters used by hydrogeologists and engineers to design / operate the MAR scheme and the modelling to manage the scheme. For quantitative empirical use of geophysics for MAR engineering, six critical factors are the empiricist approach used, the scalability of geophysics and hydrogeological calibrations, geophysical model resolution and parameter uncertainty, the important impact of clay and geophysical interpreter experience.

For regional definition of the location of MAR injection schemes airborne EM (AEM), remote sensing and airborne geophysics define the hydrogeological context of target sites (magnetics for geological structure in fractured rock, AEM for conductive targets in fractured rock and stratigraphy in alluvial / basin sediments where AEM defines conductive aquitards better than resistive aquifers). Disposal of mining pit waters either by in-stream infiltration or by re-injection in fractured rock, is a key aspect of mining environmental management and the wealth of exploration geophysics can be reinterpreted with selective ground geophysics/drilling for mine pit water disposal / MAR planning.

Knowledge of clay distribution and groundwater quality improves the interpretation regionally and at site scale, of where better sedimentary aquifers are present. For regional optimal location of MAR broad-acre flood infiltration schemes, airborne radiometrics defines optimal infiltration sandy soils, versus run-off prone, clay soils.

At injection or infiltration site level, optimal mapping for sub-soil infiltration pathway and injection site identification and drill targeting, shallow EM ground surveys or shallow AEM provides evidence of shallow shoe-string aquifers. Deeper AEM, 2D resistivity and ground time domain EM sounding identifies underlying aquitards and deeper basal aquifers. Critical to basin sedimentary MAR schemes is understanding of faulting, disrupting aquifers / aquitards. Deeper, larger faults often show subtle topographic and radiometric evidence of recent fault reactivation. High resolution reflection seismic particularly in shallow water table environments, maps stratigraphy and small faults.

For leaky irrigation / shallow aquifer conjunctive use schemes, in-channel or recharge basin EM or robotic towed resistivity (HERBI system) can show where leakage is contributing to shallow beneficial aquifer recharge. The potential for greater focus on total irrigation system leakage and shallow bore supply management conjunctive use may be a better approach than fixing leakage and could be better realized with geophysical investigation approaches.

Finally, and most importantly, optimal design and sustainable performance monitoring of expensive injection bores can be greatly assisted by initial full suite geophysical logging and using the technology transfer benefits of petroleum petrophysics logging. Recent innovations in nuclear magnetic resonance (NMR) logging, also available in penetrometer mode; induced polarization logging and (for fractured rock) thermal logging of fracture flows, together with the standard suite of geophysical logs are highly recommended to reduce MAR injection bore scheme costs and potential long-term operational failures. Satellite InSAR monitoring has been used to monitor total aquifer system subsidence due to aquifer / aquitard de-watering and has potential for larger scale MAR recharge performance.

6- Managed Aquifer Recharge Operations and Maintenance

TECHNICAL PRESENTATION

1· Biochemical process optimization for enhanced SAT operation
Alex Furman, Civil & Environmental Engineering, Technion - Israel Institute of Technology

2· Measuring and Monitoring Incentivized MAR in a Channel in Idaho, USA
Ernest M. Carlsen, Secretary, Recharge Development Corporation

3· Part 2: Bench Scale Testing: Reducing Impacts to Stainless Steel Casing While Targeting Legacy Drilling Fluids
Gary M. Gin, R.G., Vice President of AZ Operations, LRE Water

4· Ten years of ASR by deep well injection in a carbonate aquifer
Jordi Guimera, Hydrological Services Project Director, AMPHOS21

5· Shallow Aquifer Recharge Expansion Planning at the City of Yelm's Cochrane Memorial Park Reclaimed Water Facility, Thurston County, Washington
Nathan Nutter, Principal Engineer and Technical Services Lead, Murraysmith

Biochemical process optimization for enhanced SAT operation

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Sustainable irrigation with treated wastewater (TWW) is a well-established solution for water scarcity in arid and semi-arid regions. Soil aquifer treatment (SAT) provides a solution for both the need for tertiary treatment and seasonal storage of wastewater. Stresses over land use and the need to control the obtained water quality makes the optimization of SAT of great importance. This study looks into the influence of SAT systems' operational dynamics (i.e., flooding and drying periods) as well as some aspects of the inflow biochemical composition on their biogeochemical state (mainly dissolved oxygen (DO) concentrations and oxidation-reduction potential (ORP)) and the ultimate outflow quality. A series of four long-column experiments was conducted, flooding periods (FP) were kept constant at 60 minutes for all experiments while drying periods (DP) were 2.5 and 4 times the duration of the flooding periods. To examine a wider range of DP durations as well as different inflow compositions, a numerical model was developed and calibrated. The model includes both description of the water flow in the system and reactive solute transport, considering the main biogeochemical reactions that are dominant in SAT.

Our experimental results show that the longer DP (240 minutes) had a significant advantage over the shorter periods (150 minutes) in terms of DO concentrations and ORP in the upper parts of the column as well as in the deeper parts, which indicates that larger volumes of the profile were able to maintain aerobic conditions. DO concentrations in the deeper parts of the column stabilized at ~ 3-4 mg/L in the longer DP compared to ~1-2 mg/L in the shorter DP. This advantage was also evident in outflow composition that showed significantly lower concentrations of NH4+-N, dissolved organic carbon and total Kjeldahl nitrogen in the outflow for the longer DP (~ 0.03, ~1.65 and ~ 0.62 mg/L respectively) compared to the shorter DP (~ 0.5, ~ 4.4 and ~ 3.8 mg/L, respectively). Comparing experimental ORP values in response to different DP to field measurements obtained in one of the SAT ponds of the SHAFDAN, Israel, we found that despite the major scale differences between the experimental 1D system and the field 3D conditions, ORP trends in response to changes in DP, qualitatively match. The numerical model was successfully calibrated to the experimental data and sensitivity analysis revealed very high sensitivity to soil-water retention parameters. Using the model, we were able to demonstrate increased rates of microbial-mediated kinetic oxidation reactions which verify our experimental observations. A simple optimization process was performed based on simulation results and local optimum for the experimental SAT system was found at a DP duration of ~ 2.8 times the FPs.

We conclude that longer DP not only ensure oxidizing conditions close to the surface, but also enlarge the active (oxidizing) region of the SAT profile. This suggest that SAT should be treated as a pseudo-reactor that to a great extent could be manipulated hydraulically to achieve the desired water quality while increasing the recharge volumes.

Measuring and Monitoring Incentivized MAR in a Channel in Idaho, USA.

By Ernest M. Carlsen

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ABSTRACT

The State of Idaho, located in the northwestern United States, contains the Eastern Snake Plain Aquifer (ESPA). Modeling of the ESPA indicates it has been losing an estimated 300 million cubic meters (250,000 acre-feet) per year for the past 40 years. Recharge Development Corporation (RDC), a private corporation, was formed in 2013 for the purpose of abating this trend by developing recharge sites and conducting Incentivized Managed Aquifer Recharge (IMAR) that is measured, monitored, and tracked. One of the sites selected by RDC is a channel about 5.6 km (3.5 miles) long constructed years ago through a lava field for the purpose of redirecting high flows in the Little Wood River to the Big Wood River to prevent flooding in the City of Gooding. In June 2017 RDC signed a twenty-year agreement with the City of Gooding to use the channel for conducting IMAR. This paper describes the techniques used for measuring recharge for the canal, including calibration, instrumentation, telemetry, and real-time Internet data posting. These techniques serve as a model for similar installations at other sites.

Part 1: City of Phoenix, Aquifer Storage and Recovery (ASR) Well #302: Recharge, Well Rehabilitation, and Lessons Learned…

LRE Water
Gary M. Gin, R.G.
Vice President of AZ Operations
Jackie Tappan,
Hydrogeologist II
Water Systems Engineering
Michael Schnieders, PG, PH-GW
Principal Hydrogeologist

What happens when an ASR well is severely clogged and what approaches would you implement to reduce / limit clogging? This presentation will detail the recharge operations at ASR Well #302 that lead to well rehabilitation activities. Biofouling on the well screen was considered the main clogging constituent, however, during well rehabilitation efforts, the presence of residual drilling muds was identified as the main clogging constituent (97 cubic feet developed out of the ASR well). Recharge efficiency improved 134% from the clog event. Since this ASR well was impacted with a significant volume of residual drilling muds, the latter portion of this presentation will discuss construction mud management metrics and well development efforts and means of monitoring that should be considered when developing water supply and ASR wells. Participants in this session will be reminded that certain activities can be conducted during the well construction and development phases that will improve the operational efficiency of ASR wells.

Part 2: Bench Scale Testing: Reducing Impacts to Stainless Steel Casing While Targeting Legacy Drilling Fluids

LRE Water
Gary M. Gin, R.G.
Vice President of AZ Operations
Water Systems Engineering
Michael Schnieders, PG, PH-GW
Principal Hydrogeologist

The drilling business and the practices employed in drilling boreholes has evolved impacting conventional well development methods. A growing percent of amendments are being added to drilling fluids including natural and engineered materials. The presence and detection of these additives has led to the identification of residual drilling fluids in newly constructed potable water supply and Aquifer Storage and Recovery (ASR) wells. The presence of residual drilling fluids has a negative impact on well productivity and produced water quality, as well as the ability to recharge supplies into the aquifer (COP ASR Well #302). These remnant fluids can impact the well and its usefulness for years. The challenge then becomes effectively targeting these fluids while reducing the impact on the well structure, especially the stainless steel well screen 304 or 316L. We will summarize our testing protocols and provide insights on how oxidative chemistries impact the remnant fluids and the stainless (304 and 316L) steel well screen. Implementing new development methods will promote smarter/efficient development strategies that will result in improving operations for both pumping groundwater and recharging resources into aquifers.

Ten years of ASR by deep well injection in a carbonate aquifer

Guimerà, J.(*); Vilanova, E.; Mas, R.; Jordana, S. (Amphos 21 Consulting SL, Barcelona, Spain)

Serra, B. (Abaqua, Mallorca, Spain)

(*) presenter

Water management in small islands often suffer from variability in rain and natural recharge distribution. Such variability is enhanced in recent years due to climatic variability: while the total amount of rain may be maintained along the year, the distribution changes dramatically from year to year, concentrates rain periods, induces flash floods and reduces infiltration and future availability of water. In this context, Managed Aquifer Recharge (MAR) and particularly, Aquifer Storage and Recovery (ASR) play a role in regulating the water availability counterbalancing demands and supply.

The island of Mallorca, Spain in the W Mediterranean Sea offers an excellent example of ASR. A coastal freshwater spring (Sa Costera) discharges an average flow close to 4 Hm3/year. 2.5 Hm3/y in average are captured, treated and transported to the Estremera well field where water is injected through four deep injection wells. The average injection flow oscillates from year to year depending on the available discharge flow from the sa Costera spring and the urban demand, mostly during the touristic season. Peaks of 4 Hm3/year have been recorded and a total of 16 Hm3 have been injected during the period 2015-2019.

Injected water is extracted by means of six wells. Injection and extraction wells construction design is similar: 200 m deep, 200-100 slotted and 100-0m non-slotted casing with inner diameter of 500 mm (20”). Wells are grouped in four platforms, one injection in each, and one or two extraction wells at each platform separated three to five meters from the injection well. The well field is located at an altitude of 120 m above sea level and at an approximate distance of 10 km from the coast.

The aquifer is unconfined, and it is composed by massive and sandy limestone with local, well developed natural karstic systems. Average depth to water table is 60 m, although during peak injection periods may rise up to 30 m below ground. Water injection is carried out by gravity.

The efficiency of the injection well system has declined during recent years and video camera inspection has evidenced the main factors: loss of integrity of the casing and presence of mud and sand in the bottom of the wells. This latter factor has reduced the length of injection by several meters, up to ten.

The analysis of turbidity and a detailed geochemical study of injected water, native groundwater and the corresponding mixtures, showed that the former cannot be responsible for the accumulation of sediments in wells. The potential of the injected water to dissolve the aquifer carbonate is high, especially when spring water is captured after high precipitation events, when pH is slightly acidic. This may have resulted in the formation of large cavities and the corresponding non soluble fraction can have been deposited in the bottom of the wells.

This article describes the details of the ASR system, the results of the geochemical analysis and the forthcoming rehabilitation and management plan for the well field.

Shallow Aquifer Recharge Expansion Planning at the City of Yelm's Cochrane Park Reclaimed Water Facility, Thurston County, Washington

Authors: Stephen D. Thomas, CHG (GeoEngineers, Inc.) & Philip A. Brown, LHG (Northwest Groundwater Services, LLC)

The City of Yelm has been operating a Water Reclamation Facility (WRF) since 1997. The WRF produces Class A Reclaimed Water (RW) for irrigation and groundwater recharge as its primary outfall at Cochrane Park. The secondary outfall is to a nearby power-generating canal, plus an emergency outfall to the nearby Nisqually river. Up to 56 acre-feet/year (50,000 gallons per day average) is recharged at Cochrane Park into a highly transmissive, glacial outwash aquifer with up to 25 feet of unsaturated zone. The water is recharged via several shallow ponds and constructed wetlands. In 2019, Yelm began planning upgrades to the WRF to meet new water quality discharge permit limits and to support future growth. The upgrades were also made to offset potential impacts from pumping a new drinking water well. The new state rule required a water rights impairment and anti-degradation analysis be performed.

An analysis was conducted to determine whether impairments or degradation would result from increasing groundwater recharge at Cochrane Park by a factor of five (to 280 acre-feet/year). This included establishing existing conditions, conducting infiltration testing for new ponds, performing a quantitative water rights impairment analysis, an anti-degradation water quality analysis, and developing an implementation plan. The technical analysis indicates that the outwash aquifer could receive the additional water without adverse mounding, no existing water rights would be impacted, and the local groundwater quality would not be impaired.

The study faces several challenges – most notably insufficient hydrogeologic data to adequately define existing conditions, the potential to adversely impact flows in the river (which is closed to new appropriations) despite mitigating other hydrologic impacts and navigating the uncertain regulatory landscape and public resistance to change. Overall, the expansion of the artificial recharge should provide significant benefits to the community and the environment, including increasing baseflow in the mostly dry Yelm Creek which drains the sub-basin and negating the need for costly treatment prior to outfall discharge.

7- Managed Aquifer Recharge and the Environment I

TECHNICAL PRESENTATION

1· Impact of managed aquifer recharge on critical zone processes in agricultural landscapes
Helen Dahlke, Associate Professor, University of California, Davis

2· Multi-Benefit Groundwater Recharge: Saving Birds and Recharging Groundwater in California's Central Valley (V)
Julia Barfield, Project Manager, The Nature Conservancy

3· Recharge Quantification for Floodplain Restoration Opportunities on Central Valley Rivers
Michael Founds, Ecohydrologist, cbec eco engineering

4· Environmentally sound managed aquifer recharge for drinking water production
Petri Jokela, Managing Director, Tavase Ltd.

5· Catchment-scale hydrologic analysis of streambed recharge structures in Rajasthan, India (V)
Yogita Dashora, Senior Research Fellow and Vidya Bhawan Krishi Vigyan Kendra, Badgaon, Udaipur, India

Impact of managed aquifer recharge on critical zone processes in agricultural landscapes

Helen. E Dahlke, Nicholas Murphy, Elad Levintal, Yonatan Ganot

Agricultural Managed Aquifer Recharge (AgMAR) is a form of managed aquifer recharge where farmland is flooded during the winter using excess surface water to recharge the underlying groundwater. Using conventional agricultural production systems for MAR provides several benefits (e.g. large spreading areas connected to surface water conveyance systems, flood mitigation, potential capture of large volumes) but also poses several concerns including crop tolerance to flooding, soil aeration, biogeochemical transformations, long-term impact on soil texture, leaching of pesticides and fertilizers to groundwater, and potential greenhouse gas emissions. In this presentation findings from different field and laboratory experiments and numerical modeling studies will be shown to highlight the impact of Ag-MAR the critical zone processes in agricultural landscapes. Results from field experiments show that in the case of pulsed water applications for MAR, when flooding occurs at large intervals (every 1-2 weeks vs. 72-hrs), organic nitrogen mineralization potential increases and significant quantities of nitrate are leached from both sandy (137.3 ± 6.6% of initial residual NO_3^--N)) and fine sandy loam soils (145.7 ± 5.8%) and an increase of mobile nitrate in the upper root zone is observed. Decreasing the flooding frequency to 72 hrs leads to less potential mineralization and less nitrate leached with each water application. Comparison of AgMAR to growing season nitrate leaching amounts suggests that leaching amounts observed during winter recharge are comparable to growing season amounts, although impact of AgMAR on the total annual nitrate mass balance has yet to be determined. We also find that coarse textured or high K_{sat} soils promote fast and nearly complete (>70%) leaching of residual soil nitrate within hours of the first water application without ever showing a decrease in soil oxygen content. In contrast, finer textured soils (e.g. fine sandy loam) can reach partial or complete depletion of oxygen in the root zone within hours to days after flooding begins, which may damage crops but promote denitrification and reduced nitrate leaching to groundwater. To better guide decision making on optimal flooding durations that minimize crop damage, a root zone residence time model was developed that estimates the planned water application duration for Ag-MAR based on soil texture, crop saturation tolerance, effective root-zone depth, and critical water content.

Multi-Benefit Groundwater Recharge: Saving Birds and Recharging Groundwater in California's Central Valley

Authors: Barfield J[1*], Rohde M. [1], Golet G.H. [1], Luster, R. [1]

As California begins to implement its landmark groundwater management law, the Sustainable Groundwater Management Act (SGMA), there is an opportunity to demonstrate flexible and dynamic approaches that can increase water security, while providing habitat for wildlife and improving water supplies for communities. The Nature Conservancy (TNC) has been implementing such a program since 2019 in California's Central Valley. In partnership with groundwater sustainability agencies (GSAs), local landowners, the California Department of Water Resources, and water districts, we are piloting a multi-benefit, on-farm program that simultaneously recharges groundwater supplies and creates temporary flooded habitat for migratory shorebirds along the Pacific Flyway. The program is timed to provide shorebird stopover sites during early fall and spring, critical periods during migration when wetland habitat is extremely scarce on the landscape.

This multi-benefit groundwater recharge program represents a cost-effective strategy that can be adapted to changes in farming production schedules and water availability and that could be adopted by local agencies and potentially scaled up to hundreds of thousands of acres. We are examining how this approach could be adapted to provide flood risk reduction benefits as well. The program to date has been a success, but a cumbersome state regulatory process, navigation of California's complicated system of water rights, water quality concerns, and coordination with multiple state agencies made this pilot extremely complex and indicates a need for streamlining regulatory processes.

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Recharge Quantification for Floodplain Restoration Opportunities on Central Valley Rivers

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Presenter: Michael Founds

Floodplain restoration projects can be designed and prioritized to increase naturally occurring managed aquifer recharge (MAR) leading to many benefits including aquifer replenishment, climate resilience, and ecosystem enhancement. There is a need to quantify increases in groundwater recharge resulting from floodplain restoration projects so that resource managers can track progress towards meeting the goals of the Sustainable Groundwater Management Act (SGMA – a package of 2014 legislation in California) and prioritize projects that meet recharge goals. The ephemeral nature of floodplain inundation and complex infiltration processes though the vadose zone have limited quantitative estimates of recharge on floodplains. The California Department of Water Resources (DWR) and their technical consulting team has developed a pilot study to improve and update the Central Valley Flood Protection Plan (CVFPP) Floodplain Restoration Opportunity Analysis (FROA) by incorporation of projects that use floodwaters for MAR (i.e., Flood-MAR) and advanced habitat suitability metrics. To better understand how ponded water on the floodplain moves through the vadose zone, a representative soil profile will be developed for each of the six recharge potential categorizations of the Soil Agricultural Groundwater Banking Index (SAGBI) to a depth of 30 feet. These soil profiles will be represented in Hydrus 2D and simulated for multiple ponded inundation depths and durations of floodplain inundation. The results will be integrated with floodplain inundation modeling of Central Valley streams to predict how much recharge will occur at the event and annual temporal scales over connected and disconnected areas of floodplain. This systematic approach to incorporate floodplain recharge into restoration planning will provide valuable information on the potential volume of recharge available by reconnecting floodplains to rivers and may serve as a framework to track and prioritize Flood-MAR projects at the broader scale.

Environmentally sound managed aquifer recharge for drinking water production

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KEY WORDS
Drinking water treatment, Engineering, Environment, Managed aquifer recharge, Modeling

ABSTRACT

Managed aquifer recharge (MAR) can be used to remove natural organic matter (NOM) from surface waters in drinking water treatment. A typical drinking water MAR plant includes infiltration of lake or river water and withdrawal of water from wells a few hundred meters downgradient. There are over 25 MAR plants in drinking water production in Finland.

MAR is applied primarily at specific geological sites, Quaternary glaciofluvial eskers in Finland, which have good infiltration properties. These eskers attract also other interests or activities: the sites can be centres of population, recreational areas or nature conservation sites. Operations in, or in the neighbourhood of, these areas are subject to scrutiny and official approval. A license from the authorities is needed to operate a MAR plant.

The aim of this paper is to show measures how to plan, construct and operate MAR plants to fulfil environmental requirements needed to obtain the necessary permit. The basis for the conclusions shown in the paper was gathered through the mandatory environmental impact assessment and multiyear permit processes of the Tavase MAR project. The final MAR production plan was finalized in 2019 after the 2018 permit decision of the supreme court of administration in which revisions of the MAR scheme were required. Further, the permit was granted by the regional state administrative agency in 2020.

Based on earlier and additional extensive research including groundwater modeling, sedimentological analyses, drilling, and infiltration and tracer tests the MAR general plan in the production area 3 was modified (drinking water production capacity of 12,000 m^3/d). The focus of the revised plan was to comply with the environmental requirements. The requirements stated that the black alder forest zone outside the MAR area should not be affected, i.e., water flow, quality and temperature should not change.

The additional research included sedimentological studies according to which the 3D-groundwater modeling was updated. A novel engineering approach was devised to overcome problems associated with an underground threshold found restricting the groundwater flow in the earlier pilot trials. In the new design, once infiltrated lake water is abstracted, then led over the threshold (still underground) and reinfiltrated. In addition, the infiltration and abstraction site locations were readjusted. According to the modeling the change of flow in the ditches inside the black alder zone was only around 4 % and the change of groundwater levels was less than 0.2 meters. In addition, the following aspects are presented:

- choice of infiltration methods (basin, well, sprinkling)
- required pretreatment, seasonal variations of infiltration, clogging prevention
- process control to maintain water balance of the saturated groundwater zone (infiltration and abstraction adjustment coupled with observation of groundwater levels in monitoring wells)
- 3D-modeling results showing locations of infiltration and abstraction sites and necessary residence times for NOM removal and temperature adjustment
- possible excess infiltration to provide sensitive areas with sufficient groundwater supply

Tavase Ltd. is owned by municipalities and it aims to construct and operate a MAR plant (production 62,000 m^3/d) to provide drinking water. There are more than 300,000 inhabitants in the municipalities that own the company.

Catchment-scale hydrologic analysis of streambed recharge structures in Rajasthan, India

Authors: Yogita Dashora, David Cresswell, Richard Clark, Peter Dillon, Basant Maheshwari, Prahlad Soni, P.K. Singh

ABSTRACT

Investment in small-scale recharge enhancement in rural India is of the order of US$ 1 billion/year. It would be prudent to take account of impacts on streamflow and recharge downstream when planning recharge enhancement in catchments, however hydrologic studies are sparse. As a first step to provide reliable hydrologic and economic data, monitoring was conducted over seven years 2014-2020 at four streambed recharge structures (check dams) in the Dharta catchment of the Aravalli Hills in Udaipur district, Rajasthan, India. The monsoon is quite variable from year to year in this drought-prone area, influencing ephemeral inflow to checkdams and consequently their recharge and spill. During the course of this study the hydrology of two of these check dams was noticeably impacted by ~20 new streambed recharge structures and a quarry that were established upstream. A basic hydrologic model, WaterCress, was calibrated and used to assess the impacts of the new structures on those downstream. The results offer new insights to inform planning for recharge structures at catchment scale. Downstream impacts of new streambed structures were much more consequential in drier years, and the combined recharge from all structures in the catchment increased only marginally in those years. This suggests declining incremental economic efficiency of each new recharge structure especially in drier years when water supplies are most valuable. Furthermore, as upstream retention capacity increased, the availability of surface water and enhanced groundwater recharge became more spatially uneven across the catchment in drier years. This suggests the need for policy and planning guidance regarding the construction of new check dams to ensure the value for government investment in watershed development programs. Included in such guidance would be detention capacity constraints at catchment scale and design of streambed modifications to address fairness of access to water resources for the community and the environment across the catchment.

8- Managed Aquifer Recharge Engineering and Design II

TECHNICAL PRESENTATION

1· Preliminary assessment of a managed aquifer recharge pilot facility utilizing riverbank filtration and aquifer storage for sustainable groundwater-irrigated agroecosystems (V)
Andy O'Reilly, Research Hydrologist, U.S. Department of Agriculture, Agricultural Research Service

2· The Freeman Expansion project: increasing diversions and aquifer recharge during peak flows to reduce impacts of droughts and increased environmental flow requirements
Bram Sercu, Senior Hydrologist, United Water Conservation District

3· Use of Enhanced Recharge Methods to Increase Managed Aquifer Recharge Rates
Jason Keller, Senior Hydrogeologist, GeoSystems Analysis, Inc.

4· Infiltration capacity of infiltration trenches and basins in Dresden, Germany
Thomas Grischek, Professor, Dresden University of Applied Sciences, Division of Water Sciences

5· Rooftop Rainwater Harvesting by Shallow Well Infiltration – Challenges and Opportunities
Zsóka Szabó, PhD student, Eötvös Loránd University, Budapest, Hungary

Preliminary assessment of a managed aquifer recharge pilot facility utilizing riverbank filtration and aquifer storage for sustainable groundwater-irrigated agroecosystems

Andrew M. O'Reilly, Daniel R. Wren, Martin A. Locke, and Wesley J. Bolton; U.S. Department of Agriculture, Agricultural Research Service, National Sedimentation Laboratory
J.R. Rigby, U.S. Geological Survey, Lower Mississippi–Gulf Water Science Center
June E. Mirecki, U.S. Army Corps of Engineers, Jacksonville District

The Mississippi River Valley alluvial aquifer (MRVAA) is one of the three most intensively pumped principal aquifers in the United States, with withdrawals for agriculture supplying over 34 million m^3/d for irrigation spanning 32,000 km^2 of arable land in Missouri, Arkansas, Tennessee, Mississippi, and Louisiana. In the Delta region of Mississippi, decreasing water levels over the past 40 years indicate that groundwater-use practices are unsustainable. Managed aquifer recharge (MAR) has been identified as the most likely technology to mitigate groundwater depletion, supporting irrigated agriculture as well as sustaining natural ecosystems in the Delta.

In partnership with local stakeholders, the U.S. Department of Agriculture–Agricultural Research Service is conducting a MAR pilot project combining riverbank filtration and aquifer storage (RBFAS) to capture water from the Tallahatchie River for injection into the MRVAA. The MRVAA consists of sand and gravel up to depths of 55 m at the project site and is overlain by surficial fine-grained sediments of varying lithology and thickness, yielding confined and unconfined conditions that vary spatially and with fluctuating water levels. The RBFAS system consists of one extraction well 46 m from the river, a 2.9-km pipeline to transfer water to an area of greater groundwater depletion, and two injection wells 90 m apart, with a total capacity of 95 L/s. Operation began in April 2021 with an injection rate of about 46 L/s for each well. Data collection at 17 monitor wells and the extraction and injection wells includes continuous groundwater level and temperature and monthly water samples (major ions, metals, and nutrients).

Pre-operation groundwater levels measured since January 2020 show frequent drawdown events contributing to a 0.3–1.2 m decrease during the summer 2020 growing season. Over the fall 2020 to spring 2021 fallow season water levels recovered 0.3–0.9 m, with generally smaller increases in the vicinity of the river possibly due to lower surface-water levels compared to the preceding season. Hydraulic connection between the river and the MRVAA is suggested by seasonal variations in pre-operation groundwater temperature, specific conductance, and pH. Ambient groundwater prior to operation was suboxic at all wells (dissolved oxygen <0.09 mg/L) and less mineralized in the vicinity of the river than the injection site (median total dissolved solids 245 and 351 mg/L, respectively; median specific conductance 385 and 550 µS/cm) and varies with depth possibly related to variations in lithology.

After 40 days of continuous operation 320,000 m^3 of water have been injected. Positive background trends in groundwater level were about 3.0 and 1.5 mm/d in the vicinities of the injection and extraction sites, respectively, prior to operation. A groundwater mound of 1.8 m near the injection wells and a drawdown of 1.4 m near the extraction well has occurred relative to these trends. At radial distances of approximately 520 m from the injection and extraction wells, trend-adjusted water-level changes were +0.5 and –0.5 m, respectively. The groundwater mound extends beyond a radial distance of 1 km, based on a small but steady rise in water level at a 1.1 km distance. Groundwater remained suboxic at all wells (dissolved oxygen <0.12 mg/L). Specific conductance decreased from 490 to 400 µS/cm at the monitor well screened (27.4–30.5 m depth) in the gravel deposits of the injection zone (24.4–36.5 m), consistent with injection of less mineralized groundwater from the extraction well (405 µS/cm). A small decrease in specific conductance from 600 to 580 µS/cm occurred at the monitor well screened (19.8–22.9 m) in sand near the top of the MRVAA, with negligible change in the underlying Sparta Sand aquifer (57.9–61.0 m).

The RBFAS is a non-pressurized system with water levels remaining more than 1.5 m below the top of each well. Following the first backwash conducted at six weeks after operation started, a water-level drop of 0.7 and 2.9 m occurred in each respective injection well. In both wells operating water levels after backwashing were nearly 3 m below initial levels. After nine months of operation and data collection, the environmental and hydrological sustainability of the technology will be determined, and an assessment of the technical and economic feasibility of a full-scale implementation will be conducted.

Title

The Freeman Expansion project: increasing diversions and aquifer recharge during peak flows to reduce impacts of droughts and increased environmental flow requirements

Author:

Dr. Bram Sercu, Senior Hydrologist
United Water Conservation District

Abstract

United Water Conservation District (United) has been diverting water from the lower Santa Clara River for managed aquifer recharge (MAR) since 1927. Since the construction of the Freeman Diversion facility in 1991, United has diverted an average of 60,000 acre-feet a year for groundwater recharge, replenishing the aquifers beneath the Oxnard Plain and slowing seawater intrusion beneath 50,000 acres of productive prime agricultural lands. United's diversion and recharge facilities include a 1,200-ft wide concrete diversion dam in the river channel, a diversion intake with fish passage facility, a desilting basin for removal of suspended sediments and approximately 1,000 acres of recharge basins. In recent years, diversions have decreased significantly due to a combination of drought conditions and increasing requirements for in-stream flows for endangered steelhead trout migration. For example, average annual diversions between 2017 and 2019, a period with slightly above average rainfall, were only 17,000 acre-feet.

A variety of projects to increase water supply are currently being evaluated, designed and/or constructed by United and its regional collaborators. One is the Freeman Expansion project, which aims to increase annual diversions by diverting more water during peak flows. Both regulatory agencies and NGOs have encouraged the United to take advantage of these high flows when fish migration opportunity is less of a concern. Phase 1 will increase United's capability of diverting flows carrying high levels of suspended sediment and will also expand United's recharge capabilities. Phase 2 will expand the maximum instantaneous diversion rate from 375 cfs to 750 cfs. Both phases combined will yield an estimated increase in annual diversions between 8,000 to 10,000 acre-feet. The project will include modification and expansion of existing bay and fish screens, modifications to the existing desilting basin to handle increased sediment loads, and improvements and additions to conveyance infrastructure to eliminate bottlenecks, increase conveyance rates and to add a 200-acre recharge basin. The increase in instantaneous diversion rate will also require a new water right.

In addition to the benefits and challenges associated with this project, this presentation will describe United's operations modeling used to demonstrate project feasibility (is there sufficient recharge capacity for 750 cfs diversion rates?), calculate yield and compare alternative maximum diversion rates.

Use of Enhanced Recharge Methods to Increase Managed Aquifer Recharge Rates

M.A. Milczarek[1], J. Keller[2], L. Bunting[3]

Surface spreading managed aquifer recharge (MAR) operations are affected by recharge water supply, water quality, surface and sub-surface conditions and the rate of surface clogging. The primary constraint to efficient surface spreading MAR operations is typically the permeability of near-surface soils and/or the presence of shallow (i.e. < 30 m below ground surface(bgs)) layers that can reduce recharge rates due to perched water mounding. Under these conditions, recharge enhancement methods can be used to bypass low permeability sediments and direct recharge water to more highly permeable layers within the vadose zone, thereby increasing the overall recharge rate. The use of recharge enhancement methods in small basins (i.e. for stormwater detention) can also increase the capacity of these basins. Common recharge enhancement features include infiltration galleries, dry wells and vadose zone injection wells and wick drains (i.e. Parjana).

The selection of recharge enhancement technologies depends on the subsurface characteristics. Infiltration galleries are appropriate in areas with shallow low permeability layers (i.e. < 5 m bgs); infiltration galleries typically consist of trapezoidal trenches constructed with an excavator and backfilled with gravel. A geotextile should be placed across the gallery to capture sediment and reduce internal clogging rates. To bypass deeper low permeability layers, drywells are extensively used throughout the western USA; typical designs consist of drilling large diameter (i.e. 0.9 m) wells ranging in depth from 15 to 35 m and backfilled with gravel. A second chamber can be added to increase sediment capture and reduce clogging. Smaller diameter (i.e. 0.25 to 0.3 m) wells though at a higher frequency can also be used to achieve equivalent recharge. Vertical wick drains are installed by pushing a vibratory mandrel into the subsurface sediments, to typically shallow depths (i.e., < 20 m), though depths in excess of 30 m can be achieved using special equipment. However, their use is limited to sediments with low penetration resistance (i.e. < 20 Standard Penetration Test blow counts).

Recharge enhancement technologies are advantageous because they are relatively inexpensive compared to purchasing new land for expanding surface MAR, however, as with all recharge methods, maintenance and clogging is an issue. Ideally, water should be pre-treated to remove sediment and excessive nutrients prior to use for recharge into infiltration galleries, drywells or wick drains to reduce the clogging potential. Ultimately, it is an economic decision between pre-treating water and sediment control to extend the life of the recharge feature, or constructing new ones once clogging occurs. We will present examples of each recharge enhancement technology and discuss site characterization approaches that can be used to evaluate the different technologies and include a cost comparison for typical installations.

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Infiltration capacity of infiltration trenches and basins in Dresden, Germany

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Dresden-Hosterwitz is the second largest waterworks in the city of Dresden, which is located at the River Elbe. 111 vertical siphons wells and 36 wells with submersible pumps abstract water from a depth of 10–14 m below surface at a distance of 60–120 m to the river. The maximum abstraction of bank filtrate is about 30,000 m^3/day depending on river water level. Additionally, river water is directly abstracted, pre-treated, recharged via infiltration basins and recovered from wells in 15–60 m distance to the infiltration basins. The maximum capacity of the infiltration basins is 42,000 m^3/day resulting in a total capacity of the waterworks of 72,000 m^3/day. Currently, the waterworks operates four high-capacity basins with an area of 2,650 to 2,975 m^2 each and an average infiltration rate of about 6.7 m/day and one so-called Doppstadt-basin with an area of 10,540 m^2 and an infiltration rate of about 2 m/day. In 2018/2019, a 20 m long and 1 m wide infiltration trench and a 20 m long and 13 m wide infiltration basin were constructed to investigate advantages and disadvantages of infiltration trenches and basins.

The infiltration trench was tested with an infiltration rate of 100 m^3/h (120 m/day) in November 2018. The feed water had a turbidity of 0.25 FNU on average. An accidental feed with water having high turbidity of >1–10 FNU caused an immediate clogging of the upper centimeters of the filter sand. After removal and washing of the upper layer, full infiltration capacity could be restored. From June to December 2019, both infiltration facilities were operated at infiltration rates of 50–120 m^3/h, depending on pumping rates of the abstraction wells nearby. Details of the design of the infiltration trench and first results from field measurements, geohydraulic modelling using HYDRUS and MODFLOW, and a comparison of the infiltration capacities of the trench and small basin will be presented. Also planning of a hybrid infiltration scheme combining a basin and trenches will be discussed.

The major advantages of an infiltration trench are that it can be easily covered to prevent algae growth and related clogging, and that it requires less space. If infiltration facilities are operated on demand or intermittently, an infiltration trench has the advantage to achieve its full capacity within a very short time after initiation of its operation whereas the basin needs up to two days.

Rooftop Rainwater Harvesting by Shallow Well Infiltration – Challenges and Opportunities

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In the Danube-Tisza Interfluve area (Hungary), groundwater levels have declined significantly in the last decades, due to anthropogenic activities and climate change. In the past, several replenishment plans have been prepared, involving large, cross-regional technical investments, but they have not been implemented due to the lack of adequate financial resources and environmental concerns. The aim of this study is to demonstrate a local scale solution by experimental research in a small rural town (Kerekegyháza), which could contribute to easing the water shortage of the area. Rooftop rainwater harvesting coupled with shallow well infiltration was selected as a possible method due to its easy and relatively inexpensive implementation and operation. In addition, rainwater is the only adequate source of recharge water at the study area, where unused dug wells are readily available as well.

In the beginning of 2020, a field experiment was set up, leading rainwater from the roof of a family house to the dug well in the yard. The water passes through a filter mesh before it enters the tube system leading it to the well. Water level, temperature and specific electrical conductivity is recorded every half hour in the dug well and in two newly established observation wells. Water samples are taken for laboratory measurements. Precipitation is measured on a daily basis. Long-term water level, hydrochemical and isotopic changes, as well as temperature changes were monitored to determine the physicochemical effects of injected water on the ambient groundwater. Furthermore, water level changes following precipitation events were compared with the amount of precipitation falling to the rooftop to estimate the efficiency of the system. A transient numerical flow model was built to better understand the occurring underground processes and to evaluate the potential and efficiency of rooftop rainwater harvesting with different scenarios.

The obtained results can help to determine the potential of this method together with its limitations on settlement level. In addition, they provide background information for further numerical simulations and contribute to the extension of the design to similar settlements in the Danube-Tisza Interfluve.

This research is part of a project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 810980.

9- Managed Aquifer Recharge and Emerging Contaminants I

TECHNICAL PRESENTATION

1· Reclaimed Water Infiltration Study: Determining Attenuation Factors and Exposure Point Concentrations for Contaminants of Emerging Concern
Brittany Duarte, Hydrogeologist, HDR

2· Field comparison of nitrogen cycling between three agricultural managed groundwater recharge sites
Elad Levintal, Postdoctoral Researcher, Department of Land, Air and Water Resources, University of California, Davis, CA, United States

3· Treatment to Remove PFAS from Groundwater Impacted by MAR to Restore Drinking Water in Orange County, California
Manmeet (Meeta) Pannu, Senior Scientist, Orange County Water District

4· Combining Constructed wetlands and Soil Aquifer Treatment to enhance infiltration flux and water quality
Ido Negev, Chief Hydrologist, Mekorot National Water Company

Title: Reclaimed Water Infiltration Study: Determining Attenuation Factors and Exposure Point Concentrations for Contaminants of Emerging Concern

Presenter: Brittany Duarte

Contributing Authors: Shane McDonald, Jeffrey Hansen, Vincent Carsillo, Jillian Troyer

Affiliations: HDR

Abstract:

The ability of soil aquifer treatment to attenuate contaminants of emerging concern (CECs) such as perfluorinated compounds, flame retardants, pharmaceuticals, and other personal care products is of interest for the development of reclaimed water aquifer recharge projects. This presentation will include results from a multi-year water quality monitoring and fate and transport study to estimate the breakdown of CECs infiltrated at the Lacey, Olympia, Tumwater, and Thurston County Clean Water Alliance (LOTT) reclaimed water recharge facility near Olympia, Washington. This study involved a large-scale project to monitor and evaluate reclaimed water, vadose zone, and groundwater quality over a year of recharge operations combined with tracer testing and groundwater modeling to estimate long-term fate and transport of reclaimed water constituents. As part of this work, attenuation factors were developed for select CECs based on modeled and observed data. Attenuation factors were used to estimate future concentrations of CECs and to develop exposure point concentrations (EPCs) that were then incorporated into human health and ecological risk assessments. The community served by LOTT is using the results of the risk assessments to inform the future direction of the reclaimed water infiltration program.

There are several unique aspects to this field setting including an urban environment, relatively wet climate, heterogeneous glacial soils with highly variable groundwater velocities, and high dissolved oxygen and relatively low organic carbon content in the reclaimed water and groundwater. In addition to details regarding this study, the presentation will also include a comparison to findings from other large-scale reclaimed water aquifer recharge studies in the alluvial basins in drier climates (California and Arizona) and a discussion on methods of attenuation of CECs.

Field comparison of nitrogen cycling between three agricultural managed groundwater recharge sites

Elad Levintal[1], Laibin Huang[1], Adolfo Coyotl[1], William R. Horwath[1], Jorge L. Mazza Rodrigues[1], Helen E. Dahlke[1]

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Agricultural managed aquifer recharge (Ag-MAR, on-farm recharge), where farmland is flooded with excess surface water in winter to intentionally recharge groundwater, has received increasing attention by policy makers and researchers in recent years. However, there remain concerns about the potential for Ag-MAR to exacerbate nitrate (NO_3^-) contamination of groundwater, and the public health risks associated with elevated NO_3^- concentrations in groundwater and related greenhouse gas emissions. In this study, we compare nitrogen cycling processes between three Ag-MAR field sites to quantify the effect of Ag-MAR on nitrogen transformations and losses in the soil (e.g. NO_3^- leaching, N_2O losses) for different soil types and cropping systems. The first two Ag-MAR experiments were conducted on two raisin grape vineyards with different soil textures, which were each flooded for two weeks and four weeks, respectively, for two consecutive years. The third site was a fallow field, which was flooded for eight days, and is now planted with processing tomatoes. Each site's instrumentation included a suite of soil moisture sensors, water level loggers and flow meters. Other measurements (down to 1-m depth in the vineyards and to 2.5 m in the fallow field) included: redox probes, oxygen sensors, suction cups for pore water sampling, and static flux chambers for nitrogen (N_2O) and carbon-related (CO_2, CH_4) atmospheric fluxes. Soil samples were taken before and after Ag-MAR events to determine soil N species (TN, DON, TOC, NO_3^-, NH_4^+), pH, EC, and soil texture. Plant and yield were also measured to determine the effect of Ag-MAR on grape and tomatoe physiology and to close the N-mass balance. Results indicate that: (1) during flooding NO_3^- leaching was the main process with an additional but smaller contribution of denitrification; (2) there were no greenhouse gas emissions observed during the Ag-MAR treatment; (3) soil texture and crop type determined the magnitude of NO_3^- leaching at each site.

Treatment to Remove PFAS from Groundwater Impacted by MAR to Restore Drinking Water in Orange County, California

Pannu, M.W.[1]; Plumlee, M. H.[1]; Pham, C. [1]; Grieco, S.A.[2]; Hwang, M.[3]; Chang, J.[4]

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Abstract
Per- and polyfluoroalkyl substances (PFAS) are a large family of hydrophobic, oleophobic, and hydrophilic chemicals commonly used in a wide range of consumer, manufacturing, and firefighting products. Ubiquitous and environmentally persistent, PFAS are detected in drinking water supplies across the United States. Unfortunately, PFAS occurrence in the environment can impact drinking water sources. This is the case for groundwater systems influenced by managed aquifer recharge (MAR) that uses PFAS-impacted supplies. Accordingly, PFAS have been detected in the Orange County Groundwater Basin (basin) in southern California, entering via the Santa Ana River (SAR) whose flows infiltrate into the basin using MAR. PFAS inputs to the SAR include treated wastewater discharges and stormwater runoff from upstream communities. Chemical manufacturers are the original source of PFAS chemicals. Despite playing no role in releasing PFAS into the environment, cities and water agencies in Orange County must find ways to remove it from groundwater. PFAS poses a risk to the broader practice of MAR if water agencies may be less willing to perform recharge despite MAR's benefits for sustainable water supply, depending on evolving PFAS regulations and guidance worldwide.

California's Division of Drinking Water (DDW) established Notification Levels (NLs) of 5.1 ng/L for perfluorooctanoic acid (PFOA) and 6.5 ng/L for perfluorooctanesulfonic acid (PFOS), as well as Response Levels (RLs) of 10 ng/L and 40 ng/L for PFOA and PFOS, respectively. The NLs and RLs have significantly impacted water agencies in Orange County, resulting in the temporary removal of selected drinking water wells from service. Several water agencies have transitioned to imported water until PFAS treatment can be installed. Hence, the Orange County Water District (OCWD) commenced a large pilot testing program to evaluate the performance of 14 different adsorbents, including traditional granular activated carbon (GAC) and ion-exchange (IX) products as well as alternative adsorbents, to remove PFAS from the groundwater. In parallel, complimentary laboratory-scale testing of GAC and the crushable alternative adsorbents was also completed. The objective was to determine which of these media are most efficient at removing PFAS for Orange County water agencies for the best value considering the local groundwater geochemistry. Treatment of PFAS at drinking water production wells throughout north and central Orange County will allow the local water agencies to utilize local groundwater instead of purchasing costly imported water (approximately two times greater cost).

GAC products evaluated include bituminous (both virgin and reactivated), lignite, and enhanced coconut-shell based products (eight products). IX resins (four products) were single-use anion exchange adsorbents. The alternative adsorbents included a mined, non-regenerable product and a manufactured, regenerable product. The pilot hydraulic loading rate (HLR) and empty bed contact time (EBCT) were selected to match the operational parameters of a full-scale system. At laboratory-scale, the eight GACs and two alternative adsorbents were also tested (not IX) to evaluate any performance difference compared to the pilot related to local groundwater (specific water agency production wells). The results showed that all adsorbents can remove PFAS from groundwater, but certain products showed much

longer life (reducing expected O&M costs) within each category (e.g., GAC, IX, or alternative adsorbents). For example, one of the alternative adsorbents had the longest lasting media life for PFOA removal compared to any of the other products tested. The findings underscored the benefits of performing laboratory and/or pilot testing to identify superior media since performance can be different for different water agencies (different sites / source waters) which drives cost. Generalized cost estimates to compare the range of adsorbents will also be briefly presented. Design and construction of multiple, full-scale GAC and IX systems are now underway with initial systems selecting the longest-lasting IX media for implementation.

Effect of small changes in clay content in sandy soil on recharge rates: new conclusions on planning criteria of new recharge ponds, and on the ability to rehabilitate existing ponds

Ido Negev[1], Lilach Shtrasler[1], Michal Rosenthal[1], Tamir Shechter[1] and Uri Basson[2]

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Key words: Recharge ponds; Clay content; Infiltration rates; FDEM

The Dan Region Reclamation Project (Shafdan) reclaims ~140 millions of cubic meters per year (Mm^3/year) of treated wastewater from the Tel Aviv Metropolitan area. Following secondary treatment, the effluent is recharged into a sandy aquifer for Soil Aquifer Treatment (SAT). The recharge system spans a total area of about 105 hectares comprising of 5 main basins that divided to 67 operational recharge ponds. The average infiltration rate of the basins is about 2.4±1.1 cm/hr., with significant variability between the ponds. Previous studies have shown that the *Yavne-4* basin (19.2 hectare) recharge rate is substantially lower (1.5±0.8 cm/hr) than the overall average rate, mainly due to extremely slow rates that vary between 0.5 to 1.6 cm/hr in 8 of its 12 recharge ponds. Several studies over the years have tried to determine the factors causing the low recharge rate of *Yavne-4*, and to implement different measures to improve it, yet resulted in rather limited success.

The hypothesis of this study is that the hydrological properties of the top soil layer are the prime factor affecting the recharge rate in *Yavne-4*, and that limited treatment of the top layer (up to 1.5 m) may suffice for enhancing the recharge capacity of the basin. The experiment was conducted in two adjacent representative recharge ponds, characterized by fast (2.4 cm/hr) and slow (0.5 cm/hr) recharge rates. During the first stage an extensive survey was conducted to study the planning criteria and the execution parameters of the ponds (historical survey), and to characterize the soil properties and lateral variability across the two ponds up to a depth of 6-10 meters (soil survey). The soil survey included a Multi Spectral Frequency Domain Electromagnetic (MS FDEM) to create subsurface spatial/3D Electrical Conductivity (EC) imaging, accompanied by extensive soil sampling up to a 10 m depth. The results of the soil survey strongly indicate that the only significant parameter that differs the two ponds is the cumulative silt and clay (thin-particles) content, with an average of 3.6±2.9% and 7.0±3.7% in the fast and in the slow pond, respectively. Notably, the bulk soil of both ponds is characterized as "sand" (SP-SM), and the thin-particles content meets the planning criteria.

In the on-going stage of the study (2021-2022), a field experiment is being conducted in the slow pond. The experiment is designed to test the hypothesis that the recharge capacity of the pond can be increased by replacing only the top layer of the soil up to a depth of 0.5, 1 or 1.5 m.

This study offers a new approach of applying soil survey methods for recharge ponds (MS FDEM), gaining insight into the ability of reconstructing failed ponds and the planning criteria of new recharge basins. The results of the first and second stages of the study will be presented at the conference.

10- Managed Aquifer Recharge and Water Markets

TECHNICAL PRESENTATION

1· Five years of Recharge Net Metering (ReNeM) to improve water supplies and water quality
Andrew T. Fisher, Professor of Earth and Planetary Sciences, University of California, Santa Cruz

2· Creation of a Local Non-Profit Corporation to Manage and Distribute Incentivized MAR
Keith Esplin, Executive Director, Eastern Snake Plain Aquifer Recharge (ESPAR)

3· Groundwater-energy-food nexus for sustainable management of the aquifers
Makoto Taniguchi, Professor, Research Institute for Humanity and Nature

4· Creation of Local Non-Profit Corporations for the Implementation of Incentivized Managed Aquifer Recharge
David R. Tuthill, Jr., Ph.D., P.E., Vice President, Recharge Development Corporation

5· The Costs and Benefits of Managed Aquifer Recharge
Andrew Ross, Visiting Research Fellow, Fenner School of Environment and Society, Australian National University

11th ISMAR Abstract:

Five years of Recharge Net Metering (ReNeM) to improve water supplies and water quality

Andrew T. Fisher[1], Kelli Camara[2], Galen Gorski[1,3], Araceli Serrano[1], Jennifer Pensky[1], Sarah Beganskas[1,4], Erin McCarthy[2], Michael Kiparsky[3], Luke Sherman[3], Brian S Lockwood[5], and Lisa Lurie[2]

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We report on five years of results from a Recharge Net Metering (ReNeM) program operating in the Pajaro Valley Groundwater Basin, central coastal California. The ReNeM program was designed to incentivize the development, creation, and operation of infiltration systems supplied by stormwater runoff as a means to enhance groundwater resources in an overdrafted basin. This program is unique in several ways, including providing performance-based rebates on groundwater extraction fees in exchange for enhancement to groundwater supply and quality and hydrologic system services. ReNeM shares some characteristics with groundwater banking and net energy metering, but differs in significant ways. The ReNeM program is operated as a collaboration between the University of California, Santa Cruz; the Resource Conservation District of Santa Cruz County; the Pajaro Valley Water Management Agency; and regional stakeholders who host infiltration projects. Multiple field projects are currently operating as part of the ReNeM program, with rebates issued on the basis of measured project performance, and additional site assessments are underway. This presentation will summarize program development, operation, and metrics, including net infiltration benefits and challenges encountered during creation and operation of field systems.

Creation of a Local Non-Profit Corporation to Manage and Distribute Incentivized MAR

By Keith Esplin

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Abstract: Many water distribution systems in the USA were constructed with private funds and are still privately owned. The vehicle for long term management is a non-profit corporation. Incentivized MAR (IMAR) can be managed and distributed in this same manner. Eastern Snake Plain Aquifer Recharge, Inc. (ESPAR) is an Idaho nonprofit corporation established and organized to assume legal rights and responsibilities commonly associated with canal companies for operation on the Eastern Snake Plain ("ESP"). ESPAR's focus is on obtaining surface water supplies for IMAR projects and assuring that recharged water is accrued, stored and accounted for in Aquifer Recharge Units ("ARUs") for the purpose of providing its shareholders a supplemental supply of water available for irrigation use in accordance with Idaho law; and also to provide both new and supplement supplies of water available for domestic, commercial, municipal and industrial uses in accordance with Idaho law. Membership in ESPAR requires ownership or control of ARUs. All ARU owners on the ESP are shareholders in ESPAR. This paper describes the structure and operation of ESPAR, which can readily be implemented in other locations.

Groundwater-energy-food nexus for sustainable management of the aquifers

Makoto Taniguchi
Research Institute for Humanity and Nature, Kyoto, Japan

Aquifer management is important for local and global sustainability, because of not only hydrological connectivity of recharge and discharge of groundwater for water resources management, but also groundwater-energy-food connectivity. Groundwater, energy and food are interlinked each other as nexus within and beyond the boundaries of aquifer through the productions and consumptions of food and energy.

Transboundary management of aquifer in Kumamoto, Kyushu Island, Japan has been studies on the groundwater-energy-food nexus. Groundwater is the primary water resources in Kumamoto city with 700,000 populations, which is located at groundwater discharge area of the aquifer. The groundwater is mainly recharged at the foothill of the Mt Aso, where the paddy fields with rice productions allow the groundwater recharge and water allocation without additional energy. National governmental regulation of the reduction of rice productions caused the decrease of the groundwater recharge, and then groundwater depletion in the Kumamoto city occurred. However, municipals transboundary management with tariffs could recover the synergy of the groundwater-energy-food nexus.

Abundant groundwater is also used as heat energy for melting snow in many areas of Japan. The demand of groundwater pumping for melting snow increases recently in such as Obama city, Fukui prefecture. However, the direct groundwater discharge to the ocean can bring rich nutrients and fishery productions. Therefore, there is a conflict of groundwater use between terrestrial and coastal area. Integrated model of 3-D groundwater flow, nutrients discharge by groundwater into the ocean, and primary productions in the coastal area, has been made with economic analyses for transboundary management as groundwater-energy-food nexus.

In addition to the local groundwater-energy-food nexus, groundwater footprints through the global food trade have been analyzed. Decrease of global groundwater storage by food trade was 11.8 km^3/year in 2010, and 58% of total decrease was found in Asia. Local groundwater depletion and global food trade is connected, as well as impacts of climate change. Groundwater-energy food nexus with environmental, economic, and social impacts, are considered in terms of multi-scale integrated management of the aquifers.

Creation of Local Non-Profit Corporations for the Implementation of Incentivized Managed Aquifer Recharge

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Most MAR developments around the world are sponsored or implemented by government. However, the private sector also has huge potential for MAR. Just as countless surface water dams and reservoirs have been constructed by the private sector, so can aquifers be managed to store and provide water for profit incentive. Hence, we have used the term "Incentivized MAR" (IMAR) to describe for-profit implementations. The paper prepared by Ronald D. Carlson describes the tenets of this process, and the paper by Keith B. Esplin describes successful implementation of the concept in Eastern Idaho, USA. This paper describes start-up operations of the concept in three additional areas: (1) the Wood River Basin in Idaho, (2) the Boise River Basin in Idaho, and (3) the Yakima River Basin in Washington. The paper by Kent W. Foster describes legal considerations regarding implementation of this concept in the Yakima River Basin. This paper provides guidelines for initiation of IMAR from identification of opportunities to formation of corporate entities which enable implementation. While IMAR must be conducted within the legal constructs of state and federal government, implementation by the private sector greatly expands the efficiency and opportunities to optimize utilization of the water resources in a basin through true conjunctive management of ground and surface water sources.

The Costs and Benefits of managed aquifer recharge

The financial and economic performance of MAR is a key determinant of its global uptake, but there are very few studies of the economic performance of multiple MAR schemes. These schemes show a great diversity of types, objectives and sizes, which can be matched with local hydrology, hydrogeology and demand for water storage and supply. This is reflected in the wide range of costs and benefits. A standardised conceptual approach and methodology is needed to compare and assess financial and economic aspects of MAR across diverse schemes.

This contribution builds on previous work on the financial costs of MAR, and introduces a conceptual approach and methodology for assessing the benefits of MAR schemes and deriving benefit cost ratios. This is the most complete synthesis of economic information to date of MAR case studies based on two principal measures. The synthesis includes financial costs of MAR for 40 schemes in 18 countries, including capital and operating costs combined with data on volumes of water recharged and recovered to estimate levelised costs per cubic metre of water recharged and/or recovered. A separate method for costing 3 schemes that bank water for drought and emergency supplies is based on capital costs of daily emergency supply capacity. Estimates of benefits and benefit cost ratios (BCR's) are included for over 20 case studies where this could be evaluated. Several additional schemes are expected to have very high BCR's because there are no feasible alternative sources of supply. Benefits have been estimated using a range of approaches notably the cost of the next best alternative water supply and/or water treatment and the value of production using recharged water. This is the first known synthesis of benefits and BCR's for multiple MAR projects.

The analysis shows that schemes recharging unconfined aquifers with untreated water using infiltration basins or riverbank filtration are relatively cheap. These schemes either have high measured BCR's, or there is considered to be no feasible alternative. Schemes requiring wells with substantial drilling infrastructure and/or water treatment are more expensive, but even when water requires substantial and relatively costly treatment before recharge and recovery, MAR schemes using storm water and wastewater recycling can offer substantial benefits that exceed costs. Although the MAR schemes included in this study are broadly representative of global schemes, collection of data on a larger number of projects is needed to improve coverage of some regions and MAR types. Water banking in aquifers to increase security and resilience of water supplies has very significant social and environmental benefits that are not usually accounted for in cost benefit analysis. Further analysis of these benefits would provide additional evidence to guide investment in MAR and water banking, and protection of banked water.

Keywords: financial; economic; costs; benefits; managed aquifer recharge

Acknowledgement: a majority of the case studies reported in this paper are taken from the author's contribution to the pending publication "Managed Aquifer Recharge: A Showcase for Resilience and Sustainability" funded by UNESCO and the IAH with the support of the Groundwater Solutions Initiative Policy and Practice.

11- Managed Aquifer Recharge & the Environment II

TECHNICAL PRESENTATION

1· Modeling the impact of levee setback on groundwater recharge and stream flow and temperature for ecosystem and anthropogenic needs
Andrew Calderwood, UC Davis, Foglia & Dahlke Labs

2· Managed Aquifer Recharge: A No-Regret Climate Change Adaptive Measure
Jose David Henao Casas, Tragsa-Universidad Politécnica de Madrid

3· Water Security and Integrated Water Resources Management improvements due to Managed Aquifer Recharge (MAR). Selection of case studies, characterization, benchmarking and practical recommendations.
Enrique Fernández-Escalante, Tragsa Group (Spain). Innovation SD

4· MAR for Environmental Benefit - Katarapko Freshwater Injection Trial Case Study
Russell Martin, Senior Principal Hydrogeologist, Wallbridge Gilbert Aztec, Australia

5· Agricultural Soil-Aquifer Treatment: A New Concept in the MAR Arsenal
Noam Weisbrod, Professor, Ben Gurion University of the Negev, Israel.

Modeling the impact of levee setback on groundwater recharge and stream flow and temperature for ecosystem and anthropogenic needs

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Winter snowpack and late spring stream flows have sustained California ecosystems, agriculture and populations for decades, but stream flow regimes are expected to change due to a decrease in spring snow accumulation due to rising temperatures and an expected increase in precipitation volatility. Levee setback provides an approach to reduce the loss of these stream flows by designing the setback to optimize groundwater recharge while benefiting the riparian ecosystem with seasonal floodplain inundation and reducing flood risk, creating reconciliation based managed aquifer recharge (MAR). A MODFLOW model has been developed of the lower Cosumnes River to simulate groundwater-surface interactions under variable water years and with a heterogeneous subsurface. The goal of this research is to demonstrate the impact of levee setback on groundwater recharge, baseflow and stream temperature to better understand the feasibility of levee setback as a MAR project. We hope to apply the results from the levee setback simulations to determine whether levee setback can significantly improve water availability and quality for ecosystem (e.g. juvenile fish rearing temperatures) and anthropogenic (e.g. agricultural well water) needs.

MANAGED AQUIFER RECHARGE: A NO-REGRET CLIMATE CHANGE ADAPTIVE MEASURE

Henao Casas, J. D.*[1,2].; Fernández Escalante, A. E.[1]; Ayuga, F.[2]

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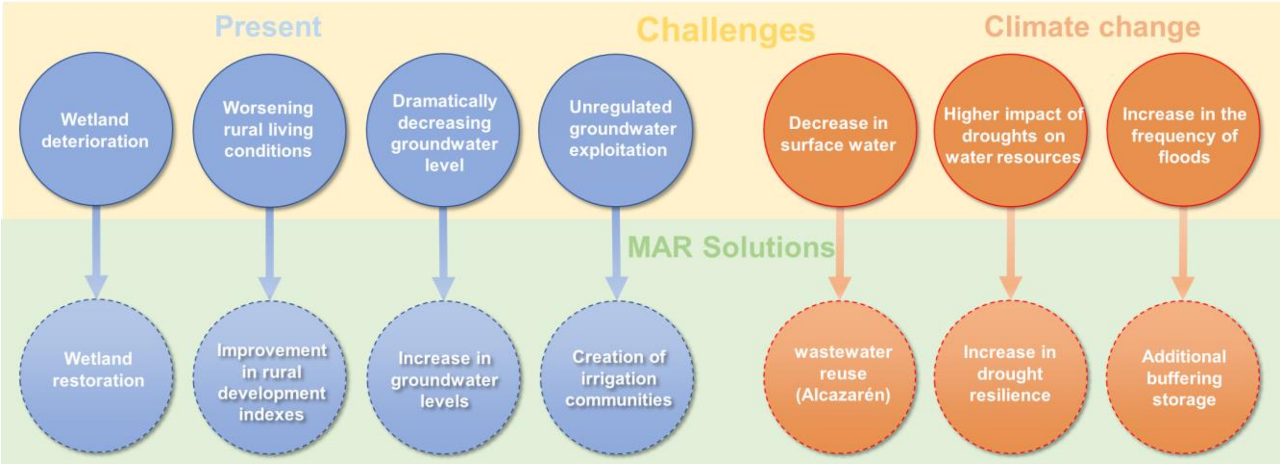
Keywords: Managed aquifer recharge, climate change, adaptation, no regret.

Two main approaches have characterised adaptation to climate change (CC) in the water resources sector. On the one hand, there is a top-down approach, in which measures are focused on the physical elements and are based on climatic models that often involve numerous assumptions and a high degree of uncertainty. On the other hand, the bottom-up approach responds to social vulnerability and focuses on historical and recent natural events, frequently disregarding the possible effects of CC. A sound bridge between both approaches are the "no-regret" adaptative measures. These measures are implemented to solve multiple challenges in the present and the future. Thus, adopting no-regret measures results in a "win-win" scenario, irrespectively of the actual unfolding of CC. This study aims to show that MAR can constitute a no-regret CC adaptive measure. To this end, we use the MAR demo site located in Los Arenales groundwater body (Spain) as an example. We show a series of challenges that the MAR sites in the study area are contributing to solving and some attributes that they have to tackle the expected impacts of CC. MAR in Los Arenales has resulted in i) the restoration of several wetlands, including one of unique geological interest; ii) the fixation of the rural population and the improvement in economic indexes, especially in the zone known as "El Carracillo"; iii) an overall increase of groundwater levels, which are particularly significant when compared to Medina del Campo neighbouring groundwater body; v) a higher degree of control on groundwater demand through the conformation of irrigation communities. In terms of proven attributes to adapt to climate change, Los Arenales demo site has shown that i) it can still be operable and enhance recharge, even if decreasing streamflow prevents the use of river water surpluses, as in the Alcazarén site, which relies majorly on reclaimed water; ii) the considerable number of MAR channels (~50 km) and infiltration ponds (19) in the area represent additional storage to accommodate extreme precipitation events; iii) MAR can lower down the detrimental effects of drought on water availability, as shown through a comparison of standard precipitation indexes (SPI) and standard groundwater indexes (SGI) between Los Arenales and Medina del Campo groundwater bodies. We demonstrate that MAR is an effective no-regret, and versatile water resources management tool, which provides solutions to several pressures at once. Furthermore, this technology proves to be adequate in complex areas with hazard drivers that include socio-economic and climatic elements, as, for instance, agricultural regions and developing countries.



Present and future challenges that have been or can be tackled by the MAR sites in Los Arenales groundwater body. The lower row circles show the specific solution to each challenge.

Co-Managed Aquifer Recharge (Co-MAR). A bottom-up approach for Integrated Water Resources Management enhancement.
Novel method employed at Los Arenales aquifer (Spain) and first results

Enrique Fernández-Escalante and Elena López-Gunn

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KEY WORDS

Co-Managed Aquifer Recharge (Co-MAR), multi-level governance, groundwater users association (CUA), space of collaboration, stakeholders, stakehomers, green solutions, Public-Private People Partnership (PPPP) and Decision Support Systems (DSS)

ABSTRACT

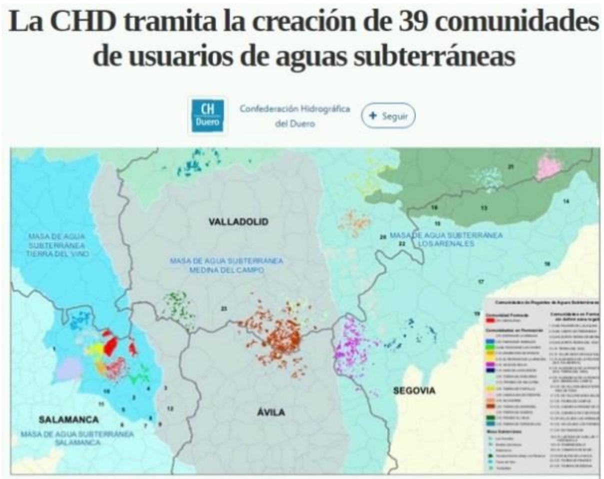
Co-Managed Aquifer Recharge (Co-MAR) is a novel concept in which the integrated water resources management techniques, including MAR, are organized with the contribution of water authorities, stakeholders/end-users, and related institutions with no direct interest in the subject (Stakehomers). This approach entails a greater contribution of groundwater users in the governance, relating MAR and multilevel governance in a participatory approach in which the whole society gets involved in water management issues by means of the creation of "spaces of collaboration". These spaces are created based on confidence for the fair use of (ground)water resources and in organizational measures with a direct influence on groundwater quality and therefore, on environmental issues and green practices. These spaces are becoming the basis for new governance schemes that are aimed to increase sensibility at the groundwater exploitation for the whole user´s collective interest, including ecosystem services and green solutions.

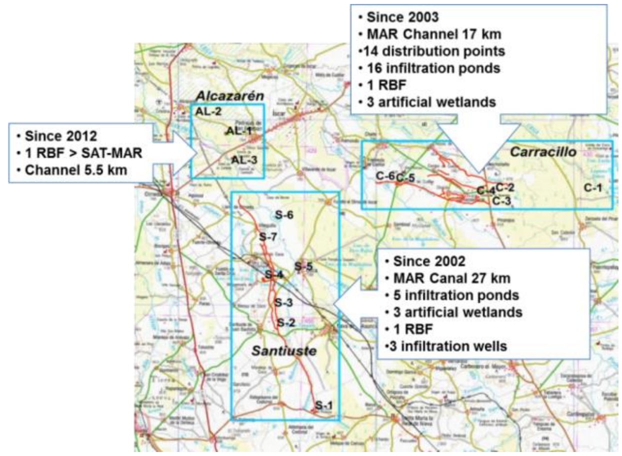
Spanish regulation requires that, for every over-exploited aquifer, responsible water authorities (CHD) must engage communities or groundwater users (CUAS), to be a unique counterpart to negotiate and reach agreements in the future management of the resources. This scheme has modified the traditional "top-down" scheme for integrated water resource management (IWRM) into a more collaborative space, in which members of the general public, in general, represented by CUAS´ Boards and external experts as stakehomers, have the possibility to propose inputs for water management regulations, assignment criteria seeking the collective benefit, controlling land-use practices, improving future water supply prospects and water quality standards for rural development, within an "environment of trust". In the case of Los Arenales aquifer, Co-MAR expects policy implications and includes a **certain control on the demand**, which is another novel issue in which end-users organize the groundwater exploitation taking into consideration not only the present but also the foreseen future resources.

The article demonstrates through real case studies at Los Arenales aquifer, with four regional-scale MAR systems and 39 CUAS how Public-Private Partnership (PPP) enhances governance and water security; and how the intervention of farmers (and the population in general) in the Decision Support Systems (DSS) are improving the application of hard and soft management measures for IWRM, taking into consideration a certain control on the demand and reserving a certain amount of the resources for green functions.

The four MAR systems closely studied are Carracillo, Cubeta de Santiuste de San Juan Bautista, Alcazarén and Medina del Campo. These locations count on Managed Aquifer Recharge (MAR) facilities, some since 2002, which provide between 22 and 25% of the total amount of water used for irrigation with quota systems for groundwater extractions. At the same time, the 39 CUAS explore MAR possibilities to be implemented in their respective areas and proposing recommendations to improve the water security, the fair distribution of the resource, and the current governance schemes.

The experience is having positive results, overall, for example with job creation and economic growth due to improved yields and productions. In addition, end-users have been able to save up to 36% in energy consumption thanks to the increase in piezometric levels. MAR is also reducing agricultural depopulation. From the experience gained, MAR has become a key element for agricultural development and water security. However, some pending issues remain and it is necessary a "shift in paradigm" in the water sector, from traditional patterns of water consumption to evolve to a circular economy approach in which wastewater resources are not considered unwanted, but rather an important asset in a context of water scarcity where MAR is an IWRM key technique.


La CHD tramita la creación de 39 comunidades de usuarios de aguas subterráneas
Confederación Hidrográfica del Duero
Seguir
VALLADOLID
MASA DE AGUA SUBTERRÁNEA TIERRA DEL VINO
MASA DE AGUA SUBTERRÁNEA MEDINA DEL CAMPO
MASA DE AGUA SUBTERRÁNEA LOS ARENALES
SALAMANCA
MASA DE AGUA SUBTERRÁNEA SALAMANCA
ÁVILA
SEGOVIA


• Since 2003
• MAR Channel 17 km
•14 distribution points
• 16 infiltration ponds
• 1 RBF
• 3 artificial wetlands
• Since 2012
• 1 RBF > SAT-MAR
• Channel 5.5 km
Alcazarén
AL-2
AL-1
AL-3
Carracillo
C-6
C-5
C-4
C-2
C-3
C-1
S-6
S-7
S-4
S-5
S-3
S-2
Santiuste
S-1
• Since 2002
• MAR Canal 27 km
• 5 infiltration ponds
• 3 artificial wetlands
• 1 RBF
•3 infiltration wells

ISMAR 2022 Abstract

MAR for Environmental Benefit – Katarapko Freshwater Injection Trial Case Study

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Organisation: [1] Wallbridge Gilbert Aztec, Australia

A major infrastructure component of the South Australian Riverland Floodplain Integrated Infrastructure Program (SARFIIP) is the construction of an extensive blocking bank to support managed inundation across the Katarapko floodplain. One of the aims of the SARFIIP program is to create an interconnected mosaic of manageable floodplains between Lock 1 at Blanchetown and the South Australian borders with New South Wales and Victoria. The intent is to improve the condition of floodplain biotic communities and to improve biological connectivity between the main River Murray channel and its floodplain environments.

However, managed inundation behind the blocking bank presents some risks including displacement of the shallow saline groundwater, driving it toward the river, increasing the salinity risk to healthy vegetation located between the blocking bank and river. Additionally, vegetation between the blocking bank and river currently exhibiting signs of salinity impacts would not benefit from the periodic inundation that would occur behind the blocking bank.

A freshwater injection trial (FWIT) has been completed to gauge the potential for managed aquifer recharge (MAR) to be used as a mitigation method to preserve and expand the existing freshwater lenses and mitigate displacement of saline groundwater resulting from inundation behind the blocking bank. Vegetation response monitoring, soil salinity monitoring and surface geophysics have been undertaken in parallel with the injection trial. The results of these investigations are provided in separate reports prepared by the respective researchers. This report presents the results of the proof-of-concept of injecting river water into the floodplain using MAR approaches to enhance existing or establish new freshwater lenses and the response of the groundwater system.

Two previous attempts to establish MAR as a water management option of the floodplain met with limited success due to site locality, source water and receiving water quality. The source water is highly turbid and algae rich and the receiving groundwater environment is hypersaline , greater than 56,000 micro-Siemens per centimetre (35,000 mg/L). The FWIT trial on the Katarapko floodplain demonstrated that a properly installed and operated MAR system can successfully develop and maintain a fresh groundwater lens. Over 114 days of operation, at an average rate of 1 litre per second, 2,500 cubic meters of water sourced from Katarapko Creek was recharged resulting in the development of a freshwater lens with a salinity of less than 5,000 micro siemens per centimetre (µS/cm) approximately 6 m thick and 40 m in diameter. Supporting vegetation and soil monitoring plus surface geophysical studies were used to independently verify the success of the trial.

This case study presents the challenges and lessons learned from the trial in a challenging hydrogeological setting and the proof-of-concept trial demonstrated that the MAR system does not need to be complex, the infrastructure can have a small footprint, and the lens established with relatively small volumes of water. Once established, the freshwater lens can be maintained without significant decay at salinities less than 5,000 µS/cm for extended periods. The success of this trial lay in the initial characterisation of the source water and the target aquifer, low injection rates and the adoption of stepwise approach to trial various combinations of pre-treatment options and supporting infrastructure. As opposed to installing a large and costly treatment system, a bespoke system was designed to be consistent with the secondary trial objectives, such as; ensuring that any future scheme could be reliably installed and operated in an environmentally sensitive and remote area with limited infrastructure minimal operator intervention and small footprint.

Abstract - Agricultural Soil-Aquifer Treatment: A New Concept in the MAR Arsenal

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Water is a limiting factor for economic and social development in most arid and semi-arid regions globally. Increasing stresses on groundwater and subsequent overdrafts have sparked the development of deliberate aquifer recharge technologies, known as managed aquifer recharge (MAR). Soil aquifer treatment (SAT) is a unique MAR practice used to recharge groundwater storage through intermitted percolation of wastewater effluent in designated infiltration basins. Often, land availability for SAT infiltration basins is a limiting factor. As a result, SAT systems face with an increase in effluent volumes meant for recharge. In our study, for the first time, we explore the feasibility of flooding an agricultural plot with treated wastewater (TWW) as an alternative for additional infiltration area for SAT, a practice named agricultural soil aquifer treatment (Ag-SAT). Citrus trees were planted in two different agricultural setups, one on flat soil and the other atop a ridge. Two winter and one summer flooding experiments were conducted. Volumetric water content and oxidation-reduction conditions were monitored continuously. Concurrently, water samples were collected and analyzed for diverse chemical properties. Prior and following the flooding events, leaf health measurement where conducted and were compared to an adjacent control plot, planted at the same time, where no TWW was applied. Results obtained demonstrate that in terms of water quality and root zone aeration the ridge is the superior setup. This study demonstrates that using agricultural plots as recharge basins for SAT is a cost-effective way to supplement permanent recharge basins while having no negative impact on trees' health.

12- Poster Session

13- TECHNICAL PRESENTATION

1 MAR as a tool to mitigate aquifer over-exploitation: insights from Los Arenales aquifer (Spain).
Henao Casas, J. D.; Fernández Escalante, A. E.; Ayuga, F.

2 Monitored Intentional Recharge (MIR). Methodological approach and guidelines
Enrique Fernández-Escalante, José David Henao Casas & Jon San Sebastián Sauto*

3 The use of MAR to improve water security and rural development. Arabayona demo-site using drainage wnater sources, Salamanca, Spain.
Enrique Fernández-Escalante. Tragsa Group (Spain), IAH MAR Commission

**4 Repurpose and recharge. Coordinating MAR and land repurposing to reduce domestic well vulnerability.
Pasner, Yara; Kourakos, giorgos; Fogg, Graham & Dahlke, Helen.

5 Identification of the main natural and anthropic variations affecting coastal SAT systems – example of the Agon-Coutainville SAT (France).
Guillemoto, Q. (BRGM); Picot-Colbeaux, G.; Valdes, D.; Pettenati, M.; Neyens, D.; Mouchel, J.M. and Kloppmann, W.

6 Feasibility of Managed Aquifer Recharge on Grand Bahama Island
Klausner, Sophia (Univ. Munich); Imig, Anne; Rein, Arno & Welsh-Unwala, Kristen.

7 A 3D numerical groundwater flow model to assess the feasibility of managed aquifer recharge (MAR) in the Tanne River Basin ofGhana.
Boansi Okofo, Louis. (Brandenburg Univ. Of Technology).

MAR AS A TOOL TO MITIGATE AQUIFER OVER-EXPLOITATION: INSIGHTS FROM LOS ARENALES AQUIFER (SPAIN).

Henao Casas, J. D.[1,2].; Fernández Escalante, A. E.[1]; Ayuga, F.[2]

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Keywords: Managed aquifer recharge (MAR), hydrogeostatistics, trend analysis, groundwater levels.

Irrigation agriculture in some areas around the globe has resulted in significant aquifer intensive exploitation of groundwater. A notable example of this problem can be found in Los Arenales aquifer (Castile and Leon, Spain), which witnessed staggering groundwater level declines in the last quarter of the XX century. Potential solutions to overexploitation in this area and beyond include the conjunctive use of groundwater and surface water, the increase in water use efficiency and the deployment of managed aquifer recharge (MAR) schemes. The scope of this study is to elucidate the contribution of MAR to reverse groundwater overexploitation in this aquifer. To this end, we compare two neighbouring and analogous groundwater bodies within Los Arenales aquifer, namely Medina del Campo (MC) and Los Arenales (LA), whose primary difference is three large-scale MAR sites in the latter water body. The comparison is carried out employing the Mann-Kendall test and Theil-sen estimator for slope analysis and an empirical approach to assess field significance. Additionally, we utilise a cross-correlation evaluation among groundwater levels, precipitation, and intentional recharge to account for considerable aquifer heterogeneity. The computation of average groundwater levels and the exploration of agricultural and climatological time series complement the statistical analysis. The slope analysis reflects the dramatic drop in groundwater levels in both water bodies between 1985 and 2001, with slope strengths in the order of -1.5 m/y. The subsequent periods analysed (i.e., 2002-2011, 2012-2020) show a substantial improvement of groundwater availability in LA and marginally in MC. No field significance was detected in the study area for any of the entailed periods. The analyses of average groundwater levels and other time series of interest demonstrate that MAR very likely accounts for the difference in groundwater storage recovery between LA and MC. Furthermore, the same analysis highlights that additional policies and initiatives besides MAR are responsible for increasing groundwater levels in the area. The research conducted proves the effectiveness of MAR as a tool to combat aquifer over-exploitation. Still, it stresses that MAR must be accompanied by other measures, including integrated water resources management and demand control to achieve sustainable groundwater usage.

Monitored Intentional Recharge (MIR). Methodological approach and guidelines

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KEY WORDS
Monitored Intentional Recharge (MIR), Managed Aquifer Recharge (MAR), guidelines, regulations, water quality standards, artificial recharge, Maximum Allowable Concentrations (MACs), monitoring.

ABSTRACT
The guidelines for the implementation of MAR projects are scarce, and most of the technicians and practitioners are using the Australian Guidelines from 2009 and the ASCE ones from 2020. There are some drafts from the European Commission, 2018; and the most employed in developing countries are the WHO standards from 2006. Some important lessons and recommendations have derived from the analysis of 18 different regulations, guidelines, and operator rules, proceeding from the five continents. Also, intentional recharge with reclaimed water (SAT-MAR) is meeting severe constraints to be implemented. Any adapted multi-barrier and multi-level approach should consider not only hydrogeochemical criteria but rather the whole MAR-related aspects from both, technical and organizational approaches.

Within this context, Monitored Intentional Recharge (MIR) acquires whole sense in the implementation of MAR systems, considering inbuilt system control, mechanism tests, monitoring systems for groundwater, surface water, and risks/impacts assessment. The operation between the temporary allowance and the full operational permit must be under permanent control.

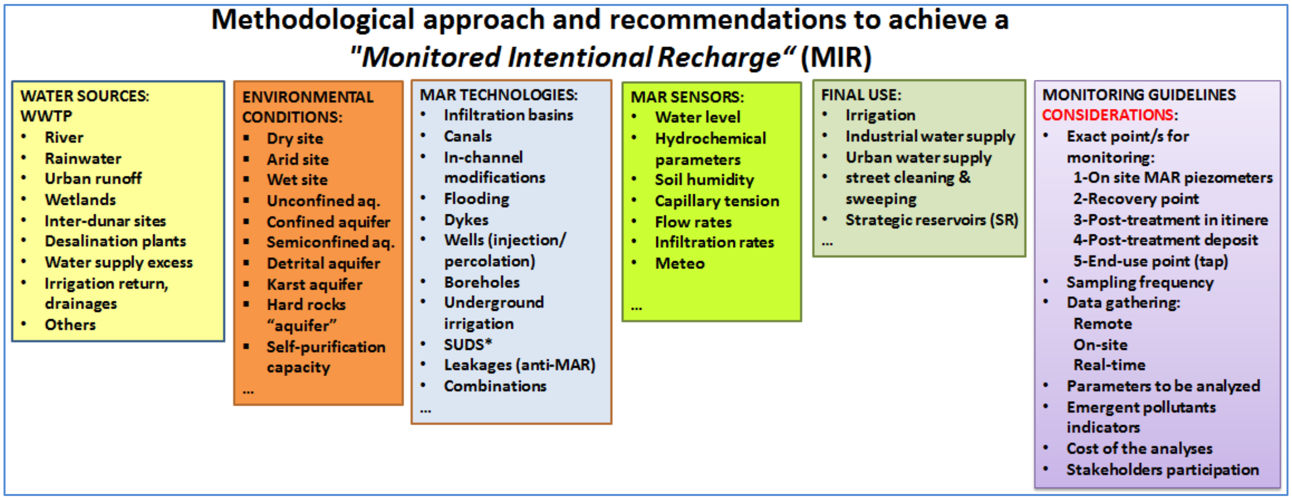
Nowadays, it is necessary to establish the basis for future guidelines, at least for the European Union. Among these MAR features, the most remarkable to have into consideration may be:
-Water sources or origin of the water to be "*MARed*" (e.g. treated wastewater, river water, rainwater, etc.)
-The environmental conditions in which MAR activities take place (climate, type of aquifer, materials, and self-purification capacity of the receiving mediums).
-The MAR technologies and systems (taking into consideration the soil and the aquifer beneath, e.g. basins, canals, wells…).
-The sensors used for monitoring and tracking the evolution of the system (water table, specific quality parameters, aggregated water quality indicators, flow rate, humidity, etc.)
-The final use of the water once recovered (e.g. irrigation of crop-lands, urban water supply, positive hydraulic barriers against seawater intrusion, etc.)
-The guidelines for monitoring the water evolution (in both, quantity and quality) and the consequent water security, food safety, and public health, i.e. the exact point of monitoring, the sampling frequency, the data gathering system (remote, on-site, in real-time), the set of parameters to be analyzed, the database structure under standardization, interoperability and ontologic criteria, the track of indicators for emergent pollutants, the cost of the analyses and the degree of involvements of end-users and stakeholders in the process (Co-MAR), etc.

This paper sheds some light on the guidelines-making process so that they count on scientific and legal assessment (including SAT-MAR), proper monitoring… to meet the water security requirements at aquifer scale counting on water quality standards for MAR.

Finally, some recommendations to assist decision-makers in the regulatory and operational frameworks regarding MAR guidelines are:

-A common terminology must be adopted for all the countries using the proposed guidelines, e.g. at the European level.
-Every multi-barrier and multi-level approach should be "aquifer-wide". Common regulations cannot be valid for a country with several aquifers with different properties.
-Distinction must be addressed depending on hydrogeochemical criteria, i.e. the source of water, the aquifer characteristics, the system of recharge, and the final use. Different Maximum Allowable Concentrations (MACs) may apply for each case.
-There is a need for legal guidelines development to acquire a mandatory character.
-Tailor-made water quality standards and MACs should be assessed for each case based on the previous criteria.
-Authorizations for MAR and SAT-MAR systems must be based on a technical background using the proposed guidelines. After a consensus process, the rules for water and environmental authorities to grant permission should be established, common for all the states sharing the guidelines.

-Control and surveillance mechanisms independent from water authorities would be an asset.
-An aquifer-scale risk assessment system should be included in the guidelines for each MAR regulation.
-The stakeholder´s involvement and a bottom-up approach in decision-making add value to the policy process.
-It is important to count on economic and legal feasibility in the implementation programs.
-Early-MAR countries usually adopt the WHO guidelines when MAR activities are developed, especially regarding water quality.
-The guidelines might pursue dialogue, a consensus, final agreement and to be specifically adapted for each site.



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

Enrique Fernández-Escalante

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KEY WORDS
Water security (WS), Managed Aquifer Recharge (MAR), rural development, drainage, Arabayona, Cantalpino.

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

This sector was formerly occupied by wetlands, which were desiccated since the 80ths, for rural development and enhancement of the economic activity in a depressed area. Since then, there is a structural and endogenous problem, since part of the irrigable land in this sector has limited irrigable lands and their natural drainage is limited too, mainly due to their topographical situation, the soil composition, and the presence of the phreatic level very close to the surface. These constraints lead to excessive water-related problems due to the surface and underground puddling, causing root asphyxia, loss of harvest, difficulties to work, etc.

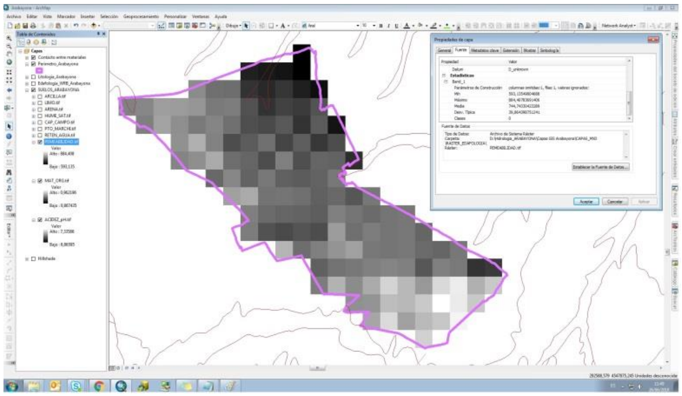
The most remarkable fact has been the reuse of the water collected through drains for a MAR canal constructed reusing a previous stream (currently dried), to recharge a different area of the aquifer with appropriate characteristics for MAR. Therefore MAR has become a complementary technology to store a fraction of "nuisance" subsurface water surpluses in the aquifer. It covers a double objective, on the one hand, it has become a component of the integrated management or water resources in the area, and on the other, it is a water security element to increase the success of the agricultural activity.

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

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

Once studied the plot drainage needs as well as the design of the main and secondary sewers to facilitate the evacuation of the excess water utilizing both, natural and artificial drainage networks in the area, MAR is contributing to rural development as a component of the local IWRM system. It includes an infiltration canal at the end of the irrigation network with a double function: to increase the water security and to reuse a volume of (ground)water that, otherwise, would abandon the system or will remain to flood the soils and affecting negatively the agricultural activity. The MAR canal recharges a neighbor part of the aquifer with a capacity to store and reuse the previously nuisance volume of water, with a flow rate between 2 and 5 l/s depending on the period.

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



Location: https://www.google.es/maps/@41.0291389,-5.3322165,6573m/data=!3m1!1e3

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

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Managed aquifer recharge (MAR) systems are often applied to coastal area to limit seawater intrusion and improve water quality for irrigations purpose (Tzoraki et al., 2018) or drinking water purpose (Van Houtte and Verbauwhede, 2012). These MAR systems are integrated into the hydrosystem in which groundwater flows may be subject to variations caused by meteorological events and tides, but also by human activities such as secondary treated wastewater (STWW) discharges from wastewater treatment plants (WWTP). These natural and anthropic activities could influence groundwater flow velocities and hence the efficiency of the MAR system, notably when it is combined to Soil Aquifer Treatment (SAT).

In this study, we have identified the environmental and human forcing factors influencing the SAT system implemented in Agon-Coutainville (Normandy, France), which is part of the full-scale operational WWTP sustainably integrated within the municipal wastewater treatment line since 14 years along the English Channel coast. The STWW discharge of ~1600m^3/day is infiltrated alternatively into three natural reed bed areas of 35000 m^2 before reaching the sand dune aquifer. The direct discharge of STWW to the sea is avoided to guaranty the sustainability of the shellfish production and preserve the touristic economy along the coast (Picot-Colbeaux et al., 2021).

To identify major natural and anthropogenic forcing factors driving this SAT system, time series analyses were carried out on environmental data such as sea tides, natural recharge estimated by Potential Evapo-Transpiration (PET) and rainfall records, STWW flow discharge in the three infiltrations pounds. The same analyses were carried out on groundwater level and electrical conductivity monitored in several observation wells. Then, these results were compared/correlated to give evidence of the impact of each factor in this SAT system.

The results show that all groundwater levels and electric conductivity are influenced by natural recharge but also locally by sea tides and STWW flows. A spatial information of the main forcing effects on groundwater is highlighted. Annual variations of natural recharge affect all the observation wells. STWW daily flow effects are identified on the closest piezometers of the infiltrations pounds. Relationship between STWW flow and natural recharge is also identified especially during winter periods showing that a large part of parasitic water was drained through sewer system, which have increased STWW flows in the SAT system. For tides, important monthly and/or diurnal effects are identified on the infiltration pound closest to seashore.

These results demonstrate that several environmental forcing factors affect the studied MAR/SAT system, potentially jeopardizing its efficiency. We hypothesized that changes in ; water level from natural recharge and STWW flow could modify vadose zone thickness, affecting groundwater flows and geochemical processes, as well for seawater intrusion.

A proposed methodology for identifying the feasibility of Managed Aquifer Recharge in Grand Bahama

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A large storm surge during Hurricane Dorian in 2019 resulted in saltwater intrusion to the aquifers of Grand Bahama Island, causing 40% of the water supply to become brackish with no or slow recovery to date. The potential of managed aquifer recharge (MAR) for the mitigation of the overwash-induced saltwater intrusion, as well as freshwater supply was evaluated.
A methodology adapted to data scarcity was developed to assess the MAR feasibility on the island. Six main steps were considered and brought in form of a decision tree: (i) determination of water demand, (ii) analysis of suitable aquifers for storage and recovery, (iii) identification of water source for recharge, (iv) selection of a suitable MAR type, (v) risk assessment related to the chosen MAR type and the final step (vi) the selection of the most suitable location for the MAR scheme. If the steps 1-3 and 5 generated a negative evaluation, we suggested extending the study area or stopping the investigation. Whereas if all steps could be followed and resulted in a positive evaluation, we considered MAR to be feasible for the study site.

For our case study, water demand was distinguished as the need for brackish water supply replacement and saltwater intrusion mitigation. Grand Bahama's shallow freshwater lens aquifers in karstified carbonates have good infiltration and storage capacities. The only available source water for MAR schemes was identified to be rainfall, as no surface or wastewater is available in sufficient quantity on the island. These results let us conclude that runoff harvesting from sealed surfaces in urban areas combined with infiltration trenches could be a feasible MAR scheme. A qualitative risk assessment indicated that, despite the identified risk treatments options, the major remaining risks are lack of funding and public acceptance. The present saltwater intrusion is in a low lying area. We considered MAR not applicable for saltwater mitigation on Grand Bahama, because of the reoccurring flood risk. Nevertheless, rooftop rainwater harvesting with drain trenches was found to be a sustainable, complementary option to Grand Bahama's water supply. Added benefits of the suggested MAR scheme include reduced urban flood risks and protection of the vulnerable fresh groundwater resources facing climate change and overconsumption. As a further step, we suggest the assessment of groundwater flow paths on the island to help understand suitable recharge locations in more detail and identify further potential MAR sites.

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

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In the Tamne River basin of Northern Ghana, surface waters are usually limited, and the available water is under constant threat due to the semi-arid nature of the area. Groundwater from the Tamne Plutonic Suite aquifers serves as the main source of water supply for the people. However, there are reported cases of declining water levels in the area mainly due to increasing population pressures and global climatic changes. There are occurrences of flooding every rainy season, but little water for use during the dry season. This has affected the livelihoods of the farmers and agricultural food production in the area.

A groundwater flow model was set up to assess the feasibility of managed aquifer recharge in the basin. For this, MAR injection and abstraction scenarios were tested to determine the maximum amount of recharge and abstraction rate. The injection was carried out using the available floodwater (40,000 m^3) that is stored during the rainy season in the area. The results show that the total volume of water injected at the end of the 4 months is 11,000 $m^{3/}$day (approximately 1.3 X 106 m^3), which significantly increases aquifer storage and groundwater levels. The abstraction scenario indicates that the volume of water that is abstracted at the end of the 8 months after MAR injection is 5968.09 m^3/day (approximately 1.4 X 106 m^3). This volume of water recovered is enough for domestic and irrigation purposes during the dry season. In general, MAR is feasible in the area when irrigation and domestic withdrawals are regulated.

This approach, when implemented, would bolster agricultural activities, especially during the dry season. This would improve the economic fortunes of the people who will get all-year-round water for irrigation farming. The developed model will help stakeholders and decision-makers to manage the limited water resources in the region.

13-Managed Aquifer Recharge Engineering and Design III

TECHNICAL PRESENTATION

1· Effect of small changes in clay content in sandy soil on recharge rates: new conclusions on planning criteria of new recharge ponds, and on the ability to rehabilitate existing ponds
Ido Negev, Chief Hydrologist, Mekorot National Water Company

2· ASR Well Hydraulics: The 'Balloon Effect' Revisited
David Pyne, President, ASR Systems

3· Soil and infrastructure suitability for managed aquifer recharge with recycled water
Sarah Paschal Gerenday, PhD candidate, University of California Santa Barbara

4· Optimizing MAR in coastal dunes by abstracting brackish groundwater: preliminary results of a field pilot in the Netherlands
Teun van Dooren, Scientific Researcher Hydrogeology, KWR Water Research Institute

5· Depth-Specific Testing Methods for Water Bank Recovery Wellfield Design
Timothy Leo, Principal Hydrogeologist & Vice President, Montgomery & Associates

Effect of small changes in clay content in sandy soil on recharge rates: new conclusions on planning criteria of new recharge ponds, and on the ability to rehabilitate existing ponds

Ido Negev[1], Lilach Shtrasler[1], Michal Rosenthal[1], Tamir Shechter[1] and Uri Basson[2]

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Key words: Recharge ponds; Clay content; Infiltration rates; FDEM

The Dan Region Reclamation Project (Shafdan) reclaims ~140 millions of cubic meters per year (Mm^3/year) of treated wastewater from the Tel Aviv Metropolitan area. Following secondary treatment, the effluent is recharged into a sandy aquifer for Soil Aquifer Treatment (SAT). The recharge system spans a total area of about 105 hectares comprising of 5 main basins that divided to 67 operational recharge ponds. The average infiltration rate of the basins is about 2.4±1.1 cm/hr., with significant variability between the ponds. Previous studies have shown that the *Yavne-4* basin (19.2 hectare) recharge rate is substantially lower (1.5±0.8 cm/hr) than the overall average rate, mainly due to extremely slow rates that vary between 0.5 to 1.6 cm/hr in 8 of its 12 recharge ponds. Several studies over the years have tried to determine the factors causing the low recharge rate of *Yavne-4*, and to implement different measures to improve it, yet resulted in rather limited success.

The hypothesis of this study is that the hydrological properties of the top soil layer are the prime factor affecting the recharge rate in *Yavne-4*, and that limited treatment of the top layer (up to 1.5 m) may suffice for enhancing the recharge capacity of the basin. The experiment was conducted in two adjacent representative recharge ponds, characterized by fast (2.4 cm/hr) and slow (0.5 cm/hr) recharge rates. During the first stage an extensive survey was conducted to study the planning criteria and the execution parameters of the ponds (historical survey), and to characterize the soil properties and lateral variability across the two ponds up to a depth of 6-10 meters (soil survey). The soil survey included a Multi Spectral Frequency Domain Electromagnetic (MS FDEM) to create subsurface spatial/3D Electrical Conductivity (EC) imaging, accompanied by extensive soil sampling up to a 10 m depth. The results of the soil survey strongly indicate that the only significant parameter that differs the two ponds is the cumulative silt and clay (thin-particles) content, with an average of 3.6±2.9% and 7.0±3.7% in the fast and in the slow pond, respectively. Notably, the bulk soil of both ponds is characterized as "sand" (SP-SM), and the thin-particles content meets the planning criteria.

In the on-going stage of the study (2021-2022), a field experiment is being conducted in the slow pond. The experiment is designed to test the hypothesis that the recharge capacity of the pond can be increased by replacing only the top layer of the soil up to a depth of 0.5, 1 or 1.5 m.

This study offers a new approach of applying soil survey methods for recharge ponds (MS FDEM), gaining insight into the ability of reconstructing failed ponds and the planning criteria of new recharge basins. The results of the first and second stages of the study will be presented at the conference.

ASR Well Hydraulics: The 'Balloon Effect' Revisited

David Pyne, President, ASR Systems
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Over 40 years of ASR experience has shown that well hydraulics during recharge and pumping are different. Whether that difference is significant for groundwater modeling and ASR design remains to be seen. The specific capacity during pumping, SCp, is typically measured in gallons per day per foot of drawdown or equivalent metric units. The specific capacity during injection, SCi, is typically less than the SCp. Injection hydraulics are typically unknown at the time the well equipping and wellhead facilities are designed, so reasonable assumptions have to be made regarding injection pressures and flow rates. For recharge into unconsolidated, sand and gravel, confined aquifers the injection specific capacity, SCi, is typically within a range of 30% to 80% of the SCp. Also, recharge flow rates tend to be lower than pumping flow rates. For ASR applications into consolidated, confined aquifers, the typical SCi range is 70% to 100% of the SCp. An 80% ratio may be assumed until data is available.

A plausible reason for the difference in hydraulics during recharge and pumping is known as the « Balloon Effect. » It is easier to let the air out of a balloon than to inflate it. During injection the required pressure increase is trying to lift any overlying confining layer. For two ASR sites, one in England and one in Australia, a small but measured increase in land elevation was noted close to the ASR well during injection, disappearing as soon as injection ceased.

Continuous, minute-by-minute, operating data from an ASR site at New Braunfels, Texas, in a brackish, confined, limestone aquifer included 21 changes in operating mode from recharge, to cessation of recharge, to pumping, and cessation of pumping during a period of two years. Nine data sets were selected for AQTESOLV analysis to determine variability in calculated transmissivity, storativity and leakance between recharge and pumping. While all leakance values were low, those during recharge were lower than those during pumping. A working hypothesis is that this reflects gravity. Analysis of comparable data sets from other ASR sites globally is suggested, supporting a proposed paper to be presented at ISMAR 12 in Capetown, South Africa in 2025, regarding the balloon effect. Co-authors and participants welcomed !

Soil and infrastructure suitability for managed aquifer recharge with recycled water

Sarah Paschal Gerenday[1], Debra Perrone[2], Jordan Clark[1]

California's Central Valley is a highly productive agricultural region which is reliant on groundwater to meet demand. A history of unregulated groundwater pumping has left the basin in overdraft, with 21 out of the Valley's 45 subbasins considered high priority and 11 critically overdrafted. One potential strategy for working towards groundwater sustainability is through managed aquifer recharge (MAR) using recycled water. Identifying suitable areas for recycled water MAR requires consideration of soil suitability, compatibility of existing land uses or land covers, proximity to a source of recycled water, and protection of drinking water sources. Drinking water quality protection is one of the more challenging criteria to satisfy, as it depends on local groundwater flow. Title 22 of the California Code of Regulations requires a minimum subsurface residence time of six months before recycled water used for MAR reaches a water supply well. In order to identify areas where recycled water MAR can comply with this regulation, we identify all of the water supply wells in the Central Valley based on well completion reports. We then use backwards particle tracking to delineate buffer zones within which water recharged at the surface would arrive at the wells prior to completing its required residence time. Areas outside of these buffer zones are determined to comply with Title 22 requirements and are ranked according to their relative suitability for recycled water MAR in terms of physical properties and recycled water availability. This analysis allows Groundwater Sustainability Agencies and other water managers to evaluate the feasibility of meeting recharge goals with recycled water within their jurisdictions and will assist in selecting sites for future MAR projects.

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Optimizing MAR in coastal dunes by abstracting brackish groundwater: preliminary results of a field pilot in the Netherlands

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As the demand for fresh water in coastal areas continues to grow, available groundwater resources are under increasing strain by overexploitation and sea water intrusion. Managed aquifer recharge (MAR) of fresh water as well as abstraction and subsequent desalination of brackish groundwater can be implemented to increase freshwater availability in coastal areas. Combined, abstraction of brackish groundwater may help optimize MAR by increasing the storage capacity for fresh water and by limiting salinization during recovery of infiltrated fresh water. To investigate the potential and optimization of this combined application, a field pilot was set up at a drinking water production site in the coastal dunes near Scheveningen, the Netherlands. Here, the application of MAR involves the infiltration of pretreated water from the river Meuse through artificial infiltration basins and subsequent abstraction by groundwater wells. For the pilot, a multi-screened abstraction well for brackish groundwater was installed, along with an additional abstraction well for fresh groundwater, multiple monitoring wells, and a facility for collection and desalination (reverse osmosis; RO) of the abstracted brackish groundwater.

Prior to the pilot, a numerical modelling study has been performed to assess the hydrogeological effects of the pilot. Moreover, a pumping test was performed with the abstraction wells for brackish and fresh groundwater directly after realization of the well field. The results of this test were used to calibrate the numerical groundwater model. Based on the pumping test and the numerical model, no significant effects on the phreatic groundwater system are expected during operation of the pilot. Furthermore, abstraction of brackish groundwater is expected to cause a downward shift of fresh groundwater, but also an upward shift of more saline groundwater, i.e. an increased thickness of the infiltrated freshwater lens and a narrowing of the brackish groundwater zone.

The pilot itself will commence early in 2022 and will run for three consecutive years. During the pilot, brackish groundwater is abstracted at an approximate depth of 90-110 meters with a continuous rate of 50 m^3/h. The hydrogeological effects of the pilot and the dynamics between fresh, brackish and saline groundwater are monitored using a range of techniques, including piezometers, electrical conductivity sensors, geohm-cables and geophysical borehole measurements. In the last year of the pilot, the abstraction well for fresh groundwater will periodically abstract fresh groundwater to manipulate the position of the interface between fresh and brackish groundwater, which will be closely followed by the monitoring setup.

The pilot will help increase our understanding of the interaction between fresh and brackish groundwater and to gain operational experience with abstraction and purification of brackish groundwater. Moreover, numerical groundwater models will be calibrated and validated to understand the observed effects in more detail during the pilot and to generically predict conditions, effects and performance for a large scale combined implementation of brackish groundwater abstraction and MAR in coastal areas. The combination of MAR and brackish groundwater abstraction is aimed to secure future water supply in the southwest Netherlands and the results of the pilot may serve as an example for advanced groundwater management in coastal areas worldwide. The results presented at ISMAR11 will comprise the results obtained during the first months of the pilot, as well as the monitoring and modelling results obtained in the preparatory phase.

Keywords: Brackish groundwater abstraction, desalination, drinking water supply, MAR, COASTAR

Abstract

Depth-Specific Testing Methods for Water Bank Recovery Wellfield Design

Timothy Leo, P.G., Justan Bell, and Mark Cross, P.G.

Montgomery & Associates

A new large-scale water banking and recovery project is being constructed to improve regional water supply reliability during dry periods. The project goal is to store over 200,000 acre-feet of surface water during multi-year recharge periods and recover this water during subsequent multi-year dry periods using a recovery wellfield. Preliminary groundwater modeling suggests the recovery wellfield will comprise 25 to 30 high-capacity wells. The recovered water will be delivered back to the conveyance system and must meet water quality requirements.

A hydrogeologic field exploration program is being conducted to develop necessary data to design the recovery wellfield. Four pilot recovery wells were constructed and tested during the field program. Results of drilling and testing will be used to update and recalibrate the groundwater flow and water quality model. The model will be used to design an optimized recovery wellfield that meets recovery objectives while minimizing wellfield capital and operating and potential water treatment costs.

A critical testing program objective is to understand how both groundwater quality and aquifer hydraulic conductivity change with increasing depth in the aquifer. To achieve this objective, zonal testing and sampling were conducted during drilling of the four pilot recovery wells to support recovery well design, and static and dynamic spinner flowmeter logging was conducted in the completed wells. Data from both testing methods were compared to evaluate the benefits and tradeoffs of conducting these comprehensive and expensive testing methods. Results of this comparison were used to optimize depth-specific data acquisition during future recovery wells installation.

14-Managed Aquifer Recharge Modeling I

TECHNICAL PRESENTATION

1· Strategizing Recharge in Complex Settings by Optimization of Recycled Water Injection
Chin Man W. Mok, Principal and Vice President, GSI Environmental Inc.

2· Assessing predictions' uncertainty at a multi-source Managed Aquifer Recharge site using stochastic modelling: the Menashe System, Israel
Daniel Kurtzman, Sub-surface Hydrology Researcher, Institute of Soil, Water and Environmental Sciences, Agriculture Research Organization – Volcani Institute, Israel

3· A novel analytical approach to calculating groundwater recharge through the vadose zone
Morteza Sadeghi, Water Resources Engineer, California Department of Water Resources

4· Using Groundwater models to support Sustainable Groundwater Basin Management in California's Monterey Bay Region
Pascual Benito, Senior Hydrogeologist, Montgomery & Associates

5· Water Availability Analysis for California Water Rights Permitting
Shelby Witherby, Water Resources Control Engineer, CA State Water Resources Control Board

Strategizing Recharge in Complex Settings by Optimization of Recycled Water Injection

Chin Man W. Mok, Barbara A. Carrera, Hiroko M. Hort, Lauren M. Santi, Anthony D. Daus, and Sorab Panday (GSI Environmental Inc.) and Everett Ferguson (Water Replenishment District of Southern California)

Inland injection of advanced treated recycled water at rates up to 4 MGD is being planned to recharge the southern West Coast Basin in southern California. An optimization model was constructed to select the injection locations/zones and rate schemes that minimize the total cost of installing the injection wells and connection to infrastructure. The cost depends on the number of injection wells, their locations, depths, injection rates, and proximity to existing recycled water transmission pipelines. Infeasible injection areas were specified as institutional constraints to well siting. Potentially feasible injection areas were classified as available land either without cost or with associated acquisition costs. Maximum injection capacity was imposed as a constraint. In addition, optimization constraints were set by limiting the injection impacts in areas within the influence of existing groundwater production wells, sites with known groundwater plumes, and existing seawater intrusion barrier injection wells. The recycled water injection impacts were assessed using a simplified existing MODFLOW model. The customized optimization tool was written in Python and linked with EXCEL spreadsheets, GIS files, and the MODFLOW model as input and output interfaces. Two robust optimization algorithms, the Differential Evolution and Artificial Bee Colony methods, were incorporated to cross-validate the optimized solutions. The developed tool is able to find a solution for the specified injection rate that minimizes cost given the complex implemented criteria. can be readily scaled and flexibly adopted for other recharge projects.

Assessing predictions' uncertainty at a multi-source Managed Aquifer Recharge site using stochastic modelling: the Menashe System, Israel

German Rudnik[1,2], Avinoam Rabinovitch[2], Hagar Siebner[3], Yoram Katz[4], Daniel Kurtzman[1]

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Abstract. Managed aquifer recharge (MAR) and seawater desalination are both widely used practices, aimed to provide water security in arid and semi-arid regions. Since the 1960s, Menashe Streams MAR site in Israel, provides a cost-efficient subsurface storage solution for runoff water that otherwise would be lost to the sea. In 2015, it became a double-source MAR site, since post-treated reverse-osmosis desalinated seawater (DSW) is recharged, in addition to ephemeral stream's runoff.

We use two years of field data of heads and tracer concentration (stable water isotopes) to validate a 3D transient flow and conservative transport model, which we then apply in a stochastic approach to predict long-term DSW spreading in the unconfined, heterogeneous aquifer within the proximity of the MAR site.

The uncertainty of the predictions of groundwater heads and fraction of DSW in selected locations in the aquifer are quantified via the transient coefficient of variation of four constructed simulation ensembles. We show that the impact of subsurface structure and parameter driven uncertainty on the predictions is small compared to the uncertainty which is driven by the variability of future runoff (climate-variability dependent). However, in a double-source MAR site where recharge rates of both sources are controlled, sub-surface-structural uncertainty is larger than that of a single-source site. Further insights are made regarding the change in uncertainty with distance from the recharge pond – the unambiguousness of the predictions is not necessarily proportional to distance.

A novel analytical approach to calculating groundwater recharge through the vadose zone

Morteza Sadeghi and Tyler Hatch

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Abstract

Aquifer recharge is an important inflow to groundwater. Monitoring and modeling recharge is crucial for sustainably managing groundwater resources. Groundwater recharge through the vadose zone can be estimated via either simple analytical models or sophisticated numerical vadose zone models. Although numerical vadose zone models provide the most accurate approach to simulate recharge, due to their high computational demand, many existing integrated surface water-groundwater models, including the California Department of Water Resources' C2VSim model, employ a simple analytical formulation to calculate the vadose zone water flow and the aquifer recharge. A major assumption underlying this approach is that the unsaturated flow is driven dominantly by the gravitational potential, thereby neglecting the diffusive flow due to the soil moisture gradient. In this study, we indicate that this approximation may lead to significant errors in the ultimate recharge estimates. As an alternative, we propose a new analytical solution to the unsaturated flow equation accounting for both gravitational and diffusive flows under temporally variable boundary conditions. We validated the proposed model using the Ameriflux network observations in conjunction with the HYDRUS-1D numerical simulations. Our results confirm that the water flux estimates from the new analytical model are comparable to the HYDRUS-1D flux estimates, while the new model is much less computationally demanding than a numerical vadose zone model.

Keywords: Groundwater recharge; vadose zone flux; soil moisture; C2VSim; HYDRUS.

Using Groundwater models to support Sustainable Groundwater Basin Management in California's Monterey Bay Region

Pascual Benito, PhD; Hanieh Haeri, PhD, Cameron Tana, P.E.,

Montgomery & Associates, Water Resources Consultants, Oakland, California

Groundwater modeling is an important decision support tool for the successful planning, permitting, and operational management of indirect potable reuse (IPR) MAR projects. The success of an IPR MAR project requires informed decision making that allows project developers to design and implement a project that simultaneously delivers its proposed benefits (e.g. increased supply, prevention of seawater intrusion, etc..), and meets its operational and regulatory requirements (such as minimum subsurface retention times between recharge sites and downstream production wells), all within the constraints of the hydrogeological conditions of the groundwater basin.

We will walk through how groundwater models are used as an important decision support tool in different phases including project planning, permitting, operational startup and management through illustrative examples from the Pure Water Monterey (PWM) and Pure Water Soquel (PWS) IPR projects currently being implemented in California's coastal Monterey Bay Region. Both projects involve the injection of highly purified treated wastewater into coastal aquifers for the purposes of augmenting water supply, reducing extraction of native groundwater, reducing sea water intrusion potential, and function as components in developing approaches for long term sustainable management of each of the basins.

The presentation will give an overview of the project settings, goals, and benefits and then will provide examples how the project teams used groundwater modeling in support of:

- Initial project feasibility and planning and regulatory permitting,
- evaluation of potential project impacts for environmental permitting, evaluating project benefits such as long-term basin sustainability, sea water intrusion prevention and increased flows of interconnected surface water systems,
- evaluating alternative project configurations and operational scenarios,
- optimizing recharge well siting and construction, and distribution of recharge water between different aquifer depths and recharge locations,
- design and establishment of monitoring well networks; planning and analyzing tracer studies needed to validate underground retention times.

We will also describe how the modeling of each of the projects impacts fits in to the broader basin management context in each basin; for example with the PWS project being an integral part of the groundwater sustainability plan being developed and implemented for the critically over-drafted basin.

As projects move from planning and permitting phases into the operational phases we illustrate how groundwater models continue to play a role in supporting decision making and planning such as for assessing the impacts and regulatory implications of planned operational changes or project expansions, and also to evaluate the impacts on the project operations of changing conditions in the basin.

Water Availability Analysis for California Water Rights Permitting

Presenter: Shelby Witherby, Water Resource Control Engineer, State Water Resources Control Board

Contributing Authors: Amanda Montgomery, Program Manager, State Water Resources Control Board

Anyone planning to take water from a lake, river, stream, or creek for a beneficial use requires a water right of some type. California law requires that every application to appropriate surface water demonstrates a reasonable likelihood that unappropriated water is available to supply the applicant. Generally, water availability for permitting is calculated by estimating the amount of unimpaired flow in a stream during the diversion season, and subtracting the demand of all senior diversions and the demand for instream needs.

The Sustainable Groundwater Management Act (SGMA), enacted in 2014, provides a state-wide framework to protect groundwater resources over the long-term. Acquisition of new water rights for the diversion of surface water to underground storage is anticipated to be a significant means for parties to achieve SGMA compliance. This presentation will provide an overview of the permitting water availability analysis process as well as case studies of Sustainable Agencies and other local public agencies targeting high flows to address basin sustainability goals.

15-Managed Aquifer Recharge and Emerging Contaminants II

TECHNICAL PRESENTATION

1· Behavior of ammonium in the hyporheic zone during riverbank filtration
Gustavo Covatti, PhD Student, M.Eng., University of Applied Sciences Dresden

2· Reclaimed Water Infiltration Study: Effectiveness of Residual Chemical Removal Through Soil Aquifer Treatment in a Glacial Aquifer System
Shane McDonald, PG, CPG, Senior Technical Leader, Hydrogeology and Modeling, HDR

3· The Effect of Dry Wells on Groundwater Quality
Thomas Harter, Professor, University of California Davis

4· Using molecular properties to predict the removal efficiency of (new) organic micro-pollutants during soil passage
Bas van der Grift, KWR Water Research Institute

5· Large-scale tank experiments simulating soil aquifer treatment – Assessing attenuation of emerging organic compounds and water quality changes
Marcel Horovitz, Laboratório Nacional de Engenharia Civil (Portugal), Technical University of Darmstadt (Germany)

Behavior of ammonium in the hyporheic zone during riverbank filtration

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Riverbank filtration (RBF) is a well-established MAR technique in which surface water is subjected to subsurface flow prior to abstraction. Ammonium is an undesirable substance in the abstracted water of RBF schemes, due mainly to the complications it causes during post-treatment. There are four possible sources of ammonium at a given RBF site: landside groundwater, surface water, leaching from the vadose zone between river and wells and reactions in the riverbed, the latter of which is the focal point of this abstract.

Column experiments with riverbed sediments from the River Elbe in Germany were utilized to evaluate ammonium reactions, sorption and desorption during riverbed infiltration under different climate conditions. Additionally, several RBF case studies from the literature were analyzed regarding ammonium sources and behaviors and a few are displayed in detail alongside data from a RBF site at the River Elbe. Typical concentrations of ammonium in the bank filtrate are between 0.1 and 1.7 mg/l. Most reactions relevant to ammonium and nitrogen during RBF occur within the first meters of infiltration, in the riverbed. The most common source of ammonium during RBF is the mineralization of organic nitrogen, while the most common sink of ammonium is nitrification, both of which occur mainly in the riverbed.

Column experiments have shown that temperature, infiltration rates, organic material in the sediments and nitrate concentrations in the input water are the main controls to ammonium behavior. The results show that higher temperatures and lower infiltration rates lead to stronger reducing conditions and increased ammonium formation in the columns. Ammonium concentrations went from nearly 0 in the input water up to 1.4 mg/l after passage through the columns. Over the course of the experiments, ammonium concentrations became progressively lower alongside weaker reducing conditions and consequent lower release of manganese and iron. This was attributed to the continuous consumption of organic material in the columns.

Based on the review of ammonium concentrations in RBF sites and the column experiments, practical implications for the operation and planning of RBF schemes are drawn. Ammonium surface water concentrations do not directly translate to abstracted concentrations. Transformations in the riverbed play a critical role in determining ammonium concentrations, whereby riverbeds with high amounts of organic material have more potential for ammonium mineralization and more electron donor competitors for oxygen, thus limiting ammonium attenuation via nitrification. Climate dependent variables such as temperature and infiltration rates can also influence ammonium behavior, highlighting the potential disruptions climate change can cause in water quality during RBF.

Title: Reclaimed Water Infiltration Study: Effectiveness of Residual Chemical Removal Through Soil Aquifer Treatment in a Glacial Aquifer System

Author List: Shane McDonald, Brittany Duarte, Jeff Hansen, PE, Jillian Troyer, Vince Carsillo

Abstract:

Budd Inlet is a sheltered embayment at the southern end of Puget Sound that undergoes seasonal stratification, increased phytoplankton growth, and decreased dissolved oxygen concentrations in the late summer months. The LOTT Clean Water Alliance is employing Managed Aquifer Recharge (MAR) of reclaimed water as a multipurpose strategy to divert discharge of treated wastewater from Budd Inlet, thereby reducing nutrient loading in the sound, while also supplementing water levels in the local shallow aquifer.

Since 2006, LOTT has produced reclaimed water, which is either used for irrigation and other non-potable purposes or is sent to infiltration basins where it recharges the groundwater. To address the challenges of increasing wastewater treatment needs and limited receiving water capacity, LOTT's long-range plan is focused on expanding reclaimed water production and groundwater recharge. Recently, questions about infiltration of reclaimed water have been raised, including concerns regarding possible public health and ecological impacts of residual chemicals such as pharmaceuticals, personal care products, and perfluorinated compounds. To address such questions, LOTT is engaged in a multi-year Reclaimed Water Infiltration Study (RWIS).

The study aims to determine the fate and transport of residual chemicals from recharged reclaimed water and their associated risk to ecological and human health. Study components included monitoring of surface water, groundwater, and reclaimed water to establish baseline water quality conditions and to assess the changes that may occur from expanding the LOTT MAR program. A year-long tracer test was conducted to determine groundwater flow properties in the local aquifer system. Field investigation data was applied to a transient groundwater model to project long-term fate and transport of reclaimed water constituents. Transient model results and observed data from an extensive monitoring well network were used to estimate attenuation factors for select chemicals of concern. The presentation will provide an overview of the RWIS methods, results, and effectiveness of the glacial aquifer system in removing residual chemicals through soil aquifer treatment in a wet, temperate climate.

The Effect of Dry Wells on Groundwater Quality

Thomas Harter[1], Emily Edwards[2], Graham Fogg[1], Hamad Hamad[3], Barbara Washburn[3], and Michael Milczarek[4]

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Drywells are gravity-fed, excavated pits/boreholes that capture and infiltrate stormwater into the deeper vadose zone in areas where drainage and diversion of storm flows are problematic. Historically, drywells have been used as a form of stormwater management, however, drywells are increasingly being evaluated as a method to increase groundwater recharge via stormwater capture or intentional recharge. Although drywells can be an effective means to increase recharge to aquifers, the potential for groundwater contamination caused by polluted stormwater runoff has prevented more widespread use of drywells as a recharge mechanism in California. Numerous studies have shown that groundwater and drinking water contamination from drywells can be avoided if the wells are properly designed with an adequate separation distance between the bottom of the drywell and the seasonal high-water table to allow for pollutant attenuation. This separation distance, and the effectiveness of drywells for aquifer recharge, depends on the hydrogeologic setting and land use surrounding a site. These studies and the recent State of California Drywell Guidance study will be reviewed to provide recommendations for siting, design and installation of drywells.

Using molecular properties to predict the removal efficiency of (new) organic micro-pollutants during soil passage

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Bank filtration systems, such as Basin Artificial Recharge (BAR) and River Bank Filtration (RBF) leads to the removal of various organic micropollutants (OMPs). Drinking water utilities are increasingly turning their attention to this additional benefit. By optimising the bank filtration systems, one can try to reduce the load of OMPs on the above-ground treatment plants. This raises the question of which OMPs are removed in during soil passage, including the interaction with microorganisms and the hydro-geochemical conditions.

Drinking water utilities in the Netherlands would like to predict the removal efficiency of individual new organic micro-pollutants during soil passage in a way that is comparable with their above-ground treatment plants. One of the mayor issues to overcome is the unknown or uncertain chemical behaviour of OMPs during subsurface flow. Therefore we need a better understanding of the mechanisms underlying the removal of OMPs through sorption and/or biodegradation. The primary objective of our research is to develop a generic tool to predict the removal efficiency of new organic micro-pollutants (OMP) during soil passage based on molecular properties. The tool will consist of two parts, that will be intergraded in a web application to control the calculation:

- A Quantitative structure–activity relationship (QSAR) module that can predict the properties of untested substances that govern their removal during soil passage based on molecular properties. These properties include the partition coefficient between water and organic carbon (K_{OC}) the acid dissociation constant (pKA) and the half-life (T½).
- A transport module to predict the concentration of OMPs in public supply well fields. This module includes analytical formulas describing the travel time distribution and the geochemical and hydrochemical setting of the soil passage system for phreatic, semiconfined, BAR and RBF well fields. The substance properties determined by means of QSAR form input for the calculation.

The QSAR module was based on a large OMP database with experimental data from laboratory and field studies. This database was merged from data in different literature sources. We trained good regression QSAR models to predict $LogK_{OC}$ values for (new) compounds and and found an existing model in the literature to predict pKa values. Training QSAR models for degradation rates (T½) is clearly more challenging, amongst others, because degradation rate constants for individual compounds in our OMP database vary within several orders of magnitude within the same experimental category (e.g. (sub)oxic field experiments). Furthermore, there is poor correlation in measured degradation rates between the different kind of experiments. Therefore, it is not possible to train a regression model. However, we were able to train a classification QSAR model with an accuracy of 69% that distributes T½ value of OMPs over four classes (T½ classes break at 1 day, 5 days and 10 yr).

Further developments on the QSAR module now are focussed on the collection of additional field-derived T½ values of OMP in well-known BAR and RBF systems in the Netherlands. To select a representative group of OMPs to be measured in the field campaign we have developed a cluster method based on molecular properties. Within each cluster one representative indicator OMP will be measured.

Large-scale tank experiments simulating soil aquifer treatment – Assessing attenuation of emerging organic compounds and water quality changes

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Managed aquifer recharge (MAR) is an important part of the integrated water resource management (IWRM) toolbox. However, MAR also poses the risk of contaminating the aquifer, such as by infiltrating treated wastewater effluent, which may still contain too high concentrations of e.g., nutrients (N and P) or emerging organic compounds (EOCs). In order to assess this potential risk and to be able to take measures, if necessary, it is important to understand the MAR system. In this context, it is necessary to study the degradation and sorption capacity of natural conditions as well as modified regimes, e.g., by incorporating reactive layers. Both experiments and models are an important tool for this.
While laboratory column experiments are widely used and provide detailed process understanding under controlled conditions, transferring the results to field size and conditions is challenging. On the other end, in-situ field experiments give great insights into real systems while they often study only one infiltration basin under distinct environmental settings which hinders to transfer knowledge between sites.
To bridge the gap between laboratory column experiments and in-situ field experiments, we design and conduct a large-scale tank experiment consisting of three tank replicates for the purpose of analyzing soil aquifer treatment (SAT) infiltration basins using treated wastewater effluent under controlled conditions.
Not many large tank experiments exist in the area of MAR which strive to combine the representativeness of in-situ experiments with the controlled feature of laboratory column studies. The tank replicates are packed with fine sand and comprise a vadose zone as well as a saturated zone. The vadose zone of two tanks incorporates a mixed layer of biochar/fine sand as reactive layer, while the third tank consists solely of fine sand and acts as reference. The tanks are equipped with automated sensors (high resolution oxidation-reduction potential, water pressure, soil moisture content, electrical conductivity, water pressure, and temperature). To capture the processes along the flow path the facilities allow sampling via suction cups in the vadose zone and micro-piezometers in the saturated zone. The infiltrating water in this study is synthetic wastewater (oxic) spiked with EOCs while the underlying flowing groundwater (suboxic) consists of local groundwater. A set of six EOCs (carbamazepine, diclofenac, ibuprofen, naproxen, gemfibrozil, and triclosan) act as model substances as they cover a wide range of physicochemical parameters and degradation potentials. Preliminary results are presented on the influence of operational regimes and reactive barriers on the attenuation of EOCs as well as on nutrients, dissolved organic carbon, and major ions in both the vadose zone as well as the underlying groundwater.

16-Managed Aquifer Recharge and Sustainable Groundwater Management

TECHNICAL PRESENTATION

1· Managed Aquifer Recharge and Climate Change in Florida-Strategies for Coping with an Uncertain Future
Robert G. Maliva, Principal Hydrogeologist, WSP USA

2· Sustainable Groundwater Management using Managed Aquifer Recharge (Dry wells)
Salini Sasidharan, Assistant Professor, Sustainable Groundwater Management Engineer, University of California, Riverside, CA; Oregon State University, OR

3· California's 2014 Sustainable Groundwater Management Act (SGMA) - Progress Update, Lessons Learned and MAR Proposed
Timothy K. Parker, PG, CEG, CHG, Senior Hydrogeologist/Sustainability Expert, Ramboll USA

4· Eastern Snake Plain MAR Program - Collaborative, Long-term Sustainable Management of an Aquifer
Wesley Hipke, Recharge Program Manager, Idaho Department of Water Resources

5· Preliminary assessment of managed aquifer recharge opportunities for irrigated agricultural areas in Australia (V)
Dennis Gonzalez, Spatial Data Scientist, Commonwealth Scientific and Industrial Research Organisation

Managed Aquifer Recharge and Climate Change in Florida-Strategies for Coping with an Uncertain Future

Robert G. Maliva and William S. Manahan
WSP USA, 1567 Hayley Lane, Suite 202, Fort Myers, FL 33907

Florida has been described as "ground zero" for climate change in the United States because its long coastline, low elevations, and large coastal population makes the state particularly vulnerable to rising sea levels. The state has a very high dependence on groundwater for its potable water supply whose use is approaching, and in some areas may already have reached, sustainable limits due to one of the most rapidly population growth rates in the nation over the past several decades, a trend that is projected to continue. Florida's groundwater supplies may be impacted by climate change through increasing saline water intrusion, changes in precipitation amounts and patterns, and temperature-driven increases in water demands. Florida is blessed with abundant rainfall on an annual basis, but it has a high seasonality that is out of sync with water demands. The winter and spring dry season coincides with the peak in tourism and seasonal residents. The water supply and demand pattern in Florida is ideal for aquifer storage and recovery (ASR) in that there is excess water seasonally available that can be stored for use in the following dry season, and the state has been a global leader in the number of the systems in various stages of development. Florida is also a leader in aquifer recharge of wastewater using rapid infiltration basins.

Climate change modeling results suggest that Florida will become even warmer but changes in average annual precipitation will likely be relatively modest. A general prediction from climate change modeling is that there will be a greater variability in precipitation with a tendency toward more frequent dry and wet spells. It is increasingly recognized in the water resources management community that managed aquifer recharge (MAR) can be an important adaptation element to climate change in areas facing water scarcity. Augmentation of groundwater supplies when excess water is available can provide additional water to bridge droughts. Salinity barriers can also be developed to protect near-coastal aquifers from saline-water intrusion accelerated by sea level rise. Successful implementation of MAR requires (1) a periodically available supply of water for recharge, (2) favorable hydrogeological conditions for recharge using either wells or surface spreading, and (3) a regulatory framework that is congruent with the practice. Systems also need to be designed and located so that recovery during dry periods does not exacerbate local adverse impacts (e.g., lowering of lake levels and dehydration of wetlands). Climate change is expected to impact surface water availability for aquifer recharge.

A major limiting factor for further implementation of ASR in Florida is regulatory constraints related to the requirement that recharged water must meet or not cause an exceedance of primary drinking water standards. Florida regulatory policies do not allow for a zone of discharge (treatment zone). The resulting requirements to pretreat water by deoxygenation to avoid arsenic leaching and to meet groundwater standards for coliform bacteria (and other pathogens) and disinfection byproducts substantially increases the construction and operational costs of projects using non-potable waters, in some cases rendering projects economically unviable. The employment of energy-intensive technologies to additionally treat water prior to recharge and for other alternative water supply projects, such as brackish groundwater salinity, will contribute to further climate change. Climate change combined with continued population growth will further stress Florida's water supplies, and MAR will be an important element toward increasing the robustness of the supply system. A key issue will be creating a regulatory framework more favorable for the practice while ensuring that public health and the environment is protected.

Sustainable Groundwater Management using Managed Aquifer Recharge

Salini Sasidharn[1, 2], Scott. A. Bradford[3], Jiri Simunek[1]

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ABSTRACT:

Episodic droughts, groundwater depletion, and growing water demand are hampering the sustainability of irrigated agriculture. Managed Aquifer Recharge (MAR) is increasingly used to augment groundwater supplies with excess surface water using various technologies such as infiltration basins (IB), drywells (DW), and flooding of agricultural land (AgMAR). Drywells are increasingly used for stormwater management and enhanced aquifer recharge, but only limited research has quantitatively determined the performance of DWs. Therefore, numerical experiments were conducted on a 2D-axisymmetric (50 m wide by 60 m deep) domain using the HYDRUS (2D/3D) software to systematically study drywell infiltration, recharge, and microbial water quality in homogeneous and heterogeneous soil profiles under constant head conditions. The influence of stochastic subsurface heterogeneity parameters on infiltration and recharge rates and cumulative volumes, the radius of recharge, and early and late arrival times and locations were determined. Additional simulations compared the performance of DWs with IBs under shared subsurface heterogeneity and steady-state flow conditions. Results demonstrated that five DWs could replace a 70 m diameter IB to achieve significantly higher infiltration and recharge over 20 years of operation. In addition to water quantity, groundwater quality management is an essential aspect of public health and successful MAR operation. Therefore, numerical experiments were conducted to quantitatively examine virus transport from a drywell under various virus removal and subsurface heterogeneity conditions. Virus detachment, solid-phase inactivation, and subsurface heterogeneity were critical factors in determining the risk of groundwater contamination. On-going research at a field site in the Central Valley, CA, is exploring the independent and joint use of AgMAR and DWs for enhanced recharge and assessing impacts on groundwater quality. This research is expected to increase the widespread acceptance of various on-farm MAR technologies to increase the long-term viability of groundwater to sustain irrigated agriculture, as well as to provide government regulators with critical science-based findings and tools to manage water resources.

California's 2014 Sustainable Groundwater Management Act (SGMA) - Progress Update, Lessons Learned and MAR Proposed - Timothy K. Parker, PG, CWG, CHG, Ramboll USA, Sacramento, California http://www.linkedin.com/in/timothy-k-parker

California passed the Sustainable Groundwater Management Act (SGMA) in 2014 that requires: (1) the creation of new groundwater sustainability agencies (GSAs), (2) preparation of new groundwater sustainability plans (GPSs), and (3) to achieve groundwater sustainability within 20 years of GSP adoption. These requirements apply to all 94 high and medium priority SGMA basins, out of 515 basins statewide, and account for approximately 90 percent of the pumping in the state. The first set of GSPs were submitted at the beginning of 2020 to the state by GSAs in the 27 critically over-drafted (COD) basins, and are currently under review by the California Department of Water Resources. Review and analysis of the COD basin GSPs suggest while many of the basins are proposing some demand reduction, many basins are proposing a large amount of managed aquifer recharge (MAR) to offset existing pumping. A key observation for the nearly 1.2 cubic kilometers proposed annual recharge is that current estimates indicate that much less source water will actually be available on an average annual basis. Additional observations from the submitted GSPs include that data gaps are significant, costs will be high to fill the GSP data gaps over the next few years, demand management is not as much of a factor as would be expected, and litigation will be necessary to address sustainability in some of the basins. More information will be presented that will be available at the beginning of 2022 as the COD basin GSP review process is completed, the remaining 73 SGMA basin GSPs are submitted to the state, and more data on California's local agency plans for MAR projects for sustainable groundwater management is revealed.

ISMAR 11

Idaho's Eastern Snake Plain MAR - A Collaborative, Long-term Sustainable Management Program

By Wesley Hipke[1] and Paul Thomas[1]

ABSTRACT

The western United States has been facing a great challenge over the past few decades concerning the management of existing water supplies along with the increasing demands due substantial growth and greater variability in water resources. The Eastern Snake Plain Aquifer (ESPA), Idaho's largest and most prolific aquifer, has experienced substantial decline since the early 1950's due to changing climate conditions, increased demands, and evolving irrigation practices. Besides reducing the amount of groundwater available the declining aquifer has a direct impact to the amount of surface water available at numerus springs along the ESPA's terminus. The decline in both surface and groundwater supplies has had a significant impact on this region of Idaho, which accounts for approximately a third of all goods and services produced in Idaho.

To address this issue, the Idaho Water Resource Board (IWRB), through a collaborative stakeholder process, finished the ESPA Comprehensive Management Plan (CAMP) in 2009. The CAMP outlines methods and goals for the replenishment of the aquifer, including the development of a managed aquifer recharge (MAR) program. The ESPA MAR program was provided dedicated long-term funding in 2014 from the State of Idaho to achieve an annual average goal of 250,000 acre-feet per year. To-date the IWRB has invested over $16 million dollars in investigations and infrastructure improvements to increase MAR capacity. The investment has resulted in over 2,200 cubic-feet per second of additional MAR capacity throughout the ESPA.

Through the additional recharge capacity and partnerships developed with a wide range of stakeholders the program has recharged over 1.8 million acre-feet of since the start of the full-scale program. Utilizing existing infrastructure and the IWRB's natural flow water rights has significantly reduce programmatic costs. The cost for conducting recharge to date has been $18 per acre-foot this includes capital cost, conveyance fees, operation and maintenance, and monitoring cost accrued since 2014. The ESPA Managed Recharge Program would not have been possible or successful without the water users and the State working together to define and proactively address the current problem while also looking towards future growth of the region.

[1] Idaho Department of Water Resources

Preliminary assessment of managed aquifer recharge opportunities for irrigated agricultural areas in Australia

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Submission to ISMAR11 conference, April 2022

Abstract

In agricultural applications, managed aquifer recharge (MAR) has the potential to increase the security of irrigation water supplies through efficient storage and delivery of water, build resilience to drought, pressures from climate change and increasing consumer demand, as well as facilitate conjunctive use of surface and groundwater resources. Wider socio-economic benefits for regional communities can be realised through stabilising agricultural production and dampening boom-bust cycles by providing options for diversified farming approaches. A preliminary study assessed opportunities for MAR for irrigation areas across Australia based on determining an ongoing demand for water, availability of surface water for recharge, and presence of suitable aquifers for storage. Irrigation areas were selected to obtain a broad geographic spread across Australia based on where high demand and competition for water exists, production of high-value agricultural commodities, potential to transition to higher value crops, and avoiding areas known to have groundwater salinity issues. A range of metrics indicating favourable conditions for MAR were developed that integrated disparate data across Australia. A set of six spatial criteria relating to unconfined aquifer suitability for infiltration-based MAR were combined to conservatively estimate potential aquifer storage volumes. Another set of indicators related to surface water availability, dependence on groundwater, volatility of irrigation water cost, and crop types grown.

Across the 17 irrigation areas assessed, significant aquifer storage potential was identified in 15 and conservative estimates of storage capacities were in the order of 10 to 280 million cubic metres (Mm^3). Six agricultural areas had storage opportunities greater than 50 Mm^3. Of these, four (Bundaberg, Macquarie, Lachlan, Namoi) satisfied criteria for surface water availability. In catchments where surface water flows are limited and or sporadic, existing upstream dam storage may be more important for determining MAR opportunities. Water demand, as indicated by total annual water entitlement volumes, was generally high (>500 Mm^3) across these four irrigation areas. All four areas had substantial groundwater use. Proportional groundwater entitlements were highest for the Lachlan and Namoi irrigation areas (around 30%), which also had comparatively high irrigation bore densities of 67-95 per 100 km^2. Water trade price range was used as an indicator of the current value of water security in a region, the degree of competition over the resource, and a measure of the variability in water availability. The Lachlan, Macquarie and Namoi areas ranged by over AU\$0.75/m^3 and reached AU\$3/m^3 in Macquarie. Trade price fluctuations indicated that stored volumes could be extremely valuable during times of low surface water availability. The type of agriculture has important implications for MAR development. Irrigation areas dominated by irrigated seasonal cropping (e.g. Namoi, Macquarie) could benefit from MAR through either supporting existing farming practices, or by enabling transition to high-value perennial cropping and horticulture that rely on reliable water supply. MAR in areas with high levels of perennial plantings and horticulture (e.g. Bundaberg) could benefit through the provision of a back-up supply to protect investments during periods of low water availability and high water cost.

This screening-level analysis indicated irrigation areas where MAR showed the most potential, and informed where effort may be best directed to explore opportunities further. Key components of further research include site-specific technical feasibility and economic analyses, quantifying potential benefits to existing or future agricultural practices, establishing long-term governance arrangements for scheme management, and accommodating MAR within regulatory frameworks.

17-International Recharge Opportunities and Innovation

TECHNICAL PRESENTATION

1· MAR for the Developing World - Guidelines for developing Community-based MAR Projects for Climate Change Resiliency and Water Security
Bob Bower, Principal Hydrologist, Mercy Corps

2· Education and outreach on riverbank filtration in India – examples from the CCRBF project
Cornelius Sandhu, Senior Researcher, Dresden University of Applied Sciences

3· Evaluating Managed Aquifer Recharge options to improve the status of an over-exploited aquifer in South Portugal
Kath Standen, Universidade do Algarve

4· Identification and characterization of cross-sector collaborative relationships enabling Managed Aquifer Recharge projects in Mexico
Mary-Belle Cruz Ayala, Water Resources Research Center, University of Arizona

5· Addressing a Severe Water Scarcity Problem by Implementing a Fast and Durable Managed Aquifer Recharge Program in Northern Algeria (North Africa)
Farid Achour, Principal Hydrogeologist, GSI Environmental Inc.

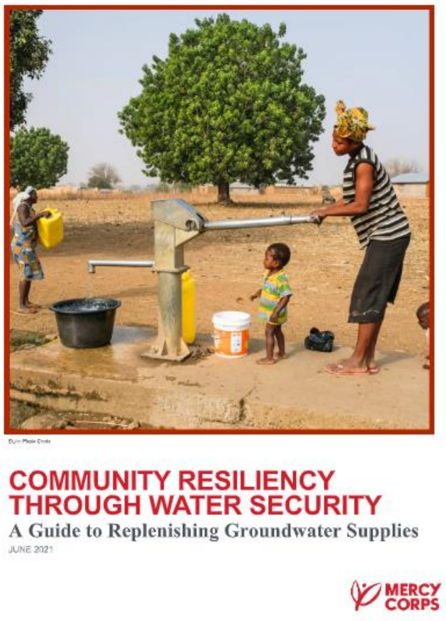
Abstract – ISMAR 11

31 July 2021

Bob Bower, H2Alluvium Pty Ltd – USA/New Zealand

Abstract note – current guide is in draft form, will be completed in September 2021.

Prepared for Mercy Corps with written approval



Abstract:

In Hardin's[1] classic 1968 paper "*The Tragedy of the Commons*", he defined a ***common*** as being a natural resource shared by many individuals. Shared in Hardin's context, relates to the fact that the individual does not have a claim to any part of a resource, but rather uses a portion of it for his/her own benefit. The tragedy is that in the absence of a collective responsibility to regulate theses uses, individuals have the tendency to exploit the commons to their own advantage, typically without limit. This results in the common resource being depleted and eventually lost or severely degraded.

Globally, groundwater has become a standout example of this tragedy of this commons-scenario. Over usage, coupled with declining groundwater quality, both of which are caused by human activities has results in significant degradation of groundwater resources. Regulatory frameworks that help to collectively manage groundwater are often either non-existent or are only being implemented after the resource has been compromised. In the developing world and where aide agencies typically operate, regulatory frameworks to support the collectively manage groundwater is likely limited to non-existent. Many of the challenges associated with improving management of natural resources that aide agencies are facing are at the community level and the need for community-based water management solutions. Yet the need to sustainably manage groundwater at the community and catchment-scale are substantial.

This need to develop locally enabled solutions for groundwater management has prompted Mercy Corp to commission a guidance training document for their thousands of in-country staff and partners that provides an overview for developing MAR projects. This guidance document focuses on '*Involving community members in a way that promotes their ownership over decision-making and builds their knowledge and skills to carry out those decisions is a complex task. Yet our experience leads us to believe that it is an essential component of rapid recovery and lasting change. At its core, the CATALYSE (Mercy Corps) process is about supporting people to work together to transform their communities from within.*'[2]

This oral presentation will provide an overview of the Mercy Corps approach. Generally, it focuses on providing a background on groundwater science and the MAR techniques to help enable communities to better understand and manage their groundwater supplies in order to improve water security and resiliency starting at the community level. It provides a basic understanding of a technique termed Managed Aquifer Recharge (MAR) which combined with the principles of CATALYSE can be used to find community-based solutions to groundwater security of supplies and improved resiliency to the pressures put upon natural resources from our changing climate and increasing global populations.

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[1] Hardin, G., 1968. The Tragedy of the Commons. Nature, 162, 1243-1248.

[2] Mercy Corp CATALYSE guide

Education and outreach on riverbank filtration in India – examples from the CCRBF project

Cornelius Sandhu[1]; Thomas Grischek[1]; Gopal Krishan[2]; Sudhir K. Sharma[3]; Rajiv Saini[3]; Kavita V. Patil[4]; Medalson Ronghang[5]; Priyabrata Banerjee[6], Sonam Jamtsho[7], Tshering Dema[7], Lobzang[7]
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Since the 1960s, groundwater extraction and overdraft in many regions of the world including India have occurred at unprecedented levels, which has driven the intentional groundwater replenishment known as managed aquifer recharge (MAR) [1]. More than 15 years of research show that riverbank filtration (RBF) as an element of MAR has significant potential to be applied at a larger scale in India. However, simultaneous education and outreach activities on RBF in India have also shown that concerted and synergized efforts between the central and state governments, their organizations, regulatory bodies and academic and research institutions as well as private service providers is needed to effectively implement RBF.

In recognition of the need to support a basic platform for continued, intensified and focused education, outreach and research on RBF in India, the Federal Government of Germany is supporting the Indo-German CCRBF project (2020–2023). A focal aim of the project is to develop four RBF nation-wide demonstration sites, accompanied with investigations on the impact of mining on RBF in the Damodar river basin and sea water intrusion at a site in south India. Following-up from a conceptual master plan for RBF in India [2], past and ongoing investigations at these sites are now developing the master plan based on scientific facts.

The presentation will highlight the diverse hydro-climatic and environmental features of the four RBF demonstration sites in India. The RBF site in Haridwar by the Ganga river is also significant from a cultural context as it provides drinking water sustainably during peak demand periods under extremely challenging operational and environmental conditions such as during the *Kumbh Mela* mega-pilgrimage [3]. In Agra, the RBF removal efficiency of pathogens, heavy metals and organic micropollutants is being demonstrated at one of the most polluted rivers worldwide. The Brahmaputra-based surface water supply scheme in Guwahati is impacted during the monsoon and RBF offers the potential of year-round supply there. In Goa, the application of RBF for irrigation water supply is demonstrated with the help of photovoltaic energy.

Experiences from courses specifically on RBF in India conducted by the CCRBF project consortium that have trained more than 100 engineers of state water supply organizations, will also be presented. These courses have shown that both basic and advanced knowledge on multiple aspects of RBF need to be taught not only to engineers, but also to scientists including hydrogeologists and water supply planners. The trainees' appreciation of these dedicated courses has increased through field visits to RBF demonstration sites and by involving other engineers to share their experiences on RBF. Consequently, a training module must be included in the RBF master plan. Experiences on the operation of the RBF scheme in Haridwar during the *Kumbh Mela* and the COVID-19 pandemic, at a time when 9.1 million pilgrims reportedly bathed in the Ganga river from mid January to end April 2021, will be shared. Multiplier effects of the outreach activities include investigations on the feasibility of RBF in the Kingdom of Bhutan, which will also be highlighted in the presentation.

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Evaluating Managed Aquifer Recharge options to improve the status of an over-exploited aquifer in South Portugal

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Abstract
The Campina de Faro (Vale do Lobo sector) aquifer system in South Portugal is set within a meso-cenozoic basin, comprising thick sequences of calcareous sandstones and limestones forming a complex, multi-layered aquifer. The aquifer has been extensively exploited for agriculture, golf and tourism, with over 300 extraction points within an area of 32 km^2. Groundwater levels have been declining since the 1980's, and a large depression now exists with groundwater levels well below sea level. As a result, the aquifer is not meeting the requirements for 'good' quantitative status under the European Water Framework Directive (WFD), and measures are required to improve the status by 2027. Managed Aquifer Recharge (MAR) schemes to capture ephemeral river flows and to recharge treated waste-water are being examined as future potential solutions to achieve the WFD objectives and/or prevent further deterioration due to saline intrusion.

A number of potential MAR schemes are being considered including infiltration basins in, or adjacent to, the ephemeral streams that cross the aquifer. This may require the use of dry well infiltrators to bypass lower permeability sediments at the surface to recharge the lower aquifer. Infiltration of wastewater at points closer to the coast to provide a barrier to prevent saline intrusion is also being considered, along with a potential transfer of wastewater from a waste-water treatment works in an adjacent catchment to increase the volumes available for MAR or direct irrigation.

Estimates of the availability of water for MAR from each of these sources will be presented alongside revised estimates of the water balance components and the current deficit to determine the likely magnitude of the impact of MAR on the aquifer water balance.

We present details of the numerical model development and preliminary outcomes of this ongoing study that show that a combination of MAR measures can be employed to improve the situation, but due to the variability in ephemeral river flows, re-use of treated waste-water for MAR should also be considered, subject to appropriate risk assessment. Whilst there is currently no legal framework to licence MAR in Portugal, the situation in the Vale do Lobo aquifer remains critical, and should significant saline intrusion start to occur, this remains a potential mitigation measure. Further assessment of the environmental impacts of using waste-water for MAR would be needed before these options could be included in the Program of Measures designed to reverse the poor quantitative and qualitative status of groundwater in the study area.

Identification and characterization of cross-sector collaborative relationships enabling Managed Aquifer Recharge projects in Mexico

Mary-Belle Cruz-Ayala*, José Soto and Margaret Wilder
University of Arizona

What makes collaboration among water managers and academics able to achieve common goals in the context of adapting water systems to the challenges of climate change? Analyzing collaborative practices can provide substantive information for stakeholders, policymakers, and researchers to make informed decisions about the goals, strategies, and structures most productive for their collective work. This study of science-policy networks engaged in Managed Aquifer Recharge (MAR) draws on existing theories of collaboration in science-policy networks to characterize and analyze working interactions between researchers, water managers, non-governmental organizations, and consultants who have participated or currently participate in water management and recharge projects in Mexico. The data were collected using a standardized, open-ended questionnaire and an online survey activated during April and May 2021. Our results find that the most critical elements identified by MAR network participants in three case study sites for building collaborative relationships are trust and stakeholder participation. Results of this study align with the scholarly literature that suggests that the engagement of water users and the inclusion of scientific sound information are key elements that can trigger collaboration and build adaptive capacity for the adoption of sustainable water resources technologies like Managed Aquifer Recharge.

Keywords: Managed Aquifer Recharge, collaboration, Mexico, trust, science-policy, networks

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Addressing a Severe Water Scarcity Problem by Implementing a Fast and Durable Managed Aquifer Recharge Program in Northern Algeria (North Africa)

The 2,500 km^2 Sebaou watershed, located near the Mediterranean Sea in northern Algeria, is characterized by its mountains that cover 82% of the watershed. A coastal chain occupies the northern portion of the watershed while the precambrian Kabylia massifs and Djurdjura limestones reach an elevation of 2308 m to the south. Average annual rainfall within the watershed ranges from 850 to 1800 mm.

The approximately 100-Km long Sebaou river has an average discharge ranging from 0.45 to 43.5 m^3/s and is subject to significant flooding from time to time. The sediments in the riverbed have been overexploited for decades to produce sand and gravel for use in construction projects. The gravel pits have extended to the top of the underlying aquifer at several locations, thus reducing the thickness of the alluvial aquifer and aggravating the regressive erosion resulting in bridge scouring and seriously compromising the integrity of several bridges. Historical studies carried out in the Sebaou plain show a strong hydraulic connection between the river and the alluvial aquifer.

While the recent prolonged drought conditions in Algeria have been dramatic, the year 2020/2021 has been the worst on record, resulting in significant water shortages. A solution is urgently needed in order to promptly address this problem. Our recommended solution consists of the construction of several gabion dams along the river. The construction of gabion dams requires a river slope of less than 2% and a river width of less than 400 meters, conditions which are met on the Sebaou river. A multicriteria evaluation taking into account parameters such as the river's width, depth of the lower river terrace, site morphology, thickness and lateral extent of the alluvial aquifer, and presence/absence of water supply and agricultural wells was used to evaluate the optimal locations of the gabions along the river.

Our analysis shows that the use of gabion dams is the fastest, cheapest, and most suitable solution to implement a successful managed aquifer recharge (MAR) program. Gabions made of cages filled with rock and sand are inexpensive and rapid to construct (less than a month), are immediately available for use, and require minimal to no maintenance; they dissipate the energy of flowing water, minimize flooding and promote infiltration of river water into the aquifer. When properly placed, these structures will also address existing gullies by promoting deposition of sediments in selected locations. Building gabion dams along the river will create "localized dams" which will replenish the aquifer during times of intense pumping and/or drought.

To determine the optimal gabion dam's height to prevent flooding, a hydrological peak flow attenuation model was used, the results were used to build a groundwater numerical model and simulate the impact of the gabion dam structure and height on the groundwater elevation within the aquifer. Preliminary results indicated that an approximate volume of 50 million m^3 can be stored within the aquifer using this approach. This type of approach is expected to be broadly applicable to many rivers throughout Algeria.

18-Managed Aquifer Recharge Engineering and Design IV

TECHNICAL PRESENTATION

1· The use of regional groundwater flow characteristics for optimized screening of MAR potential and application conditions
Ádám Tóth, ELTE Eötvös Loránd University

2· Electrical Resistivity Tomography to Site Recharge Basins and Improve Groundwater Models in Southern California
Kristen Marberry, Senior Geophysicist, Collier Geophysics, LLC

3· Site suitability analysis for managed aquifer recharge in karst aquifers (V)
Nourelhoda Itani, American University of Beirut

4· Methodology for evaluation of potential sites for large scale river bank filtration
Thi Ngoc Anh Hoang, M.Eng, Dresden University of Applied Sciences

****5·** What Drives Cities to Adopt Groundwater Banking? A Cross-Case Analysis of U.S. Cities
Lauren Bartels, University of Nevada, Reno

The use of regional groundwater flow characteristics for optimized screening of MAR potential and application conditions

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Managed Aquifer Recharge (MAR) interventions are usually designed for local water availability. However, regional hydrogeological conditions can be of major influence on the suitability and performance, depending on MAR type and size. Therefore, to facilitate site selection and suitable MAR scheme design and conditions, it is important to incorporate aspects of the groundwater flow systems for which MAR is considered thus reducing risks of the operation and avoiding failures. For this purpose, the regional groundwater flow theory was introduced to the MAR concept in this research. The aim is the understanding of hydrogeological behaviour on a broader basin scale, taking into account processes affecting the local conditions but might originate far from the local study site. Considering the natural characteristics of the system, e.g. groundwater flow directions, intensity and surface water–groundwater interaction, will allow design for optimal operation for the intended goal of MAR such as providing the highest recovery efficiency for ASR facilities.

Besides hydrogeological factors, on a regional scale, the extent of MAR to contribute to ensuring sustainable water availability will depend on temporal and spatial distributions of often a variety of water sources and demands in both quantity and quality. This will also influence for example whether many smaller MAR systems are preferred over a few large-scale MAR systems. Based on theoretical considerations and numerical simulations, the suitability of different MAR types depends strongly on the local characteristics of the regional groundwater flow system. 1) Spreading methods, which are based on the infiltration of water by gravity, cannot be realised at a discharge area. 2) At a recharge area, the water can be injected quite easily without any excess energy investment. 3) Local flow systems with shorter characteristic residence time are the targets for short-term socio-economic use. However, longer residence times are required for treated water due to the natural decay of components by bio-physico-chemical processes and filtering. This is especially important in a regional context, where all water demands (highlighting the environmental needs) should be considered and MAR is applied for environmental benefits.

Overall, regional groundwater flow system characteristics in evaluating MAR potential and scheme selection will allow the more efficient site and MAR type selection as well as optimize MAR performance.

Electrical Resistivity Tomography to Site Recharge Basins and Improve Groundwater Models in Southern California

Nicole Pendrigh, Michael Blazevic, John Jansen, Kristen Marberry

Proper site selection is critical for optimizing the performance of recharge basins. Permeable shallow soils that are in direct connection with a permeable vadose zone and potentially deeper aquifers are critical to efficiently get water into the ground and being able to recover it. Screening large areas by traditional drilling methods is expensive and does not provide continuous coverage. There are several geophysical methods, including electrical resistivity tomography (ERT), that can efficiently map subsurface stratigraphy to identify areas suitable for Managed Aquifer Recharge (MAR). This presentation will use case histories from the San Juan Basin of Southern California to illustrate how ERT can be used to screen many miles of riverbed to identify the most favorable sites for additional testing and direct investigation.

Two separate geophysical investigations were conducted; the lower San Juan Basin (LSJB) and the middle San Juan Basin (MSJB). The objectives of the LSJB geophysical investigation were to map a sand and gravel aquifer lying above bedrock, and to look for formation changes or truncations affecting the hydraulic continuity (flow system) of the aquifer. The geophysical investigation performed by Collier was part of a collaborative project with the Doheny Ocean Desalination Project Workgroup. The Project Workgroup consists of members from the South Coast Water District, the San Juan Basin Authority, the Santa Margarita Water District, and the members' technical consultants, including the United States Geological Survey.

The objectives of the MSJB investigation were to map the shape of the bedrock valley fill; map favorable areas for shallow recharge basins; and map the stratigraphy above bedrock. Both project areas used ERT to achieve the objectives.

Five ERT lines were collected in the LSJB, with a total line length of approximately 7,200 feet. The site consisted of mostly flat terrain ranging from residential park, to dirt lots and parking lots filled with cars, to the San Juan Creek. In the MSJB, site conditions ranged from marshlands to riparian forest with steep slopes and heavy vegetation, to sandy/rocky retention ponds. Twenty-one lines were collected for a total line length of approximately 23,000 feet.

General lithologic and hydrologic patterns observed in the resistivity consisted of multiple layers: a thin low resistivity layer at the surface that is interpreted as silty material at or near the surface, a higher resistivity middle layer that is interpreted as sand and gravel with varying amounts of fine grained material, a low resistivity layer beneath the upper sand unit that is interpreted as a clay layer, an intermediate resistivity layer at the base of the clay layer that is interpreted as a lower sand unit, a low resistivity layer interpreted to be intact bedrock.

Using contour intervals from the ERT data as guides, and correlating to boreholes, 3D interpretations of the geologic units were generated, allowing for 3D perspective visualization which could be used in a hydrogeologic model. The results of the survey will be used to identify favorable sites for recharge basins and to upgrade the existing groundwater models to better represent the hydro-stratigraphy and groundwater flow-systems and produce more accurate time of travel estimates from the recharge basins to recovery wells.

Site suitability analysis for managed aquifer recharge in karst aquifers

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Abstract

Managed aquifer recharge (MAR) has proven to be an effective process for water storage and subsequent recovery. However, adopting MAR in karstic aquifers is challenging, especially when selecting potentially suitable recharge sites due to their associated heterogeneity as compared to uniform porous-media aquifers. The adoption of the Aquifer Rechargeability Assessment in Karst (ARAK) method has been promoted as an effective way towards assessing the rechargeability of karstic systems. Moreover, coupling additional relevant geospatial data along with numerical and qualitative indicators of water availability have the promise to improve the site selection process. In this paper, MAR site suitability is assessed in a karst aquifer in a semi-arid Mediterranean watershed, using ARAK coupled with a multi-criteria decision analysis (MCDA) technique. The approach made use of hydrologic modelling of streamflow to account for water availability in terms of quantity and inter-annual variability. Economic attractiveness was also examined based on several relevant indicators. The MCDA assigned weights to various criteria based on a pairwise comparison defined by the analytical hierarchical analysis and through linear score functions for each decision criterion. The results showed that 52% of the river basin area was not suitable for artificial recharge, particularly areas underlain by Cretaceous formations that are unsuitable for water storage and recovery. More suitable areas were located within the Cenomanian C4-C5 geologic formation, which is a dependable water aquifer along the eastern Mediterranean. Using the water availability indicator, high potential and lower variability were located further downstream in the basin. Finally, our analysis concluded that the watershed areas, which are currently under stress and experiencing saltwater intrusion, had both the lowest investment costs and the highest potential to provide additional sustainable water to meet agricultural and domestic demands. Overall, the integrated analysis shows that less than 8% of the watershed had good to very good potential for MAR. These areas were disproportionately located along the coastal plain to the west of the watershed.

Methodology for evaluation of potential sites for large scale river bank filtration

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River bank filtration (RBF) is a MAR technique where surface water infiltration is induced by water abstraction near to a river. Processes in the aquifer such as filtration, biodegradation and adsorption result in positive changes in the infiltrated water quality. Although it is a simple concept, successful and cost-effective operation of large-scale RBF sites depends on complex hydrogeological and hydrochemical variables particular to each site. Therefore, much of the research on RBF comprises the assessment of feasibility of new sites.

Site investigation can be costly and limited to a small area, usually involving boring, borehole logging, pumping tests, hydrochemical sampling and analysis for several months. For this reason, a methodology for pre-selecting and evaluating suitable sites in a wider area using large databases and multi-criteria analysis is critical, particularly in regions where RBF is not widely applied yet. A few methodologies have been proposed in the past, but so far there is no agreement on a general methodology to evaluate site suitability for RBF. Here we intend to propose a new method, which builds on past attempts and improve where they were lacking.

The evaluation method is based on three groups of criteria: an essential criterion, quantity criteria and quality criteria. The essential criterion which must fulfilled for any RBF application is that the river must be hydraulically connected to the adjacent aquifer. Without this, any abstracted water will consist exclusively of groundwater and not bank filtrate (BF). The quantity criteria are based on two principles - that the goal is to abstract large quantities of water and that the majority of this water should consist of BF. For this a quantity index is calculated based on the site aquifer's thickness and hydraulic conductivity. Furthermore, several factors are applied to calculate the site suitability index (SSI), factors which include aspects of riverbed clogging, the river width and the gradient between river and groundwater.

The quality criteria refer to site's surface and groundwater quality parameters. In the view of the authors water quality parameters have been overweighed in the site evaluation in previous methods. Water quality in RBF site selection is heavily dependent on the goals of RBF. Rejecting a site for poor surface water quality can mean to reject a site where the potential of RBF as pre-treatment is the most valuable. Therefore, an overview of which water quality parameters are the most relevant for RBF application is given as well as ranges of which the quality criteria should best be applied to the SSI. The current study is not meant to be a final site selection methodology, but a way of continuing the discussion on this topic in order to reach an agreement on concrete ways to evaluate potential sites and regions for RBF application.

Lauren Bartels
ISMAR 11 Abstract
6/4/2021

Title: What Drives Cities to Adopt Groundwater Banking? A Cross-Case Analysis of U.S. Cities

Abstract

As climate change continues to increase the variability and decrease the reliability of water supplies, urban water utilities must adopt and implement innovative strategies to enhance water security and promote system sustainability. Groundwater banking, which includes managed aquifer recharge and in-lieu recharge methods, is becoming an increasingly common water management strategy in response to these challenges. As more states and cities turn to groundwater banking, there is a need to better understand factors contributing to the adoption and implementation of groundwater banking as a long-term water management strategy, as well as its impacts on broader urban water sustainability.

Using a two-stage comparative case study design, this research investigates 16 large-scale urban water systems in the United States to understand various drivers of and barriers to groundwater banking. Then, a longitudinal comparison of two cases of water-stressed cities in the southwestern U.S. is conducted to identify patterns in groundwater banking development and assess the variables that enable sustainable groundwater banking. Data was collected from utility planning documents, archival reports, and interviews with water managers, among other sources. By systematically analyzing the drivers underlying groundwater banking and comparing the implementation and impacts across cases, this research will elucidate critical factors, and the relationships between factors, that promote or hinder a utility's use of groundwater banking.

Presenter

Lauren Bartels, University of Nevada, Reno

Contributing Author(s)

Elizabeth A. Koebele, Ph.D., University of Nevada, Reno

19-Managed Aquifer Recharge and Emerging Contaminants III

TECHNICAL PRESENTATION

**1· Implications of Groundwater Contamination on Managed Aquifer Recharge Development: An Unforeseen Loss
Maria Gibson-Daugherty; Geologist IV, EA Engineering, Science, and Technology, Inc.,

2· Managed Aquifer Recharge at West Richland, Washington, USA: Displacing Poor Quality Groundwater with High Quality Potable Water
Kevin A. Lindsey, Principal Hydrogeologist, GeoEngineers, Incorporated

3· The fate of trace organic contaminants in managed aquifer recharge combined with pre-oxidation and nanofiltration
Sung Kyu Maeng, Professor, Sejong University

4· Chronic Toxicity Mystery at an Advanced Water Treatment Facility
Phuong Watson, Senior Engineer, Water Replenishment District of Southern California and Eric Gonzales, Director of Operations, PERC Water Corporation

5· Identifying SAT efficiency by modelling its specific aquifer environment influenced by natural and anthropogenic activities - Example of the Costal SAT of Agon-Coutainville (France)
Picot-Colbeaux Géraldine, Hydrogeologist,BRGM

Managed Aquifer Recharge at West Richland, Washington, USA: Displacing Poor Quality Groundwater with High Quality Potable Water

Presenter: Dr. Kevin A. Lindsey, GeoEngineers, Inc.; Contributing Authors: Phil Brown, Northwest Groundwater Services, LLC; Alicia Candelaria, GeoEngineers, Inc.

The City of West Richland, Washington installed Water Supply Well No. 10 in 2006 to replace a failed water supply well and provide additional potable water supply. However, soon after completion customers noticed aesthetic issues likely related to biofouling and included high iron, manganese, and odor. Well No. 10 has remained idle since 2008 and West Richland has purchased potable water from an adjacent city to supplement its other seven wells.

West Richland is in the semi-arid Columbia Basin, a part of the U.S. Pacific Northwest characterized by little precipitation in hot summer months. West Richland, like many municipalities in the region derive most of their potable water supply from the Columbia River Plateau Aquifer System (CRPAS), a regional aquifer system hosted within the Columbia River Basalt Group. CRPAS basalt aquifers are very productive, but groundwater geochemical data shows that: (1) recharge into most of the CRPAS is slow and (2) much of the water pumped by high-capacity production wells has aggregate ages exceeding 10,000 years. Consequently, as demand grows extraction will increase and groundwater levels will decline.

Faced with future demand growth and limited alternatives West Richland evaluated wellhead treatment alternatives and Managed Aquifer Recharge (MAR). The MAR option will improve delivered water quality from Well No.10 by storing treated water from the Columbia River available through an intertie with an adjacent city. Treated potable water will be injected into Well No.10 in the winter months, displacing native, low quality groundwater away from the well. Some, but not all injected potable water will be recovered during peak demand periods in the summer. From year to year the potable water left in the ground will build a buffer surrounding Well No. 10, allowing it to contribute more water to the West Richland water system as demand increases.

Field tests conducted to-date show that this plan is feasible, and injection/recovery testing planned for 2022 will provide data needed to permit MAR and convert Well No. 10 to operational MAR status. Water quality issues associated with native groundwater at Well No. 10 include off-gassing oxygen-depleted air and elevated metal concentrations contributing to taste and odor complaints. The ability of MAR to mitigate for off-gassing and the effects of advective dispersion in the storage zone on metals, taste, and odor will be examined in testing planned for 2022 to determine the mixing needed to produce water acceptable to the City's customers. Successful conversion of Well No. 10 to MAR operations restores a stranded infrastructure asset by re-starting pumping at Well 10 while decreasing summer demand on the surface water intake. If successful, MAR at Well No. 10 offers a template for building high quality potable water supplies in other wells with poor water quality.

The fate of trace organic contaminants in managed aquifer recharge combined with pre-oxidation and nanofiltration

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Abstract

A hybridization of managed aquifer recharge (MAR) coupled with pre-oxidation processes was conducted in this study to investigate the attenuation of selected trace organic contaminants (TrOCs) and changes in dissolved organic matter characteristics. In the pre-treatment process, potassium permanganate, chlorine, and ozone treatments were used to primary attenuate TrOCs; notably, the combination of MAR with ozone achieved 84–99% attenuation. The pre-oxidation step using potassium permanganate showed effective removal of carbamazepine (96%). Moreover, nanofiltration (NF) was used after MAR as a multi-barrier concept to remove of persistent TrOCs. Perfluorobutane sulfonic acid, a short-chain polyfluoroalkyl substance, was effectively removed after combining MAR columns with NF membranes. Thus, pre-oxidation coupled with MAR followed by NF could potentially enhance the removal of the selected TrOCs.

Keywords: *Aquifer recharge, nanofiltration, pre-oxidation, recalcitrant, trace organic contaminants*.

Acknowledgement

This work was supported by the Korea Ministry of the Environment (MOE) and the Korea Environmental Industry & Technology Institute (KEITI) through the Demand Responsive Water Supply Service Program (#146523).

Chronic Toxicity Mystery at an Advanced Water Treatment Facility

Presenters: **Phuong Watson of Water Replenishment District of Southern California and Eric Gonzales of PERC Water Corporation**

Contributing Authors: **Phuong Watson, Water Replenishment District of Southern California**
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The Albert Robles Center (ARC) is a 14.8 MGD advanced water treatment facility (AWTF) owned by the Water Replenishment District of Southern California (WRD) and located in Pico Rivera, California. The main ARC treatment processes consist of screens, ultrafiltration, reverse osmosis, ultraviolet advanced oxidation, partial decarbonation, and remineralization for corrosion control. Advanced treated recycled water produced by the ARC plant is discharged to the Montebello Forebay Spreading Grounds or San Gabriel River for groundwater replenishment. From August 2019 through February 2020, monthly compliance samples of the AWTF Effluent that were analyzed for chronic toxicity failed intermittently. WRD launched a year-long, phased investigation and discovered a surprising cause for the chronic toxicity test failures.

Identifying SAT efficiency by modelling its specific aquifer environment influenced by natural and anthropogenic activities - exemple of the costal SAT of Agon-Coutainville (France)

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Most of Managed Aquifer Recharge (MAR) sites in France allow to preserve groundwater, to support an over-exploited groundwater table as well as to prevent saline intrusion, to reduce environmental pollution or to complete water treatment, through soil aquifer treatment (SAT). Groundwater modelling can provide the possibility to preview de feasibility of MAR or SAT system in its regional context and give a tool to identify and optimise the choice for its implementation. The application of a model for testing the influence of projects and management actions on site conditions may provide a framework for stakeholders to screen and select appropriate strategies for the management of water resources and environment. Further on, model allow long-term predictions when it calculated forecasting effects resulting from the natural specific environment as climate change or human-related changes in water use (Rossetto et al., 2018; Criollo et al., 2018; Ringleb et al., 2016; Kloppmann et al. 2012).

On the coastal environment of Agon-Coutainville (Normandy, France), SAT efficiency is questioned by natural and anthropogenic activities that could modify groundwater in flow velocities and quality. This SAT is as part of the full-scale operational wastewater treatment plant (WWTP) and which is sustainably integrated within the municipal wastewater treatment line during more than 14 years along the English Channel coast. The secondary treated wastewater (STWW) of ~1600m^3/day is infiltrated alternatively into three natural reed bed areas of 35000 m^2 before reaching the sand dune aquifer. The direct discharge of STWW to the sea is thus avoided to guaranty the sustainability of the shellfish production and preserve the touristic economy along the coast (Picot-Colbeaux et al., 2021).

To forecast SAT efficiency in a such hydrosystem for which major natural and anthropogenic forcing factors change in time and space, an hydrogeological model included the SAT system is provided. First, a conceptual model is carried out based on the analysis of a significant amount of information that has been collected on five observation wells and on WWTP in order to identify the main factors driving this SAT system (Guillemoto et al. 2021). These data include geology, land-use, LIDAR digital elevation model, rainfall, potential evapotranspiration, streamflow, monitored groundwater levels and water quality, sea tides, as well as SAT functioning (STWW flow and quality, basin geometry and dynamic of infiltration). Second, a hydrodynamic and hydrodispersive numerical model for sustainable groundwater management is carried out on transient state based on the conceptual model and the data analysed. The model integrates SAT dynamic, atmospheric recharge, saline intrusion and river flow. Finally, the numerical model is calibrated with groundwater levels and groundwater quality before being used for simulating future natural and anthropogenic conditions. At each selected time step, the model calculates maps of the groundwater level and quality (solute concentration) that complete punctual groundwater observations, and then, it provides water balance and mass balance that is powerful to determine the efficiency of the SAT in producing fresh water on the surrounding brackish groundwater.

20-Managed Aquifer Recharge of Stormwater: Rural and Agricultural Applications

TECHNICAL PRESENTATION

1· Increased Recharge to the Orange County Groundwater Basin from Forecast Informed Reservoir Operations (FIRO) at Prado Dam, Riverside County, California
Adam Hutchinson, Recharge Planning Manager, Orange County Water District

2· Tools to Assess Groundwater Quality Effects when Flooding Agriculture Fields to Recharge Aquifers
Michael Milczarek, Program Director, GeoSystems Analysis, Inc.

3· On-Farm Recharge at the McMullin Projects: Local expectations, and considerations
Philip Bachand, President, Principal Investigator, Bachand & Associates

4· Basalt Aquifer Recharge in the Columbia Basin: Agribusiness Working to Reverse Aquifer Water Level Decline, Southern Columbia Basin, Oregon, USA
Kevin Lindsey, Principal Hydrogeologist, GeoEngineers, Inc.

5· Managed Aquifer Recharge (MAR) for Agriculture: A Pilot Test Case Study of Direct Injection in the San Joaquin Valley, California
Robert Anderson, Principal Scientist, Geosyntec Consultants.

11th International Symposium on Managed Aquifer Recharge, April 2022

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Abstract:

Title: Increased Recharge to the Orange County Groundwater Basin from Forecast Informed Reservoir Operations (FIRO) at Prado Dam, Riverside County, California

The Orange County Water District (OCWD), located in Orange County, California, has been capturing and recharging stormwater since it began managed aquifer recharge operations in the Santa Ana River channel in 1936. Prado Dam, constructed up stream of OCWD's recharge system, was constructed by the US Army Corps of Engineers (USACE) in 1941 to mitigate flood risks to Orange County. OCWD and the USACE have worked together to allow for the capture of stormwater behind the dam that is subsequently released to OCWD for recharge. Currently, USACE temporarily holds up to 20,000 acre-feet (AF) of water for groundwater recharge downstream of Prado Dam.

To increase the efficiency of stormwater capture at Prado Dam, OCWD is working with USACE, the Center for Western Weather and Water Extremes (CW3E) at the Scripps Institution of Oceanography and stakeholders to assess the viability of Forecast Informed Reservoir Operations (FIRO) at Prado Dam. FIRO is a reservoir-operations strategy that better informs decisions to retain or release water by using enhanced monitoring and improved weather and water forecasts.

Modeling work to evaluate the additional water that could be captured behind Prado Dam and subsequently recharged to the Orange County groundwater basin included using Ensemble Forecast Operations (EFO) and simulating recharge in OCWD's MAR system. EFO is a risk-based approach of reservoir flood control operations that incorporates ensemble streamflow predictions made by NOAA's California-Nevada River Forecast Center (CNRFC). As a result of the higher storage levels maintained in the reservoir under EFO, additional water is available for release to OCWD's recharge facilities resulting in approximately 6 percent increase in median water year recharge volume. Model results also show no increase in the frequency of uncontrolled spillway releases from the reservoir that could cause flood damage to downstream communities. These investigations demonstrate that FIRO is a promising management approach for Prado Reservoir that can result in increased storm water capture and recharge without affecting flood risk management. Additional studies are underway to confirm the viability of FIRO at Prado Dam.

Tools to Assess Groundwater Quality Effects when Flooding Agriculture Fields to Recharge Aquifers

M.A. Milczarek[1], P.A.M. Bachand[2], R.C. Rice[1], Jaime Banuelos[1], J. Keller[3]

Managed Aquifer Recharge (MAR) operations in former or active (i.e. On-Farm Recharge) agricultural fields can flush high concentrations of salinity, fertilizers and other potential contaminants from residual pore water from drainage stored in the vadose zone. In addition, high concentrations of antecedent nitrate and/or soluble oxyanions (i.e. arsenic and selenium) can be found in alluvial sediments located in arid and semi-arid environments even if agriculture has never occurred. Although long-term MAR operations will eventually flush the vadose zone and dilute the residual constituents, if nearby water supply wells are present an assessment of potential water quality effects from the initial MAR operations is warranted to determine the potential extent and duration of poor water quality conditions.

We present case studies to illustrate the process of characterizing and monitoring the vadose zone water quality and subsequent effects on groundwater quality. A baseline assessment of the potential solute loading from residual agricultural water can be made by estimating the evapo-concentration from estimated leaching fractions and the historic agriculture period(s), and using Green-Ampt assumptions to estimate the penetration depth of drainage water. Drilling/coring samples from within the proposed recharge areas are then tested for electrical conductivity (EC) at each sample depth (i.e. every five feet), with intermittent samples sent for more extensive geochemical analyses. Typically, the soil EC decreases with depth from the surface in the vadose zone, with some variability associated with sediment texture and parent material type.

Laboratory leaching experiments can be useful to assess potential leaching durations and maximum solute concentrations. Depending on the sediment type (i.e. coarse vs fine-grained), solute flushing can require anywhere from 2 to 15 pore volumes of recharge water. Nonetheless, because the finer-grained sediment layers may transmit only a small fraction of the recharge water, the vadose zone water quality typically spikes within 5 pore volumes and subsequently improves to the recharge source water quality. During MAR operations, a monitor well(s) can be installed with dual-chamber suction lysimeters which allows vadose zone water quality sampling to great depths. These samplers can provide valuable data on how the vadose zone water quality improves during MAR and the residual constituent loading.

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On-Farm Recharge at the McMullin Projects: Local expectations, and considerations

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California's San Joaquin Valley is a world leader in specialty crops which has had increasing reliance upon groundwater pumping. This increase has been due in part to both climate change and to advances in irrigation technologies. Climate change is decreasing snowpack storage in California's Sierra Nevada range. Rain is increasingly replacing snow as precipitation in the mountains, and higher temperatures contributing to earlier mountain runoff are prominent drivers. Micro- and drip irrigation have been increasingly used to conserve water across most crop types. Overall, this transformation improved agricultural water use efficiencies and water productivity yet also resulted in greater agricultural yield and production, many times offsetting water savings. California's Sustainable Groundwater Management Act (SGMA) was passed in 2014 to require that all groundwater basins in California reach groundwater sustainability over a 20-year time frame. These changes in climate and regulatory requirements have led California's Department of Water Resources (DWR) to promote On Farm Recharge (OFR) and Flood-MAR, the flooding of working landscapes (e.g., agriculture, managed lands), to capture legally available flood water and stormwater to replenish groundwater aquifers. Discussed in California's most recent Water Plan, Flood-MAR represents a critical step in re-operating California's reservoir and groundwater basins to greatly increase California's conjunctive use capacity and to manage California's water more sustainability.

Many research questions have been raised and over the past decade, some research has followed, with plans for more. Yet under SGMA, local regions are required to propose actions to improve groundwater management, which increases the need to create a reasonable template for implementing FloodMAR and OFR. A current need is developing templates and large-scale demonstration projects to show what can currently be done, and what key information and data gaps exists for moving forward in a responsible and timely fashion.

We discuss the McMullin On-Farm Flood Capture and Recharge Projects, the largest Flood-MAR/OFR project in California, specifically through the lens of local Flood-MAR and OFR needs. We present recharge rates achievable on agricultural lands from case studies and experiments; management practices being developed for that region to optimize those rates; and important science- and engineering-based constraints and considerations to help successfully implement OFR while considering such issues as water quality, nutrient and salt leaching, and engineering. We discuss crop considerations: e.g., root zone saturation and hypoxia risks, crop selection and management, yield. Many considerations are pulled together in a Flood Flow Capture Plan, discussing the how, where and when to implement OFR and developed to assist farmers in planning and implementing OFR projects.

Basalt Aquifer Recharge in the Columbia Basin: Agribusiness Working to Reverse Aquifer Water Level Decline, Southern Columbia Basin, Oregon, USA

Presenter: Dr. Kevin Lindsey, GeoEngineers, Inc.; Contributing Authors: Phil Brown, Northwest Groundwater Services, LLC; Ali Leeds, Carollo, Inc.

A confidential agribusiness client located in the southern Columbia Basin in northeastern Oregon is in the third year of a 5-year effort to develop deep basalt aquifer recharge to mitigate for basalt aquifer static water level declines observed in local wells. Water level declines such as are seen in this area are endemic in the Columbia River Plateau Aquifer System (CRPAS), a regional aquifer system hosted within the Columbia River Basalt Group. Successful mitigation will result in slowing, stopping, and eventually reversing the static water level declines seen in recent years in the project area. This multi-year effort will apply existing municipal and agricultural water treatment and supply technology to address, at least locally, a pervasive regional problem.

In the project area Columbia River water, supplemented by CRPAS groundwater, irrigates tens of thousands of acres. These lands, like most of the lands within the CRPAS region are semi-arid with very limited precipitation in the summer growing season. The Columbia River and its many tributaries' funnel snow and rain runoff from the surrounding mountains and provides most, but not all, of the water that sustains the people, habitats, and industries active in the region. CRPAS groundwater pumping makes up the balance of the regions water needs. This groundwater pumping, coupled with competing demands for Columbia River water during the summer, is at the heart of the regions water supply issues and this aquifer recharge project.

The basalt hosted aquifers comprising CRPAS are very productive, but because the region is semi-arid, these aquifers receive very little modern recharge. Groundwater geochemical data shows that recharge into the most of the CRPAS is slow, and that much of the water pumped by high-capacity production wells has aggregate ages exceeding 10,000 years. Taken together, groundwater is being mined in this region.

This project is one of several public and private efforts to address the aquifer depletion issues seen in this portion of the Columbia Basin. In its first 2 years (2019 through 2021) the project characterized the physical hydrogeology and water quality of the basalt aquifer system locally. These studies show that the CRPAS in the project area is very conducive to aquifer recharge via injection, much as has been demonstrated by aquifer recharge projects elsewhere in the region. Water quality data indicates that treating injection source water to not degrade existing groundwater quality is feasible. Year-three of the project (2021/2022) is devoted to field testing treatment options agribusinesses have experience with. Successful treatment testing sets the stage for injection tests later in 2022 to refine system operations and begin the process of aquifer recovery at least locally in the southern Columbia Basin.

This project is a departure from most groundwater supplied irrigated agriculture in the region which, with few exceptions, mine underlying aquifers. It will use surface water when demands on it are low to replenish a deep groundwater system that many rely on, including surface waters in regional discharge areas

Managed Aquifer Recharge (MAR) for Agriculture: A Pilot Test Case Study of Direct Injection in the San Joaquin Valley, California.

Robert Anderson[1], Amer Hussain[2], Claire Wildman[3], Mason Albrecht[4], Alex Pytlak[5]

The Sustainable Groundwater Management Act (SGMA) requires all groundwater basins in California to achieve a balanced level of groundwater pumping that does not cause "undesirable results" by the year 2040. To achieve this balance, groundwater managers and stakeholders are weighing options for both reducing groundwater demand and increasing groundwater supply. Managed Aquifer Recharge (MAR) is viewed as an important management tool throughout California to achieve sustainability under SGMA. This talk will present the results of a pilot study of injection MAR for agricultural purposes. The test was conducted in the Tulare Lake Subbasin, Kings County, California, using surface water from an irrigation canal as the source water. The agriculture sector is the largest user of both groundwater and surface water in California, and is the predominant land use in the Tulare Lake Subbasin. The expected reductions in groundwater pumping from SGMA are placing increasing emphasis on the efficient and integrated use of both surface water and groundwater in the agricultural sector. Without changes in how both surface and groundwater are managed, there will be direct economic consequences for growers and the supporting services that anchor local agricultural economies in California.

The upper portions of the aquifer system in the area contain extensive layers of clay that prevent the use of surface infiltration as a preferred MAR methodology. Therefore, direct injection was evaluated for enhancing groundwater supply from an intermediate semi-confined aquifer. Importantly, an underlying objective of the Pilot Test was to evaluate the use of using typical existing agricultural wells, pumps, and filtration systems with modest enhancements. Ultimately, the vision is to develop an owner-financed MAR program (with oversight from the local groundwater sustainability agency) that allows individual growers to use injection MAR as an additional tool to manage compliance with future pumping limits.

A preliminary feasibility analysis was initially conducted that included modeling to assess the likely hydraulic response and water quality interactions that could occur during a pilot test. A pumping test of the proposed injection well was also conducted to establish baseline hydraulic and water quality conditions. After receiving a permit from the appropriate state agencies, a pilot test was conducted. At the time of this abstract submittal, the injection phase had just completed with a total injection volume of 23 million gallons of surface water from the Kings River over a period of 40 days. A 45-day storage phase of the pilot test will now commence, followed by complete withdrawal of the injected water and analysis of all hydraulic and water quality data. These data will be presented at the conference, along with conclusions, observations regarding injection MAR for agriculture, and next steps for the Tulare Lake Subbasin MAR program.

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21-Aquifer Storage and Recovery (ASR) II

TECHNICAL PRESENTATION

1· Aquifer Storage and Recovery using Desalinated Water in United Arab Emirates
Mohsen Sherif, United Arab Emirates University, Al Ain, United Arab Emirates

2· ASR Implementation Challenges in Texas, USA
David K. Smith, Environmental Scientist, CDM Smith

3· Power Regeneration During ASR Injection
Kent Madison, Owner of 3RValve LLC

4· Aquifer Storage and Recovery in the Brackish Edwards Aquifer, Central Texas
Neil Deeds, Senior Water Resources Engineer, INTERA Incorporated

**5· Advanced monitoring of storage and recovery of unmixed drinking water in a brackish groundwater aquifer
Caspar van Genuchten, PWN Water Supply Company

Aquifer Storage and Recovery using Desalinated Water in United Arab Emirates

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Abstract

The United Arab Emirates (UAE) is located an arid region with limited renewable water resources due to the scarcity of rainfall and lack of perennial surface water bodies. The water demands in UAE have increased significantly due to the remarkable expansion in the green areas, economic development and prosperity, rapid population growth, and changes in the lifestyle. The freshwater availability in UAE is becoming more challenging under the conditions of climate changes. To meet the current and future freshwater demands, large scale desalination plants have been established in UAE. The desalination plants are designed to meet the peak demands and, hence, significant amounts of high-quality water are available during low demands period and could be wasted if not utilized or stored.

Aquifer Storage and Recovery (ASR) systems are used to store large volumes of water in groundwater systems for a longer period and at a much less cost as compared to other water storage options. In UAE, the excess of desalinated water is injected into the suitable groundwater formations for two main objectives. First, to create a strategic reserve of freshwater and second to store the desalinated water during the low water demand time and to be recovered during high demand seasons. This research discusses the setting and performance of one of the ASR projects in UAE. The dynamics of groundwater levels as well as the changes in its salinity under the conditions of injection, storage and recovery are presented and discussed. The effect of the rates and durations of injection and recovery and the duration of storage on the overall performance of ASR systems are investigated. In small scale projects, injection and recovery from the same well would be a feasible and an economical option. However, in large scale systems, and a higher efficiency would be achieved if injection and recovery are performed from different wells. The optimum design of ASR systems depends on the geological conditions and the hydraulic conductivity and transmissivity of the porous medium. Based on the average plume velocity, recovery wells should be placed downstream of the injection wells and at appropriate depths to maximize the recovery efficiency. The hydraulic conductivity of the porous medium should not be high so that the injected water would be maintained within the protected zone of the ASR system. The overall efficiency of ASR systems will improve significantly from one cycle to another and may exceed 90%.

Keywords: United Arab Emirates, ARS, efficiency, desalinated water, strategic water reserve

ASR Implementation Challenges in Texas, USA

Water is a key component of the economic engine for Texas. With continued rapid population growth particularly in its major Cities, aging water infrastructure, declining groundwater levels, climate variability and the ongoing threat of severe drought that primarily impacts surface water resources, the need for a reliable water supply continues to be critical. The State of Texas is responding to these challenges in many ways including embracing alternate water supply strategies that include seawater desalinization, brackish groundwater development and Aquifer Storage Recovery (ASR).

After decades of study and analysis, and only limited utilization of ASR as an alternative water management strategy in Texas, ASR regulations have now been amended with the passage of House Bill 655 by the Texas Legislature and subsequent amendments to corresponding regulations at the Texas Commission on Environmental Quality (TCEQ), which allow for a much more flexible, stream-lined, and lower risk permitting process for ASR project sponsors. This along with funding opportunities being provided by the Texas Water Development Board (TWDB) has encouraged a renewed interest in ASR in Texas with over 10 new ASR projects in feasibility, pilot testing or full scale implementation phases – demonstrating that this strategy is quickly gaining interest in the water resources community.

ASR projects, the practice of storing surplus water in confined "reservoir like" aquifers for later recovery and distribution when required, have the potential to address many water management issues. In concept ASR is simple, however experience gained from implementing ASR systems for several decades elsewhere has shown that it is wise to implement with a phased approach – proceeding only to the next phase if successful. This paper will present an overview of two signifciant ASR projects currently being successfully implemented in Texas but will also outline some of the technical design challenges encountered and overcome, further demonstrating the need for a phased approach.

The City of Bryan is implementing ASR utilizing the Simsboro Aquifer. In concept it involves the conveyance of groundwater to an ASR wellfield located in a deeper portion of the same aquifer, but closer to the Cities water treatment plant for easy distribution to meet future peak water demands, and in a location that will also assist with controlling the movement of more brackish groundwater towards the City's freshwater wellfield. However the target storage zone is deep, with well depths in excess of 3,000 feet, consequently the recovered water requires cooling due to the natural thermal gradients. To reduce the initial cost of ASR pilot testing, primarily designed to investigate possible water quality changes during storage, an existing well was retrofitted for Cycle testing. This included modification of the wellhead piping, instrumentation and control and the installation of a downhole control valve to prevent water cascading during recharge. Although Cycle testing was successfully completed and the City is now constructing an ASR well field, there were significant challenges during the retrofit that provide important lessons learnt.

The City of Georgetown with support from the Brazos River Authority (BRA) is evaluating the storage of surface water, including storm water flows during "wet weather years". Using spare water treatment capacity during low demand periods, the City proposes to treat the surface water and store in an ASR system. The concept has been fully evaluated with analysis that included surface water hydrology, climate change scenarios, hydrogeology, geochemical compatibility, groundwater modelling and concept ASR designs. However, the hydrogeological setting beneath the City is not favorable for large scale ASR development (a recovery capacity of 22 MGD is being contemplated). The most favorable hydrogeological locations are located at distances that would significantly impact the cost of ASR implementation due to pipeline costs and the depths of the ASR wells. Therefore, alternate wellfield locations closer to the City are being evaluated, which include using seismic data to identify geological structures and test wells to confirm geologic properties.

Over the past years power generation during ASR (Aquifer Storage and Recovery) has been meet with failure and heavy speciesism. Now with an Oregon municipality and myself a private farm owner using the new and developing technology, the analyzed results indicate and prove power regeneration during ASR injection is viable with a short return on investment. ASR power regeneration can be achieved with a minor addition to a typical ASR well project. In order to generate power from the motor, the pumping motors ratchet is removed and the motor and pump is allowed to run in reverse during the ASR injection process. With the use of a regeneration module and a VFD (Variable Frequency Drive) we program the VFD to run in the reverse direction but at a slower speed than the pump would naturally want to spin at during injection. This process results in generating braking energy on the DC buss of the VFD that then is converted to AC by the regeneration module. This AC power is then placed back on the grid reducing the overall consumption of power by the end user. One specific well, for example, was analyzed over a five-year period. The total amount of non-native ASR water stored after that five-year period was 103.37 billion gallons. During that same period of injection, with the use of power regeneration, the consumer offset and reduced the total power consumption by 269.27 megawatts. The potential amount of power generated from ASR regeneration has the ability to offset the cost of pumping by tens of thousands of dollars. Power utility credits and the amount of money saved over the lifetime of a well pumping application, gives the end user comfort and flexibility to utilize surplus capital for other necessary projects. As aquifers continue to decline and the need for ASR grows along with the desire to produce green energy ASR Generation is a natural fit for both new and old ASR projects.

Aquifer Storage and Recovery in the Brackish Edwards Aquifer of Central Texas

A pilot aquifer storage and recovery (ASR) project is ongoing in New Braunfels, a city about 30 miles northeast of San Antonio in south-central Texas. The pilot well program is the latest phase in a multi-year project by New Braunfels Utilities (NBU) to demonstrate that ASR is feasible in the brackish portion of the Edwards Aquifer. To date, the project included two main phases.

Phase 1: Recommendation of ASR Sites for Pilot Testing. Using evaluation and ranking factors that included the hydrogeology in the NBU service area, the amount and timing of NBU's surplus water supplies, and the location of existing water supply infrastructure, potential sites for an ASR operation were identified and recommended. During this phase, potential sites were identified in the brackish portion of the Edwards Aquifer, and the Middle and Lower Trinity aquifers. After selecting a site overlying the saline Edwards Aquifer, NBU acquired a small plot of farmland adjacent to the airport for the ASR pilot, with the larger airport land being the eventual target for an expanded ASR wellfield. A field testing and data collection plan was developed and implemented that included drilling a test hole that could be converted to a monitoring well, and obtaining a continuous wireline core (1,000 feet) of the Edwards Aquifer. Analysis of the test hole and continuous wireline core provided confidence that the site was suitable for the ASR pilot project, based on the productivity of the test hole, and the hydraulics/mineralogy of the cores.

The native groundwater is high in total dissolved solids at around 8,000 mg/L. The objective of the ASR operation is to displace this native groundwater with recharge water and establish a "bubble" of fresh water that can be recovered with minimal effect on the water quality of the recovered water. While the hydrogeology seems favorable for meeting this objective, a pilot ASR well and cycle testing program was required to prove out the concept.

Phase 2: Design and Implementation of an ASR Pilot Project. In Phase 2, three additional monitoring wells and an ASR pilot well were sited, designed, and constructed. The monitor wells are used to both assess operational conditions and to provide information about far-field response to the ASR well. The far-field response is important because of the presence of Comal Springs, about five miles updip of the well in the freshwater portion of the Edwards Aquifer. NBU has worked closely with the local groundwater regulatory agency, the Edwards Aquifer Authority, to ensure that the ASR well will have no impact on the springs in terms of water quality.

The pilot well has been in operation, primarily recharging, for over a year. The target storage volume has been achieved, and about 180 million gallons have been stored to date. Continued cycle testing will provide information required for getting a permit for the well from the Texas Commission on Environmental Quality. Cycle 1 demonstrated that fresh water was successfully stored in the brackish aquifer (i.e., water quality was maintained during a recovery cycle). Cycle testing will continue through 2021, with the permit application anticipated late in the year.

22-Managed Aquifer Recharge Geophysics II

TECHNICAL PRESENTATION

1· Rapid Mapping of Aquifers and Water Quality Using a Towed Cart Time-Domain Electromagnetic Induction System
Doug Laymon, Geophysicist, Collier Geophysics, LLC

2· Connected Waters - Saline Discharge Into, and Aquifer Recharge Out of Australian Waterways – an Investigation Using Electrical Conductivity Imaging
David Allen, Principal, Groundwater Imaging Pty. Ltd.

3· Airborne Electromagnetic Mapping for Managed Aquifer Recharge
Jared D. Abraham, Geophysicist/Geologist, Aqua Geo Frameworks LLC

4· A geostatistical workflow for evaluating flood-MAR sites using geophysical data
Zach Perzan, Stanford University

5· Improving hydrogeological characterization for managed aquifer recharge with borehole magnetic resonance
Ned Clayton, Principal Hydrogeologist, NMR Services

6 Airborne geophysics and groundwater modeling to support a managed aquifer recharge project in the Mississippi Alluvial Plain
J.R. Rigby; Burke Minsley; Moussa Guira; Andrew M. O'Reilly and, Daniel Wren

Rapid Mapping of Aquifers and Water Quality Using a Towed Cart Time-Domain Electromagnetic Induction System

Doug Laymon, P.G., and David Allen*, Ph.D.**

Mapping aquifers and water quality using electrical geophysical methods is well established but has been limited by slow data collection time in the field. Several Airborne Electromagnetic (AEM) induction methods have been developed to rapidly cover large areas. However, these methods do not produce the same lateral and vertical resolution and are less sensitive to the shallow subsurface as ground-based methods. The cost of AEM methods can be prohibitively high to screen sites of a few hundred to a few thousand acres. This has left a gap between the coverage that can be provided by traditional ground-based methods and the coverage that can be economically provided by AEM methods. A new towed time domain electromagnetic induction (TEM) systems has been developed to quickly provide dense subsurface coverage on sites of hundreds to thousands of acres to fill this gap.

The AgTEM is a cart based TEM exploration system that has been developed in Australia and is new to the US. The system can produce high resolution images of the subsurface to depths of 300 feet with field production rates of tens of linear miles per day. Sites of several hundred acres are easily surveyed in one day with much higher subsurface data density that can be provided by other methods. The system can be used to:

- identify favorable recharge areas,
- map sand and gravel aquifers and clay confining units,
- map the depth to bedrock,
- map saline zones in aquifers,
- find productive fracture zones in hard rock aquifers, and
- identify zones of connection between surface water bodies and groundwater.

The AgTEM system uses a compact design with the ability to pass over rough terrain and can be towed by a small ATV. The system provides real time data output to monitor data quality during acquisition. The data is inverted to continuous resistivity profiles in a matter of hours after collection. Horizontal data slices and 3D renderings can be made as desired to visualize the data and identify targets of interest. The system is less affected by power lines and other noise sources than AEM methods and can collect data closer to cultural features such as buildings, fences, and pipelines.

AgTEM is well suited to screen large areas for suitable recharge basins, map the connectivity of aquifers and surface water bodies, map large areas for channel sand aquifers and map zones of fresh water in costal aquifers. This presentation will show the key technical elements of the system and present several case histories that illustrate the data density and resolution the system can provide.

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Sediment texture and seepage mapping beneath earth irrigation infrastructure using electrical conductivity imaging.

By Dr David Allen, Principal, Groundwater Imaging Pty. Ltd.
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For MAR projects that use surface water infrastructure for infiltration, either intentionally or inadvertently, knowledge of seepage and infiltration pathways is of great importance. Alluvial geology is typically highly heterogeneous and complex, with coarser grained permeable deposits, left from river flood action, interconnecting each other and cross-cutting clays left by overbank flood deposition and volcanic ash falls. A common anecdotal rule cited is that 90% of seepage can disappear through 10% of ground covered. Whatever the percentages are, it is best to map the high seepage pathways to sort out how infrastructure can constructively contribute to MAR. For a large flood capture reservoir, there may be opportunity to partition a part and enhance infiltration into the right geology while sealing the remainder by clay reworking. Similarly, for irrigation canal networks, some parts may suit use as part of MAR schemes while other parts are best sealed or piped to avoid inappropriate waterlogging and salinization. The same mapping, monitoring and control used to manage recharge can be exactly what is needed to also manage crop waterlogging and salinization.

Electrical conductivity (EC) correlates excellently with ground moisture salinity. As MAR works with fresh water, which prefers to flow through permeable sediment, features of interest in EC maps are typically low conductivity anomalies in otherwise saturated clay substrate which retains old moisture with a build-up of salt from rock weathering and concentration by evapotranspiration. In coarser more glacial environments EC may distinguish seepage from otherwise dry coarse sediment of extremely high resistivity.

From earth irrigation infrastructure I have mapped substrate at depths from decimeters to 10m deep and more using towed submarine streamers of electrodes and am surprised at how each depth slice can tell a rather different story.

Across land I have mapped substrate at depths from 1m to 100m using electromagnetic induction from towed antennae. This is sufficient depth to span the water table and to image through stacks of crosscutting prior stream deposits. In some instances groundwater discharge through such deposits, from times of wetter climate, has potentially cleaned what are now seepage pathways so that very pronounced anomalies can be seen. Interpretation, on a pragmatic level, can be simple, but on a paleo-climatic and geomorphological level can be challenging.

Establishment of good MAR projects using direct infiltration requires an exploration process similar to oil/gas exploration but at a much shallower depth. Electrical conductivity imaging using towed streamers and electromagnetic sources is a most appropriate tool for establishing the detailed spatial information needed for such a task.

Airborne Electromagnetic Mapping for Managed Aquifer Recharge

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Airborne Electromagnetic (AEM) mapping can provide critical information to a Managed Aquifer Recharge (MAR) program. However, for AEM to be useful, the electromagnetic contrast of the materials needs to be such that the imaging of the critical components of the earth materials for MAR (i.e. sand and gravel versus clay and silt) can be achieved. AEM has seen growing use within the United States (US) over the past 20 years and several of these projects have been specifically for MAR programs. The elements of the selection of an AEM system and the way in which those data are used to create a hydrogeological framework are the key steps in the usefulness of the AEM. Prior geological investigations including boreholes and or any previous geophysical studies are critical for integration into any AEM based mapping program. Two examples each of the use of AEM for MAR in Nebraska and California are presented to provide a range of example environments. Nebraska is the leader in the US for acquisition of AEM with an excess of 41,000 line-km of data acquisition, historically. California is third in the nation behind North Dakota but is beginning to utilize AEM. The examples from Nebraska are in the central portions of the state along the Loup River and the western boundaries along the North Platte River. The central Nebraska site is an alluvial aquifer that is overlaying the Tertiary Ogallala Group that contains heterogenous deposits of sand-sandstone interlayered with clays and silts. The key in this environment is to find the windows of coarse alluvial aquifer material overlaying the sand and sandstone portions of the Ogallala. AEM successfully mapped those windows and was used to develop a MAR project plan. The second example from Nebraska is an alluvial aquifer overlying the Tertiary White River Group. The area is dominated by an irrigation system that provides large amounts of recharge water to the area. Additional recharge sites were identified using AEM to be utilized as recharge basins in areas of thick coarse aquifer materials adjacent to the canals as well as well-defined conduits to the North Platte River. The examples from California are from the northern Sacramento Valley in the Butte area and in the central San Joaquin Valley. The Butte AEM investigation showed connections between the Sacramento River floodplain and coarse aquifer materials at depth. In the San Joaquin Valley massive alluvial fan and lacustrine deposits along both sides of the Valley would make very strong MAR sites. These examples utilized the coarse aquifer mapping and the proximity of water sources in the area to indicate the zones of the best MAR. Note that the proximity of clay layers, and the extent of these layers, are critical to the success in the areas of MAR's.

A geostatistical workflow for evaluating flood-MAR sites using geophysical data

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In water-stressed regions of the world, flood-managed aquifer recharge (flood-MAR) – a recharge strategy in which land is flooded with excess river discharge to replenish depleted aquifers – is a potential tool to combat modern groundwater challenges. However, many areas, including California's Central Valley, exhibit complex subsurface stratigraphy that hinders the evaluation of potential flood-MAR sites. Although geophysical techniques, in combination with lithology logs, can map out interwoven beds of coarse- and fine-grained sediment, the magnitude and rate of recharge in response to surface flooding cannot be predicted from texture and spatial distributions alone. Though sands and gravels are highly conductive when saturated, they can act as capillary barriers and inhibit recharge when dry. Similarly, low-permeability silt and clay layers can restrict flow, but they also account for a significant fraction of subsurface storage. Thus, even once a subsurface lithologic map has been acquired, additional hydrologic evaluation is necessary to determine site suitability.

Using a Central Valley almond grove as a case study, we develop a workflow for evaluating potential flood-MAR sites using geophysical data. We first survey the site with a towed transient electromagnetic (tTEM) system and, in combination with lithology data from cone penetrometer testing, use geostatistical methods to obtain a suite of 3D models of subsurface lithology. We then import these lithology maps into a high-performance groundwater flow model (ParFlow) and run Monte Carlo simulations while varying model input parameters. Using this suite of simulations, we perform uncertainty quantification and global sensitivity analyses to evaluate the most likely recharge outcomes and identify which subsurface properties contribute to uncertainty in model output. In total, this workflow serves as a comprehensive tool for evaluating flood-MAR sites and forecasting recharge outcomes.

Improving hydrogeological characterisation for managed aquifer recharge with borehole magnetic resonance

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Keywords

Borehole Magnetic resonance logging, hydraulic conductivity, groundwater replenishment

Abstract

The demand on Perth's water supply is ever increasing due to population growth and a drying climate. To ensure a long-term water supply for the city, the Water Corporation has introduced a Groundwater Replenishment (GWR) Scheme (Water Corporation, 2019), which involves the injection of treated wastewater into confined aquifers for storage. The injection will supplement traditional groundwater supplies and natural recharge systems. The Perth GWR scheme is in its' second stage and is currently being expanded to enable a 28 billion litre recharge capacity from the Leederville and Yarragadee aquifers. On the last drilling campaign considerable analysis at the injection site was undertaken to improve well management and performance during drilling, injection, and clean-up operations. As an input into the analysis a comprehensive wireline logging suite was used to provide hydrogeological characterisation of the aquifers. Of particular interest is borehole magnetic resonance (BMR) which provides accurate measurement of reservoir porosity and an estimate of well permeability or hydraulic conductivity using well-known empirical correlations (Kleinberg, 2001, Neville and Hopper, 2017). Once hydraulic conductivity in a continuous log format is obtained it can then be used to determine a hydraulic transmissivity. The permeability model typically used for sandstone reservoirs is the Timur-Coates model (Timur, 1968, Coates *et al.* 1991). This model requires calibration to local well information such that the model parameters correctly reflect the local geology. This is typically achieved by core analysis of plugs obtained from the well-sites of interest. The GWR project included flow-logging measurements at the injection sites to measure well transmissivity. We provide an alternative method of calibrating the Timur-Coates parameters using the transmissivity determined from flow logging tests across multiple wells (Dlubac *et. al.* 2013). The measured Timur-Coates parameters and resultant transmissivities are compared to results obtained from the standard core calibration method. The proposed method allows permeability to be more accurately captured at the well-scale. Permeability measurements via BMR can then be used at other small monitoring bores for aquifer management.

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Airborne geophysics and groundwater modeling to support a managed aquifer recharge project in the Mississippi Alluvial Plain

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The USGS Mississippi Alluvial Plain (MAP) project provides responsive, consistent, and seamless high-quality science for sustainable groundwater management for the Mississippi River Valley alluvial aquifer in the Lower Mississippi River Basin. The MAP project is a complex, integrated water availability project composed of seven component teams contributing modeling and data collection related to recharge, irrigation water use, water levels, streamflow, water quality, hydrogeologic framework, and decision support. As part of this project, the USGS began an airborne geophysical mapping initiative using airborne electromagnetic (AEM), magnetic, and radiometric surveys to refine the hydrogeologic framework of the alluvial aquifer and adjacent units. This effort began in 2018 with a high-resolution survey of ~2,500 line-km of airborne data over a 1000 sq. km area near Shellmound, MS in support of a USDA-ARS managed aquifer recharge pilot project enroute to approximately 40,000 line-km of acquisition across the entire alluvial valley. Geophysical interpretations are helping to refine estimates of confining layer thickness, thickness of and heterogeneity within the surficial aquifer, and the geometry of subcropping Tertiary units beneath the surfical aquifer. In addition, vertically integrated connectivity metrics were developed to provide spatial representations of hydrologic connectivity between the aquifer and the land surface, streambeds, and subcropping hydrogeologic units. The component models and data sets were used to develop a MODFLOW 6 groundwater model to evaluate projected impacts of project operation on groundwater levels in the aquifer at the extraction and injection points.

23-Managed Aquifer Recharge Modeling II

TECHNICAL PRESENTATION

1· Groundwater Modeling to Support Permitting of Recycled Water Recharge Projects in California
Abhishek Singh, Principal Engineer; Vice President - Western Region, INTERA Incorporated

2· Flood Water Allocation and Agricultural Site Suitability for Potential Flood Managed Aquifer Recharge
Francisco Flores-López, Ph.D., California Department of Water Resources

3· Fluid Dynamics Assessment using Numerical Modeling of Water Flow through Different Screen Types for ASR Well Design
Salvador Jordana, Project Director, AMPHOS21

4· Mapping the potential for water quality improvements during infiltration for MAR with machine learning informed by field and laboratory experiments
Galen Gorski, Postdoctoral Researcher, University of California, Berkeley

5· The impact of storage conditions on the recovery efficiency during ASR: an analytical and numerical evaluation to optimize system design
Niels Hartog, Principal Scientist — Geohydrology, KWR Water Research Institute

Groundwater Modeling to Support Permitting of Recycled Water Recharge Projects in California

The California Department of Drinking Water (DDW) has developed a comprehensive set of Title-22 regulatory requirements for the permitting of recycled water recharge projects. A key part of these regulations is estimating subsurface residence/travel times the injection/recharge facility to monitoring wells and drinking water wells. Groundwater models can be useful tools in evaluating residence time requirements for recycled water recharge projects. This talk will provide an overview of California Title-22 regulations for subsurface recycled water recharge projects, especially as they pertain to 'soil aquifer treatment' (SAT) credits, monitoring requirements for response/retention times, and ensuring the safety of drinking water supplies. We will discuss hydrogeologic and hydraulic drivers of the travel times in the subsurface and present modeling approaches for the estimation of these travel times. Consideration of scale effects is key to ensuring robust modeling estimates of travel times. We will present the hierarchy of model resolutions (from analytical site-scale to numerical regional models) that may be used to assess recycled water transport at multiple scales. Case-studies from several recycled water injection projects in Southern California including the West Basin Barrier Project, the Alamitos Barrier Project, and the Leo J. Vander Lans Inland Injection Well will be used to demonstrate the successful use of groundwater models for the permitting and compliance reporting of recycled water recharge projects in Southern California Basins. We will also discuss data requirements for the development and calibration of these models, in addition to limitations and uncertainties associated with the travel time estimates, especially as they pertain to regulatory requirements for Title-22 permitting.

The 11th International Symposium on Managed Aquifer Recharge (ISMAR 11)
April 11-15, 2022 Long Beach, California

PRESENTATION TITLE: ***Flood Water Allocation and Agricultural Site Suitability for Potential Flood Managed Aquifer Recharge***

PRESENTER NAME: ***Francisco Flores-López, Ph.D.***

AUTHORS: David Arrate[1], Francisco Flores-López[1], James Wieking[1], Jenny Marr[1], Aleksander Vdovichenko[1], Shem Stygar[1], Karandev Singh[1], Iman Mallakpour[1], Romain Maendly[1], Wyatt Arnold[1], Glen Low[2], Lee Bergfeld[3], Wesley Walker[3], Daniel Mounjoy[4], Taylor Broadhead[4], Ladi Asgill[4], Taylor Broadhead[4], Lisbeth DaBramo[5], Sercan Ceyhan[5], Ali Taghavi[5], Betty Andrews[6], John Pritchard[6], Travis Hinkelman[6], Paul Bergman[6].

AFFILIATIONS: [1]California Department of Water Resources, [2]Earth Genome, [3]MBK Engineers, [4]Sustainable Conservation, [5]Woodard & Curran,[6]ESA Environmental

ABSTRACT:
Expanded integration of water management sectors and activities at the watershed-scale can help water managers enhance their water supply portfolio, increase resiliency, and support multiple benefits. The California Department of Water Resources (DWR) recognizes the need to rehabilitate and modernize water and flood infrastructure in California and promotes using flood water for managed aquifer recharge (Flood-MAR) to support sustainable water resources and achieve SGMA objectives.

DWR, in partnership with the Merced Irrigation District (MID), conducted a study in the Merced River watershed within the San Joaquin Valley. The study aims to quantify and describe the multi-benefits of planning and implementing Flood-MAR as part of a watershed scale water management strategy, evaluating flood risk reduction, groundwater sustainability, ecosystem enhancement, and water supply benefits of Flood-MAR projects. In addition, the study has assessed water sector vulnerabilities to climate change in the Merced River watershed and then assessed the potential resilience provided by these Flood-MAR strategies.

Factors affecting potential Flood-MAR opportunities at the field scale are conveyance, recharge potential, crop suitability, and seasonal farming practices among others. DWR's Integrated Water Flow Model Demand Calculator is used to simulate the root zone saturation levels for the main crop and soil types combinations identified in the MID service area and determine the acceptable recharge duration and dry-down intervals to maintain acceptable soil oxygen conditions. Water allocation is performed using a GIS modeling decision support tool, Groundwater Recharge Assessment Tool (GRAT), designed to identify optimal placement and timing of available water to the highest potential recharge locations. GRAT does an optimized allocation of floodwater for groundwater recharge through the following 5 actions: (1) evaluate where and when flood water is available for recharge, (2) evaluate available conveyance capacity, (3) understand recharge site suitability based on soil properties and types and crop and land use suitability, (4) identify allowable volumes of recharge water for on-farm and fallow recharge (using a crop compatibility calendar), and (5) quantify the recharge benefits and associated costs. Additionally, GRAT considers the effects of flooding agricultural fields on crop productivity.

The described approach can assist with efficient application of Flood-MAR, can be used to quantify the diverse multi-benefits, and aids GSAs in achieving long-term sustainability of California's groundwater basins as mandated by SGMA.

Fluid Dynamics Assessment using Numerical Modeling of Water Flow through Different Screen Types for ASR Well Design

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Aquifer storage and recovery (ASR) wells are viable solutions for managed aquifer recharge (MAR) when recharge is not viable or achievable from surface trenches, detention ponds, or other surface methods.

Injection well efficiency depends on various parameters including aquifer properties (confined/unconfined, porous/fractured, transmissivity, etc), borehole characteristics (hole diameter, depth, etc), and well design and construction (screen type, filter gravel pack, etc).

ASR wells have a dual purpose, injection and extraction, and require periodic maintenance and rehabilitation, which include pumping schedules and other methods to clean the screen and clear gravel pack of clogging materials such as fine sands, incrustations, and biofilm. This means screen and gravel pack design for these wells requires consideration for hydraulic efficiency, prevention of fine particles entering the well, and mechanical resistance to flow reversal during rehabilitation. ASR well design must guarantee optimal injection performance, proper operation and maintenance, and system longevity.

The majority of studies in this field are devoted to design of ASR wells from a physical/hydrodynamic and chemical/biological point of view. Most studies performed to assess the impact of screen length in ASR applications have been empirical (Bonilla et al. 2019*). Field studies and numerical modeling of aquifer recharge are classic groundwater research approaches.

This study focuses on a small interphase zone between screen opening and gravel pack, and employs a numerical tool to explicitly model fluid dynamics from the well bore to the porous media (gravel pack and aquifer) through different screen slot geometries. Use of this methodology allows calculation of well screen head loses using numerical simulation of groundwater flow in porous media coupled with turbulent flow through well screens. This multi-physics approach opens a door to quantify pressure distribution and screen head loss by analyzing the processes at sub-millimetric scales for any well configuration (well diameter, type of screen, slot opening, filter/gravel pack thickness and hydraulic conductivity, aquifer hydraulic conductivity and pumping rate, etc.) for production and injection wells.

Flow was simulated both into the well and away from the well. Simultaneously, head losses and velocities for both flow scenarios were estimated. Water pressure calculated along the entire system domain resulted in quantifying head distributions and the resulting depression or injection cones attributed to flow direction. In addition, other values, including water flux, water velocity, and water particle flow path (streamlines) can be visualized and used to predict eddy formation and water jet distribution in the slot opening.

The flexibility of this model readily allows changes of slot opening, filter pack thickness, and permeability factors for various screen types and flow rates (in pumping and injection mode) thereby quantifying their impact on head loss.

* Bonilla, J. P., Händel, F., Kalwa, F., Sharu, A. and Stefan, C. (2019). Laboratory and field experiments on the significance of the screen lengths for maximum well injection rates in an unconfined aquifer. Proceedings of the ISMAR 10. Topic No: 8 (135#) pp 376-384.

Session: MAR Emerging Contaminants and Water Quality

Mapping the potential for water quality improvements during infiltration for MAR with machine learning informed by field and laboratory experiments

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Infiltration during MAR can improve water quality, under certain conditions, through the bioreactive removal of contaminants such as nitrate (NO3). A better understanding of the processes that lead to NO3 removal during infiltration could lead to simultaneous improvements in water quality and supply during MAR. Additionally, this could allow for the use of non-pristine source waters for infiltration. However, the conditions under which water quality improvements can be achieved during MAR have not been systematically examined in a spatially explicit manner. We synthesize observations from laboratory tests, field experiments, and operational MAR facilities at four MAR locations within the Pajaro Valley, California, USA to develop a predictive model of nitrate removal during infiltration. We compare several different modeling approaches, and the preferred model uses boosted regression trees based on four predictor variables describing soil and fluid conditions. We apply this model to simulate the spatial distribution of potential nitrate removal (NR_p) across a heterogeneous and mixed-use landscape. We combine a map of NR_p with independently simulated hillslope runoff (used as an MAR source water in the area), and find for this study region that potential load reduction is highest in urban areas (median = 18.2 kg-N/yr) where large runoff volumes are collocated with soils of high nutrient cycling capacity compared to forest and agricultural areas (median = 1.6 and 3.5 kg-N/yr, respectively). These, and other associated results could help guide decisions in resource management and identify promising MAR sites while elucidating factors controlling water quality improvements during MAR.

The impact of storage conditions on the recovery efficiency during ASR: an analytical and numerical evaluation to optimize system design

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Across the globe, fresh water respources are increasingly under pressure, quantitatively by intensifying droughts and demand, and qualitatively by salinization and contamination. MAR techniques, such as aquifer storage and recovery (ASR), are well-positioned to play a vital role to sustainably increase water availability. However, it is known that ASR performance varies strongly with site-specific storage conditions.

To facilitate site selection and optimal ASR design it is therefore crucial that the controlling factors of ASR performance, particularly its recovery efficiency can be confidently anticipated and evaluated. The main factors known to affect ASR recovery efficiency are losses due to 1) dispersion, 2) displacement by ambient groundwater flow and 3) buoyancy flow. Here, we evaluated their impact of these factors by the adaption and development of analytical solutions. Using Modflow-MT3DMS-Seawat simulations for a wide range of realistic field conditions we validated their accuracy and limitations of the analytical solutions for these different factors, both in separation and combined.

Results showed that a simple, analytically derived, formula describing dispersion losses solely based on the dispersion coefficient (α) and the hydraulic radius of the injected volume (Rh) provided an excellent match for all conditions tested where $\alpha/Rh<0.2$. An expansion of the formula to include the development of recovery efficiency with subsequent cycles (i) was also derived and in keeping with simulation results.

Simulation results showed that dispersion losses were particularly increased by ambient groundwater flow, when displacement losses were dominant in determining the overall recovery efficiency. An analytical formula developed to describe thermal losses by ambient flow in aquifer thermal energy storage systems based on the degree of displacement (x) during time of storage (t) was adapted and provided a reasonable agreement for simulations with ambient flow in addition to dispersion. For the ASR simulation scenarios affected by buoyancy flow during fresh water storage in saline aquifers, dispersion losses were less expressed also under conditions of ambient groundwater flow. Thus far, the evaluations in this study have been assumed equal injection and abstraction volumes, ongoing are evaluations on the impact of using threshold concentrations and temporally dynamic pumping regimes.

Overall, the results of this study allow an evaluation of the dominant factor(s) that will determine ASR recovery efficiency. Along with other components of ASR performance such as well capacity, this can be valuable when evaluating regional potential for ASR based on stratigraphical and groundwater flow characteristics as well as input for preliminary ASR designs and site characterization plans.

Keywords: ASR, recovery efficiency, storage conditions, modelling, analytical solutions, operation design

24-Managed Aquifer Recharge and Integrated Water Management II

TECHNICAL PRESENTATION

1· Challenges and Experiences on Managed Aquifer Recharge in the Mexico City Metropolitan Area
Adriana Palma Nava, Master Engineering, UNAMF Institute of Engineering

2· Leveraging Existing Information to Assess the Potential Impacts of Managed Aquifer Recharge Projects
Carolina Sanchez, Senior Engineer, West Yost

3· Managing Aquifer Recharge: An Integrated Assessment of Global Best Practice (V)
Karen Grothe Villholth, Principal Researcher, IWMI - International Water Management Institute

4· Potable Reuse of Municipal Wastewater in the United States
William M. Alley, Director, Science & Technology, National Ground Water Association

5· MAR's Role in One Water – Building Resilience
Don Corbett, Senior Hydrogeologist, Hydrogeology and Water Programs, Region of Waterloo, ON, Canada

CHALLENGES AND EXPERIENCES ON MANAGED AQUIFER RECHARGE IN MEXICO CITY METROPOLITAN AREA

Carmona Paredes, R. B., Palma Nava A., Parker T.

The water supply of Mexico City Metropolitan Area is currently unsustainable: demand exceeds supply in one of the biggest urban centers in North America, with a population of almost 22 million. The main source of water supply for this area currently is groundwater. The total water demand for Metropolitan Area is 84 m3/s and is provided by groundwater (63%), imported water (27%) and recycled water (10%).

Hydrologic analysis reflects only two main opportunities to increase water supply: water reuse and managed aquifer recharge with recycled water and storm water. This paper presents an inventory of MAR projects and an overview of recharge projects that have been conducted in the Mexico City Metropolitan Area, methods for recharge, water sources, geographical distribution, and the main results obtained in each project for the last 80 years.

We found three types of MAR efforts: (1) exploratory and feasibility studies for MAR, (2) pilot projects, and (3) MAR facilities that currently operate.

This study includes the examination of the legal framework for MAR to identify challenges that Mexican regulation contains in this regard. We find that beyond the technical and economic issues that MAR projects normally address, the regulatory framework and the continuous change in water board chairs in charge of the operation and supply of water is a barrier to develop or increase MAR facilities in Mexico City.

The preliminary design here presented offers an opportunity to improve the integrated management of the resource in the basin. The increment of groundwater storage represents a strategy of great value to solve the resource sustainability in situations of shortage and climatic change.

Leveraging Existing Information to Assess the Potential Impacts of Managed Aquifer Recharge Projects

Garrett Rapp, PE;[1] Carolina Sanchez, PE;[1] and Mark Wildermuth, PE[1]

As interest in, and implementation of, managed aquifer recharge (MAR) projects increase, there is a need to identify how MAR projects impact groundwater basins. The Chino Basin Watermaster (Watermaster) has a process that relies on modeling and comprehensive monitoring to evaluate the benefits and potential impacts of MAR projects in the Chino Basin.

Watermaster evaluates the following impacts to determine the potential for material physical injury (MPI) to the groundwater basin from the proposed recharge:

- Changes in groundwater levels (e.g., liquefaction, land subsidence, and increases in pump lift)
- Balance of recharge and discharge in areas and subareas of the Chino Basin
- Changes in water quality (impacts to receiving waters and Basin Plan compliance for salt and nutrient management)

Watermaster leverages past and ongoing efforts to perform MPI analyses including (1) groundwater-level and water-quality monitoring programs, (2) land subsidence monitoring program, (3) surface-water discharge and quality monitoring programs, (4) groundwater modeling studies, (5) groundwater-quality analyses, (6) past MPI analyses, and (7) other readily available data. These data and information allow Watermaster to conduct efficient and thorough MPI analyses and provide information and technical opinions to the Chino Basin stakeholders on the potential for MPI associated with proposed MAR projects. If potential MPI is identified, the Watermaster provides guidance on how best to mitigate the potential impacts.

Watermaster has successfully employed this process to evaluate a variety of MAR projects, including recharge in areas at risk of leaching of contaminants, recharge of recycled water, and recharge in areas of impaired groundwater quality.

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1 - Garrett Rapp is an engineer at West Yost. Mr. Rapp has been involved in surface water modeling and facility design for flood control and surface water recharge. He is currently a project engineer assisting the Chino Basin Watermaster and the Inland Empire Utilities Agency on the implementation of the Chino Basin Recharge Master Plan update.

Carolina Sanchez is a senior engineer at West Yost. Ms. Sanchez has been involved in surface water modeling and facility design for flood control and surface water recharge. She is currently a project engineer assisting the Chino Basin Watermaster and the Inland Empire Utilities Agency on the implementation of the Chino Basin Recharge Master Plan update.

Mark Wildermuth is a Vice President at West Yost. Mr. Wildermuth has over 40 years of experience in water resources planning, hydrology and modeling. He is known for innovated and rigorous analysis in hydrologic investigations, groundwater management plan development and regulatory compliance.

Managing Aquifer Recharge: An Integrated Assessment of Global Best Practice

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Abstract: The sustainability of groundwater is threatened by overexploitation and pollution, exacerbated by perturbations of the hydrological cycle stemming from climate change exerting poorly understood risks with uncertain outcomes. “Managing Aquifer Recharge: A Showcase for Resilience and Sustainability”, a UNESCO publication, with contributions from GRIPP partners, compiles innovative and integrated solutions to tackle a series of intertwined water security challenges represented in 28 case studies from 21 countries. Annual recharge of these MAR schemes ranges from micro (640 m^3/yr) to large (250,000,000 m^3/yr), with a wide range of techniques utilized to recharge, store and treat water in aquifers or to induce recharge by river bank filtration. This has generally been achieved at less than half the cost of alternatives. The volume-weighted mean levelized cost of 3 riverbank filtration schemes is US$0.10/$m^3$, of 11 schemes recharging natural water by infiltration or wells US$0.16/$m^3$ and for 6 schemes recharging reclaimed water by infiltration or wells US$0.75/$m^3$. To facilitate the development of MAR strategies under the UNESCO IHP-VIII Phase, 6 environmental and 3 social sustainability indicators were established and applied to qualitatively assess sustainability of these MAR schemes. Water quality and quantity challenges both need to be addressed to maintain resource integrity. Schemes from higher income countries received better ratings primarily due to supportive regulatory systems. Strengthening institutional capacity for regulatory frameworks for water allocation, permit granting, and water quality protection are especially relevant for developing countries and localities challenged by climate change. Ecological flow and ecosystem impacts are often secondary to other objectives and deserve more attention by MAR promoters. Energy intensity, while important, is often poorly tracked. Community engagement also warrants greater attention. Applying the same rigorous environmental and social sustainability assessment, along with conducting a standardized cost and benefit analysis, enhance best practices that are sustainable and economical. The documentation of evolution of exemplary schemes, together with the applied systematic assessment of sustainability and economic analysis are rich resources for water managers considering MAR and for stakeholders of MAR projects to enhance climate resilience and other social, economic and environmental benefits of their projects.

Potable Reuse of Municipal Wastewater in the United States

William M. Alley, National Ground Water Association, San Diego, CA

Municipal wastewater is increasingly viewed as a resource to be used to recover water, energy, and nutrients rather than as a waste to be disposed. In particular, use of treated wastewater for drinking water (potable reuse) is increasingly promoted as part of the One Water paradigm. This presentation reviews the history of potable reuse and lessons learned from examination of about two dozen potable reuse projects in the United States. Case studies illustrate varying conditions that motivate water utilities to consider potable reuse, which not long ago was considered the solution of last resort. Indirect potable reuse projects that use groundwater as an environmental buffer through managed aquifer recharge are emphasized, with lessons from a few surface-water augmentation projects and increasing interest in direct potable reuse presented for comparison.

MAR's Role in One Water – Building Resilience

The Region of Waterloo is one of the fastest growing tech hubs in Canada with its population expected to reach nearly 1 million by the year 2051. Located one hour west of Toronto, Waterloo is unique in the Great Lakes Basin as it relies almost solely on groundwater for its drinking water supply with over 100 production wells and an intake on the Grand River.

Waterloo, like many municipalities around the world, is feeling the impacts of climate change. Waterloo is embracing the "One Water" concept to help build resilience, which is key to achieving sustainability. One Water recognizes water as a single resource that should be managed holistically. All the ways we use water touches on one another – from drinking water to wastewater. It involves breaking down historical silos in the water sector and working together with various partners and stakeholders in the community to find solutions to sometimes-competing water interests. MAR can play a strategic role in One Water and help our communities grow sustainably.

This presentation will draw upon some examples of One Water in action, such as developing water budgets and groundwater sustainability plans, delineating water quantity protection areas (WHPA-Q), and developing policies to manage water quantity risks and protect recharge areas. The presentation will show some innovative approaches to MAR, including Waterloo's ASR program, as well as other examples of MAR in the community, such as Low Impact Development.

25-ISMARx Presentations & others

TECHNICAL PRESENTATION

1 Well Efficiency and Performance: Influencing Factors and Management Guidelines
C. Engelbrecht and P.J.H. Lourens

2 Significance of the topography of water table in MAR solutions - the example of the Danube-Tisza Interfluve area, Hungary
Judit Mádl-Szőnyi, Zsóka Szabó, Daniele Pedretti, Marco Masetti*

3 Advantages and challenges of using vadose-zone water stable isotope profiles for assessing groundwater recharge.

Advantages and challenges of using vadose-zone water stable isotope profiles for assessing groundwater recharge

Four (4) sites under different climate conditions (arid, semiarid, subhumid, and humid) were selected from North-American and North-African areas, wherein high-resolution vertical subsurface sediment sampling along the vadose zone of the investigated sites was conducted. The collected sediment samples were analysed in laboratory to determine their stable isotopes ratios (δ^{2}H and δ^{18}O) and volumetric water content that were used for estimating groundwater recharge. Using the stable isotope-based method called ''peak-shift method'', the humid site experiencing seasonally variable meteorological inputs revealed high groundwater recharge rates ranging from an average of 41 to 75% of the total precipitation. The peak-shift method, which was successfully applied at humid site, revealed some difficulties to be applied at sites under arid, semiarid, and subhumid climate conditions. Such difficulties were mostly related to the absence of clear distinction of the seasonal isotopic peaks. Using accordingly another stable isotope-based method called ''piston displacement method'', annual groundwater recharge rates of 0.2% (±0.1%), 2.5 %, and 18% of the total annual precipitation were obtained for the arid, semiarid, and subhumid sites, respectively. Applying the piston displacement method at arid site revealed some difficulties due to scattered distribution of the deeper isotopic signatures, suggesting more uncertainty in groundwater recharge estimate compared to semiarid and subhumid sites. Here, groundwater recharge rates at the semiarid and subhumid sites were found to be comparable to those previously estimated in other studies using water balance-based methods, while groundwater recharge rate at the arid site was observed to be lower than that previously estimated for that site using the water budget-based method.

Significance of the topography of water table in MAR solutions - the example of the Danube-Tisza Interfluve area, Hungary

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KEY WORDS

topography, water table, infiltration pond, injection well, numerical simulation

ABSTRACT
The significance of the topography of the water table in MAR studies in most cases is not highlighted. For example, if the water table is in some ten meters depth under the surface, we can use the storage capacity of the unsaturated zone without significant side effects. However, in areas where the topography slope is significant, and there are local undulations with a closed water table, appropriate MAR solutions are more complicated. This is because the water table under the recharge area is relatively deep while along the direction of the slope; it can be close to the surface in discharge areas. In these situations, if we increase the water table under recharge areas, it can cause side effects, inland flooding in the closest discharge areas. Therefore, it is worth taking into consideration this effect during planning. The Danube-Tisza Interfluve (DTI) area in Hungary is located in a ridge region, up to 130 m asl between Danube and Tisza Rivers, while the river valleys are situated at 85-90 m above sea level. We can find alluvial sediments of the Danube and aeolian sands close to the surface in the area. The shallow flow systems of the elevated ridge region are under the effect of gravity-driven meteoric flow regime and characterized by different orders of flow systems (local, intermediate) (Mádl-Szőnyi and Tóth 2009). In the area, groundwater levels have declined significantly in the last decades due to anthropogenic activities and climate change (Pálfai, 2010 and Nagy et al., 2016). These effects appeared only under the topographically elevated interfluve (recharge) area with a 2-3m water table decrease. This problem influences the local agriculture and ecological conditions significantly. During the study we delineated the local study area based on a preliminary MAR suitability map for the region (Silva Cisneros, 2019). After a complex field study, systematic numerical simulations were carried out along a 2,2km long profile from the elevated interfluve area (recharge) as long as the closest discharge area. During different simulation scenarios, the effect of the geology (upper aquifer, shallow aquitard, lower aquifer), different MAR solutions (an infiltration basin and injection wells - shallow, deeper well) were evaluated. We found that local geological build-up plays an important role in MAR planning. Determination of appropriate MAR method and amount of water provide the base to decrease flooding risk and find the best water table increase ratio. The future MAR solutions in the area can contribute to sustainable water management. In addition, the study highlights the significance of the topography of the water table in MAR studies. This research is part of a project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 810980.

Conceptualisation of watershed tool to improve water coastal quality by implementing soil aquifer treatment solution

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The impact of discharges of wastewater partially treated by wastewater treatment plant (WWTP) on coastal areas is a major challenge, particularly in the fields of tourism and shellfish farms. These essential activities in many maritime territories are thus exposed to significant risks of contamination that can potentially block economic activities.

To protect against these ecological and economic impacts, solutions can be implemented. This is the case, for example, at the Agon-Coutainville site where the WWTP discharges the treated wastewater into a dune aquifer (Picot-Colbeaux et al., 2021). Thanks to this soil aquifer treatment (SAT) system, water quality is improved through natural treatment before reaching coastal waters.

The aim of Antea Group in the EviBAN project is to give an information and communication tool (ICT) solution to determine whether SAT systems could improve the quality of coastal water impacted by discharges of treated wastewater from conventional WWTP. To answer this question, it is necessary to work on a larger scale than the site. For this, Antea Group relies on its Norrman software, which deals with the impacts of discharges from treatment plants on watercourses at the scale of the water basin to develop a SAT module that will determine the favorability of the environments where the WWTP are located. By having a polygonal geographic layer precomputed on its territory, the Norrman user will be able to easily determine whether SAT system could be envisaged close to WWTP location and assess SAT benefice on water quality.

The steps necessary to achieve this objective are initially to gather the data of the hydrographic network of the Seine-Normandie basin as well as the positions and characteristics of the WWTP of this territory. In a second step, the decision support map layer will be provided and integrated into the Norrman software. The application of the tool to the Agon-Coutainville SAT system allows to verify the suggested Norrman-SAT approach.

P-ISMAR 11

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

INTRODUCTION

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

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

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

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

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

Further information on this event can be found at:
http://recharge.iah.org/ismar
http://ismar11.net

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P-ISMAR 11 (mini-book access):
https://dinamar.tragsa.es/file.axd?file=/PDFS/P-ISMAR-11.pdf

The book has been assembled by IAH-MAR co-chair Enrique F. Escalante, on behalf of ISMAR 11 organizers and ISMAR initial institutions (IAH. UNESCO, ASCE) for the MAR Community.
2022 September

ISMAR 11

ABSTRACTS BOOK

IAH-MAR Commission and ISMAR 11 organizers, 2022 September