INSTITUTO DE INGENIERÍA UNAM

CONAGUA
COMISIÓN NACIONAL DEL AGUA

ISMAR9

Mexico City

9th International Symposium on Managed Aquifer Recharge

June 20th to 24th, 2016

Palace of Mines

ISMAR9

Mexico City

“ISMAR Around the World”

About ISMAR SYMPOSIUM

ISMAR is the sole series of international symposia focused on advancing the science, application and value of managing aquifer recharge (MAR) also called groundwater replenishment and formerly artificial recharge. It is widely regarded as the premier international event on managed aquifer recharge research and practice. ISMAR was born in August 1988 in Anaheim California as the 1st International Symposium on Artificial Recharge of Ground Water by the American Society of Civil Engineers (ASCE). It continued in Orlando, Florida (1994) before the International Association of Hydrogeologists (IAH) partnered ASCE in Amsterdam (1998). It has been held successfully since in Adelaide 2002, Berlin 2005, Phoenix 2007, Abu Dhabi 2010 and Beijing 2013 will be the 8th in the series.

The conference advances the goals of IAH Commission on MAR: to expand water resources and improve water quality in ways that are appropriate, environmentally sustainable, technically viable, economical, and socially desirable. This conference series have attracted attendance by international experts in all facets of hydrogeology, geochemistry, microbiology, modeling, economics, water resources management and water supply. It has brought together water utilities, practitioners, hydrogeologists, consultants, the wider water industry, and all levels of government, academics and students. All have shown great interest and passion in this conference because water banking and water re-use via aquifers is a very practical solution to securing water supplies and improving water quality to meet critical water needs.

ABOUT ISMAR9

This is the first time International Symposium on Managed Aquifer Recharge (ISMAR) will be held in Latin America, and this unique international meeting will be conducted jointly with the Biannual Symposium on Managed Aquifer Recharge (BSMAR15), making ISMAR9 highly relevant to this world arena. This event is a great opportunity to learn about water resources management and the varied MAR projects underway internationally and also to gain insights into the innovation of the Mexican water industry. ISMAR9 provides an excellent opportunity for networking on this topic in Mexico and Latin America, whose diversified landscape and climate, varied culture, huge population and pressing water needs make managed aquifer recharge critically important to sustain water resources for future generation

Mexico City

Contents

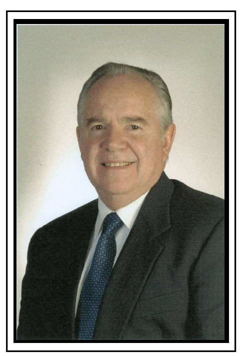
Welcome

The Engineering Institute of the National Autonomous University of Mexico (UNAM) is proud to host the 9th International Symposium on Managed Aquifer Recharge (ISMAR9) in conjunction with the Biennial Symposium on Managed Aquifer Recharge (BSMAR15) in Mexico City.

Managed Aquifer Recharge (MAR) is growing rapidly around the world as it addresses the need to efficiently secure water supplies in the face of population growth and climate change. New technical and policy innovations involving water recycling, desalination, storm water harvesting, natural treatment, design, monitoring and control structures and water banking are cutting costs, increasing resiliency of supplies and improving water quality. Research has never been stronger to help ensure that MAR is effective and safe. Mexico is facing these challenges with energy and creativity, and is a crucible for fresh thinking, testing of ideas and implementation within an advanced water policy framework. Geographically and culturally, Mexico is a natural bridge between South and North America and thereby offers a unique perspective on MAR.

A number of important organizations are endorsing and participating in ISMAR9 and BSMAR15 including: CONAGUA, ANEAS, IAH, AHS, GRA, UNESCO and ASCE. We encourage you to attend and experience ISMAR9 and Mexican culture. Please attend this important Symposium and connect with your peers from around the world, be surprised by MAR technological advances, present your research and projects and acquire new knowledge to revolutionize your local water management agenda.

This spirit can be summarized in the conference theme of "bringing together Spanish and English speaking worlds to accelerate exchange of MAR knowledge".



Dr. Fernando J. González Villarreal
Coordinador técnico de la Red del Agua
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Organizations

National Autonomous University of Mexico	**UNAM**
Engineering Institute of UNAM	**UNAM-II**
International Association of Hydrogeologists	**IAH**
National Water Commission	**CONAGUA**
National Association of Water Operators	**ANEAS**
Groundwater Resources Association of California	**GRA**
Arizona Hydrological Society	**AHS**
Mexico Valley Water Board	**OCAVM**
Mexico City Water System	**SACMEX**
Engineering Faculty of UNAM	**UNAM-FI**
Engineering Academy	**AI**
American Society of Civil Engineers	**ASCE**
Orange County Water District	**OCWD**
United Nations Educational, Scientific and Cultural Organization	**UNESCO**
National Ground Water Association	**NGWA**

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ANEAS
Asociación Nacional de Empresas de Agua y Saneamiento de México A.C.

Groundwater Resources Association of California

iah aih

UNESCO
United Nations Educational, Scientific and Cultural Organization

50 years
International Hydrological Programme

ARIZONA HYDROLOGICAL SOCIETY

ASCE
American Society of Civil Engineers

ISMAR9

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MARHub

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Conference Venue

Palace of Mines, masterpiece of Latin American neoclassicism, is situated in Mexico City, at the end of Tacuba Street, facing the plaza named after Manuel Tolsá, where the equestrian statue of Charles IV, better known as "El Caballito", creation of the same artist, is located. The most important civil building, made up by this Valencian sculptor and architect, was built to house the Royal Seminar of Mines in order to give academic instruction to miners since 1813.

The majestic monument of elegant forms and exact proportions where light, space and functionality merge, is one of the most outstanding constructions within Mexican architecture. It is part of the artistic and cultural patrimony of the National Autonomous University of Mexico (UNAM), which, at present time, is under the custody of the School of Engineering.

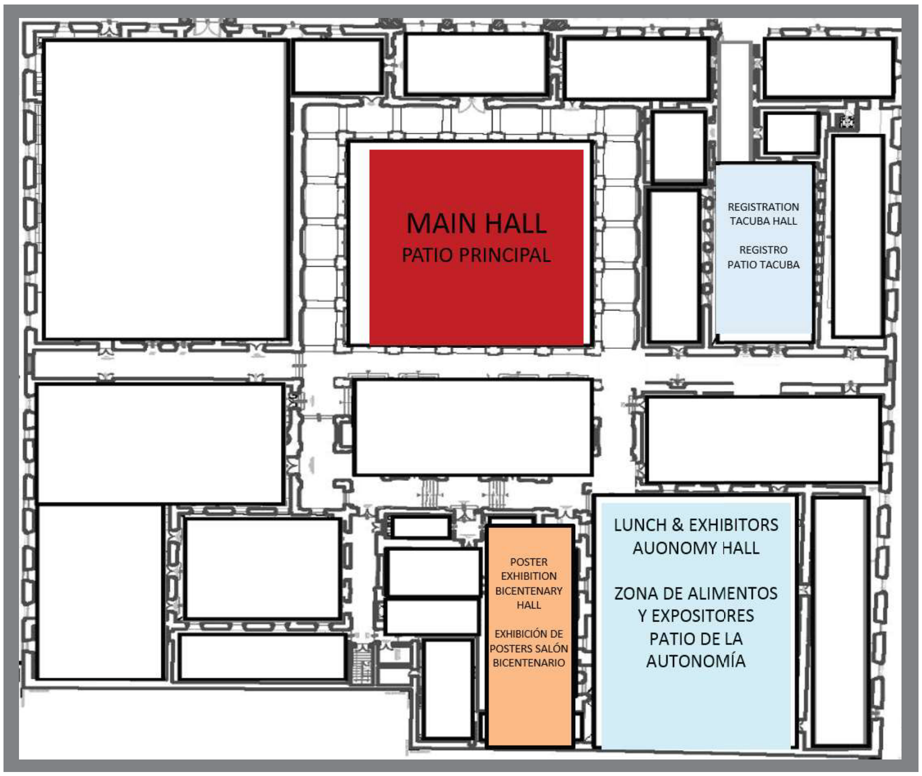
The extraordinary Ancient Chapel, the Ceremonies' Hall, the Dean's Hall, the Principal's Hall, the Deans' Gallery, and the Library contribute to the beauty of the Palace, in some of them great examples of mural painting (XIX century) are kept as the Manuel Tolsá Museum that houses academies and objects related to his duties as well as masterpieces of some other artists from his time. To these spaces five patios are added: the main one with two floors, framed with arches, pilasters and beautiful and singular columns that lead to a master staircase.

Every year the Palace of Mines is used as temporary home office of one of the most important world-wide known publishing events in the country: The International Book Fair.

Floor Plan

Congress Venue: Tacuba 5, Centro Histórico, Mexico City



First floor

	MAIN HALL **PATIO PRINCIPAL**
	TACUBA HALL **PATIO TACUBA**
	BICENTENARY HALL **SALÓN BICENTENARIO**
	AUTONOMY HALL **PATIO DE LA AUTONOMÍA**

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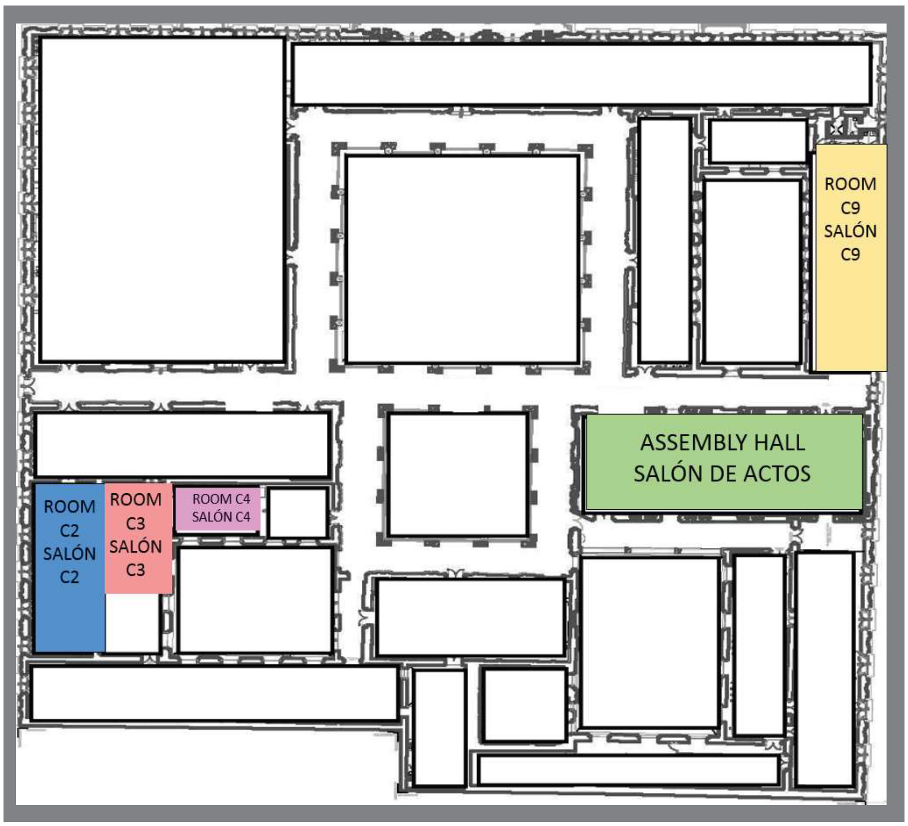

Second floor

	ROOM C9 SALÓN C9
	ASSEMBLY HALL SALÓN DE ACTOS
	ROOM C2 SALÓN C2
	ROOM C3 SALÓN C3
	ROOM C4 SALÓN C4

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Detailed Program

Workshops

Monday June 20th, 2016				
TITLE	**INSTRUCTOR**	**OBJECTIVES**	**SCHEDULE**	**ROOM**
Global inventory of managed aquifer recharge (MAR)	Peter Dillon, Nienke Ansems, Catalin Stefan, Christoph Sprenger	Introduce the global MAR inventory, Identify gaps of information, Generate national MAR networks, Validate the web-based GIS portal	9:00 – 13:00	C2
Managed Aquifer Recharge for Development: Lessons Learned and the Way Forward	Yan Zheng Robert Bouwer	A discussion based workshop to identify institutional, technical, and other challenges encountered in implementing MAR for development projects and to summarize lessons learned in overcoming these challenges.	14:00 – 18:00	C2

Tuesday, June 21th, 2016				
TITLE	**INSTRUCTOR**	**OBJECTIVES**	**SCHEDULE**	**ROOM**
MAR Modelling with FEFLOW	Peter Schätzl	Introduction to FEFLOW, hands-on example for a simple MAR system (flow simulation), discussion of additional topics	9:00 – 13:00	ASSEMBLY HALL

Courses

Monday June 20th, 2016				
TITLE	**INSTRUCTOR**	**OBJECTIVES**	**SCHEDULE**	**ROOM**
Water quality aspects of Managed Aquifer Recharge systems	Pieter J. Stuyfzand	The course is intended for water managers, regulators, engineers, geologists and hydrologists interested in water quality aspects of Managed Aquifer Recharge	9:00 – 13:00	C3
State of the Art Techniques in Identifying and Characterizing Optimum Surface Spreading Groundwater Recharge Projects	Michael Milczarek Adam Hutchinson	The objective of the course is to provide participants with knowledge of the best tools and exposure to real-life conditions to ensure success in siting, characterizing, designing and operating surface spreading groundwater recharge operations.	9:00 – 13:00	C4
How to Identify and Resolve Technical and Other Issues Associated with Successful Groundwater Recharge Through Wells / Operational Management and Maintenance of MAR Systems to Prevent Clogging	David Pyne	Provide each attendee with a practical understanding of the technical, scientific and other issues associated with ASR, and their solutions. This will include a recommended, phased approach to well recharge projects to ensure their success.	14:00 – 18:00	C3

Study Case

Monday June 20th, 2016 / 14:00 – 18:00			
THEME	**EXHIBITOR**	**TIME (min)**	**ROOM**
Welcome	Dr. Víctor Alcocer Yamanaka	15	ASSEMBLY HALL
Mexico Valley Aquifer	Ing. Rubén Chávez G.	30	
MAR in Mexico Valley	OCAVM/SACMEX	30	
Numerical model of the Mexico Valley aquifer	M. I. Adriana Palma	30	
Coffee break		30	
Atotonilco WWTP	CONAGUA/Fideicomiso	20	
Mexico Valley Watershed	M.I. Fernando González C.	30	
Panel discussion on the implementation of MAR	All atttendees	40	
Conclusions and closing	All atttendees	15	

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Special Session: "Groundwater Management Policy Principles"

THEME	EXHIBITOR	DAY	SCHEDULE	ROOM
Groundwater Managment and Managed Aquifer Recharge Around the World	Martin Russell -Australia. Antonio Chambel – European Union. Timothy Parker - California. Rubén Chavez - Mexico.	Tuesday June 21, 2016	14:00-15:20	ASSEMBLY HALL
Development of Policy Principles	All atttendees	Thursday June 23, 2016	14:00-15:20	ROOM C2

IAH Commission on Managing Aquifer Recharge

Tuesday, June 21^{th}, 2016 / 15:40 – 17:00		
THEME	**EXHIBITOR**	**ROOM**
• Welcome • Workshop objectives	Co- Chairs	MAIN HALL
• UNESCO IHP VIII 2014-2021 context for IAH-MAR role	UNESCO representative	
Reports of Working Groups (and call for volunteers) • Clogging and its management monograph • MAR for development • MAR Global Inventory • Governance of MAR • Economics of MAR • MAR to Market	OCAVM/SACMEX Russell Martin Yan Zheng Catalin Stefan Sharon Megdal Peter Dillon Enrique Fernandez	
ISMAR10 – announcement and presentation		
IAH Executive Award(s) for advancement of MAR	IAH Executive representative	
Information sharing – items of international significance, or opportunities for networking on MAR		
Suggestions for new activities of value for IAH-MAR	working groups	
Election of co-Chairs for 2016-2019	IAH Executive rep	
Concluding remarks	IAH Executive Rep	

Mexico City

Keynote Speaker

Climatic Variations and Uncertainties in Groundwater Management and the Role of MAR

William M. Alley*

*** National Ground Water Association, 4731 Winona Avenue, San Diego, CA 92115**

Keywords
resilience; climate; managed aquifer recharge; storage; groundwater governance

Groundwater is characterized by high storage capacity relative to inflows. It is commonly taken for granted as a buffer storage that can assure water availability during times of drought. In this context, terms such as "insurance policy" or "water savings account" are often applied to groundwater. The reality is often somewhat different with groundwater management failing to adequately consider the natural cycles of wet years and dry years, let alone potential long-term climate change. As a result, groundwater often fails to meet its expected role in drought mitigation and droughts simply intensify the over exploitation of groundwater resources. This presentation discusses analogies with design of surface-water reservoirs and considerations in addressing the uncertainties of future climatic conditions in the management of groundwater systems. Implications for good groundwater governance and the role of managed aquifer recharge are addressed.

Dr. William M. Alley is Director of Science and Technology for the National Ground Water Association (NGWA). Prior to this position, he served as Chief, Office of Groundwater for the U.S. Geological Survey (USGS) for almost two decades. Dr. Alley has published over 90 scientific publications and received numerous awards for his work, including the Meritorious Presidential Rank Award. He and his wife, Rosemarie, are currently completing a book on the world's growing dependence on groundwater.

Groundwater Management and Managed Aquifer Recharge in México

Víctor Hugo Alcocer Yamanaka*

***Comisión Nacional del Agua, Insurgentes Sur 2416, Ciudad de México, CP 04340**

Keywords:
Marco legal, gobernanza, manejo sustentable

En México el agua subterránea es vital para el desarrollo de todos los sectores. La escasez natural de este recurso en las zonas áridas que ocupan parte del país, el variado mosaico de condiciones hidrogeológicas naturales, la sobreexplotación de acuíferos, el acelerado crecimiento demográfico, plantean formidables retos en materia de gobernanza de agua subterránea. A los problemas tradicionales se agregan ahora los tópicos hidrogeológicos "emergentes" como los relacionados con el cambio climático, el desarrollo energético y el impulso a la desalinización del agua salobre en la faja costera de los acuíferos, entre otros. En la presentación se expone el marco legal mexicano en materia de agua, el avance en el conocimiento de los acuíferos, la estrategia para su manejo sustentable, los programas que se están llevando a cabo para incrementar la disponibilidad de agua, las innovaciones tecnológicas y las adecuaciones al marco legal que se tienen en proceso para darle una flexibilidad compatible con la dinámica de la gestión de los recursos hídricos. Se destaca la necesidad de impulsar la aplicación de la recarga artificial como una tecnología versátil que contribuye a la solución de variados problemas.

Semblanza

Dr. Víctor Hugo Alcocer Yamanaka

Ingeniero Civil con estudios de Maestría y Doctorado en Ingeniería Hidráulica por la Universidad Nacional Autónoma de México. Actualmente es Subdirector General Técnico en la Comisión Nacional del Agua. Tiene más de 14 años como Profesor de Posgrado de la Facultad de Ingeniería de la UNAM. Miembro del Sistema Nacional de Investigadores y Ganador de los Premios Nacionales de Ingeniería Civil “Miguel A. Urquijo” en 2005 y “José A. Cuevas” en 2009, otorgados por el Colegio de Ingenieros Civiles de México. Ganador del Premio Nacional “Enzo Levi” a la investigación en Hidráulica en 2014, otorgado por la Asociación Mexicana de Hidráulica.

Mexico City

Herman Bower Award

Herman Bouwer Award at 9th International Symposium on Managed Aquifer Recharge (ISMAR 9)

Groundwater Resources Association of California

ARIZONA HYDROLOGICAL SOCIETY

Dr. Mario Lluria to Receive Herman Bouwer Award at 9th International Symposium on Managed Aquifer Recharge (ISMAR 9)

The Groundwater Resources Association of California (GRA) and the Arizona Hydrological Society (AHS) are pleased to announce that Mario Lluria will receive the 2nd Herman Bouwer Award.

"I am delighted to learn that Robert Rice is the inaugural recipient of the Herman Bouwer Award. I clearly remember Bob's collaborative work with my father on infiltration and soil clogging studies. This work eventually helped to optimize the performance of the Flushing Meadows project and other MAR projects. Congratulations to Bob for his contributions over his long career and for starting this pioneering work with my father."

Gary Small, Presdient, HydroSystems, Inc.

Dr. Mario Lluria is highly deserving of the Herman Bouwer Award due to his long commitment to fostering and developing groundwater recharge, one of Dr. Bouwer's key contributions to the profession of hydrogeology. Dr. Lluria has practiced hydrogeology for 46 years as both a consultant and as a project manager for major industrial and utility companies.

Schedule at a glance

Monday, June 20th, 2016

Time			
8:30 - 14:00	Registration Tacuba Hall		
	ROOM C4	ROOM C3	ROOM C2
9:00 - 13:00	Course 1 Water quality	Course 2 Infiltration Systems	Workshop 1 Global MAR Inventory
	ROOM C4	ROOM C3	ROOM C2
13:00-14:00	Lunch		
	ASSEMBLY HALL	ROOM C3	ROOM C2
14:00-18:00	Sudy case: MAR opportunities in Mexico Valley	Course 3 ASR Wells	Workshop 2 MAR for development
18:00-20:00	Autonomy Hall Welcome Ice Breaker		

Tuesday, June 21th, 2016

Time			
8:30 - 14:00	Registration Tacuba Hall		
9:00 - 10:00	MAIN HALL		
	Opening Ceremony		
10:00 - 11:20	ROOM C9	ROOM C2	ASSEMBLY HALL
	Integrated water management strategies	Geochemistry in MAR	MAR Modeling with FEFLOW
11:20 - 11:40	Coffee break Autonomy Hall		
	Integrated water management strategies	Water quality and selection of pre-and post-treatments	MAR Modeling with FEFLOW
13:00 - 14:00	Autonomy Hall Lunch		
14:00 - 15:20	ROOM C9	ROOM C2	ASSEMBLY HALL
	Integrated water management strategies	Rainwater harvesting and urban stormwater harvesting with MAR	Special session "Groundwater Management Policy Principles"
15:20 - 15:40	Coffee break Autonomy Hall		
15:40 - 17:00	MAIN HALL		
	IAH Session		
17:00 - 18:00	Poster session Bicentenary Hall		
18:00 - 20:00	Special meetings ASSEMBLY HALL		

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Wednesday, June 22th, 2016	
Registration Tacuba Hall	
MAIN HALL	
"Groundwater management and Managed aquifer recharge in Mexico". Dr. Victor Alcocer Yamanaka.	
ROOM C9	ROOM C2
Site selection for MAR	MAR in hard rock and karstic systems/ Hidraulics, clogging, recovery efficiency
Coffee break Autonomy Hall	
Monitoring and management	Hidraulics, clogging, recovery efficiency
Main Hall Lunch	
ROOM C9	ROOM C2
Bank filtration, infiltration systems, soil aquifer treatment	MAR in depleting aquifers and protection of groundwater dependent ecosystems
Coffee break Autonomy Hall	
ROOM C9	ROOM C2
Bank filtration, infiltration systems, soil aquifer treatment	Innovation in well injection and recovery systems
Poster session Bicentenary Hall	
Special meetings ASSEMBLY HALL	
20:00-23:00	Dinner Main Hall

Thursday, June 23th, 2016	
Registration Tacuba Hall	
MAIN HALL	
"Climatic variations and uncertainties in Groundwater Management and the role of MAR". William M. Alley.	
ROOM C9	ROOM C2
MAR in developing countries	Regulations, guidelines and governance
Coffee break Autonomy Hall	
MAR in developing countries	Regulations, guidelines and governance/ Advances in engineering and geotechnical aspects
Autonomy Hall Lunch	
ROOM C9	ROOM C2
Modeling of systems that include MAR/ Aquifer microbiology and health aspects	Special session "Groundwater Management Policy Principles"
Coffee break Autonomy Hall	
ROOM C9	ROOM C2
Modeling systems that include MAR/ Groundwater and Energy	New topics in MAR and water banking
17:00-17:30	Closing ceremony Main Hall

	Friday, June 24th, 2016	
8:30 - 17:00	MAIN HALL	
	Technical Field Trip WWTP Atotonilco	Tourist Trip Teotihuacan Pyramids

Monday June 20th, 2016				
TIME	ROOM C3	ROOM C4	ROOM C2	ASSEMBLY HALL
09:00 - 13:00 h.	**Course 1** Water quality	**Course 2** Infiltration systems	**Workshop 1** Global MAR Inventory	
13:00 – 14:00 h.	Lunch by yourself			
14:00 – 18:00 h	**Course 3** ASR wells		**Workshop 2** MAR for development	**Study case** MAR opportunities in Mexico Valley
18:00 – 20:00 h.	Welcome Ice Breaker Autonomy Hall			

Tuesday, June 21th, 2016			
09:00 - 10:00 h.	**Opening ceremony Main Hall (1st floor)**		
Two Parallel Sessions			
Time	Geochemistry in MAR/ Room C2	Integrated water management strategies/ Room C9	Autonomy Hall
10:00 – 11:20 h.	Observations and prediction of recovered quality of desalinated sea water in the Strategic ASR Project in Liwa, Abu Dhabi. **P.J. Stuyfzand, E. Smidt, K. Zuurbier , N. Hartog , M. Dawoud.**	Benchmarking Proposal for Mar Systems. Benching and Comparing Seven Mediterranean Marsol Sites. **J. San Sebastián Sauto.**	MAR Modelling with FEFLOW
	Prediction of iron and manganese release during riverbank filtration. **T. Grischek , S. Paufler.**	Protection of groundwater dependent ecosystems in Canterbury, New Zealand: the Targeted Stream Augmentation Project. **B. D. M. Painter.**	
	Raw Water Quality and Pretreatment in Managed Aquifer Recharge for Drinking Water Production in Finland. **P. Jokela, T. Eskola, T. Heinonen, U. Tanttu, J. Tyrväinen , A. Artimo.**	Designing MAR as a management tool for catchment-scale water quality and quantity issues. **R. J. Bower, B. Sinclair.**	
	Investigating conditions for denitrification during controlled MAR experiments using reactive barrier technology. **G. Gorski, S. Beganskas, W. Weir, J. Murray, C.W. Saltikov , A.T. Fisher.**	Artificial Recharge of Groundwater: High Time to Rethink Our Approaches. **Y. B. Sharma, K. B. Biswas.**	
11:20 – 11:40 h.	Coffee break Autonomy Hall		

11:40 – 13:00 h.	**Geochemistry in MAR/ Room C2**	**Water quality and selection of pre- and post- treatments /Room C9**	**Autonomy Hall**
	Sequential Managed Aquifer Recharge Technology (SMART) for Enhanced Removal of Trace Organic Chemicals. **K. Hellauer, U. Hübner, J. Regnery, J. E. Drewes.**	Meeting Water Management Objectives through Water Storage and **Recovery in Arizona, USA. Sharon. B. Megdal**	MAR Modelling with FEFLOW
	Experimentation Field to Know the Effects of Treated Residual Water Infiltration in the Aquifer of Valle de Las Palmas, B.C., Mexico. **R. Morales , A. Borja**	Integrated web-based framework for planning and assessment of managed aquifer recharge applications. **C. Stefan , A. Fatkhutdinov , J. Ringleb, J. Sallwey**	
	Development of adsorption treatment by iron oxide nanoparticles and biological degradation in mimetic column for managed aquifer recharge. **S. U. Yoon, B. Mahanty, C. G. Kim.**	Identification discharge and recharge zones related to regional groundwater flow in northern part of Mexico and their impact in groundwater balance. **R. Sención, A. Molina**.	
	Combination of Ozonation and Managed Aquifer Recharge for Advanced Wastewater Treatment and Reuse. **U. Hübner, M. Jekel, J. E. Drewes.**	Managed aquifer recharge project for Chihuahua, Mexico. **F. Gonzalez, C. Cruickshank, A. Palma, A. Mendoza.**	
13:00 – 14:00 h.	**Lunch Autonomy Hall**		
14:00 – 15:20	**Geochemistry in MAR/ Room C2**	**Rainwater harvesting and urban stormwater harvesting with MAR /Room C9**	**Autonomy Hall**
	Management Aquifer Recharge used for water reservoir against climatic change in paper plant in Mexico. **M. Juárez, J. A. Gutiérrez.**	ASR in Barcelona: new operational regimes of aquifer recharge to deal with new scenarios. **M. Hernández, P. Camprovín, J. Martín, J. Castelló, E. Custodio**	Special session "Groundwater Management Policy Principles"
	Generation of DRWHS Design Parameters for Marginalized Communities in Mexico using Probabilistic Prediction of Daily Precipitation. **A. Chávez-Mejía, M. Mautner, F. J. González, B. Jiménez.**	Evaluation of pre-potable water injection in ASR and expected impacts: pilot experiment in Barcelona system. **P. Camprovín, M. Hernández , J. Martín, J. Mesa**	

	Evaluating Impact of Artificial Groundwater Recharge Structures using Geo-spatial Techniques in Hard-rock Terrain of Rajasthan, India. **S. Kumar, B. K. Bhadra, R. Paliwal.**	Meeting Melbourne's Growing Demand for Water Using Aquifer Storage and Recovery. **M. Hudson, M. Muthukaruppan**	
	Surface runoff use for manage of aquifer recharge in fractured zones. Study case: Ojos del Chuvíscar, México. **M. González, H. Silva.**	Feedback of MAR experiences in France and USA. **E. Mauro, A. Zuluaga, J. Mateos.**	
15:20 – 15:40 h.	**Coffee break** **Autonomy Hall**		
15:40 – 17:00 h.	IAH Session **Main Hall**		
17:00 – 18:00 h.	Poster Session **Bicentenary Hall**		
18:00 – 20:00 h.	Special Meetings **Assembly Hall**		

	Wednesday, June 22th, 2016	
09:00 - 10:00 h.	"Groundwater management and Managed aquifer recharge in Mexico". **Dr. Víctor Alcocer Yamanaka.** **Main Hall**	
	Two Parallel Sessions	
Time	**MAR in hard rock and karstic systems / Hydraulics, clogging, recovery efficiency /Room C 2**	**Site selection for MAR/ Room C9**
10:00 – 11:20 h.	Windhoek, Namibia: From conceptualizing to operating and expanding a MAR scheme in a fractured quartzite aquifer for the city's water security. **R. Murray ,I. Peters, D. Louw ,B. van der Merwe**	Evaluating locations for distributed storm water collection with regional surface hydrologic models in central coastal California. **S. Beganskas ,K. Young , R. Harmon, E. Teo ,W. Weir ,S. Lozano , A. Fisher.**
	Seasonal Water Storage and Replenishment of a Fractured Granitic Aquifer **Using ASR Wells. Mario R. Lluria, Gary G. Smal.**	Managed Aquifer Recharge and Aquifer Characterization Within The Complex Esker Deposits in Pälkäne, Finland. **J. Mäkinen, E. Kallio, P. Jokela**
	Analysis of ASR clogging investigations at three Australian ASR sites in a Bayesian context. **P. Dillon, J. Vanderzalm, D. Page, K. Barry, D. Gonzalez, M. Muthukaruppan and M. Hudson.**	Mapping Potential Zones for artificial Recharge using a GIS. **L. Marín, R. M. Leal.**
	Site characterisation for MAR infiltration basins using percolation testing and SEEP. **W. B. Sinclair, C. Cockburn ,R. J. Bower. G. Gorski, S. Beganskas, W. Weir, J. Murray, C.W. Saltikov , A.T. Fisher**.	MAR Site Suitability using GIS and Modeling: Case studies in coastal California, US and Guanajuato, Mexico. **T. Russo.**

ISMAR9

Mexico City

11:20 – 11:40 h.	Coffee break Autonomy Hall	
11:40 – 13:00 h.	Hydraulics, clogging, recovery efficiency / Room C 2	Monitoring and management/ MAR as a key to adapt to climate change ROOM C9
	Types Of Clogging, Distribution and Interaction With Groundwater Quality in an Aquifer Under Long M.A.R. Practices. Los Arenales (Spain). **E. Fernández, J. San Sebastián, C. Schütz.**	Quantifying Apparent Groundwater Ages Near Managed Aquifer Recharge Operations using 35S as an Intrinsic Tracer. **J. F. Clark, S. H. Urióstegui, R. K. Bibby, B. K. Esser, G. Tredoux.**
	Riverbed clogging and sustainability of riverbank filtration. **T. Grischek, R. Bartak**	The Cabo Aquifer System: Regional Groundwater Level Dynamics in Recife City (Brazil). **S. M. G. L. Montenegro ,A. L. R. de Paiva, V. H. Coelho, G. S. Fagundes.**
	Maximizing Infiltration Rates by Removing Suspended Solids: Results of Demonstration Testing of Riverbed Filtration in Orange County, California. **Adam S. Hutchinson ,Greg D. Woodside**	Web-GIS of global inventory of managed aquifer recharge applications. **C. Stefan, A.S. Strues, N.Ansems.**
		Engaging Village Communities in Groundwater Monitoring and Management – Lessons from Rajasthan and Gujarat, India. **B. Maheshwari, Y. Jadeja, R. Packham Hakimuddin, R. Purohit , B. Thaker, V. Goradiya, S. Oza ,P. Soni, Y. Dashora ,R. Dashora, T. Shah , J. Gorsiya, P. Katara, J. Ward, R. Kookana, P. Dillon, S. Prathapar , P. Chinnasamy , M. Varua.**
13:00 – 14:00 h.	Lunch Main Hall	
14:00 – 15:20	MAR in depleting aquifers and protection of groundwater dependent ecosystems / Room C 2	Bank filtration, infiltration systems, soil aquifer treatment / Room C9
	Community driven MAR using a pilot to develop a Groundwater Replenishment Scheme, Poverty Bay, New Zealand. **C. Houlbrooke, B. Sinclair ,R. J. Bower.**	The Use of d2H and d18O Water Isotopes as Tracers in SAT and in Regional Water System. **I. Negev , J. Guttman.**
	Artificial Recharge of Aquifers as a Mitigation Measure in the Atacama **C. Ortiz, F. Varas, M. Solari ,M. Lluria.**	Temperature measurements during Managed Aquifer 3 Recharge for safeguarding subsurface travel times. **C. Sprenger, H. Schwarzmueller, G. Lorenzen, R. Gnirss, G. Gruetzmacher.**
	Groundwater Modeling to Support Water Resources Management in Clarkdale, Arizona, USA. **L.J. Lacher, J. Filardo, G. Mabery, D. Von Gausig.**	Managed Basin Recharge – Proper Planning Ensures Success. **Donald P. Hanson, R.G.**
	Supporting agro-ecological resiliency through managed aquifer recharge practices in the Southwestern United States. **C. Maxwell, R Davidson.**	
15:20 – 15:40 h.	Coffee break Autonomy Hall	

ISMAR9

Mexico City

15:40 – 17:00 h.	Innovation in well injection and recovery systems / Room C 2	Bank filtration, infiltration systems, soil aquifer treatment / Room C9
	Increasing freshwater recovery upon aquifer storage in brackish-saline aquifers: what can hydrological engineering bring? **K.G. Zuurbier, P. J. Stuyfzand, N. Hartog**	Processing drinking water by managed aquifer recharge in Tuusula region, Finland. **Unto Tanttu.**
	Successful Implementation of Aquifer Storage Recovery. **R. David G. Pyne**	Management of Aquifer Recharge in River Bank Filter: Study Case. **E.Y. Mendoza Cázares ,R.D. Hernández López ,J.H. Aguilar-Damián**
	Design and Testing of Recharge Wells in a Coastal Aquifer: Summary of a Field Scale Pilot Test. **I. Negev , G. Rubin, J. Guttman.**	Prediction of Removal of Contaminants during Soil Passage. **W. Z. Huaman, S.K. Sharma, M. Kennedy.**
	Aquifer Storage and Recovery Well Systems Factory Pump Injection Testing: Is This Necessary? **N. Nutter ,G. Gin, R.G.**	Application of cylinder infiltrometer for analyzing the vertical water flow to bankfiltration technology in Beberibe river, Pernambuco - Brazil. **T. B. V. Albuquerque, J. J. S. P. Cabral, A. L. R. de Paiva.**
17:00 – 18:00 h.	Poster Session Bicentenary Hall	
18:00 – 20:00 h.	Special Meetings Assembly Hall	
20:00 – 23:00 h.	Dinner Main Hall	

Thursday, June 23th, 2016		
09:00 - 10:00 h.	"Climatic variations and uncertainties in Groundwater Managenemet and the role of MAR". **William M.Alley**. Main Hall	
Two Parallel Sessions		
Time	Regulations, guidelines and governance / Room C 2	MAR in developing countries / Room C9
10:00 – 11:20 h.	Guidelines for MAR water quality. International overview and lessons learnt. **E. Fernández Escalante, J. San Sebastián Sauto , A.M. Vidal Medeiros**	Aquifer recharge proposal for Metropolitan Area of Mexico City in the 2nd secction of Chapultepec Forest . **M. Vidal**
	Water Banking in Australia: Progress and Issues. **A. Ross**	Chapultepec WWTP, a reuse and aquifer recharge project for sustainable management of water resources in Mexico City. **A. Zuluaga , S. Donnaz, A. Canales, R. Chicho, J. M. Ortega**
	Authorising MAR projects within the context of South Africa's National Water Act. **S. A. Fourie, R. Murray, D. Hohne, N. Vermaak, F van der Merwe**	Inventory of managed aquifer recharge schemes in Latin America. **J. P. Bonilla Valverde, E. B. da Silva, H. L. Pivaral Vivar, C. Stefan , A. Palma.**
	Regulatory Scheme for Assessing the Feasibility of Proposed MAR Schemes. **M. Sapiano, M. Schembri, F. Capone, M.E. Bonfanti**	MAR for Irrigation in the Yellow River Floodplain Area of North China. **W. Wang, Q. Rong, S. Qu, J. Li**

11:20 – 11:40 h.	Coffee break Autonomy Hall	
11:40 – 13:00 h.	Regulations, guidelines and governance / Advances in engineering and geotechnical aspects / Room C 2	MAR in developing countries / Room C9
	Updated ASCE\EWRI Guidelines on Managed Aquifer Recharge. **D. Bartlett, G. McCurry, P. Barkmannc, Z. Sheng ,P. Stanine , D. McGrane**	Managed Aquifer Recharge Opportunities in the Arid and Semiarid Cordilleran Region of the Americas. **R. G. Maliva, W. S. Manahan, J. Miguel Zuñiga, A. Tacho.**
	Evaluating Current and Historical Asr System Performance In Florida. **June E. Mirecki , Don Ellison, Mark B. McNeal ,R. David G. Pyne, Robert Verrastro**	Aquifer Recharge Experiences in Mexico City. **J.M Lesser, D. González**.
	MAR technical solutions assessment. Guidelines obtained from the experience in eight Mediterranean demo sites. **E. Fernández Escalante, J. San Sebastián Sauto, M. García-Rodríguez**	MAR in san Luis Rio Colorado, Mexico. **H. Hernández**
	Minimal hydrological parameters necessary for the feasibility evaluation of shallow managed artificial aquifer recharge projects and an overview of the most cited analytical solutions for estimating groundwater mounding. **A. C. Petrides-Jimenez**	Artificial Recharge Pilot Testing in Chile: Lessons Learned, the Aconcagua Case. **C. Ortiz, N. Ramirez ,M. Lluria ,B. Ronda ,P. Rengifo**.
13:00 – 14:00 h.	Lunch Autonomy Hall	
14:00 – 15:20	Special session"Groundwater Management Policy Principles" /Room C 2	Modeling of systems that include MAR / Aquifer microbiology and health aspects / Room C9
	Special session "Groundwater Management Policy Principles"	Computational modeling of aquifer system of Nazareno Etla, Oaxaca, **México. L. A. García-García, S. I. Belmonte-Jiménez, E. A. Ojeda-Olivares**
		Transient flow modelling of an exploited aquifer in the city of Hanoi, Vietnam and simulation of managed aquifer recharge measures. **J. Ringleb, D. A. Via Rico.C. Stefan ,V. N. Tran**
		Potential of unsaturated soil zone models for assessment of managed aquifer recharge. **J. Sallwey, J. Ringleb, C. Stefan.**
15:20 – 15:40 h.	Coffee break Autonomy Hall	

15:40 – 17:00 h.	**New topics in MAR and water banking / Room C 2**	**Modeling of systems that include MAR / Groundwater and Energy / Room C9**
	Three-In-One Uses Of A Managed Aquifer Recharge System: The Triplets In Los Arenales (Spain). **E. Fernández Escalante, J. San Sebastián Sauto**	Coupled Surface Water and Groundwater Model to Manage Artificial Recharge for the Valley of Santo Domingo. **J. Wurl, M. Imaz-Lamadrid.**
	Could the MAR be a main path to the pollution of aquifers? Investigations on the risk factors on the MAR of Geneva - Switzerland. **G. de los Cobos, S. Vargas**	Modeling the impact of aquifer recharge, instream water savings, and canal lining on water resources in the Walla Walla Basin. **J. Scherberg, J. Keller,S. Patten ,T. Baker, M. Milczarek**
	Co-managing disastrous floods and droughts through UTFI: An innovative MAR modality. **P. Pavelic , Brindha, Gangopadhyay, S. Sharma**	Managed Aquifer Recharge (MAR) from an operator´s perspective. **D. Boris**
	Evaluation of aquifer-circulating water-curtain-insulated greenhouse system coupled with various MARs. **Y. Kim, K. Y. Lee, S. H. Moon, S. Y. Kim, M. K. Ki ,S. Y. Cho ,J. H. Ahn ,J. H. Lee**	Groundwater and Energy in Mexico. **R. Guillén.**
17:00 – 17:30 h.	Closing ceremony **Main Hall**	

Friday, June 24th, 2016	
09:00 - 19:30 h.	Technical Field Trip WWTP Atotonilco
09:00 - 19:30 h.	Tourist Trip

Poster presentations

Tuesday, June 21th, 2016

An integrated modelling approach to the design of the Hinds catchments proposed regional scale MAR Project.
P. Durney

Impact in the quality of surface and groundwater generated by the leachates at the Municipal Landfill Linares, Mexico.
H. de León-Gómez, R.A. Dávila Pórcel, A. Cruz López

Groundwater modelling of the Coastal Aquifer of Santa Marta, Colombia, under different hydrological and pumping scenarios, including sea-water intrusion, artificial recharge and Interbasin transfer.
G. Cifuentes, C. Molano

Temperature measurements during Managed Aquifer Recharge for safeguarding subsurface travel times.
C.Sprenger, H.Schwarzmueller, G.Lorenzen, R. Gnirss, G.Gruetzmacher

Quantification of recharge and assessment of region benefitted due to a check dam by numerical modelling.
S. P. Renganayaki, L. Elango

Soil Moisture Retention in Gradational Burn Severity: Arizona Ponderosa Pine Forests.
W. Woods, A. Springer, Frances

Integrated Approach for Artificial Recharge to Ground Water in an Infrastructure Project, Haryana, India.
D.K. Chaddha, S. K. Mohiddin

Integrated Modeling Approach for Sustainable Water Resources Management: The Case of Mexico City Metropolitan Zone Aquifer.
M. C. Hernández-Rendón, E. Abdelshahid, M. Schöniger

Characterization of the Yucatan karst aquifer: intrinsic vulnerability scenarios and possible solutions.**M. Moreno, C. Stefan and R. Liedl.**

The Influence of Filtration Treatment on Soil Aquifer Treatment (SAT) Infiltration Rates and Water Quality.
G. Arye, O. Mienis, A. Aharoni, Ido Negev

Infiltration Basin: an Alternative Recharge Method for El Paso's Managed Aquifer Recharge Program.
Z. Sheng, A. Shalamu, G. Miller, S. Reinert, B. Smith, O. Rodriguez

Measures to mitigate flood-risks at riverbank filtration sites with a focus on India.
C. Sandhu1, T. Grischek, W. Macheleidt, A. Heisler, P.C. Kimothi, P.S. Patwal.

Decentralised Stormwater Management: Focus on Infiltration over Street Tree Pits in Steindamm, Hamburg, Germany.
B. Adcock, A. Arrazola.

Measures to mitigate flood-risks at riverbank filtration sites with a focus on India.
C. Sandhu1, T. Grischek, W. Macheleidt, A. Heisler, P.C. Kimothi, P.S. Patwal.

Decentralised Stormwater Management: Focus on Infiltration over Street Tree Pits in Steindamm, Hamburg, Germany.
B. Adcock, A. Arrazola.

Pilot test design for MAR projects in Northern of Mexico
A.Mendoza , F. Gonzalez, C. Cruickshank, A. Palma.

Assessing infiltration rates and clogging impacts during recycled water managed aquifer recharge (MAR) in Floreat (WA) and Alice Springs (NT), Australia.
K. Barry , J. Vanderzalm ,E. Bekele, M. Donn, K. Miotlinski, P. Dillon.

Wednesday, June 21th, 2016

Integrating suitable sites for managed aquifer recharge with drinking water demand in Costa Rica.
J. P. Bonilla Valverde, C. Stefan, J. L. Arguedas

Methodology for Identification of aptitude of basin-scale aquifer artificial recharge áreas.
N. Ramirez, C. Ortiz, A. Palacios

Using numerical modelling to investigate the behavior of the shallow quaternary aquifer in the west part of Damascus and possibilities to optimize this process.
W. Wannous, F.Bauer, U .Tröger.

Blending Stormwater and Treated Wastewater for Managed Aquifer Recharge to Support Irrigation Expansion and Economic Development.
R. R. Martin, J. Vanderzalm, D. Page, D. Gonzalez

Identification of recharge area for potential flooding recharge in Leizhou Peninsula, Guangdong, China.
J. Chen, D. Liang, J. Cao

Problems of Artificial Recharge in Unconfined Aquifers – Examples from Germany and Syria.
U. Tröger, M. Wannous

Coupled surfaces water and groundwater model to managed artificial recharge for the valley of Santo Domingo.
J.Wurl, M. Lamdrid

Can village ponds be modified to mitigate floods and meet local irrigation demands?
K. Brindha, P. Gangopadhyay, P. Pavelic, N. Sharma, C.L. Verma, V.K. Mishra, L. Kant

Water recharge reduction in the Alto Atoyac subbasin, Oaxaca, by climate change, and identification of recharge zones.
E. A. Ojeda-Olivares, S.I.Belmonte-Jiménez, T. K. Takaro, L. A. García-García, M. A. Guevara-Torres

Understanding Groundwater Recharge Dynamics of Anicuts in Hard Rock Areas in Rajasthan, India.
Y. Dashora, P. Dillon, B. Maheshwari, R. C. Purohit, R. Dashora, P. Soni

An account of Artificial Groundwater Recharge in an Overexploited Block with special reference to Kottukal Micro watershed, Kerala S.India,
L. Thompson, P. Nair

Groundwater Quality Improvement due to Rainwater Harvesting in Costal Aquifers.
N. K. Gontia, P. G. Vadher,y Y. Sharma

Combining aquifer storage and recovery with reverse osmosis (ASRO Westland.
K.G. Zuurbier, M. Paalman, K. Haas, G. van den Berg

Multiple barrier processes for indirect potable reuse: a lab-scale study for the Metropolitan Area of Mexico City
I. Navarro, R. Martínez, S. Lucario, C. Maya, E. Becerril, J. Barrios, B. Jiménez

Economic viability of recycled water MAR.
J. Vanderzalm, P. Dillon, P. Pickering, N.Arold, S. Tapsuwan, D. McFarlane and E. Bekele.

Analysis of ASR clogging investigations at three Australian ASR sites in a Bayesian context.

P. Dillon*, J. Vanderzalm**, M. Muthukaruppan*** and M. Hudson*** , D. Page, K. Barry, D. González

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Keywords: aquifer storage and recovery; clogging; specific capacity; value of research; economics

When evaluating uncertainties in developing an ASR system, under normal budgetary constraints, a systematic approach is needed to prioritise investigations. In the case of the Werribee recycled water ASR system a key issue was to appraise the potential for clogging of the ASR wells to determine the required combination of source water treatment and periodic well redevelopment regime in order to achieve target storage volumes. Sufficient initial investigations had been performed, together with evidence from past research and operational experiences at other sites, that a priori probability distribution for a range of outcomes could be produced. A clogging study was performed in a laboratory, using clean aquifer material derived from sonic coring of the aquifer and two water types representing different treatment processes. This enabled the derivation of a posterior probability distribution of outcomes. An economic evaluation tool was used to ensure systematic account of capital and operating costs and delays in completion of the system with and without the research. This paper will present these results, and the Bayesian analysis used to derive the value of the clogging research. In producing this paper a new approach is used to derive the optimum costs for managing redevelopment, for a given set of assumed acute and chronic rates of hydraulic conductivity decline. Respectively, these determine the rate of decline in specific capacity of a well following any redevelopment event, and the rate of decline in recovered specific capacity for a sequence of redevelopment events. The results depend on these assumptions, so a sensitivity analysis is presented, and in due course would be refined based on long-term operational history of the site. Heterogeneity of the site results in different hydraulic conductivities and injection rates among wells, so operational experience will ultimately be valuable in differentiating clogging behaviour under different aquifer conditions for the same water type.

TOPIC: **M10 Hydraulics, clogging, recovery efficiency**; could also fit in M18 MAR and water reuse; or in M22 Water quality and selection of pre- and post- treatments. Could also follow on from M. Hudson's paper *Meeting Melbourne's Growing Demand for Water Using Aquifer Storage and Recovery*.

PRESENTER: Peter Dillon who performed Bayesian analysis is willing to present the paper.

BIOS: Peter Dillon, Co-Chair of IAH-MAR, contributed to the project and volunteered to assist with the Bayesian analysis for this paper. Joanne Vanderzalm is a Senior Research Scientist and leads the MAR research group within the Liveable, Sustainable & Resilient Cities Program in CSIRO Land and Water. Joanne has led a small research project performing column studies to predict clogging in ASR wells for City West Water. City West Water lead a commonwealth government funded project to recharge advanced treated recycled water into an aquifer near Melbourne for recovery to meet

non-potable urban water supplies through a separate distribution system for a new subdivision. Muthu Muthukaruppan is Manager Water Innovation, City West Water, who conceived and manages the project and Matthew Hudson is Senior Hydrogeologist, City West Water and is responsible for hydrogeological oversight.
PUBLICATION: The authors are willing for this paper to be considered for publication in a special issue of the most appropriate journal.

Application of cylinder infiltrometer for analyzing the vertical water flow to bankfiltration technology in Beberibe river, Pernambuco - Brazil

T. B. V. Albuquerque*, J. J. S. P. Cabral** and A. L. R. de Paiva**

* Civil Engineering Pos-graduate Program, Federal University of Pernambuco - UFPE, Av. Prof. Acadêmico Hélio Ramos s/n, Recife, Pernambuco, Brazil
** Civil Engineering Department, UFPE, Recife, Pernambuco, Brazil

Keywords
Bankfiltration; river-aquifer interaction; cylinder infiltrometer; infiltration

Water transport between a superficial water course and groundwater has been the subject of several studies, once the understanding of water flow dynamics in river-aquifer interaction is of great importance to application of Bankfiltration technology (BF). A pilot project with the use of BF technique was installed on the Beberibe river banks, in Caixa d'Água neighborhood, located on the border between Olinda and Recife cities, State of Pernambuco, Brazil.
This technique is characterized by the river-aquifer interaction, in order to better understand the vertical flow of Beberibe river and aquifer and the physical processes involved in BF technology, water transport has been monitored and characteristics of the material in the hypoheic zone has been assessed. Potentiometric levels has been monitored over a period of 10 months two production wells and seven observation wells implemented in BF pilot project, in addition to the water level in the Beberibe river and the local rainfall.
River-aquifer interaction was analyzed by the data obtained in this monitoring. In Beberibe river bed near BF pilot system, infiltration testing was performed using cylinder infiltrometer for assessing the capacity of water volumes between the river and the aquifer. In place of the infiltration tests, samples were taken of the hypoheic zone for particle size analysis.
From the results of monitoring, it became evident that there is a hydraulic connection between the shallow wells and the Beberibe river, featuring river-aquifer interaction. It was observed that the Beberibe river in its middle course, contributes to the groundwater recharge, with the exception of a few days that the flow in the river presented upflow after long periods of rain. The average rate of infiltration in the tests was of 0.78 mm/min. The sand percentage in the samples collected were more than 82% and percentage of organic matter was variable.
Results have shown that river bed sediments are predominantly sandy, the hypoheic zone is highly permeable and most part of the year water flows from river to aquifer.

Aquifer recharge experiences in Mexico City

J. M. Lesser* and D. Gonzalez*

*Lesser y Asociados, S. A. de C. V.

Keywords
Recharge, injection, infiltration, clogging, aquifer

An experience analysis and gathering was carried out of artificial recharge to the Metropolitan Zone Aquifer of *[ZMCM by its abbreviation in Spanish: Zona Metropolitana de la Ciudad de México].* The first and most standing experience was conducted by Eng. Ignacio Sainz Ortiz, Agriculture and Hydraulic Resources Secretary, consisting on 3 drilled recharge wells, between 1953 and 1956, located down stream Mixcoac dam (to the west of ZMCM), to infiltrate surface water. The recharge system included the existing dam to regulate the water yield and the thick material sedimentation; an additional sedimentation tank to hold the fine particles and thereafter its gravity injection through 3 drilled wells in granular materials with a water yield of 1 m^3/sec. Approximately, during 20 years (1956-1975) they operated. The great height of the hydraulic charge was the one that let the injection of the high water yield (more than 300 lps per well).

In 1991, the Federal District Government [GDF by its signals in Spanish] constructed experimental units of artificial recharge that operated during 9 years (1991-2000), injecting reclaimed water through materials of different granulometries. Water quality variations were obtained regarding the covered distance and the clogging degree regarding the injection time. Results let to establish maintenance and cleaning politics of injection wells. In 1998, GDF adapted a well located at the South of Sierra de Santa Catarina (SC-6 well) for aquifer recharge, as well as an infiltration lagoon of 4 Ha. As part of the system, the construction of a treatment plant at a third level was included with a capacity of 20 lps, destined for the recharge through the well and the lagoon. The subsoil of this zone is constituted by basaltic pyroclastics of high permeability.

In 2012, Water National Commission (Conagua) carried out artificial recharge tests at El Caracol, to the North ZMCM, through 2 wells of 250 and 300m in granular material injecting 14 to 22 lps for gravity as well as under pressure.

There are hundreds of shallow wells of storm water absorption which have primarily been constructed at the South of ZMCM, to avoid floods and recharge the subsoil with water. Shallow absorption wells outstand in fractured basalts southeast zone of ZMCM, constituting the current storm and house wastewater drainage.

Additionally, a great number of studies and projects tending to determine the feasibility of recharging the aquifer of ZMCM with pluvial water as well as treated wastewater have been performed.

Aquifer recharge proposal for Metropolitan Area of Mexico City in the 2nd section of Chapultepec Forest

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Keywords
Aquifer ZMCM, hill zone, Tarango formation, Geophysical methods, land subsidence

Abstract

The aquifer in the Metropolitan area of Mexico City (ZMCM) is over-exploited. This cause land subsidence, groundwater level decline and deterioration of groundwater quality. For that reason, the Water System of Mexico City (SACMEX); has implemented a sustainability and management program of water services. The objective is to achieve sustainability of the sources of supply for future generations, reduce the overexploitation and mitigate land subsidence.

In this work we propose a recharge site at Chapultepec forest, located toward the west of the city, in the so called hill zone. The forest is considered the oldest and largest urban forest in Latin America with an area of 686 hectares. In that site emerges a volcanic sequence: tuff layers of ash and pumice Tarango formation resulting from the activity of San Miguel volcano.

By conducting detailed studies of stratigraphy and geophysical studies (electrical, electromagnetic and seismic), we characterized the first 120 meters deep. Between 0 to 80 meters of deep exist permeable horizons that have the ability to store water (volcanic ash and pumice materials). This horizons give water the aquifer ZMCM where the saturation level is 100 meters deep.

Aquifer Storage and Recovery Well Systems Factory Pump Injection Testing: Is This Necessary?

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Topic Theme: M13 - Innovation in well injection and recovery systems

Summary:

How do we estimate injection rates for an Aquifer Storage and Recovery (ASR) well? Why is factory injection testing for line-shaft turbine pumps critical? What have we learned over the years? This presentation will address these questions and summarize how the City of Phoenix has improved the understanding of injection well hydraulics by incorporating reverse flow pump tests into their ASR design program.

Abstract:

Designing a pump and motor for a water supply well requires pump testing the new well and aquifer with a temporary pump/motor assembly. Results of these pumping tests provide estimates for drawdown, productivity, and pump setting within the well and horsepower for the motor. However, with ASR wells, design considerations much also be addressed for recharge operation. The following questions should be asked when designing pumps for injection flows:

- How do we design the appropriate line-shaft turbine pump for both recharge and recovery operations?
- What are the critical design set points?
- How is the injection rate estimated during the design/early construction phases?
- What is a factory pump injection test?
- What is the testing protocol?
- What decisions are made if the injection rate is greater than the recovery rate?
- What is the breakpoint at which a down-hole control valve is necessary to control reverse flow hydraulics?

This presentation will use the City of Phoenix ASR Well Program as a case study to show the importance of understanding reverse flow hydraulics through the bowl assembly for ASR well recharge operation. City of Phoenix, Carollo Engineers, Weber Water Resources, and National Pump have been working closely to address the questions listed above. A summary of our findings from multiple factory pump injection tests will be used to explain why these tests are critical for optimizing recharge and pumping operations.

Artificial Recharge of Aquifers as a Mitigation Measure in the Atacama Desert

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Keywords
Artificial Recharge, Mitigation, Atacama Desert, Puquios

Although artificial recharge of groundwater techniques have been developed mostly as a tool for water management, they can also be used for environmental management. Indeed, in Chile's Atacama Desert, the driest in the world, injection wells have successfully been used to mitigate the impact of pumping water out of a small lake system.

2006 was the start of mining projects using groundwater to supply their production processes. The water is pumped out from Salar de Llamara, an area which features small bodies of surface water called *Puquios*, which correspond to surface expressions of the aquifer as a result of the sinking of the ground, which leaves groundwater exposed. The environmental assessment of the system shows that, although the impacts of pumping are lower in the *Puquio* area, they are enough to partially or completely dry these water bodies.

A proposed mitigation measure consisted of the construction of injection wells to prevent the cone of depression reaching the *Puquio*. The mitigation measure was implemented by building eight injection wells of diameters varying between 6” and 10" and depths between 10m and 30m. The system has an injection capacity of approximately 50 l/s. To control and understand how the system works, the monitoring network has 32 monitoring wells, 5 water depth gauges measuring the height of the surface water, and 24 boreholes drilled in the active field of the salar.

Prior to designing the injection system, it was necessary to develop a detail conceptual model to attempt to understand the functioning of the hydrogeologic system. The model was built on: stratigraphic information, chemical and physico-chemical water quality, isotopic analysis, x-ray refraction, piezometric levels, and hydrological studies to understand recharge systems.

Finally, injection to the system, which began working steadily since May 5, 2012, has been successful in maintaining the level of *Puquios* within the committed values. The injection rate has spatial differences, i.e., it is not the same in all *Puquios* and shows a strong seasonal pattern, making it necessary to perform larger injections in the summer, when evaporation is higher, and very smaller flows in the winter, with even one *Puquio* requiring no injection during the latter season.

9th International Symposium on Managed Aquifer Recharge

Artificial Recharge of Groundwater: High Time to Rethink Our Approaches

Authors: Y. B. Sharma[1] and K. B. Biswas[2]

ABSTRACT

Groundwater plays a crucial role in maintaining both the ecosystem services and mankind. For all human needs, it continues to serve as a preferred source of water supply to meet most of our agricultural, industrial, recreational, and domestic demands. A rapid increase in the human population and its impact on groundwater resources have trespassed the hydrodynamic limits of this precious resource in recent decades. Most of the developing countries are unable to regulate the abstraction levels to ecologically feasible quantities. This unprecedented rate of groundwater withdrawal has caused severe or permanent damage to the aquifers. As a result, artificial recharge to augment groundwater is becoming increasingly important in groundwater management plans throughout the world. Although literature is rich in documenting the quantitative gains through these recharge structures, there has been little research to assess the impact of artificial recharge on qualitative aspects of groundwater. There has also been relatively little work to link these interventions to ecologically acceptable changes in the catchments and aquifer parameters. Therefore, the key objective of this review paper is to understand the long-term impact of artificial recharge measures on groundwater quality, the catchments, and aquifer parameters. The paper argues that it is high time to rethink the approach of artificial recharge before making the practise common in all groundwater management plans irrespective of time and space.

Keywords: *Ecosystem Services, Aquifer, Artificial Recharge, Groundwater Management, Ecology, and Long-term Impact*

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Artificial Recharge Pilot Testing in Chile: Lessons Learned, the Aconcagua Case

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Keywords
Aconcagua Valley, Pilot Test, Chile

Artificial recharge projects in Chile are currently in a very preliminary stage, in fact, only pilot projects have been developed, none of which are permanently in operation. Since nearly 50% of the country has an arid to semi-arid climate, water management tools are necessary to further ensure supply for different types of consumption.

The Aconcagua Valley has favorable and unique climatic conditions within the country to grow profitable crops, fruit trees being the most common. The Aconcagua River basin, which begins at the slopes of the mountain of the same name, the highest in the Americas and the second highest in the world after the Himalayas system, stretches out to the Pacific Ocean, having a pluvial regime during the winter and a snowmelt regime in spring and summer season. Water rights are completely granted and over the last 4 years the basin has suffered severe drought, which has impacted agricultural production and drinking water supply as well. As a measure to offset the effects of the drought, the government has ruled it a "water shortage area", allowing the Water Works Division (DOH, Spanish acronym) to pump wells with no officially granted rights.

To improve the water management of the basin and take advantage of the water surplus produced during the snow-melting period and winter season, when irrigation is not necessary, together with of the DOH a basin pilot infiltration project has been developed in the first section of the Aconcagua Valley. The project consisted of the construction of 2 adduction canals, a 4,500 m^2 decanter, and 2 infiltration basins of 2,200 m^2 each. For monitoring, 4 observation wells 65 m deep were drilled at between 10 and 550 m distance from the ponds. In addition to measuring the aquifer's and the infiltration ponds' levels, actions included measuring the inflow rate, sampling for chemical quality analysis, recharge water physical quality measurements, evaporation, and rainfall.

Chile's valleys have unique characteristics, which sometimes are not optimal to develop these kinds of projects. The upper area of the Aconcagua Valley comprises thick aquifers, high infiltration rates, and a huge storage capacity. However, other features, such as a high hydraulic conductivity associated with the presence of surface streams, in some cases results in shorter water residence times in the aquifer. Another relevant issue deals with the fact that the physical quality of the water is very changeable, since the rivers have a rain-nivo regime in the spring, meaning a very significant sediment load. Last but not least is the availability of water and associated legal matters related to the use of this water for groundwater recharge.

Despite achieving the study objectives, various technical and administrative issues which arose in the course of the work, generate the need for a change in the implementation strategy of this type of projects. The main problems deal with water availability due to the drought still affecting the country, while a second problem has to do with the physical water quality, which rapidly changes from one season to the next within the same year.

The results show that the artificial recharge is a technically and economically feasible option to be implemented in the study area. Furthermore, it is necessary to get stakeholders and irrigation communities actively involved in this type of projects in order to ensure their cooperation during tests and their commitment at the time this technique is applied at an industrial level.

ASR in Barcelona: new operational regimes of aquifer recharge to deal with new scenarios

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Keywords
Aquifer Storage and Recovery, Well Injection, Llobregat aquifer, Drinking Water Production

The treatment plant of Sant Joan Despí provides 48% of total potable water to the Barcelona metropolitan region. More than 3 million of inhabitants, local agriculture and industries need fresh water to develop their activity. Sant Joan Despí DWTP has a capacity of 5.3 m^3/s. The average annual production is about 115 Mm^3/year, with a total contribution of pumped groundwater of 27 Mm3, which means that almost 25% of the fresh water resources come from the Llobregat Delta aquifer. In 1696, the pumping system was adapted to create the largest ASR system of Spain. The ASR system is a dual system of injection and recovery consisting of 12 wells, with a total capacity of injection of 75,000 m^3/day. During the decades of 90's, the range of injected water varied from 5 Mm3/year to 15 M^3/year.

Despite the suitability of the alluvial aquifer and the good results achieved, the system has been operated less and less. In 2009 took place the last extension of the drinking water treatment, with the incorporation of a line of ultrafiltration and reverse osmosis. Nowadays the ASR system is not operating due mainly to the high water production costs and the unsustainability (broadly defined) of the ASR scheme using potable water.

In the last decade, numerous ASR experiences using non-potable water have been reported injecting stormwater and reclaimed water (Dillon *et al*., 2001). In this line, Aigües de Barcelona, drinking water operator of the ASR system, has started a project to evaluate the impacts of the injection of pre-potable water to increase locally groundwater resources to better assure the supply of water to the Barcelona area in water scarcity periods.

Literature review revealed a great number of parameters to consider both at level of regulations (WBMWD, 2008) and recommendations (Fernández Escalante, 2006; Pérez-Paricio 2001). Physical clogging seems the most avoidable, as it can be controlled by individual parameters as turbidity, TSS (Total Suspended Solids) or MFI (Modified Fouling Index). The most challenge parameters are those affecting biological clogging, which usually is a complex combination of nutrients, available carbon source, temperature, etc.

Along DESSIN project the injection of pre-potable water will be analysed using a multidisciplinary evaluation. Numerical modelling will be used to quantify groundwater replenishment in terms of quantity. Hydrogeochemical interactions will also be assessed. Finally, ASR will be evaluated using the ecosystem services approach to highlight its benefits from the economic and social perspective.

Topic M2: Regulations, guidelines and governance

Authorising MAR projects within the context of South Africa's National Water Act

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Keywords
Authorisation; legislation; planning

South Africa has one of the world's best Water Acts that uses sustainability and equity as central guiding principles in the protection, use, development, conservation, management and control of water resources. But does it cater for authorising and regulating MAR projects? In the 17 years of the National Water Act's (Act 36 of 1998) existence, no MAR schemes have been authorized and the legislation has not been tested with respect to processing MAR applications until now.
The National Water Act (NWA) of South Africa only requires authorisation or a license if an aquifer is intentionally recharged with water containing waste; it does not cater for recharging aquifers with fresh water for later use. An option has been to use the section of the Act that refers to "storing water", but this was written specifically with dams and not MAR applications in mind. Bank filtration options could possibly be covered in a section that refers to "altering the bed, banks, course or characteristics of a water course", but again, this section was written for construction works in river courses and not MAR applications. While the Department does have documented guidelines for authorising MAR schemes, these are now being tested for the first time.
Three MAR scheme applications are currently under review at the Department of Water and Sanitation (government), and the challenge is to establish the appropriate legislation under which they can be authorised. The reasons for the scheme vary from disposing of excess groundwater; correcting the groundwater flow around an open pit mine; and enhancing the recharge too an aquifer in a river bed.
This paper presents the Department's MAR authorisation guidelines, and shows that if authorisation is considered at the outset in a phased approach to assessing and implementing MAR schemes, it can make the authorisation and regulation a lot easier than if left as an afterthought in the planning stages. It does however also highlight the challenges faced when legislation specific to MAR is not in place.

Presenter

Fanus Fourie is a Scientific Manager at the Department of Water and Sanitation (DWS) in Pretoria, South Africa. He responsible for national groundwater planning initiatives that includes: resource planning, assessments and development; development of the National Groundwater Strategy for South Africa and MAR projects. His background is in hydrogeology and geology; from B.Sc degree in Geology (1994) and B.Sc (Hons) in Geohydrology (1996) at the University of the Free State, South Africa. He started with the Department of Water Affairs and Forestry in 1997 and worked in Upington and Kimberley till 2000. For the last 10 years he is working Pretoria in the Chief Directorate: Integrated Water Resource Planning. Some of the projects were: development of the Groundwater Strategy, development of the Artificial Recharge Strategy, Aquiworx groundwater management tool, and the Guideline for Assessment, Planning and Management. The project that is very close to his hart is the

Langebaan Road Aquifer System Artificial Recharge (LRASAR) and Grootwater Aquifer System Assessment (GASA) projects.

BENCHMARKING PROPOSAL FOR MAR SYSTEMS. BENCHING AND COMPARING SEVEN MEDITERRANEAN MARSOL SITES

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Keywords
Managed Aquifer Recharge, MAR, artificial recharge, groundwater quality, benchmarking, Mediterranean climate, water management

The main aim of the Managed Aquifer Recharge (MAR) cannot be any other but the amount and quality of the resource obtained after its pass through the system, so these two variables have to be the focus of the benchmarking when comparing the different cases considered in the MARSOL European project .No matter the complicated the scheme could be, the question is the net water recharge. Then, quantity and quality are the main objectives but they can also be measured in many different ways.

In order to be able to compare the efficiency and efficacy of the MAR based on terms of energy balance or cost/profit, a methodical characterization of the whole process must be carried on to assure functions and devices are clearly comparable independently of size, budget or location.

The seven chosen MAR demo-sites are located in the Iberian Peninsula: Rio Seco and S. Bartolomeu de Messines (Campina de Faro Aquifer) and Cerro do Bardo in (Querença-Silves) in Algarve, Portugal covering 4 separated MAR systems and Santiuste and El Carracillo (Los Arenales, Castilla y León) and Llobregat (Catalonia) in Spain.

Systems have been defined using a form made of 4 datasheets including alpha-numerical data, ortophotos, sketches and schedules sent to every demo-site leader. Later revision meetings and data feedback help to check that all data is correctly defined and measurements can be comparable.

- Main data and big numbers are covered in the first sheet as MAR class, functions, geology, water cycle, water quality, soil control and benchmarking indicators.
- The second sheet shows the location of the demo site on orthofoto using Arc/Map or Google Earth. The main aim is focused on in and out flow directions and net connectivity for benchmarking design.
- Third sheet is supposed to be a sketch of the demo-site where Q_0 to Q_x represent main inlets and outlets so it can be made out which device or stretch is playing a different role in each point of the recharge net.
- The operative devices have been represented in a calendar for each campaign in the fourth sheet

Thus, this characterization covers the technical solution aspect and the local features of site where the MARSOL is implemented. Article covers MAR benchmarking serial steps for infrastructure measurements (surfaces, lengths, devices, costs), functions categorisation (transport, infiltration, treatment, restoration) and evolution in time and space (maps, calendars and sketches). Measuring MAR displays unlike interpretations depending on scale. Main numbers show different reliability features, considering measurement issues (operational dimensions versus geometrical sizes), deduction (diversion flow/volume or infiltration rates) and time line (cost sharing or lifespan).

Efficiency is relative to multi-functionality so benchmarking should be used to compare only tested similar devices and that implies parting systems into homogeneous operational stretches or facilities.

Mediterranean water irregularity, amplified by Climate Change previsions, can benefit from MAR in very different functions (flood control, WWT or ecological restoration) not generally seen as goals attached to recharge. No Energy cost and low initial investment (former infrastructures: wells, quarries, pits…) can also play an important role in short term to boost MAR development as a real choice in water management planning.

M3

Chapultepec WWTP, a reuse and aquifer recharge project for sustainable management of water resources in Mexico City

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Abstract: Water scarcity is a reality in Mexico City, in 2013 the National Water Commission of Mexico (CONAGUA) published that the pressure on the water resources in the Valley of Mexico was 136% coming from a deficit between the renewable water of the region, 3468 hm3/year, vs the granted water for all uses, 4720 hm3. Recently, it was estimated that the aquifer from the metropolitan area of Mexico City is overexploited by 3.5 m3/s, aquifer that is responsible for around 40% of the water supply to the area.

Within this context, reuse and aquifer recharge represent a key scheme for sustainable management of the water resource. Through this presentation Suez will introduce the Chapultepec WWTP project, which is a first example of how CONAGUA is tackling the water scarcity problem to its roots. The WWTP will treat the wastewater with the ultimate technology in order to provide water for recreational activities (the lakes of the Chapultepec Park), for irrigation of the forest of Chapultepec, and for groundwater recharge of the aquifer of Mexico City.

The project includes a biological reactor for carbonaceous and nutrient (N&P) removal as well as technologies like the Ultrafor ™ (biological membrane reactor), in order to comply with the water quality required for the recreational activities and irrigation. In the case of the aquifer recharge, the treated water from the lakes will go through an additional UF membrane filtration, reverse osmosis and UV treatment before going into the injection wells. These technologies will allow to comply with the water quality requirements needed for a direct recharge of the aquifer. This project is a first step and an example to follow in the sustainable management of the water resource in Mexico.

Keywords: Chapultepec; aquifer recharge; reuse, biological membrane reactor; ultrafiltration, reverse osmosis, UV disinfection

Co-managing disastrous floods and droughts through UTFI - an innovative MAR modality

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Keywords: floods; droughts; groundwater depletion; livelihoods, Ganges basin; Barind Tract

Abstract Submitted for **Oral Presentation**. Possible Sessions to present could include:
‘*New topics in MAR and water banking*’ (M17) / ‘*Flood water harvesting via MAR for agriculture*’ (M20)

Major advancements are needed to avert increasingly frequent water-related disasters globally, and especially in the developing country context where cost-effective and upscalable solutions are most needed. One such solution curently under development involves facilitating recharge with wet-season high flows to refill depleted aquifers in upstream regions of catchments, thus preventing downstream urban flooding and simultaneously providing additional groundwater for intensifying irrigated agriculture and mitigation of droughts. This solution we have aptly named "underground taming of floods for irrigation" (UTFI). Thoughtful planning and staging are needed when applying UTFI to ensure the technical, economic, social, institutional and environmental risks are addressed in progressing from concept definition to sustainable mainstream implemetation.

Conditions that favour the establishment of UTFI appear to be prevalent across the various regions that have been examined, including much of the Gangetic Plains of South Asia. The economic benefits to the rural economy in the implementaiton areas and the wider public benefits from flood reduction appear to be substantial and make UTFI attractive and support the transfer of investments from downsteam flood relief to upsteam prevention through UTFI. Pilot scale implementation has commenced in western Uttar Pradesh, India to more clearly reveal actual performance, benefits, costs and trade-offs. The characteristics that lead to sustainable development models and raise awareness amongst the local and higher level stakeholders needed for upscaling are being revealed. A similar process has commenced in northwest Bangladesh.

By taking a fresh look at the co-management of frequent negative seasonal floods and groundwater depletion, decisions makers and investors can begin to consider UTFI amongst the portfolio of options when planning for climate change adaption/mitigation and disaster risk reduction. Although this research is firmly grounded in South Asia there may are clear opportunities to extend the approach to other regions.

Combination of Ozonation and Managed Aquifer Recharge for Advanced Wastewater Treatment and Reuse

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Keywords
Dissolved organic carbon; managed aquifer recharge; ozonation; soil aquifer treatment; trace organic chemicals

Managed aquifer recharge systems (MAR) are engineered processes that use the aquifers natural capacity for water treatment and storage, such as bank filtration, artificial groundwater recharge and soil aquifer treatment. MAR is highly effective for the removal of many wastewater-derived contaminants including many trace organic chemicals (TOrCs). Operation, however, is facing some limitations including breakthrough of some polar and persistent residues of TOrCs and dissolution of metals under anoxic conditions. Ozonation is a well-established treatment process for disinfection and oxidation of TOrCs. Besides the transformation of target contaminants, reactions of ozone with the water matrix result in an increase of biodegradable organic carbon and the formation of transformation products and by-products. The combination of ozone and MAR may provide i) multi-barrier treatment of target chemicals by applying different removal mechanisms (oxidation vs. biodegradation/sorption), ii) enhanced removal of bulk organic carbon, e. g. DBP precursors and iii) removal of undesired oxidation by-products during subsequent infiltration. In addition, ozonation provides disinfection and excess oxygen to increase redox potential in SAT systems.

In this study, laboratory- and pilot-scale experiments were conducted to evaluate, predict and optimize the removal of TOrCs, to assess the removal of bulk organic carbon in a combined ozone/MAR system and to analyse the potential of MAR for the removal of by-products and transformation products from ozonation.

The ozone/MAR hybrid system removed most analysed compounds below the limit of detection with the exception of some persistent and ozone-resistant compounds such as primidone, which are just partly transformed by OH-radicals during ozonation. In addition to efficient TOrCs removal, results from pilot-scale and sand column experiments revealed an enhanced degradation of dissolved organic carbon (DOC) in MAR systems after ozonation (>40 %) in comparison to direct infiltration (≈20 %). This can be attributed to transformation of organic compounds into more biodegradable products as well as supply of excess oxygen as electron acceptor for microbial processes during MAR.

An improvement of biodegradability by oxidation was also observed for the antiepileptic drug carbamazepine (CBZ). In contrast to CBZ, which is highly persistent under most infiltration conditions, three of its four major transformation products were efficiently removed during MAR. For the carcinogenic by-product bromate, no significant removal was observed for aerobic infiltration. Thus, oxidation in ozone/MAR hybrids with the purpose of potable use needs to be optimized to meet the limit of the drinking water directive of 10 µg/L for bromate.

Community driven MAR using a pilot to develop a Groundwater Replenishment Scheme, Poverty Bay, New Zealand

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Keywords: Catchment-scale, conjuntive water management, community consultation, Groundwater Replenishment Schemes (GRS)

The Poverty Bay community in New Zealand has identified long term water availability in the area as being a potentially limiting factor in future regional development. A substantial proportion of the water used for irrigation of the intensive horticultural area of the Poverty Bay Flats is derived from groundwater, with most of the abstraction being from the confined Makauri Aquifer. Reviews of groundwater levels have identified declining groundwater pressure trends in this aquifer as an environmental and water supply reliability issue. The Gisborne District Council (GDC) together with interested community partners is investigating water management options to stabilize and restore groundwater trends and improve future water supply reliability, including Managed Aquifer Recharge (MAR). Golder Associates (NZ) Limited (Golder) was commissioned by GDC to undertake a pre-feasibility assessment for a MAR program. The outcomes indicated a groundwater replenishment scheme (GRS) focused on the Makauri Aquifer has the potential to:

- Stabilize and restore current downward groundwater level trends within the aquifer
- Restore groundwater pressures within the aquifer
- Enable the establishment of a sustainable yield from the aquifer that exceeds current usage.

A Groundwater Management Tool (GMT), incorporating a calibrated water balance model for the Makauri Aquifer, has been developed for GDC using the Goldsim software package. The purpose of the GMT is to:

- Enable an increased understanding of the Makauri Aquifer water budget and how this budget influences historic and future groundwater level trends.
- Support an assessment of groundwater management options and basic economic benefits of MAR.
- Provide the community with a groundwater management tool to facilitate decision making for future limit setting scenarios.

A full feasibility study has now been initiated by GDC, including construction of a pilot injection bore to be drilled into the Makauri Aquifer and an injection trial to be undertaken during 2016. Monitoring systems will be installed in the production and selected nearby bores to track aquifer pressure and water storage responses to the trial. Changes in groundwater quality in response to the injection program will also be monitored. The information gained from the trial will be used to update the GMT.

Computational modeling of aquifer system of Nazareno Etla, Oaxaca, México

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Keywords
Model; hydraulic head; recharge; hydraulic conductivity; calibration; pumping

This study aimed to build a computational model for aquifer system of Nazareno Etla, Oaxaca, to assess two gabion dams as recharge source. Information collected included hydraulic head, hydraulic conductivity, aquifer geometry, specific storage coefficient and total porosity. The discretization of geometric model domain consisted of 15 row per 32 columns array and 100 m per 100 m cells in horizontal axes; depth varied from 26 m to 78 m and it distributed in two stratigraphic units: upper unit consist of sand and gravel and lower unit formed by sand and clay. The model simulated in steady state; the calibration allow to obtaining a normalized Root Mean Squared error (nRMS error) of 6.4 %. Then, the model simulated in transitory state showed nRMS error of 5.9 % and 6 % for 365 and 730 days, respectively. The model represented the aquifer dynamic suitably, due the nRMS error was less than 10 %; it showed that the gabion dams do not contribute to recharge and the actual pumping exceed approved pumping. The model is useful tool to improve aquifer management in municipality.

Controlling the formation of the reaction zone around an injection well during subsurface iron removal

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Keywords
injection wells; subsurface iron removal; reaction zone

Theme: M13 – Innovation in well injection and recovery systems

The complex hydraulic system of filter screen, gravel pack and adjacent aquifer can still not be very well described with analytical nor numerical tools. The reaction zone created around an infiltration well during subsurface iron removal (SIR) has therefore been geometrically abstracted as cylinder. A short "appropriate" filter length is recommended for SIR-wells resulting in a nearly cylindrical shaped reaction zone. However, vertical wells often have long filter screens to reduce intake velocities and are thus considered to be unfavorable for SIR. In addition to the hydraulic conductivity the groundwater quality often varies over the depth of an aquifer. Mixing processes of different waters in the well are described as the cause of chemical and biologically well aging. Well design optimization approaches have been investigated for pumping but not previously been investigated in more detail for injection wells. This paper presents a novel approach of water quality based formation of an SIR reaction zone.

A series of field tests were performed using one uncontrolled and one controlled vertical well alternately for injection and abstraction. An inflatable packer was used to control the outward movement of oxygen enriched infiltrate through the well penetrating an aquifer with a semi-confining layer separating nearly iron-free groundwater from iron-rich groundwater. The breakthrough of electrical conductivity (EC), dissolved oxygen and iron were monitored in pumped water and at different depths and distances from the well during injection and abstraction. These experiments were also numerically simulated using an advective groundwater flow model (PMWIN). When no packer was used for injection, test and modeling results showed that the outward migration of the injection front and thus the reaction zone was 1) non-uniform, 2) disproportional to the vertical dissolved iron distribution, and 3) not significantly affected by the location of the pump inlet or the infiltration pipe outlet. The numerical model was used to define the optimum position for the inflatable packer in order to control the outward migration with regard to the dissolved iron concentration found in the groundwater. A packer placed inside the well was used to seal 2/3 of the upper filter screen length. This measure successfully increased the outward migration into the lower iron-rich part of the aquifer by means of an accelerated breakthrough for EC and significantly delayed the breakthrough of iron in the abstracted water.

Web-GIS of global inventory of managed aquifer recharge applications

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Keywords
managed aquifer recharge; MAR; web-GIS; Global Groundwater Information System

Managed aquifer recharge (MAR) is being successfully implemented worldwide for various purposes: maximization of natural storage, management of water quality, physical aquifer treatment, management of water distribution systems and ecological benefits. To better understand the role of MAR in the mitigation of global change impact, about 1200 case studies from over 50 countries were collected and analyzed in respect to historical development, site characterization, operational scheme, objectives and methods used, as well as quantitative and qualitative characterization of both influent and effluent. The data harvested was used for the compilation of a global inventory of MAR schemes whose main goal is the promotion of MAR technologies and demonstration of their benefits.
The statistical analysis of the data revealed interesting patterns among different countries and continents: while in Australia and North America the most used techniques are 'well, shaft and borehole recharge', European MAR projects are based on 'induced bank filtration', while in South America the focus lies on 'in-channel modifications'. Contradictory, in Africa and Asia the interest is shared almost equally between several MAR schemes.
To increase the availability and facilitate continuous update of the MAR inventory, a MAR web-GIS portal was developed and integrated into IGRAC's Global Groundwater Information System. The MAR portal contains a map view to visualize the selected data on a geographic location, a catalog containing the data arranged in a systematic way, and a features panel providing tabular output of the selected data. The web-GIS allows to build advanced queries on the data, to generate new pieces of information by creating overlays of map layers and to share the data by making use of web map services (WMS). These web services follow the international standards of the Open Geospatial Consortium making it possible to connect to external data sources and systems on the internet. By facilitating access and promoting international sharing of information and knowledge on MAR, the web-GIS MAR portal encourages stakeholders to regard MAR as a viable solution for sustainable groundwater resources development and management.

Coupled Surface Water and Groundwater Model to Manage Artificial Recharge for the Valley of Santo Domingo

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Keywords:
Arid climate, aquifer overexploitation, artificial recharge, saline intrusion, recharge dams.

The Valley of Santo Domingo is the most important agricultural region in the southern part of the peninsula of Baja California, with an area of irrigated agriculture of 323,115 acres. Due to the climatic characteristics of the region, runoff occurs mainly between the months of May to October as a result of intense and short rain events, originated from tropical cyclones.

The uncontrolled extraction of groundwater, and especially the over-exploitation of the Santo Domingo aquifer from 1957 on, has caused modifications to the natural flow system and induced lateral inflow of seawater from the Pacific coast. As a result the groundwater quality in the Santo Domingo Irrigation District is deteriorating, where seawater intrusion and irrigation return water, combined with the mobilization of deeper groundwater, have been identified as important sources of salinization. The reduction of extraction volumes led to the equality between discharge and recharge volume in 2007 but the deterioration of groundwater quality still goes on.

In order to plan different scenarios of artificial recharge, a *Modflow* model with 40000 cells (500 x 500 meters) in two layers was created, using the *Groundwater Modeling System* software. The observed groundwater levels (from 1996 on) were used to calibrate the regional groundwater flow in the model, taking in account the extraction rates of more than 500 wells. In order to simulate infiltration of surface water, runoff data were introduced to the *Streamflow* package, using results from a HEC-1 model. In the Valley of Santo Domingo, a natural recharge of 145 million m^3 and an infiltration of irrigation return water generate an average annual recharge of 188 million m^3. As main part of the Water Resources Management, the runoff from the Sierra de la Giganta is accumulated in four reservoirs, with an annual volume of 30 million m^3, which allows feed smaller dams on four recharging sites, located downstream, during three months of a year. In the proposed scenario, the recharge dams are introduced into the model with a storage volume of 206.525 m^3, 524.632 m^3, 757.935 m^3, 572 884 m^3, which could recharge an annual volume of at least 22.6 million m^3. With four aquifer storage and recovery facilities, included in the model, we would expect a positive annual balance of at least 16.8 million m^3, minimizing salinization effects.

M4. Modeling of systems that include MAR

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Design and Testing of Recharge Wells in a Coastal Aquifer: Summary of a Field Scale Pilot Test

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Keywords:
Recharge well, desalination, MAR, IWRM

Subject Category: M13 - Innovation in well injection and recovery systems.

The use of recharge wells in MAR as a tool of IWRM (Integrated Water Resources Management) is widely known. During the 70's and the 80's dozens of wells were drilled In Israel for that purpose. Most of these wells were designed as a dual purpose wells, enabling the recharge of surplus water during the winter and pumping during high demand seasons. Other wells were originally designed and drilled for production only, and later were converted to recharge due to different reasons. Most of these wells were practically abandoned after several years of use. The reasons for this were predominantly water shortages for recharge and/or inappropriate water quality that caused well clogging. Another major reason was the failure of the dual purpose concept due to weakening of the gravel pack during successive recharge-pumping cycles, which eventually led to sand penetration.
Israel's water sector has changed dramatically following the development of several large seawater desalination plants during the past decade, that provide up to 50% of the nation's annual consumption. The additional water creates surplus conditions in the national water system for hours and days during low demand seasons. This situation has necessitated the development of new tools to inject and store the surplus water in the aquifers. Hence, the implementation of the MAR methods is the solution to create the platform for promoting water sustainability in the basin.
In order to re-evaluate the feasibility and profitability of recharge wells as part of a general MAR policy to handle excess water, Mekorot designed and built 2 pilot sites. Each of these sites contains a set of production, recharge and 2 observation wells. The recharge wells were designed specifically to enable high flow rates so that maximum water quantities could be recharged during a relatively short period by a minimum number of wells. Attention was also given to the recharge equipment and to the need to prevent air from entering the aquifer along with the recharged water.
The pilot tests includes various examinations in order to evaluate the hydrological conditions of the aquifer, the effect of the technical design of the recharge wells, the recharge capacity and its changes with time, the effect of trapped air on clogging, and the needs for a back-flushing routine. In this lecture we will present preliminary findings regarding the recharge capacity, the effect of the technical design and the effect of trapped air on the hydraulic properties of the recharge well.

Designing MAR as a management tool for catchment-scale water quality and quantity issues

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Keywords: Catchment-scale, conjunctive water management, socio-hydrology, community consultation, Groundwater Replenishment Scheme (GRS)

The Hinds Plains catchment is located in the Ashburton District on New Zealand's Canterbury plains. This region is governed by Environment Canterbury Regional Council (Environment Canterbury) who manages natural resources on behalf of the general public for both protection and use. In 2009, Environment Canterbury developed the Canterbury Water Management Strategy (CWMS) that provides a framework by which local decision making would help to determine the most appropriate balance for each catchment between ten CWMS target water management components including drinking water quality, ecosystem health and biodiversity, irrigation, and Maori cultural values (Golder, 2014). This CWMS framework was actioned through 'zone committees' which were selected from community members who embodied the varied stakeholders and future aspirations. The Ashburton Zone Committee (AZC) was set up to address the Hinds Plains catchment zone, which is an intensively farmed catchment dominated by dairy production.

One of the primary issues requiring management in the Hinds catchment is a historical trend of decreasing groundwater levels due to changing land use and irrigation practices. A second but linked issue is a more recent, sharp increase in nitrate concentrations in the shallow aquifer beneath the catchment. The majority of the outcomes sought by the AZC were either directly or indirectly related to the sustainable management of groundwater levels and quality.

In order to achieve these outcomes, catchment-scale mitigations were developed. To address groundwater and spring-fed waterbody quality conditions, Managed Aquifer Recharge (MAR) coupled with changes to farm management practices were assessed to result in a catchment-wide reduction in nitrate-nitrogen (nitrate-N) leaching loads. MAR was applied in this context through using high quality source water to provide dilution and thereby helping to reduce elevated aquifer contaminant concentrations. MAR was also used to help restore an imbalance between aquifer water inputs (recharge) and outputs (discharge), which had resulted from dramatic increases in groundwater abstraction (1995 to present) coupled with the associated reduced incidental recharge to groundwater (e.g. piping of unlined canals). These water balance changes had resulted in a net decrease in groundwater storage, leaving environmentally and culturally important spring-fed waterbodies in a degraded and declining condition.

Through a community consultation process, various numerical modelled scenarios were used by the AZC to best assess the role of MAR in a recommended Solution Package for the Hinds/Hekeao catchment. The results were coupled with a range of technical assessments of the economics, environmental, cultural and social issues associated with developing MAR as a water management tool in the catchment. To address the catchment-scale issue of quality and quantity, a Groundwater Replenishment Scheme (GRS) was proposed, that could be developed over the first decade of the plan implementation period (2015 through 2025). For the first stage of this scheme development, the zone committee recommended that a MAR demonstration (pilot) project be initiated, which is currently being designed and permitted. Uncertainty around the effectiveness of MAR to mitigate water quality and quantity at the catchment-scale coupled with concerns around the economics (e.g. who pays and cost of source water), cultural, and social (e.g. drainage capacity of spring-fed waterbodies) required that a trial help provide assurances and further information about MAR as a tool for the Hinds catchment.

Development of adsorption treatment by iron oxide nanoparticles and biological degradation in mimetic column for managed aquifer recharge

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Keywords
Carbamazepine; diatrizoate; physicochemical treatment; column test

Use of treated wastewater can be a sustainable water resource management policy. However, high organic matters and pathogen load along with the array of emerging recalcitrant micro-pollutants, that escape the sewage treatment plant, requires expensive advanced oxidation processes (AOPs) before use. Utilization of treated waste water in managed aquifer recharge (MAR), either in the form of riverbank filtration (RBF), lake bank filtration (LBF) and artificial recharge (AR) are cost-effective and have been shown to degrade recalcitrant pharmaceuticals and personal care products (PPCPs). Carbamazepine (CBZ) and diatrizoate (DTZ) are two such persistent pharmaceuticals not degraded in in sewage treatment process. CBZ is an antiepileptic drug prescribed in seizure disorder, bipolar disorder, neuralgia, schizophrenia and depression. DTZ is used as iodinated X-ray contrast agents.

Objective of this study was to evaluate removal of CBZ, and DTZ in simulated MAR with functionalized iron oxide nanoparticle and biological treatment. A long cylindrical acrylic column was filled with sand (0.8 ~ 1.2 mm). Hydraulic conductivity, flow rate and retention time were calculated before injecting CBZ and DTZ containing artificial wastewater at estimated load of 7.89 μg/g and 10.62 μg/g, respectively. The effluent concentration at different sampling point on the column during the experimental period was analyzed by SPE-HPLC. When inoculated with a mixed microbial culture, previously known for its metabolic potential, 89.63% of CBZ and 83.66% of DTZ were removed. Because the degradation capacity of pharmaceutical substances was more than 70% in the long-term operation in the soil layer, it will be combined the adsorption and bio-degradation process. This study not only confirmed the ability of MAR to treat the CBZ and DTZ in physicochemical and biological process, but also envisioned the possibility to treat the effluents from sewage plants.

Engaging Village Communities in Groundwater Monitoring and Management – Lessons from Rajasthan and Gujarat, India

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Keywords: Participatory approach, community engagement, groundwater and capacity building

Topic area of the Abstract: M7 - Monitoring and management

Groundwater is an essential resource for farmers in India, especially in arid to semi regions where the rainfall is a most non-reliant phenomenon. Post green revolution irrigation in India has encouraged irrigation agriculture initially through surface water storage dams, but then groundwater. There are many reasons behind the worsening groundwater situation that have led to a scarcity of quality water supply for sustaining lives and livelihoods in India, as well as in other parts of the world. The lack of a proper scientific understanding of this situation by the various stakeholders has been identified as one of the important gaps in the sustainable management of groundwater. This paper shares experiences from Gujarat and Rajasthan in western India where scientists, NGOs, government agencies and village leaders have worked together to explore strategies for sustainable groundwater management. The study involved a total of eleven villages in Gujarat and Rajasthan, India.

The main aim of this project was to educate these communities through an intensive capacity building of (mainly) rural youth, called Bhujal Jaankars (BJs), a Hindi word meaning ‘groundwater informed’. The BJs were trained in their local settings through relevant theory and practical exercises, so that they could perform a geo-hydrological evaluation of their area, monitor groundwater and share their findings and experiences with their village community. The BJs went through a training program of a series of sessions totalling 45-days that covered mapping, land and water resource analysis, geo-hydrology, and water balance analysis, and finally groundwater management strategies.
This approach has highlighted important learning that can be replicated in other parts of the two states and beyond. There are now 35 trained BJs who regularly monitor groundwater and rainfall in the two study watersheds, and provide data to both scientific and their own rural communities. This study has demonstrated that BJ capacity building has helped to provide a scientific basis for village level groundwater dialogue. This is now leading the communities and other stakeholders to improve their decision making regarding groundwater use, crop selection, agronomy, recharge strategies and other aspects of sustainable groundwater management.

Although the BJ program has been successful and BJs can act as a valuable interface between

local communities and other stakeholders, there still exists some challenges to the BJ programme, such as the need for mechanisms and funding sources that will sustain the BJs over the longer term; wider acceptance of BJs among scientific communities and policy makers; and the acceptance of the role and involvements of BJs in natural resources management programs of the State and Central governments in India.

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EVALUATING CURRENT AND HISTORICAL ASR SYSTEM PERFORMANCE IN FLORIDA

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Keywords
ASR cycle testing, permit, governance, performance

Criteria to define successful implementation of ASR systems in Florida are not well defined. Successful implementation depends on fundamental hydrogeologic and engineering considerations, set within an evolving economic and regulatory environment. ASR systems are developed in the framework of Florida Dept. of Environmental Protection (FDEP) Underground Injection Control (UIC) regulations in a 3-phase permitting sequence: 1) completion of an exploratory ASR well for aquifer characterization; 2) construction and cycle testing of the ASR system; and 3) routine operation. To date, most Florida ASR systems have not completed all three permitting phases, a process that takes years to complete. Despite this, there are many potable and reclaimed ASR systems that are functioning successfully in the cycle testing phase, and the number of ASR systems having a permit to operate is increasing. At least 14 operation permits for ASR wells or wellfields have been issued by FDEP since September 2013 compared to 2 such permits from 2001 to 2013.

Here, we evaluate Florida ASR system performance within the context of the UIC permitting process. Sixty-one potable/surface water/groundwater systems and twenty-five reclaimed water ASR systems are tracked in the FDEP Oculus database. All ASR systems were (or are) involved at some stage of the UIC regulatory process between 2004 and the present, although many of these systems were in the operational testing phase or were permitted prior to 2004. The first permitted ASR system was in Manatee County, and was issued in 1983 with Peace River, Cocoa and Palm Bay following by 1990. Only limited performance data are in electronic format available prior to 2004 since earlier project results were generally in hard copy report format. Each ASR system is classified by current 2015 status: 1) permitted but not constructed; 2) active; 3) idle but available; 4) re-purposed; 5) inactive; or 6) plugged and abandoned. The performance of ASR systems that were constructed and that have completed cycle testing (all but (1), above) will be evaluated primarily by comparing technical data obtained during the cycle testing phase (for example, recovery efficiency and storage volume) with original objectives of the ASR system. Many factors can improve ASR system performance, as shown by the existing system data. These factors include adapting operations to optimize ASR system performance, and also to allow sufficient time for cycle testing. Conclusions about best practices for ASR system management will be presented.

Submitted for consideration in theme M2.

Evaluating Impact of Artificial Groundwater Recharge Structures using Geo-spatial Techniques in Hard-rock Terrain of Rajasthan, India

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Key Words
Groundwater recharge; Water harvesting structures; Kriging; Hard-rock; Monsoon rainfall

The present study was taken up to assess the impact of artificial groundwater recharge structures in the hard-rock area of Rajasthan, India. This study used groundwater level data (pre-monsoon and post-monsoon) of 106 sites spread over the area of 413.59 km^2. The gneissic rocks mainly act as a major groundwater potential aquifer in the area. The spatial maps for pre- and post-monsoon groundwater levels were prepared using kriging interpolation technique with best fitted semi-variogram models (Spherical, Exponential and Gaussian). The maximum average groundwater recharge observed as 0.31 m in 2010 and minimum of 0.01 m in 2008 against the monsoon rainfall (June to September) of 998 mm and 294 mm respectively. The entire study period (2004-2011) was divided as pre- (2004-2008) and post-intervention (2009-2011) periods. The relationship between monsoon rainfall and groundwater recharge was fitted by linear functions for pre-intervention and entire study periods with R^2 values of 0.94 and 0.82 respectively. The average groundwater recharge found as 17% of total monsoon rainfall prior to intervention and it became 28% during the post-intervention period. Based on the similarity in monsoon rainfall, two combinations of average (2007 and 2009) and surplus (2006 and 2010) rainfall years were selected from the pre- and post-intervention periods for further comparisons. During average rainfalls, 82.7% of area showed increase in groundwater recharge after construction of water harvesting structures. After intervention, more than 99% of area showed increase in groundwater recharge during surplus rainfalls and out of which, 32.33% of area showed the increase in recharge more than 0.1 m. All the water harvesting structures were grouped as *anicut* (Masonry overflow structure), percolation tank, sub-surface barrier and renovation of earthen pond/ *nadi*. The groundwater recharge increased by 0.05 m and 0.09 m within the 100 m distance from intervention sites during average and surplus rainfall years. The influence of *anicuts* was found to be more effective among all other types of structures. In the hard-rock terrain, water harvesting structures have the significant and positive consequences in groundwater recharge. The geo-spatial techniques have been successfully employed for evaluating the response of artificial groundwater recharge techniques.

Evaluating locations for distributed stormwater collection with regional surface hydrologic models in central coastal California

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M21. Site selection for MAR

Keywords
stormwater, PRMS, surface hydrology modeling, precipitation data, California, MAR

We are developing tools to apply a regional surface hydrology model, Precipitation–Runoff Modeling System (PRMS), to evaluate locations for managed aquifer recharge (MAR) projects using stormwater collection in the Pajaro Valley Groundwater Basin (PVGB), central coastal California, USA. In this region, stormwater-MAR projects are being considered to help address chronic groundwater overdraft and seawater intrusion. A previous study analyzed surface and subsurface conditions in the PVGB and found that about 7% of the region (3,700 acres) appears to be highly suitable for MAR. We are applying PRMS in a new way, to assess which of these areas could generate enough runoff to support stormwater-MAR projects. Our models explore the spatial and temporal variability of runoff generation, infiltration, and recharge on a scale that is relevant to stormwater-MAR projects (25–250 acres). We are also examining how surface hydrology responds to changing land use and climate, and what implications this could have for MAR in the future. We will use our results to quantify the historic impact of land use and climate on basin recharge, and test model results against field observations at MAR project sites.

To gather and construct input data sets, we are using a geographic information system (GIS) and Python. The complete data sets that we have generated for our study region include soils, vegetation, land use, slope, and other physical landscape characteristics. Climate records are required to drive the model simulations; we will run the model under “normal”, wet, and dry precipitation regimes. We are tuning long-term regional climate records with local meteorological station data to produce high-resolution daily climate records for the PVGB. We are making all data and modeling tools available so that our methods can be applied in other settings.

Evaluation of aquifer-circulating water-curtain-insulated greenhouse system coupled with various MARs

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Keywords
Water-curtain-insulated greenhouse; groundwater shortage; borehole injection; infiltration gallery; sustainability

Over 100 km^2 of rural area in South Korea is covered by water-curtain protected cultivation facilities, which use heat source in groundwater to keep warm inside of the greenhouse during winter night by splashing groundwater inner roof of the green house. Those cultivation methods can produce various vegetables and fruits in winter, but induce groundwater level decline over a large area because it discharge the used groundwater to the stream via drain ditch. To restore groundwater level, aquifer-circulating water-curtain-insulated greenhouse system (AWIGS) was facilitated at 9 greenhouses in Cheongju, Korea, which can reuse groundwater through dual purpose injection-pumping well and infiltration sand gallery. Groundwater usage was measured to be 739 m^3/d and injection rate through dual purpose well was measured to be 404 m^3/d on forced injection mode and 139 m^3/d on natural injection mode (Syphon). The averaged injection rate was calculated to be 162 m^3/d, which corresponds to about 22% of the groundwater usage. Infiltration sand galleries, located at the space between each greenhouse, can capture the used groundwater during flowing over those and recharge it before it discharge to ditch. The infiltration sand gallery is evaluated to recharge water more than 50% of the used groundwater. Radon (Rn-222) as a natural tracer was applied to evaluate recharge and recovery efficiency of the dual purpose well. A continuous radon monitoring system was used to measure radon activity continuously in pumped from the dual purpose well. A radon mass balance equation was derived from radon activity of intrinsic groundwater, injected used groundwater and mixed pumped groundwater. The recovery rate of the injection water was estimated to be 95.6% by a simple radon mass balance model. The AWIGS coupled with various MARs is evaluated to be energy saving, groundwater protecting and sustainable system for the protected cultivation facility during cold winter season.

Evaluation of pre-potable water injection in ASR and expected impacts: pilot experiment in Barcelona system

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Abstract: The Aquifer Storage and Recovery system of Llobregat (Barcelona) has been injecting potable water since its construction in 1969. In order to increase the environmental and economic sustainability of the process, within the DESSIN project the impacts of the injection of pre-potable water are being evaluated. Before the demonstration phase of the project in a well of the ASR system, a pilot experiment has been conducted to assess the clogging potential of sand filtered water (SFW) by reproducing the ASR system in column-type experiment. The observation of the developed clogging by direct visualization and by SEM microscope, the measurement of column head loss and the analysis of extracellular polymeric substances formed, suggest that with the injection of SFW although there is a detectable clogging formation it is not menacing in operational terms for the ASR Llobregat system.

Keywords: Aquifer Storage and Recovery; Llobregat aquifer; clogging; column experiment

Experimentation Field to Know the Effects of Treated Residual Water Infiltration in the Aquifer of Valle de Las Palmas, B.C., Mexico

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Keywords
Aquifer recharge; reuse, treated residual water; free aquifer; NOM-014-CONAGUA-2003

Located in the northeastern region of Mexico is the city of Tijuana and southwest of the city is the Las Palmas Valley. According to the latest population census, the Tijuana municipality has over 1,560,000 inhabitants (INEGI, 2010) and, consequently, a high water demand. However, this is a semi-arid region where annual rainfall averages 231 to 270 mm (CONAGUA, 2014). It is for these reasons that human development of the area is considered of great importance.

Through the years, expensive infrastructure has been built to meet the population's water demand. Most remarkable among it is the 114 km-long aqueduct that draws off 4 m^3/s of water from the Rio Colorado Delta, and which has to run more than 1,000 m up hill. As a result of water usage, Tijuana generates over 2.5 m^3/s of treated residual water.

Aimed at putting to use the treated residual water of the area, a pilot project was developed. An experimental field made up by an infiltration structure with a capacity of 25 m^3 and 16 monitoring wells modeled and finished based on the aquifer kind. In order to locate the most advantageous area for the project, a variety of investigations were required, such as a geologic, geophysical, hydrogeologic, hydro-chemical, and underground hydraulics' study.

Once built, an infiltration test was carried out in the field where 160 m^3 of treated residual water were discharged during a period of 14 hours and 05 minutes. The infiltration structure and monitoring wells were instrumented in order to get to know the piezometric level variation before, during, and after the test. In addition, a total of 90 chemical analyses were performed, including the characterization of the native groundwater, of the treated residual water, and of the mixed water. With the results, and using the geochemical model PHREEQC-2, a hydro-chemical model was developed.

This infiltration test was based on the specifications of the norm NOM-014-CONAGUA-2003, which establishes the requirements for the artificial recharge of aquifers with treated water.

The results of the test brought to light the infiltration capacity of the non-saturated area (it was a free aquifer); the area's auto-depuration ability; and the parameters in the treated residual water that had a higher concentration than that allowed by the norm NOM-127-SSA1-1994 (quality and treatment limits that water has to go through in order to render it drinkable). Finally, an analysis of the test's results allowed to make the necessary recommendations that will permit the implementation at high scale of the process of infiltration with treated water.

Feedback of MAR experiences in France and USA

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Abstract: Suez designs and operates MAR schemes since more than 40 years ago in France, Spain and USA. MAR can be seen as the identification and management of all actions on groundwater that can improve water resource quantity or quality upstream of a given use. The scientific background required is at the crossroads of hydrogeology, geochemistry, limnology, and biology. Like in many management problems, a step by step approach consists in data acquisition, understanding of the groundwater system, and action. This type of approach is very promising for treating microbiological and chemical pollution, sea water intrusion, and storage management by artificial recharge and recovery. As many regions of the world are being affected by increasingly prolonged and intensive events of water scarcity, verified by IPCC forecasts, new water resources and enlarged storage capacity will be ever further demanded. Managed Aquifer Recharge and water reuse offer environmentally clean and cost effective solutions for this kind of requirements. Through this article Suez presents the feedback of Flins-Aubergenville (France) and West Basin (USA) operations, where reuse, river bank filtration, ASR and barrier protection against seawater intrusion schemes are being implemented.

Generation of DRWHS Design Parameters for Marginalized Communities in Mexico using Probabilistic Prediction of Daily Precipitation

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Abstract

Domestic rainwater harvesting systems (DRWHS) have been shown to be a viable option for providing potable water to marginalized communities in Mexico, however, realistic design parameters are necessary for regional decision-makers to implement programs to encourage installation. Previous studies have shown that monthly rainfall data can produce storage volumes and catchment areas that are either overly optimistic or overly conservative, which affects either reliability or economy. This study used daily rainfall data from Mexican meteorological stations to probabilistically predict daily precipitation amounts. A computer program was developed to process the daily rainfall simulation and generate values for rainwater catchment area and storage volume. The program was tested on 27 municipalities identified as high potential candidates for DRWHS in a previous study, which used monthly rainfall. Results from this study and the previous study were compared to those generated by the computer program using observed precipitation data from corresponding meteorological stations. Catchment area and storage volume determined in this study were found to closely match those generated using observed precipitation values and monthly averages, which corroborates the method proposed in a previous study in Mexico and delivers a more versatile method for future use. This method is recommended as the most robust and reliable method for decision-makers in Mexico.

Groundwater Modeling to Support Water Resources Management in Clarkdale, Arizona, USA

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Keywords
Effluent; Recharge; Reuse; Baseflow; Injection; Economic Development

Topic M23: MAR in depleting aquifers and protection of groundwater dependent ecosystems

The small town of Clarkdale, Arizona currently depends almost entirely on groundwater for its water needs. Drainage from a local abandoned mine provides irrigation water for the local school grounds and a few residential lots. Municipal groundwater is produced primarily from fractured bedrock and mixed sedimentary rock units more than 100 meters below ground surface. The few existing water level data suggest that groundwater levels are declining rapidly, and several private wells along the mountain front on the western edge of town have gone dry in recent years. Clarkdale acquired control of its municipal water system in 2006, and made major upgrades to its wastewater treatment system in 2013. The class A+ effluent produced by the Town's wastewater treatment plant is presently permitted for land application disposal only. The Town values effluent at its least expensive and only increasing source of water, and seeks to optimize its use to meet the Town's various needs. Groundwater modeling of several water management scenarios has helped the Town determine how to prioritize its limited water and financial resources in planning for a sustainable future. These scenarios include high, low, and probable pumping; regional recharge to reflect climate change; and various application rates, mechanisms, and locations for effluent recharge. While protecting the nearby Verde River is a high priority for Clarkdale, modeling helped to demonstrate that the small quantity of effluent that the Town controls would produce the most long-term benefit to the Town and the river through some combination of recharge and reuse rather than direct discharge to the river.

Guidelines for MAR water quality. International overview and lessons learnt

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Keywords
MAR guidelines, overview, regulations, artificial recharge, quality standards, parameters

The MAR Guidelines affirm aquifer water quality should be protected beyond a defined attenuation zone so sustainably may meet all its existing environmental values/beneficial uses, and that recovered water quality should meet the water quality parameters relevant to its uses.
Most of these guidelines specify water quality requirements on recharge water generally without a detailed study of the biogeochemical processes that occur in aquifers. Subsequently the achievement of these essential objectives could be compromised.
A collection of 11 examples of MAR guidelines has been gathered from different international sources: WHO guidelines, “Water Quality Guide to Managed Aquifer Recharge in India”, Australian water quality guidelines, and specific regulations from Israel, California, Chile, México, The Netherlands, Belgium, Spain and Portugal.
After a detailed study, most of them demonstrate that setting criteria on injectant does not necessarily assure you of achieving your water quality objectives. E.g., reducing the ionic strength of water by purifying it to a high degree invokes increased dissolution of aquifer material, and may yield worse quality than a less pure injectant. You can add low arsenic water to a low arsenic aquifer and get water with high arsenic concentrations that exceed drinking guidelines. You can chlorinate water to remove harmful bacteria and viruses but in some aquifers chlorine continues to react and you can recover unacceptably high concentrations of trihalomethanes…
As product water is a function of recharge water quality, groundwater quality and aquifer mineralogy, these facts dictate the redox conditions and temperatures which result in quite varied reactions between these three components, but most of the analysed regulations have avoided further explanations about the context when the procedures have been written and published.
The existing guidelines present certain constraints and some aspects to be developed and improved, such as:

a) Need for a homogeneous definition for artificial recharge;
b) Insufficient theoretical background on legal aspects of artificial recharge;
c) Control of the operation, surveillance;
d) Ensurance of a certain continuity of the experiences;
e) Specific procedure for authorizations;
f) Artificial recharge consideration as a spill in some cases;
g) Financial aspects on artificial recharge of aquifers is neglected and
h) Study for each case if the proposed technical solutions are legally viable in each country.

After the analyses 4 main conclusions are achieved:

1. “*You don´t need to be a scientist to deploy a MAR project*”
2. Before implementing a MAR activity, it is necessary to choose the most appropriate method and study its legal feasibility for each context
3. The majority of the problems arisen during MAR devices deployment can be avoided or reduced conducting prior detailed technical and legality studies.
4. A joint strategy for the conservation of water, would be an important asset to satisfy the water growing demand

Identification discharge and recharge zones related to regional groundwater flow in northern part of Mexico and their impact in groundwater balance

Keywords
Regional flow, recharge zone, discharge zone.

The recharge and discharge zones identification of regional groundwater flow, in some closed basins in Mexico, is the object of this paper as well as recognize their importance in recharge evaluation process of aquifers.

Some closed basins in the northern part of Mexico (34 “Cuencas Cerradas del Norte”, 35 “Bolsón de Mapimí” 36 “Nazas-Aguanaval”), are endorheic groundwater basins, with arid, hot and dry climates. On that, the three kind of regional flows exist: local, intermediate and regional flows that begin where the rainfall drop over high mountains chains and finish at lowest topographic lands or at sea level where the water quality has high salinity and high temperature and some special geochemical characteristics.

The scientific people had identified clear evidence of recharge and discharge zones of regional flow in some aquifers of Mexico, but the problems are how to evaluate these flows to know the aquifers’ recharge rates. The Mexican country is a land with two slopes, to the Atlantic Ocean and to the Pacific Ocean, that develop some models of regional flows. Water inside in mountainous recharge zones and outsides on sea level, and low lands in closed basins.

El objetivo de este trabajo es identificar zonas de recarga y descarga de sistemas de flujo regional en tres regiones hidrológicas del norte de México, y analizar la importancia del flujo regional en la evaluación de los recursos hídricos subterráneos.

Las Regiones Hidrológicas: 34 “Cuencas Cerradas del Norte”, 35 “Bolsón de Mapimí” y 36 “Nazas-Aguanaval”, son cuencas endorreicas que se localizan en la porción norte del Altiplano Mexicano, donde el clima es árido y semiárido. Los tres sistemas de flujo regional identificados se inician en los terrenos de mayor altitud y terminan en la zona topográficamente más baja de las regiones hidrológicas, donde el agua subterránea se caracteriza por su elevada salinidad, alta temperatura y características hidrogeoquímicas particulares. Adicionalmente se observan otras evidencias que permiten identificar zonas de descarga de flujo regional, como la presencia de antiguos lagos, suelos salinos e incluso notables acumulaciones de sales en cantidades económicamente explotables.

En varios acuíferos del país, donde se tienen evidencias de descarga de flujo regional, el cálculo del balance de agua subterránea realizado de manera tradicional permite inferir que existen entradas adicionales no contempladas, provenientes del flujo vertical ascendente del sistema de flujo regional; mientras que existen otros acuíferos situados en las zonas de recarga de un sistema de flujo regional, en los que se observan descensos en los niveles a pesar de que la extracción sea menor que la recarga, debido a que parte de esa recarga se incorpora al flujo regional, se profundiza y no es posible su aprovechamiento total en ese acuífero, sino que circula hacia otros acuíferos.

La importancia de identificar, entender y caracterizar los sistemas de flujo regional es fundamental para evaluar adecuadamente estas regiones, y estimar con mayor precisión el potencial de una región como fuente de abastecimiento segura. Las decisiones del manejo relacionadas con intensificar las extracciones, mantener el ritmo actual o acotar el desarrollo y su distribución en tiempo y espacio, exigen la revisión de los métodos de evaluación del recurso hídrico subterráneo, para dimensionar la participación de los sistemas de flujo regional en la cuantificación de la recarga y en el deterioro de la calidad del agua subterránea, por la presencia en el subsuelo de elementos en concentraciones nocivas para la salud.

Increasing freshwater recovery upon aquifer storage in brackish-saline aquifers: what can hydrological engineering bring?

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Keywords
Aquifer storage and recovery; ASR; brackish/saline aquifers; well designs; water quality

Aquifer storage and recovery (ASR) can be successful in storing and recovering freshwater via wells. It is attractive thanks to the limited space requirements above ground and the generally successful conservation during storage. However, the ASR recovery efficiency ('RE', the fraction of the injected water that can be recovered with a satisfying quality) can be limited in brackish–saline aquifers. This is due to the lower density of the injected freshwater with respect to the ambient brackish or saline groundwater, which causes early contamination with ambient groundwater at lower parts of the ASR well. Recent advances in hydrological engineering allow, however, the mitigation of buoyancy effects and an increase of RE. In this way, ASR can offer a valuable contribution to freshwater management in the more and more water-stressed coastal areas, which typically have shallow brackish-saline groundwater and therefore a lack of suitable ASR target aquifers.

To test the ability of hydrological engineering to improve RE, two dedicated ASR set-ups were recently implemented in coastal areas of The Netherlands. The first used low-cost, independently operated multiple partially penetrating wells (MPPW) in a single borehole. The RE was increased by 20-40% at two MPPW-ASR systems storing greenhouse roofwater in confined, brackish aquifers thanks to preferential deep injection in the target aquifer and recovery at the aquifer's top. Interception of brackish water via the deepest well screen further increased the RE (10-20%). Detailed hydrochemical monitoring also highlighted relevant water quality changes occurring during MPPW-ASR, mainly a Na-enrichment due to cation exchange. Also, the deeper aquifer had a dominant impact on the final water quality due to the preferential deep injection and the geochemical composition of this interval.

In the second set-up, horizontal directional drilled wells (HDDWs) were implemented in an ASR-system for the first time. Two 70m long, superimposed, low-cost HDDWs were assembled in a 'Freshmaker' system to enlarge a shallow freshwater lens by simultaneous infiltration (shallow HDDW) in the lens, and deep abstraction of underlying saltwater (deep HDDW). In dry periods, the shallow HDDW was used for abstraction of freshwater from the lens, while the deep HDDW prevented upconing of deep saltwater by continuation of the abstraction. A maximum yearly volume of around 6,000 m^3 of surface water could be successfully injected, followed by successful abstraction of an equal freshwater volume for irrigation at a fruit orchard.

The presented innovative ASR set-ups were successfully tested in the horticultural sector to provide irrigation water. The estimated cost per m^3 are 0.3 to 1.5 US $/m^3$, and can compete with the local (yet less sustainable) alternatives (piped water, desalination). In the freshwater management strategy of the National Deltaprogramme, the innovative ASR solutions were therefore embraced to attain local 'self-reliance'.

Integrated web-based framework for planning and assessment of managed aquifer recharge

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Keywords
Managed aquifer recharge; MAR; modeling; web-GIS

The success of managed aquifer recharge depends on selecting the most appropriate technologies and adapting their operational parameters to the site-specific conditions. Modeling studies help to estimate the feasibility of MAR at a selected location prior to construction of field-scale experiments. General objectives include mostly planning or optimization of MAR schemes, geochemical processes during water infiltration and storage, the recovery efficiency and the impact of infiltrated water on the native groundwater quality. In less frequent cases, the modeling studies address also the risks for possible failure of MAR systems such as low recovery efficiency or clogging related issues. To reach these objectives, several model concepts are applied, such as groundwater flow models, unsaturated flow models, non-reactive and reactive transport models, as well as watershed models. In terms of site selection, methods based on geographic information systems (GIS) are assessing the suitability of different locations for MAR by weighted analysis of thematic maps.

Given the complexity of processes occurring at a MAR site and the multitude of objectives proposed, the selection of the appropriate approach is often a challenge amplified by the availability and accessibility of suitable modeling tools. The present paper introduces a new integrated framework for web-based planning and assessment of managed aquifer recharge applications. The platform represents a compilation of common public domain models and tools ported on a web server for better accessibility and data sharing. The workflow proposed is structured on four interconnected layers: a) estimation of groundwater deficit based on actual and global change driven prognosis of groundwater balance; b) objective-oriented selection of suitable sites and of MAR techniques; c) scenario analysis for the assessment of MAR efficiency; and d) compilation of technical sheets for the design, operation and maintenance of MAR schemes. The system architecture includes GIS tools for data input, management and visualization and web portability of simulation tools of various degrees of complexity (from empirical equations to analytical and numerical models). A dynamic environmental information system provides additional support in parameter estimation and data management and visualization. The new framework presented includes several advantages over conventional simulation approaches: a) various model complexity levels reduce unnecessary workload and optimizes the simulation time; b) web portability provides best accessibility of project data and enables shared access to results; c) open-source tools reduce investment costs of expensive software; and d) database adds additional support for parameter estimation.

Inventory of managed aquifer recharge schemes in Latin America

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Keywords
managed aquifer recharge; MAR index; Latin America; MAR types

Managed aquifer recharge (MAR) is an important tool for the sustainable management of water resources. This paper presents an analysis of case studies from different countries in Latin America. The data was collected from freely available scientific papers, reports and academic theses published in English, Spanish and Portuguese. The resulting database is part of a larger study focused on the compilation of a global inventory of MAR schemes that spreads over 50 countries from all continents. The global inventory aims to provide guidance for the planning and implementation of new MAR projects.

The majority of study cases (more than 70%) were found in Brazil, followed by Mexico (12%), Chile (7%) and Argentina (3%) while Bolivia, Colombia, Costa Rica, Paraguay and Peru represent all together 8% of the total number of entries. The MAR case studies collected were classified according to the specific MAR type developed, the source of the influent water and the main MAR objective. Brazil is the only country that has reported at least one case study for all MAR types – Mexico has four out of the five MAR types, the exception being ‘induced bank filtration’. The main MAR type reported in Latin America is ‘in-channel modification’, which represents more than half of the reported MAR schemes. This result is strongly influenced by Brazil, where the mentioned MAR technology is used in around two thirds of the study cases. The main influent water used are river water and storm water (counting for more than 90% together). Regarding the objective, approximately two thirds of the MAR cases in Latin America were developed to ‘maximize natural storage’, while the purpose of almost one quarter of the studies was ‘physical aquifer management’.

Publication of freely available scientific reports on MAR in Latin America is scarce, which does not necessarily lead to the conclusion that MAR projects are inexistent, but rather suggest the insufficient motivation in sharing the experience with the international scientific community. Nevertheless, MAR has been successfully implemented in several countries in Latin America and the application of MAR is expected to grow further as sustainable and reliable tool to address challenges related to global change.

Investigating conditions for denitrification during controlled MAR experiments using reactive barrier technology

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M5. Geochemistry in MAR

Keywords: Water quality, California, geochemistry, denitrification

We are using field experiments to observe and quantify nitrate removal during infiltration, with applications for developing a low-cost water quality amendment for managed aquifer recharge (MAR) systems. Under certain conditions MAR has been shown to quantitatively increase water quality by reducing concentrations of nitrate ($NO3^-$), a pervasive groundwater contaminant. The most commons form of nitrate removal is denitrification, a microbially mediated redox process carried out in low-oxygen environments primarily in the subsurface. Although preliminary studies have shown evidence of denitrification during MAR operations, it has been shown to be highly heterogeneous in nature, with the rates of denitrification depending on factors such as infiltration rate and carbon availability. If the fundamental mechanisms and controls on denitrification during infiltration were better understood, MAR systems could be designed to encourage nitrate removal and thus improve water quality.

To explore these relationships, we constructed a series of controlled percolation tests where nitrate rich water was applied to experimental plots at measured rates. Replicate plots were constructed with native soil, and with a carbon-rich permeable reactive barrier (PRB) in the form of redwood chips. Using fluid samples collected at the surface and subsurface (30, 55 and 80 cm depth) coupled with vertical infiltration rates, nitrate concentration was calculated as a function of depth and infiltration time. Further, dissolved organic carbon coupled with nitrate concentrations suggest that the PRB drives dynamic subsurface chemistry in contrast to the native soil plots, but variable initial water chemistry precludes simple interpretation of solute concentrations with depth. Soil samples collected before and shortly after each experiment are being tested for total C/N and the presence of microbiological activity associated with denitrification. In addition, nitrate isotopic work is underway in an effort to characterize nitrate reduction pathways and confirm the occurrence of denitrification. These results will expand our knowledge of the conditions under which denitrification occurs by making direct connections between experimental parameters and favorable conditions for denitrification. Furthermore, our innovative experimental design has the potential for additional experimentation with variables that impact water chemistry during infiltration. This study has broad application for designing MAR systems that effectively improve water quality and water supply.

Managed Aquifer Recharge (MAR) from an operator´s perspective

D. Boris

This presentation will review several MAR development schemes and R&D projects Veolia has been involved in over the last few decades with a focus on operational issues and scientific challenges that had to addressed and discuss some lessons learned fron such projects.

Managed Aquifer Recharge and Aquifer Characterization Within The Complex Esker Deposits in Pälkäne, Finland

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Keywords
Managed aquifer recharge, aquifer characterization, hydrogeology, groundwater

Managed aquifer recharge (MAR) is used for drinking water treatment in Finland. A standard MAR procedure consists of the infiltration of surface water in a Quaternary glaciofluvial ridge (esker) with subsequent withdrawal of the MAR treated water from wells a few hundred meters downstream. The infiltrated water should have a residence time of at least around one month before withdrawal to provide sufficient time for the subsurface processes needed to break down or remove humic substances.
Tavase Ltd. aims to construct a MAR plant (capacity of 70 000 m^3/d) to provide potable water for over 300 000 inhabitants in Tampere and Valkeakoski region in Southern Finland. The location and design for the MAR plant has been extensively investigated and part of the work (capacity of 20 000 m^3/d) focused in the Isokangas-Syrjänharju unconfined esker aquifer in Pälkäne. This area is 3 km long segment of structurally complex Tampere interlobate esker that formed between two different ice masses fringed by the ancient Yoldia Sea. Deposit thickness, material distribution and groundwater environment were first studied with gravimetric surveys, drilling, and groundwater observations followed by infiltration tests.
A more detailed aquifer characterization was needed to finalize the design of the infiltration and well areas. This was done by using sedimentological interpretation of ground penetrating radar (GPR) soundings (100 and 40 MHz antennas) supported with areal reference from previous data as well as detailed line reference from drill hole logs. The characterization was supplemented with tracer tests indicating flow paths and residence times of the infiltrated groundwater. The data synthesis was used to determine depositional stages and related large-scale esker structures that predict the hydrogeological properties. Accordingly, the following main hydrogeological units were compiled: (1) branching subglacial esker core (main aquifer) and superimposed ice-marginal deposits, (2) kettle holes and other disturbed deposits fringing the esker core, (3) ice-marginal esker deltas or fans, and (4) fine-grained deposits along the esker margins. The interpretation includes also marked erosion and redeposition by shore processes during the forced regression of the shoreline. Moreover, the transverse bedrock threshold divides the groundwater flow regime into two preferred flow paths. The sedimentological interpretation formed conceptual understanding of the MAR processes and was applied to evaluate infiltration and pumping test results, and to determine the variation of hydraulic conductivities for groundwater flow modeling. Sedimentological information together with hydrogeological studies was used in designing the sites and capacities for infiltration and withdrawal.

Paper presenter: Joni Mäkinen, University of Turku, Finland

Topic: M21 Site selection for MAR

Managed Aquifer Recharge Opportunities in the Arid and Semiarid Cordilleran Region of the Americas

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Keywords
Managed aquifer recharge, Mexico, South America, arid, wastewater

Groundwater resources in the arid and semiarid Cordilleran region of Mexico and elsewhere in the Americas (southwestern United States and South America) occur predominantly in coarse siliciclastic alluvial sediments (and less commonly volcanic deposits) in intermontane basins and in shallow alluvial stream aquifers. Due to inherent low recharge rates in arid and semiarid regions, both basin and stream aquifers are vulnerable to over abstraction. Increased climate variability and a shift to even drier conditions may exacerbate water scarcity.

Managed aquifer recharge (MAR) can be a valuable tool for addressing water scarcity. The primary potential water sources for MAR in the region are stormwater and wastewater treated to various degrees. Important technical challenges associated with stormwater (including seasonal runoff) MAR are high turbidities and limited temporal availability. In general, recharge wells and infiltration basins completed in siliciclastic aquifers have a relatively high susceptibility to loss of capacity from clogging, which necessitates some pretreatment of recharged water and periodic rehabilitation of the wells. An additional general consideration is regulatory requirements for recharged water, particularly microbiological standards for injection. Engineered treatment systems can provided high-quality water but are often not economical for MAR for non-potable uses. Bank filtration and the use of reservoirs as stilling basins are potential natural treatment options.

MAR of wastewater, treated to various degrees, can be an important supplemental water source option. Where wastewater is discharged to stream channels or ponds, its recovery by bank filtration can improve its quality and reduce health risks. Infiltration basins, vadose wells, and injection wells are used for wastewater recharge for aquifer augmentation, such as in Arizona. Unplanned aquifer recharge of wastewater through channel losses and irrigation return flows also locally occurs (e.g., Tula Valley of Mexico. Opportunities exist to optimize the process and convert unplanned recharged to MAR.

There is great variability in the financial and technical resources within the Cordilleran region, which impacts the feasibility of various MAR options. Successful implementation of MAR requires that the systems be capable of meeting water storage and treatment objectives and being appropriate for local technical and economic resources. Knowledge of the various options and their limitations and creativity are required to determine optimal local solutions. Detailed aquifer characterization and modeling are required to evaluate the aquifer response to recharge and the fate and transport of injected water and chemical constituents. Key issues are evaluating flow paths, retention times, and geochemical processes that can either enhance or degrade water quality. “Right-sized’ applications of aquifer characterization technology can be critical towards ensuring that projects are both completed economically and provide needed water resources benefits.

Topics: M9 – MAR in developing countries (Alternative M1. Integrated water management strategies)

Managed aquifer recharge project for Chihuahua, Mexico

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Increase demanding for water, mainly for public urban use, industry and services has generated groundwater withdrawals increase in recent years. The geo-hydrological basin Chihuahua - Sacramento (CGCS), which represent the main source of supplying to Chihuahua´s city,that presents consequential effects of overexploitation.

A previous analysis of the hydrological cycle of the basin, reflects only two areas of opportunity to increase the supply of water volumes: reuse and the optimization for infiltration process with a recovery of volumes, through artificial recharge of aquifers (MAR, for acronym in Spanish) with residual treated water.

In order to contribute to the solutions to deal with the problem mentioned, the Institute of Engineering of the UNAM (IIUNAM) offer various options of water management, to improve the conditions of achieve sustainable management use, of surface and subsurface resources of this basin. The general objective of the project was to define the best artificial recharge technique as well as the location and feasibility thereof by designing a pilot.

Four stages major development in this work are: a) problem definition, b) characterization of geological environment of the study area and definition of the conceptual model, c) Proposal for hydrological characterization by designing water infrastructure of pilot made up a gap of infiltration and monitoring drillings for measuring hydrodynamic and hydrochemical parameters and d) determination of scenarios and operations policy.

Keywords: artificial recharge pilot, regulation, aquifer, infiltration, treated waste water infiltration ponds, observation wells, monitoring, MAR

MANAGED BASIN RECHARGE – PROPER PLANNING ENSURES SUCCESS

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Keywords
Site selection, vadose zone, aquifer anisotropy, perched aquifer, O&M, enhancement features

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

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

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

Management Aquifer Recharge used for water reservoir against climatic change in paper plant in Mexico

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Keywords
Methodology, water reservoir, rain harvest , paper plant.

Since 1953 the Management Aquifer Recharge (MAR) has been development in different projects in México. Although, the obtained exit in some of cases, there is not followed the effort and recorded the results and the performance of this projects; therefore, the development technical and scientific in this aspects for the country has been delayed. The development and application of different methodologies and actual techniques can obtain results for the feasibility of quick and economic implementation with an acceptable uncertainness. The next step is development the executive project with knowledge of the specific and particular characteristics to implement a MAR in the site of the project. In addition, the hydrogeology knowledge of the region in where will be applied the performance is very important like the correct construction of the wells systems and their support infrastructure in superficial or subsuperficial systems, even in deep wells with a design for recharge with concern of fulfillment of the regulations for the Aquifer Recharge in Mexico.

The application and execution of these activities in development of any aquifer recharge project, it allows having a vision for the best conditions for obtain the results that justified the required inversion.

The study case that will be presented in this document is a real case of a project development by Geoevaluaciones y Perforaciones S.A. de C.V. for a paper plant recent built; the application of the mentioned methodology for the determination of feasibility of construction of a MAR for rain harvest and storage in aquifer with the objective to have a water reservoir or recharge the aquifer with rain water, that in determinate time, can be supply the water needs of the production paper plant.

The infrastructure built for this project, consist in tree wells for water production and two recharge wells which form the infiltration system and complete the water cycle in addition with the waste water treatment plant of the paper´s plant. These facilities for production and recharge concern of fulfillment of the regulations for the Aquifer Recharge in Mexico.

Management of Aquifer Recharge in River Bank Filter: Study Case

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Keywords: Recharge wells, River Bank Filter, Radial well
Topic: M12. Bank filtration, infiltration systems, soil aquifer treatment

ABSTRACT
"Management of Aquifer Recharge" (MAR) is a term given to describe the intentional banking and treatment of waters in aquifers (Dillon, 2005).
MAR techniques may be classified in: a) distribution, b) changes in channels, wells and tunnels, c) bank filtration and d) rainwater harvesting (UNESCO, 2015).

Bank filtration takes advantage of natural filtration occurring as water flows through the bank of a river, lake or other surface water body. Bank Infiltration may lead to: pathogenic microorganism's reduction or elimination, suspended solids and turbidity reduction, surface water geochemical stabilization and water supply access (Maliva, 2012).

Primarily, the current study focuses on the selection and characterization (hydrogeology and hydrology), as well as in the radial well design located near a stream. The site selection was made through Geologic analysis (satellite images and geological details) and Geophysical campaigns. The selected site is represented by a bank filtration system presenting permeable sand bodies communicating with the riverbed.

The geohydrological characterization has been focused on the river bank direct drilling and parameter measurements in relation to permeable layers.
The results show a three layers system. The top layer has a thickness of 3-4 m and is made of sand grains (0.5 to 1 mm); the middle layer has a thickness of 5-6 m and presents horizontal continuity along the riverbed axis, interdigitating with silt layers (0.05 mm- grain size); last, the bottom layer is composed by a sedimentary coarse sand body (middle sand -0.5 to 1 mm diameter).
Hydraulic conductivity values are the following: 1 m / day (permeable layers) and -0.05 m / day (less permeable layers).

The radial well has been developed with a central caisson and seven (7) lateral wells measuring: 60 m length and 10 inches (diameter). In an unconfined aquifer located near a steady stream (Hantush and Papadopulos, 1962), the water depletion analytical solution was implemented in order to predict the spatial distribution head around the radial collector. In the same way, the increased number of collector wells establishes shallow head depletion. The water pump is a fundamental part of the radial well as it defines the recharge which flows to the river. Nonetheless, it does not constitute part of the aquifer storage.
The MAR technique guarantees a constant flow to the treatment plant, as well as the reduction in suspended solids. All this is translated in low- cost drinking water and equipment maintenance.

Mapping Potential Zones for Artificial Recharge Using a Geographical Information System

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In this paper, we provide a brief description of the SIGAM©, particularly, as the methodology used may be appropriate for other countries where there is no ready national data bases, followed by a brief description of the Decision Support Systems/Decision Support Tools. Escolero (2004), and Escolero et al. (2002), proposed the development of a Hydrogeologic Reserve Zone for the Yucatan. Additional studies were conducted by Marin et al., (2005) and Escolero et al., (2005) in the Riviera Maya, Quintana Roo, Mexico. This work was used by two independent teams, Pacheco et al., (unpublished) from the State University of Yucatan, and Rebolledo and Hernández from the UCIA-CICY. Pohle (unpublished) used a GIS to look at how the groundwater resources of the state of Morelos might react to different changes in precipitation as a result of climate change. Marin et al., (2012) used a GIS to show how to select a sanitary landfill in Mexico following the Mexican Environmental Ministry´s federal guidelines (Anonymous, 2003).

MAR for Irrigation in the Yellow River Floodplain Area of North China

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Keywords: open canal-underground perforated pipe-shaft; managed aquifer recharge; cone of depression in plain area;agricultural irrigation

Abstract

Linqing City is located in Yellow River floodplain of North China, where groundwater was overexploited by the agriculture irrigation. Aiming at the feature of the Yellow River water quality and the status of local existing system of irrigation ditches, the open canal-underground perforated pipe-shaft system was proposed. The system is mainly composed of diversion ditches, pre-filter, underground perforated pipe and vertical shaft. It is designed to use water from the Yellow River through local canals system as source water, the surface water in open canal flows into underground perforated pipe after filtered and then infiltrates to the shallow groundwater. The shaft can receive most remainder silts, which can be dredged late.

In order to solve the problems of clogging and still no a simple calculation method for the seepage quantity of this system, four methods were conducted to determine the design scheme and related parameters:(1) An analytical method of the hydraulic calculation formula of the system at different seepage stages with regard to the unsteady flow of groundwater near a single channel when a free seepage period was adapted to designed the technical scheme and parameters. (2) The numerical simulation based on Hydrus-2D model in two scenarios of the open canal and underground perforated pipe respectively during 7 days of water diversion time. (3) 1:15 lab physical model experiment was used to simulate comparably the influence degree on infiltration capacity and turbidity of the system in different constant head conditions, perforated pipe materials and its cover materials and pre-filter unit so that the optimal recharge system could be selected. The results show that the pipe wrapped with geo-textile has the best seepage effect; design schemes of pre-filter and perforated pipe covered materials respectively have the impact on the turbidity of rear outlet and bottom outlet water. The pipe and the inlet of pre-filter unit wrapped with two layers of 60-meshes filtration screen have the best removal effect on the sediment of source water, and the sediment removal rate was 75%. (4) The pilot project was built which covers 5.4 hm^2 including three subsystems, the specific parameters of the single subsystem consist of the filter tank of the bottom area of $4m^2$, underground perforated pipe diameter of 30cm, the length of the 200m made from plastic blind drains wrapped with geo-textile and 20cm of coarse sand filled around the pipe, slope of 1 / 500, the depth of the shaft of 10m. The distance between the pipes is 90m. And the water diversion experiment was implemented in April 6-11, 2015 for 7 days, the total amount of infiltration was $65925m^3$ with average amount of infiltration $21975m^3$ for a single pipe. The calculation results were basically accorded with the actual monitoring value.

In a word, the seepage area and the amount of groundwater recharge to a certain extent of the system were increased through the perforated pipe on the basis of the canals system during the water diversion period. Combining with water-saving irrigation measures, it could reduce the irrigation quota to avoid groundwater non-point pollution from flood irrigation leaching of fertilizer and pesticide.

MAR in San Luis Colorado

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Abstract

The Artificial Aquifer Recharge project in San Luis Río Colorado City, Sonora, was the result of finding an alternative to reuse wastewater generated by the city.

The pilot study discharged to meet the hydraulic characteristics and removal of subsoil in the recharge area, showed the high capacity of the unsaturated zone of the aquifer to reduce contaminants still present in the waste water from a secondary treatment plant lagoon level. The results of these tests showed Saturated Hydraulic Conductivity values (K) = 4.8 mts/day, Average transmissivity = 2246 m^2/day, Porosity = 25%, Storavity = 25%, reduction of total and fecal coliforms 42,000 and 206,000 times the original water infiltrated and lower concentrations of soluble salts as total hardness, and nitrates except sodium chloride, sulfate and total dissolved solids, which increased as a result of the presence of mineral salts in the infiltration layer or unsaturated zone.

Now, concerning the elements related to heavy metals like Barium, cadmium, aluminum, arsenic, copper, iron, mercury and sinker, didn't show a defined trend, perhaps, although they were within Standard with the exception of manganese, which is also exceeded in some wells in the city.

To carry out the project of Artificial Recharge Aquifer, two trains infiltration ponds were constructed with four gaps each with dimensions of 120 meters x 120 meters and 1 meter in height and a center channel feeder operation cycle gap filling a day for six days drying.

The results of physico-chemical and bacteriological from the water extracted from the observation wells analysis yielded similar values to those found in the pilot study designed to define the project.

MAR Site Suitability using GIS and Modeling: Case studies in coastal California, US and Guanajuato, Mexico

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Keywords: MAR site suitability; geographic information system; hydrologic modeling; seawater intrusion

We completed a geographic information system (GIS) analysis to assess site suitability for managed aquifer recharge (MAR) using an area in central coastal California, US and the State of Guanajuato, Mexico as case studies. Both of these regions are experiencing severe groundwater depletion due to agricultural pumping, and could potentially benefit from MAR projects. The GIS analyses use topographic, land use, surficial geology, soil infiltration capacity, aquifer and associated confining layer locations, properties, thicknesses, and historical changes in water levels, where available. Data was obtained from federal and local agencies and collaborators at the Comision Estatal del Agua Guanajuato (CEAG) in Mexico. Using an active MAR site as a reference, we found ~7% of the land area in the California study to be “highly suitable” for MAR. Field testing is still essential when planning an MAR project, but the GIS suitability analysis greatly reduces the total cost and labor of field work by isolating the “highly suitable” areas. With results from the California GIS study, we used a groundwater model to assess the hydrologic impact of potential MAR operating scenarios, illustrating how a comprehensive analysis of MAR suitability can help with regional water supply planning and seawater intrusion management. Model results show simulated MAR projects in locations identified as “highly suitable” for MAR reduce seawater intrusion more than projects simulated in “unsuitable” locations, supporting the GIS analysis results. Results from the model also illustrate the variability in seawater intrusion reduction and head level changes throughout the basin and over time. Projects distributed throughout the study area were more effective at reducing seawater intrusion than projects located only along the coast, at the time scale of several decades. Collectively, these studies demonstrate a novel data integration method and help to evaluate management options for improving long-term groundwater conditions.

MAR technical solutions assessment. Guidelines obtained from the experience in eight Mediterranean demo sites

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Keywords
Managed Aquifer Recharge, MAR, artificial recharge, technical solutions, Mediterranean, DSS, strategies, guidelines

The MARSOL project aims at providing scientists, practitioners and end-users with an engineering-enabled set of technical solutions to improve Managed Aquifer Recharge (MAR) efficiency in areas where it is applied, and consequently, in general water management.
This array will rely on a shared understanding and tests performed at the different demo sites, with the objective of achieving maximum infiltration rates at minimum cost and minimal environmental impact.
Within this context, the main purpose of this article is to provide several sets of "technical solutions" improving the already published sets, as a repository for storing all types of activities applied or about to be deployed in the different demo site scenarios.
The different available techniques have been aggregated to a data base, offering different problem-solution binomials after 30 months of activity at eight demo sites in six Mediterranean countries (Portugal, Spain, Italy, Greece, Malta and Israel), so that, the interaction among the users, the smart solution, the demo-site's infrastructure and the repository of experiences is/are guaranteed.
The technical solutions have been classified, according to their scopes, in three groups related to:

- ✓ Design and construction;
- ✓ Operation;
- ✓ Management.

The applied *modus operandi* accomplishes the following functions:

- ✓ To summarize and analyze the technical solution currently active in MAR sites, to define the background and their impact on water availability;
- ✓ To examine the technical solutions at the MARSOL demo sites and evaluation of their performance in terms of advantages and shortcomings towards benchmarking;
- ✓ To develop new designs and proposes construction criteria and technical guidelines for the implementation of MAR facilities and for the selection of appropriate MAR technical solutions under various boundaries and environmental conditions;
- ✓ To combine as many technical solutions as possible, including dissemination and technology transfer activities.
- ✓

Finally, it exposes a final corollary containing 73 techniques, distinguishing four sorts of operations:

- ✓ Applied to water from its original source (in both quantity and quality)
- ✓ To the receiving medium (in both soil and aquifer)
- ✓ Management parameters plus cleaning and maintenance operations.

Mainly two out of eight demo-sites (Menashe in Israel and Los Arenales in Spain, the most mature of them), have provided relevant insights to face the key steps mentioned above. Furthermore, taking inspiration from the state-of-the-art solutions and the expertise of the partners, a preliminary set of over 25 relevant designs have been identified to achieve the most appropriate behavior of MAR facilities in the Mediterranean countries, applicable to other scenarios.

M15. Advances in engineering and geotechnical aspects

Maximizing Infiltration Rates by Removing Suspended Solids: Results of Demonstration Testing of Riverbed Filtration in Orange County, California.

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*Presenter

Keywords
Clogging, sediment removal, filtration

Maximizing the capacity of Orange County Water District's (OCWD) surface water recharge system is critical but constrained by clogging caused by suspended sediments in the recharge water. OCWD tested multiple treatment methods to remove suspended sediments from the recharge water. While treatment methods that used chemical additives were successful in reducing suspended sediment concentrations, they were unsuccessful in reducing clogging. The two methods that reduced clogging were Cloth Filtration and Riverbed Filtration, both of which are mechanical filtration methods that require no chemical additives.

Multi-year demonstration projects using Cloth Filtration and Riverbed Filtration are underway. A 12,000 m^3/day AquaDisk cloth media filter system manufactured by Aqua-Aerobics Systems, Inc. (http://www.aqua-aerobic.com) started operations in September 2012 and is sending treating water to a small dedicated recharge basin. So far the cloth filter has shown the ability to reduce clogging and improve recharge rates; however, it appears it can only handle a limited range of suspended solids load. Testing performed to date indicates that this type of system operates efficiently when total suspended solids concentrations range from 2 to 30 mg/L. This limited loading range limits the wider application of this technology within OCWD's system.

The Riverbed Filtration project is a variation of riverbank filtration in which infiltrated surface water is collected several feet below the riverbed and conveyed to a dedicated recharge basin. Pilot study results showed that this method was extremely effective in removing suspended solids and resulted in some water quality improvements, such as organic carbon removal. The larger Demonstration Project has been sized to collect up to 50,000 m^3/day. Initial results show excellent water quality with no detectable suspended solids. Hydraulic performance testing is ongoing and data collected in the winter of 2015 will be presented.

Results of the Demonstration Projects will be used to assess whether or not it is economically feasible to apply the techniques at a larger scale in other locations. The results of this study will be applicable to surface recharge facilities in other parts of the world that are wrestling with clogging caused by suspended sediments in the source water.

Meeting Melbourne's Growing Demand for Water Using Aquifer Storage and Recovery

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Keywords

Integrated water cycle management, artificial storage and recovery, recycled water

Melbourne is one of the fastest growing cities in Australia. The increase in water demand due to rapid growth coupled with an increasingly variable climate presents challenges to City West Water's (CWW) mission of providing affordable and safe water and sewerage services for today and tomorrow.

CWW's Integrated Water Cycle Management (IWCM) Strategy includes the development of Aquifer Storage and Recovery (ASR) schemes to store recycled water and storm water to assist with meeting future growth, where these schemes can be demonstrated to be viable and cost effective.

The investigation and delivery of ASR projects by CWW is being undertaken in accordance with Australian guidelines, which set out a staged, risk-based process for developing a scheme involving the use of recycled water.

Detailed investigations into the Tertiary sand aquifer, including drilling, test pumping, injection testing, and groundwater and hydrochemical modelling, were used to inform the risk assessment process. These investigations have confirmed the viability of ASR at the lead site (West Werribee) following a risk-based multi-stage approach with increasing levels of assessment and financial commitment. An ASR scheme is now under construction at West Werribee with injection trials proposed at a second site.

This paper describes the staged investigation process, the key outcomes to date of CWW's investigations, the opportunities that ASR could enable, and the challenges of implementing ASR at CWW.

Meeting Water Management Objectives through Water Storage and Recovery in Arizona, USA

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Keywords
Recharge; storage; recovery; groundwater; Arizona; Colorado River; effluent

ISMAR Conference Topic
M1. Integrated water management strategies

Abstract: This presentation is designed to explain how Arizona's regulatory program groundwater storage and recovery is used to meet water management objectives in Arizona. It will provide an update to the author's prior work, including a paper (Megdal, et al., 2014), which was based on an ISMAR 8 presentation, and a book chapter (Megdal, 2007). The presentation will show how Arizona's program for groundwater storage and recovery allows for: (1) integrating surface water use, particularly the use of Colorado River water delivered through the Central Arizona Project, and groundwater use; (2) meeting water demands in times of deep shortage on the Colorado River; and (3) providing a mechanism for accommodating growth through the Central Arizona Groundwater Replenishment District. The presentation will discuss how the Tucson region has used storage and recovery in lieu of surface water treatment through conventional treatment facilities (Megdal and Forrest, 2015), along with the important role of long term storage credits, including their sale and transfer, and will provide an update on recovery planning by the Arizona Department of Water Resources, the Arizona Water Banking Authority, and the Central Arizona Project (AWBA et al., 2014).

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Title: Minimal hydrological parameters necessary for the feasibility evaluation of shallow managed artificial aquifer recharge projects and an overview of the most cited analytical solutions for estimating groundwater mounding

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Keywords
Shallow managed artificial aquifer recharge; Groundwater mounding; Site feasibility evaluation

This study evaluates the minimal hydrological parameters required for the engineering design of infiltrating basins for surface shallow managed artificial aquifer recharge projects. An initial site assessment would estimate the maximum amount of recharge from a water budget analysis considering land availability, aquifer unsaturated capacity and the conceptualization of the local groundwater flow boundaries. Following the recommendations from the standard guidelines for artificial recharge of groundwater (ASCE 2002) pilot tests, and monitoring of groundwater water elevations from the center of the infiltration to discharge boundaries are necessary for site characterization. The parameters obtained from such tests could then be non-linearly scaled to larger projects (Petrides 2015) by simulating the water table response to surface recharge. A number of analytical solutions have been proposed to simulate the growth and decay of groundwater mounds underneath the infiltrating basins governing the maximum potential amount of water recharge. These solutions however, have limitations in their assumptions, differ in their ease of use and in their applicability to different boundary conditions. This research provides an overview of the most peer-reviewed cited analytical solutions Baumann (1965) Hantush (1967) Hunt (1971) Morel-Seytoux (1990) Manglik (1995) Bouwer (1999) Schmitz and Edenhofer (2000), Goo (2001). The objective is to help the reader select the most appropriate solution to be incorporated in their methodology for evaluating potential locations and to design an effective monitoring plan implementation.

9th International Symposium on
Managed Aquifer Recharge

Modeling the impact of aquifer recharge, instream water savings, and canal lining on water resources in the Walla Walla Basin

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Managed Aquifer Recharge; Conjunctive Water Management; Salmon

The Walla Walla Basin, located in Eastern Oregon and Eastern Washington, USA, faces challenges in sustaining an agricultural water supply while maintaining sufficient flow in the Walla Walla River (WWR) to sustain endangered fisheries. Managed Aquifer Recharge (MAR) is currently used in the basin to supplement groundwater with the goal of maximizing instream flow during dry summer months. The numerical groundwater-surface water model, Integrated Water Flow Model (IWFM), was calibrated to hydrological conditions in the Walla Walla Basin and applied to predict future hydrological conditions under current management practices (baseline model) and for three alternative water management scenarios. Alternative management scenarios assumed unlined canals were converted into pipelines to improve the efficiency of irrigation water deliveries and a concurrent reduction of diversions from the WWR during summer months. MAR is incrementally increased among the three management scenarios, with “Current MAR” using the current annual MAR input of 11.1 million cubic meters per year (Mm^3/Y) at the seven currently active MAR sites, “Increased MAR” using 17.7 Mm^3/Y among 22 MAR sites, and “Maximum MAR” using 29.3 Mm^3/Y among 60 MAR sites.
Model results indicate that canal piping without increased MAR will increase instream flow in the lower portions of the WWR by up to 0.20 m^3/s relative to baseline conditions. The predicted impact of MAR on instream flow is minimal in the upper portion of the WWR. Under the “Increased MAR” and “Maximum MAR” scenarios summer flows in the lower portions of the WWR are predicted to increase by up to 0.45 m^3/s and 0.51 m^3/s, respectively, relative to baseline conditions due to an increase in groundwater return flows in the WWR and tributaries. Conversion of canals into pipelines is predicted to decrease seepage from canals as a source of groundwater recharge, resulting in decreased groundwater storage in the “Current MAR” scenario relative to the baseline model. Under “Increased MAR” and “Maximum MAR scenarios groundwater storage was predicted to be greater than baseline conditions. Model results indicate that canal piping in combination with increased MAR provides benefits for riparian and instream habitat by allowing for significantly increased summer flows in the WWR and inflowing tributaries, while stabilizing groundwater storage levels. This supports that MAR is a tool that can be used to apply conjunctive water management effectively in the Walla Walla Basin.

Observations and prediction of recovered quality of desalinated sea water in the Strategic ASR Project in Liwa, Abu Dhabi

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Keywords
ASR, desert dunes, desalinated seawater, water quality, geochemistry, chromate, arsenate

ABSTRACT
To be able to overcome any emergencies in water availability, Abu Dhabi Emirate started pioneer projects for developing strategic fresh water reserves about ten years ago. The Aquifer Storage and Recovery (ASR) technique was chosen with desalinated seawater (DSW) as source water. One of these projects aims at a strategic fresh water reserve near Liwa, which is considered the largest ASR project in the world. In this project, DSW is infiltrated into a desert dune sand aquifer using ‘sand-covered gravel-bed’ recharge basins.
Construction of the full ASR system started in 2009 and was completed in February 2016. The project aim is to infiltrate 26,500 m^3/d (= 9.7 Mm^3/a) of DSW with TDS < 250 ppm, to be able to cover an emergency water demand for 90 days with a recovery rate of 170,280 m^3/d (= 15.5 Mm^3/90 d) with ~400 ppm TDS.
A hydrogeochemical study was conducted to: (i) evaluate water quality measurements prior to and during trial infiltration runs; (ii) predict water quality changes of the fresh DSW after 27 months of infiltration into the groundwater aquifer system, during 90 days of intensive recovery without storage, and ditto after 10 years of storage in the aquifer system; and (iii) predict the behavior of chromate (CrO_4^{3-}) and arsenate (AsO_4^{3-}) in the aquifer, which were considered the main critical quality parameters for distribution of untreated, recovered water.
Field data was obtained during a pilot study in 2003-2004 when DSW was infiltrated via a recharge basin, and from observations in the same pilot area after about 6 years of storage in the local aquifer system. These data are interpreted in terms of redox reactions, carbonate and SiO_2 dissolution, Ca/Na exchange, mobilization of trace elements As, B, Ba, F, Cr, Sr and V from the aquifer, and immobilization of PO_4, Al, Cu, Fe and Ni from DSW.
These quality changes are subsequently translated into leaching and retardation factors and into semipermanent concentration changes. This approach, together with a simple analytical solution to account for bubble drift during prolonged storage, facilitated a rapid prediction of the quality of water to be recovered. A high quality of recovered water meeting drinking water standards is predicted, notwithstanding a high potential of water quality problems due to desorption of hazardous trace elements from the aquifer and by admixing of natural ambient groundwater with elevated concentrations of NO_3, SO_4, Na and the above-mentioned trace elements,. This outcome reassured the authorities that invested ~600 million US $ in this project.

Potential of unsaturated soil zone models for assessment of managed aquifer recharge

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Keywords
modeling; unsaturated soil zone; managed aquifer recharge; MAR; scenario analysis

Planning, monitoring and evaluating managed aquifer recharge (MAR) projects pose challenges that can be addressed using different types of simulation models. Groundwater models are commonly applied to assess the recovery efficiency of MAR systems or their impact on the groundwater. Unsaturated soil zone models are less commonly used though in recent years their application increased. Frequently applied codes such as MARTHE(-REACT), HYDRUS and COMSOL have been used to evaluate contaminant breakthrough during infiltration, to test the applicability of those models to evaluate aquifer storage and recovery (ASR) and to compare different recharge methods.

To date, unsaturated soil zone models have rarely been applied in the planning stage of aquifer recharge schemes. However, potential of vadose zone models in particular lies within the designing phase of these sites. Building groundwater recharge systems needs careful planning beforehand in order to achieve field conditions that can be controlled and managed, to reduce construction costs and to understand the local geohydraulic conditions. For vadose zone models this applies especially to MAR technologies that are built within the vadose zone such as infiltration basins and galleries.

Planning a MAR test field in Pirna, Germany, the unsaturated soil zone models HYDRUS 1D and 3D were used to aid in the dimensioning of a surface infiltration system, the understanding of local flow processes and the preparation of the experimental set-up. Investigations included size and geometry of the test site, placement and number of measuring devices and possible experimental schemes and time frames. A scenario analysis conducted explored different infiltration scenarios and soil types that were considered to be used in the final set-up of the test field.

The study shows the opportunities and limitations of model-based planning of the proposed test site and how unsaturated soil zone modeling in general can support the design of a MAR scheme.

Predictability of Water-table Changes Using Artificial Neural Networks and Support Vector Machine Modeling

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Keywords
Water resource, Aqiufer Monitoring, Climatology, Evapotraspiration

The main goal of this paper is to predict groundwater withdrawals in response to climate variability in the Northern High Plains, USA. Water-table changes have evidenced the intensive use of groundwater resources in the world. Also, an increasing demand of groundwater due to a growing population and the associated demands of food and energy anticipate the need for better water management strategies and more informed decisions. However, predictive estimations of groundwater withdrawals due to precipitation deficits and/or management are unclearly coupled. Our objective is to develop a prognostic framework for groundwater withdrawals in response to climate variability in the Northern High Plains. Thus, we assume that the spatial distribution of changes in water-table is driven by natural forcings (i.e. precipitation) and water demand (i.e. evapotranspiration). The study's area is the northern High Plains (or the state of Nebraska), which, is the most irrigated state in in the USA and groundwater is the main source of water supply in agriculture. While water-table data are obtained from the Nebraska Geological Survey and the High Plains Regional Climate Center provide the forcings used by the Variable Infiltration Capacity (VIC) Model to simulate Evapotranspiration at 1/16th degree resolution. A precipitation gradient of 40in occurs West-to-East of the state. Isohyetals define the discretization of the domain in 5 sub-domains (west to east). Each region's historical precipitation records illustrate that the internal variability in rainfall distribution its negligible. Also, each region is characterized by a high number of groundwater observations used to develope two different predictive models: Artificial Neural Network (ANN) and Support Vector Machine (SVM). The input values used for training the models are the daily precipitation records and the evapotranspiration levels computed by the VIC model. Since output and input sampling frequency are inconsistent, a time adaptation algorithm is developed before training the models. Then, we assess the validity of each approach by computing predictions in other wells of the region. Preliminary results show that both the ANN and the SVM have solid performances if the validated wells are located in the same watershed of the training model, and if the variance of the sampling frequency remains approximately constant with time.

Prediction of iron and manganese release during riverbank filtration

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Keywords
riverbank filtration; anoxic conditions, iron, manganese

Theme: M12 – Bank filtration, infiltration systems, SAT

From a water resources perspective, riverbank filtration (RBF) is normally characterized by improved water quality. Therefore, RBF is a well-proven treatment step, which at numerous sites is part of a multi-barrier approach to drinking water supply. The positive effects of bank filtration arise primarily in the mixing, sorption and degradation processes. Many organic, especially nonpolar water substances are completely retained during bank filtration. Depending on the quality of the surface water, the redox conditions arising in the subsurface and the mineral composition of the aquifer, increase in concentrations of dissolved iron and/or manganese may occur as a disadvantage. If the biodegradable portion of total organic carbon (TOC) in river water is relatively high, biodegradation processes can consume all dissolved oxygen and often even nitrate. This again can cause anoxic environments in the aquifer (especially in aquifers that exhibit low hydraulic conductivity and/or confined conditions) and dissolution of iron and manganese. A simple DOC analysis is not sufficient because particulate organic matter (difference between TOC and DOC) often accumulates in the river bed and consumes oxygen and nitrate.

At many sites, anoxic conditions and dissolution of iron and manganese are already present or would develop during RBF. Thus, iron and manganese removal is required as a further treatment step, making RBF more costly and representing a drawback that may limit its wider use as an alternative to direct surface water abstraction and treatment. Thus, prediction of iron and manganese release during riverbank filtration is required. Different methods have been tested at RBF sites in Germany – water and sediment analysis, batch and column experiments using river water, sequential extraction, and mass balance approach – and compared with results from the literature. At these sites, a “wash out” effect was observed, resulting in a slow decrease in iron concentrations between the riverbank and the abstraction well. Exchange processes in the aquifer can cause a long-term release of iron and manganese even if the DOC concentration is low. A combination of sequential extraction of aquifer sediments and mass balance approach prove that iron release can last several decades. Thus, at some sites a short distance between the riverbank and the wells would be of advantage to lower costs for further treatment. Conclusions regarding the design of new RBF sites will be accompanied by an estimation of the time of well operation necessary (and/or monitoring) to achieve steady state conditions at a new RBF site.

Prediction of Removal of Contaminants during Soil Passage

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Keywords
Managed aquifer recharge; water quality, contaminants; removal efficiency; prediction

Managed aquifer recharge (MAR) systems namely bank filtration (BF), artificial recharge and recovery (ARR) and soil aquifer treatment have been employed for treatment of water and wastewater worldwide. These soil-based natural treatment systems (NTSs) are robust, efficient, cost-effective, environment-friendly and have high potential for removal of various contaminants from different source waters (surface water, stormwater and wastewater). These NTSs function as a multiple barrier system for a variety of microbial and chemical contaminants and are also attractive as environmental buffer and psychological barrier for water reuse applications.

NTSs utilize physical and bio-chemical processes during soil passage to treat water, stormwater or wastewater under different process conditions. The removal efficiencies of these systems are dependent on source water quality, local hydrogeological conditions as well as the process conditions applied. The experience so far with these systems are site specific and there are no tools or models available for the prediction of the removal of different contaminants namely bulk organic matter, organic micropollutants, nitrogen and pathogens during soil passage. This particular study focused on improving the understanding of the removal processes and conditions controlling the fate of different contaminants during soil passages and development of a tool for prediction of effluent quality.

Extensive literature review was conducted to collect laboratory- and field-scale data on removal of various contaminants during BF, ARR and SAT. The literature data was further analyzed by sorting them in different bins with respect to travel time/travel distance. Travel time and travel distance were assumed to be the key variable in determining the rate of removal of a contaminant during soil passage. Where available, redox conditions was used as a secondary variable. The next step was the development of guidelines for estimation of removal of a contaminant during soil passage based on averages and standard deviations in different data bins. The guidelines are based on statistical analysis of removal data, without distinguishing between different hydrogeological conditions. Finally a spreadsheet model was developed to predict water quality after soil passage for bulk organic matter, organic micropollutants, nitrogen (nitrate and ammonia) and pathogens in different NTSs.

In general, it was observed that the removal of almost all contaminants increased with increase in travel time and travel distance. However, there was a big scatter of data on removal of a contaminant as the data were from different sites with varying hydrogeological conditions. Based on the literature data, several guidelines were developed for the estimation of the removal of different contaminants during soil passage (for BF, ARR and SAT systems) based on travel time or travel distance. The guidelines can be used during pre-design engineering of soil-based NTSs or feasibility studies without conducting costly laboratory or field-scale experiments. Data analysis pointed out that travel distance of 100-150 meters and/or travel time of 100-150 days are reasonable guideline values for BF and ARR systems to ensure the sufficient removal of majority of the contaminants present in source waters.

All the guidelines for estimation of removal of contaminants were combined into a user-friendly spreadsheet model. After selecting the NTSs (BF or ARR or SAT), the spreadsheet model requires input data such as influent concentrations and travel distance/time for the prediction of minimum and maximum removal efficiency as output. Secondly, the model can be used to estimate the minimum travel time or travel distance necessary to achieve the required % removal of a contaminant during soil passage in a specific NTS.

Processing drinking water by managed aquifer recharge in Tuusula region, Finland

By Unto Tanttu, MD, Tuusula Region Water Utility

Keywords: ground water, managed aquifer recharge, total organic carbon

In the use of managed aquifer recharge (MAR) for water supply we can aim at achieving a variety of benefits. These may include securing of water quantity, water storage, preventing infiltration of salty water, or improving water quality. In Finland MAR is seen as an integrated part of water drawing and treatment whereby nature's own processes are utilized for producing drinkable water.

The Tuusula Region Water Utility in Southern Finland has since 1979 produced drinking water based on MAR. The esker where the process takes place is of glaciofluvial origin. From the beginning, attention has been laid on removing Total Organic Carbon (TOC). In Finnish surface waters, humic substances are very common. However, qood quality raw water, taken from the 120 km tunnel from Lake Päijänne, has made it possible to use MAR without pretreatment. Aeration and sand filtration is used as final treatment for iron and manganese removal. In addition, limestone filtration is used for alkalization. Finally disinfection is made by UV treatment. It is, therefore, fair to call our water "organic water".

The paper will include full scale results on TOC concentration at three steps of the process: raw water to be infiltrated, infiltrated water after MAR, and outgoing water. In average, TOC concentration figures are 6–7 mg/l in the first, and 2–3 mg/l in the second step. Detention time in the soil is 1–2 months depending on the pumping rates. In the last step, TOC content does not significantly change. Other interesting parameters to be shown include iron, manganese, temperature, oxygen, carbon dioxide, alkalinity and hardness.

In Tuusula, two methods of infiltration are used: basin recharge and well recharge. In addition, combinations of the two methods are used. The paper analyzes the differences between these methods in terms of water quality, operation and maintenance and related costs and worths.

When selecting post treatment methods the principles of sustainable development have been emphazised. Industrial chemicals have not been used. Limestone alkalization is made by natural limestone mined in Finland. Furthermore, UV treatment does not cause any odor or flavour.

On the whole, the use of MAR has shown to be an appropriate and cost-effective method in the Tuusula Region and the use of MAR seems to be increasing in Finland in spite of remarkable resistance in some cases.

Protection of groundwater dependent ecosystems in Canterbury, New Zealand: the Targeted Stream Augmentation Project

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Keywords: Native species habitat, targeted recharge and discharge, New Zealand

Abstract
In Canterbury, New Zealand, native aquatic species habitat has significantly declined over the last century due to land use change and climatic influences. The Canterbury Water Management Strategy (CWMS) is progressing objectives to improve such habitat while also meeting other economic, environmental, social and cultural objectives. A preliminary assessment of Managed Aquifer Recharge in progressing CWMS objectives identified specific opportunities that are now being trialed through pilot projects. The focus of this presentation will be on the Targeted Stream Augmentation project in the Selwyn-Waihora Zone in Canterbury. The semi arid climate, significant demand for irrigation water and the changing up-gradient aquifer pressure provided by a coastal lake provide significant aquifer management challenges, particularly with respect to providing sufficient lowland stream flow for native aquatic species without causing the aquifer/lake system to overbalance and cause flooding in lowland populated areas. In response to these challenges, the local CWMS committee recommended that MAR trials to improve groundwater dependent ecosystems start in a highly targeted manner before gradually increasing the distance from recharge site to the target spring/s.

Initial investigations included integrated ground and surface water modeling, ecological and cultural assessments. These assisted with the prioritization of source and receiving water options. The first trial utilized deep groundwater supplied through an existing well to dry tributaries of a key lowland stream. A 30 day trial met all its objectives, with downstream monitoring showing increased flow equivalent to the supply flow, reduced nitrate concentrations, slightly dampened diurnal temperature variation, minimal change in dissolved oxygen, and no identified negative ecological effects. The technique is appealing to the local community as it is easy to understand and control, with obvious benefits to groundwater dependent ecosystems when they are under stress due to high temperatures, high nitrate concentrations and low flows.

The second trial is expected to be underway in early 2016. The target ecosystem comprises a series of reaches disconnected at the surface but highly connected via the underlying aquifer. The disconnected surface water reaches have historically been high quality habitat for native aquatic species including the Canterbury mudfish (*Neochanna burrowsius*) which is classified "At Risk: Nationally Critical". Investigations have identified a preferential flow channel in the shallow aquifer that connects the proposed recharge site with the most up-gradient spring. Monitoring wells have been drilled to assist analysis of the system and the effects of the MAR trial. Consents have been lodged, with construction to follow. Up to date analysis of both trials will be available to present at ISMAR9.

Quantifying Groundwater Travel Time Near Managed Recharge Operations Using ^{35}S as an Intrinsic Tracer

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Keywords
Hydrologic tracers, travel time, retention time, Sulfur-35, California MAR sites, Atlantis (South Africa)

Identifying groundwater retention times near managed aquifer recharge (MAR) facilities is a high priority for managing water quality, especially for operations that incorporate recycled wastewater. To protect public health, California guidelines for Groundwater Replenishment Reuse Projects require a minimum 2 to 6 month subsurface retention time for recycled water depending on the level of disinfection, which highlights the importance of quantifying groundwater travel times on short time scales. This study evaluates a new intrinsic tracer method using the naturally occurring radioisotope sulfur-35 (^{35}S). The 87.5 day half-life of ^{35}S is ideal for investigating groundwater travel times on the <~1 year timescale of interest to MAR managers. We evaluated the ^{35}S tracer method by measuring natural concentrations of ^{35}S found in water as dissolved sulfate ($^{35}SO_4$) in source waters and groundwater at the Rio Hondo Spreading Grounds in Los Angeles County, CA, USA, the Orange County Groundwater Recharge Facilities in Orange County, CA, and the Atlantis MAR facility, South Africa. At the Californian sites, $^{35}SO_4$ travel times are comparable to travel times determined by well-established deliberate tracer studies. The study also revealed that $^{35}SO_4$ in MAR source water can vary with season and therefore careful characterization of $^{35}SO_4$ in source waters is needed to accurately quantify groundwater travel time.

Raw Water Quality and Pretreatment in Managed Aquifer Recharge for Drinking Water Production in Finland

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Keywords
drinking water, Finland, managed aquifer recharge, pretreatment, water quality

The main objective of the 26 managed aquifer recharge (MAR) plants in Finland is the removal of natural organic matter (NOM) from surface waters. A typical MAR procedure consists of the infiltration of surface water in a Quaternary glaciofluvial esker with subsequent withdrawal of the MAR treated water from wells a few hundred meters downstream. The infiltrated water should have a residence time of at least around one month before withdrawal to provide sufficient time for the subsurface processes needed to break down or remove humic substances. MAR is considered a sustainable water management alternative for chemical surface water treatment.

Most of the MAR plants do not have pretreatment and raw water is infiltrated directly into the soil. Depending on raw water quality, infiltration processes and local conditions, pretreatment is needed in some plants. The objectives of the paper are to present experiences, full-scale operational pretreatment data and cost considerations, and to draw conclusions on the need and choice of pretreatment, based on knowledge acquired from 6 Finnish water organizations utilizing MAR. The production rates of the studied MAR plants vary 10 000 - 63 000 m^3/d. The oldest plant was taken in use in 1976 and the newest in 2011.

Different types of raw waters are presented: lake waters with low NOM concentration and low turbidity, lake waters with high NOM concentration (TOC > 10 mg/l), lake waters with moderate turbidity, and river water with fluctuating NOM concentration and turbidity (3 - 21 FNU). Operational data from basin infiltration, sprinkling infiltration and well infiltration processes are presented and the need for pretreatment is discussed. Pretreatment processes presented include chemical precipitation, dissolved air flotation, lamella sedimentation, rapid sand filtration, drum sieving and reverse osmosis. Operational data are shown. Emphasis is given both to the reasoning of the choice of pretreatment and to practical considerations. For instance, pretreatment for NOM removal may be justified if there is a danger for formation of anoxic conditions in the soil (due to biodegradation of NOM). Anoxic conditions could lead to dissolution of iron and manganese present in the soil, and would then necessitate an extra treatment step for their subsequent removal from the infiltrated water. Also, according to experiences gained, chemically pretreated water may clog basins and wells unless the process is designed and operated with care.

Regulatory Scheme for Assessing the Feasibility of Proposed MAR Schemes

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Keywords
Water Framework Directive, Groundwater Directive, MARSOL, Regulatory Structure

TOPIC: M2 - Regulations, guidelines and governance

The Water Framework Directive (Dir 2000/60/EC) considers artificial recharge as one of the management tools which can be utilized by EU Member States for the achievement of good groundwater status. In fact, whilst listing artificial recharge as one of the basic measures to be considered by Member States in their River Basin Management Plans, Article 11 of the Directive requires the establishment of "***controls, including a requirement for prior authorization of artificial recharge or augmentation of groundwater bodies***". This in order to ensure that such practice does not "***compromise the achievement of the environmental objectives established for the source or the recharged or augmented body of groundwater***". The provisions of the Directive in this regard, are directed to ensure that the necessary controls are in place to eliminate the possibility of any degradation in the qualitative status of the receiving body of groundwater.

The MARSOL project aims to demonstrate that Managed Aquifer Recharge (MAR) is a sound, safe and sustainable strategy that can be applied with great confidence. As part of this project an in depth review of MAR regulatory approaches in a number EU Member States was carried out to characterize the wide range of approaches, which at times can be even conflicting. This was followed by the development of a common regulatory framework which incorporates the regulatory requirements of the EU's Water Framework and Groundwater Directives to ensure their consideration in the feasibility assessments for MAR schemes. The proposed regulatory framework thus combines the 'prevent and limit' objectives of the Groundwater Directive within a regulatory scheme through which MAR proposals can be assessed for their adherence with the guiding principles of these Directives.

The regulatory framework developed is based on the following guiding principles:
(i) the undertaking of a risk assessment to assess the potential adverse impacts of the MAR scheme on the receiving body of groundwater,
(ii) the establishment of effective control mechanisms to ensure the reliable performance of the MAR scheme, and
(iii) the monitoring of the performance of the MAR scheme and its impact on the augmented body of groundwater; and
(iv) the development of a series of decision stages, intended to assess the compliance of the proposed MAR scheme with the regulatory requirements of both the EU's Water Framework and Groundwater Directives.
The present contribution pursues a twofold aim, namely i) to present an overview of the legal framework governing MAR-schemes in EU Member States, and ii) to analyse the applicability of the regulatory framework, highlighting its strengths and shortcomings.

Riverbed clogging and sustainability of riverbank filtration

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Keywords
sustainability; riverbank filtration; riverbed clogging

Theme: Mxx – Clogging .. or M12 – Bank filtration

A very important aspect of the sustainability of riverbank filtration is the effect of riverbed clogging. Clogging is the result of the infiltration and accumulation of both organic and inorganic suspended solids, precipitation of carbonates, iron- and manganese-(hydr)oxides and biological processes. There are not only variations in the pressure head between the river and the aquifer but also remarkable variations in the concentration of suspended solids in the river water. Due to difficulties in determining the thickness of the clogging layer, the term leakage coefficient is introduced, which is defined as hydraulic conductivity of the clogging layer in meter per second divided by the thickness of the clogging layer in meters. Under specific conditions, the leakage coefficient can be calculated for RBF sites using water levels in the river and observation wells positioned between the river and the production borehole using an analytical solution. Otherwise it has to be determined by calibration procedures in groundwater flow modelling. Infiltration experiments are difficult to carry out in rivers having flow velocities >1 m/s and depths of >1 m. Based on water levels and known pumping rates, the leakage coefficients at two different RBF sites along the River Elbe in Dresden have been determined for different river stages and measuring campaigns and compared with former data. A specific clogging experiment with a mobile channel was carried out in 2013 and compared with data from similar experiments in 1974 and 2003.
At Tolkewitz, a significant decrease in groundwater levels was observed between 1914 and 1930 and attributed to riverbed clogging by suspended materials since 1901. In the 1980s severe river water pollution caused by organics from pulp and paper mills in conjunction with high water abstraction led to unsaturated conditions beneath the riverbed. A leakage coefficient of $1\times10^{-4}\,s^{-1}$ was calculated for the riverbed without RBF and a mean value of $5\times10^{-7}\,s^{-1}$ at RBF sites. After improvement of river water quality from 1989 to 1993, hydraulic conductivity of the riverbed increased. In 2003 and 2015, groundwater flow modelling was used to test former assumptions about riverbed clogging: a leakage coefficient of $1\times10^{-5}\,s^{-1}$ was determined. In 2015, a leakage coefficient of $1\times10^{-6}\,s^{-1}$ was determined during a long low-flow period. Results from water level monitoring proved higher clogging rates compared to results from channel experiments by a factor of up to 10. Based on findings from RBF sites in Dresden, conclusions will be drawn for the design of new RBF sites in other countries with a clear plea for low abstraction rates or long lines of wells along a riverbank. In terms of sustainability, it will be clearly shown that the observed clogging of the riverbed did not result in the closure of wells under the existing erosive conditions in the river. After a period of severe organic pollution there was a marked recovery of hydraulic conductivity in the riverbed.

Seasonal Water Storage and Replenishment of a Fractured Granitic Aquifer Using ASR Wells

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Keywords: hard rock aquifer, seasonal and long-term storage, new water source

The Town of Payson is located in central Arizona, 150 kilometers north of Phoenix. Owing to its elevation of 1,524 meters above sea level its climate is classified as Mediterranean with a mean annual precipitation of 561millimeters. Its present population is 15,000, but expected to more than double by the year 2030. The sole water source for Payson is groundwater. Forty two wells with a production rate between 2 and 50 liters/second meet daily peak and an annual demand of 3.1 million cubic meters. All these wells pump from a fractured granitic aquifer that when full has been estimated to hold a minimum of 27.1 million cubic meters of recoverable water. The natural recharge to this aquifer is snowmelt from the Mogollon Rim, the highlands to the north. This recharge is therefore strongly influenced by weather fluctuations and affects the town's water supply. As a result of a law, the Arizona Water Settlement Act of 2004, Payson obtained a water right to use 3.7 million cubic meters of water stored in the nearby Cragin Reservoir. This additional water supply will be used to offset future groundwater pumping to meet their growing municipal water supply. A pipeline to convey the surface water from the reservoir to a new treatment plant will be added to Payson's municipal water system, along with the addition of ASR wells. These wells will be used for seasonal and long term storage and recovery of the stored surface water and will contribute to a considerable improvement of the management of Payson's municipal water resources. Two igneous intrusive rock units of Precambrian X age underlie Payson: the older the Gibson Creek Batholith and the Payson Granite. Structural fractures in the latter unit contain the groundwater that is produced by nearly all of Payson's municipal wells. Pumping and injection tests indicated that the pumping and the recharge capacities of these wells are nearly equal. The total ASR storage capacity is estimated at 5.4 million cubic meters. For the ASR operation a number of existing production wells will be selected and retrofitted by adding a VOSmart valve to their pumping pipe column and the necessary gages, recording and control units. The treated surface water will be delivered to the ASR wells from the town's potable water distribution system for aquifer storage. There will be base-load and on-call ASR wells and their operation will be automated via a SCADA system. The groundwater in the fractured granitic aquifer is of a calcium-bicarbonate type and so is the water stored behind the Cragin dam. Both have very close mean pH values (GW-7.7 and SW-7.3). They have drastically different TDS with a mean of 42 milligrams/liter for the reservoir water and a mean of 270 milligrams/liter for the groundwater and a ratio of 1/6. Geochemical modeling indicates precipitation of iron ferrihydrite in the fractured granitic aquifer but dissolution of calcite and gypsum as a result of the recharge operation. An evaluation of the chemistry of the reservoir water and the groundwater, the mineralogy of the aquifer rocks and the physical-chemical conditions in the aquifer determined that arsenic contamination is not likely, neither is iron oxides clogging of the aquifer.

Sequential Managed Aquifer Recharge Technology (SMART) for Enhanced Removal of Trace Organic Chemicals

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Keywords
Dissolved organic carbon; sequential managed aquifer recharge; soil aquifer treatment; trace organic chemicals

Managed aquifer recharge (MAR) systems (e.g., riverbank filtration, soil aquifer treatment) are natural treatment processes with low energy demand and little chemical input. In these systems, water infiltrates through the vadose and saturated zones where microorganisms play an important role for the removal of dissolved organic carbon (DOC) and trace organic chemicals (TOrC)[1,2]. In our previous research, we observed the establishment of a more diverse microbial community under oxic conditions with low content of biodegradable organic carbon as primary substrate resulting in an enhanced degradation of TOrCs. Based on these results the sequential managed aquifer recharge technology (SMART) was developed combining two infiltration steps in series with an in-between aeration (oxidation) step providing more favorable conditions for microbial degradation of TOrC in the second infiltration step.

The innovative concept has already been tested at a full-scale application for indirect potable reuse using a wastewater impacted stream in Aurora, Colorado. Primary riverbank filtration with hydraulic retention times (HRT) of approximately 10 days provides water with relatively low content of biodegradable dissolved organic carbon. Subsequent aeration prior to artificial recharge and recovery with hydraulic retention times of also 10 days resulted in a significant improvement of TOrC removal including removal of more difficult degradable chemicals such as sulfamethoxazole, meprobamate, TCPP and diclofenac.

Current research focuses on the transfer of the SMART concept to short-term soil aquifer treatment using secondary effluent from the wastewater treatment plant Garching, Germany. Using SMART, preliminary results indicate high efficiency of the second infiltration step especially for the removal of TOrCs containing amino groups. Future challenges are related to the optimization of redox regimes at comparably low HRT and the robustness against changing water qualities from wastewater treatment plants. In addition, biomolecular tools are being used to elucidate the role of structure and function of the microbial community while removing TOrCs. An improved fundamental understanding can result in further process optimizations of the SMART system.

Site characterisation for MAR infiltration basins using percolation testing and SEEP/W.

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Keywords: Managed Aquifer Recharge, infiltration trial, groundwater modelling, unsaturated zone

The Hinds Plains catchment is an intensively farmed area of the Ashburton District on New Zealand's Canterbury Plains. Groundwater and surface water management issues have arisen in the catchment through the progressive increase in farming intensity and groundwater abstraction for irrigation coupled with improvements in irrigation efficiency. These issues primarily relate to a long-term decrease in groundwater levels and a progressive increase in nitrate concentrations in the shallow aquifer beneath the catchment.

To help address the catchment-scale issue of groundwater quality and quantity, the Ashburton Zone Committee (AZC), which is a community body set up to address the Hinds/Hekeao Plains catchment zone issues, recommended that a Managed Aquifer Recharge (MAR) pilot trial be initiated.

Site investigations were undertaken to evaluate the effectiveness of an infiltration basin to recharge the shallow unconfined aquifer beneath the Hinds/Hekeao catchment. These investigations included the performance of percolation tests in pits excavated to depths of 2 m and 6.5 m at the pilot trial site. The data generated from monitoring of the tests was interpreted conceptually to develop an understanding of the seepage flows from the test pits. The conceptual model was converted into a SEEP/W numerical model to simulate the seepage flows around the two pits. The models were calibrated against water level records from the pits and from nearby shallow monitoring wells.

The SEEP/W model outcomes highlighted the rapid responses observed in the monitoring wells, which suggested very rapid preferential lateral flow of infiltrated water from the pits in preference to downward seepage. Sensitivity analyses however showed that the pore water content in the unsaturated aquifer zone surrounding the pits contributed significantly to a perceived high lateral seepage rate. During the test periods the observed lateral groundwater pressure response to the infiltration became balanced by downward seepage toward the underlying groundwater table, which was approximately 14 m below ground level.

The test and model outcomes indicated that the planned infiltration basin would function effectively at the site and provided insight to the unsaturated zone seepage processes that will occur around the pilot trial during the start-up phase. The results also indicated that final construction designs of the infiltration basin should include artificial vadose zone infiltration paths to help direct percolating water downward to the local water table and avoid the risk of infiltration water 'perching'.

Successful Implementation of Aquifer Storage Recovery

R. David G. Pyne/ ASR Systems/ Gainesville, Florida USA

Keywords

aquifer storage recovery, water supply reliability and sustainability, managed aquifer recharge

Aquifer Storage Recovery (ASR) is the storage of water in a suitable aquifer through a well when excess water of suitable quality is available, and recovery of the water, usually from the same well, when it is needed. ASR, combined with Surface Recharge, comprise what we refer to as “Managed Aquifer Recharge.” Approximately 175 ASR wellfields and over 500 ASR wells are operating in the United States and Canada. Within the United States, ASR wells are operating in at least 25 states. ASR wells and wellfields are also operating in England, Australia, Netherlands, Israel, United Arab Emirates, South Africa, Namibia, India, Bangladesh, and probably other countries. The stored water comes from a wide variety of sources: drinking water, rainwater, treated surface water, groundwater from the same aquifer, groundwater from a different aquifer, and reclaimed wastewater. Storage occurs in confined, semi-confined and unconfined aquifers with a wide variety of geologic and lithologic settings. Well depths range from about 30m to 900m. Storage aquifers include fresh, brackish and saline aquifers with total dissolved solids (TDS) concentrations ranging from 30 mg/l to 35,000 mg/l. Almost all of the sites storing drinking water in a fresh aquifer have native groundwater that does not meet drinking water standards, such as for iron, manganese, arsenic, nitrate, or hydrogen sulfide. To date, 28 different applications of ASR have been identified, the most common of which are seasonal storage, emergency storage and water banking. Achieving water supply reliability and sustainability is emerging as a powerful driving force for ASR implementation to meet urban, industrial, agricultural and environmental water needs. This presentation will address the most important technology, science and other lessons learned from the wide diversity of ASR experience during the past 35 years that would be helpful for those considering starting a new ASR program or to enhance performance of an existing ASR program. It will also address how to define ASR “success,” drawing from recent case studies and experience.

Supporting agro-ecological resiliency through managed aquifer recharge practices in the Southwestern United States

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Abstract: In the Southwestern United States, what underlies drought as a social crisis is a water storage problem. Less winter rain has diminished snowpacks and resulting runoff. Water users pump ground water to supplement, further reducing surface flows. Agriculture often withdraws the largest water quantities, yet these “working landscapes”- farming and ranching lands - also have the largest potential to influence recharge and contribute to longer term system resiliency. A key driver for management changes is the capacity for innovation, developed when communities fit innovative practices to local conditions, and when outside agents such as scientists cross-pollinate potential solutions across locations and scales. In a rural working landscape in New Mexico with high flood energy, collaborative action-based experimentation resulted in the design of practices to increase recharge through watershed-scale floodplain reconnection. The team tested two practices’ feasibility: introducing large wood to increase surface roughness in arroyos (ephemeral systems); and retention ponds to dampen energy before reconnecting flow to agricultural fields. These interventions resulted in slowed flood flow, increased infiltration, and increased vegetation cover. As agencies build climate-change adaptation plans, such as the Bureau of Reclamation aiming to “replumb the West”, strategies that replenish our ground water system will become increasingly critical.

9th International Symposium on Managed Aquifer Recharge

Surface runoff use for artificial recharge in fractured zones. Study Case: Ojos del Chuviscar, Mexico.

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Abstract

Hydrogeological basin Ojos del Chuviscar was studied in Chihuahua, Mexico. The hydrogeological study included structural geology and hydrochemically and showed that because of their physical characteristics, the storage area should be considered a separate aquifer system from Chihuahua-Sacramento, which has served administratively. An analysis of how does an artificial recharge of aquifers works, which is located within the basin and that was installed in 2004. The structure intercepts torrential runoff and consists of a gabion dam and a slotted pipe recharged through a deep well. The results indicate the advantage of establishing works seize runoff from rainfall in arid areas. This information will work as a basis for building a second structure, because the first was a pilot project whose results have been favorable to increase the volume of water entering the aquifer system studied. Also, these works in fractured zones can be applied in other aquifers in deficit for enhancing natural recharge.

Keywords: artificial recharge, hydrogeology, fractured aquifers, Ojos del Chuviscar, Mexico

The Cabo Aquifer System: Regional Groundwater Level Dynamics in Recife City (Brazil)

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Keywords
Wells; Potentiometric; Drawdown; Overexploitation

The Recife Metropolitan Region (RMR), in Pernanbuco State (Brazil) is composed of 14 municipalities and a population over to 3 millions people, which has a water demand approximate of 14 m³/s. In the last decades, the number of private deep wells drastically increased in because of the quick urbanization and increase in water demands, and lack of capacity of the water supply company to securely meet all the demands. This process reached a level of overexploitation of the deep aquifer with drawdown upper to 50 meters in some places near to the coastal region. In the last years, the Pernambuco State Water and Climate Agency (APAC), responsible for the water resources management, has increased the supervision and restriction the permission for drilling news wells. The current study analyses the regional dynamics of the potentiometric levels of the Cabo Aquifer, one of the most exploited formations in the region, based in the observed annual levels (1989 – 2014) of 33 wells located in the Boa Viagem neighborhood, one of the most rich areas in the city with high income population and many private wells drilled in residential buildings. The selection of the wells was based on the influence region, such as the proximity with the beach, the mangroves and the river channels. The similar behavior of the depth of the wells were also taken into consideration for this selection. Additional information, such as rainfall, number of wells concessions, land use/cover and expansion of the public system of water supply were used in the analyses. The regional analysis showed that some locals remain with increased drawdown in the potenciometry, but with a lower rate when compared with recente years. However, in others areas, it was observed a recovering process of the potentiometric levels over the study period. This small recovery can also be attributed to increased support in water supply, after the construction of a new pipeline in 2011. It is evident that the control and the supervision of the government can help the population to reduce the impacts over the groundwater resources and the environment. However, the recovery of the levels in the aquifer is very slow, mainly because there is few recharge areas. It is necessary to advance in studies for an artificial recharge project.

The Challenges of Operating a Large Scale Spreading Basin Recharge Program in a Semi-Arid Region

Timothy Gorey

Central Arizona Project

Keywords
Recharge; Recharge Program; Large Scale Spreading Basin; Challenges; Semi-Arid Region; Operating Challenges; Central Arizona Project; Nitrates

The Central Arizona Project (CAP) operates a large scale recharge operation consisting of six projects located in Maricopa (Phoenix metropolitan area) and Pima (Tucson metropolitan area) Counties, Arizona (USA). In total, the projects consist of approximately 390 acres of spreading basins with an annual capacity of approximately 275,000 acre-feet per year (AF/YR). The Phoenix and Tucson areas average approximately 8-12 inches of rain per year with an evaporation rate of approximately 7-8 feet per year. During the summer months thunderstorms can produce 2-3 inches of rain in an hour.

One issue that was unanticipated is the naturally occurring nitrate salts in the vadose zone. The projects are located in the Basin and Range Physiographic Province, a series of broad alluvial valleys separated by fault blocked mountain ranges. As the valleys were filling with sediment, evaporitic deposits, including the nitrate rich salts, were interspersed with the sands and gravels.

Hieroglyphic Mountains Recharge Project (HMRP), located in Maricopa County, began operations in 2003. The project can store up to 35,000 AF/YR. After operating for approximately 4 years, high nitrate results began appearing in one of the project's monitor wells. After consulting with state regulatory agencies, a program was developed to sample 35 domestic wells surrounding the facility. In four of the domestic wells, nitrates were detected above the USEPA drinking water standard of 10 mg/L (after the initial round of sampling, three more wells later tested positive for elevated nitrates). Elevated nitrates are a serious health risk to infants, some elderly people, and certain animals, including horses.

It was determined that as the water level rose, the water came into contact with pockets of the highly soluble nitrate salt deposits. The source of the recharged water, Colorado River water, has negligible nitrate concentrations (< 1 mg/L). During the study period, over 112,000 AF were stored. The thinking was that the salts would be flushed out of the aquifer as recharge continued. This approach worked for 6 of the wells. But in one, the Lingren well, nitrate concentrations remained above the drinking water standard for over 5 years. In 2012, the nitrate levels in the Lingren well finally dropped to a level below the drinking water standard. It has not been determined why this well remained high when all the other wells surrounding it were below 1 mg/L.

Another Challenge has been the occurrence of the areas summer monsoonal rains. All of the projects are built at least within the 100-year floodplain. On three separate occasions unusually large summer storms has caused extensive damage to the projects.

The Use of Water H and O Isotopes as a Tracers in Regional Water Systems

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Keywords:
Isotopes, SAT, desalination, effluent

Subject Category: M7 - Monitoring and Management.

The fractionation of the water molecule isotopes □^{18}O and □^{2}H under natural conditions is affected mainly by phase transformation, that is, evaporation - condensation and freeze - melt processes due to temperature and pressure changes. As these isotopes are relatively inert to other processes they form an excellent tool for tracing the spreading of water bodies in the environments.

The addition of massive quantities of desalinated sea water to the Israeli water system significantly affected its H_2O isotopic signature, due to its relatively heavy composition in compare to water of natural sources. This study examines the feasibility of tracing and quantifying the progress of the desalinated water along the water system chain, starting from the sources, and progressing through the supply system, the effluent system, a SAT system, and eventually the reclaimed water at the recovery wells.

The research is conducted at the Dan Region Reclamation Project (Shafdan), which reclaims approximately 130 Mm^3/y of secondary treated wastewater, originating from the Tel Aviv Metropolitan area. Following secondary treatment, the effluent is recharged into a sandy aquifer and undergoes a SAT treatment. Retention time in the aquifer is approximately 3-12 months. The high quality reclaimed water is then pumped and transported southward to the northern part of the Negev, where it is used for unrestricted agricultural irrigation. During two surveys conducted in 2012 and 2014, water from 22 recovery and observation wells located at different distances from a recharge pond were sampled and analyzed. Samples were also collected from the recharged effluent and from different locations along the National Water System. Mixing ratio calculations between the recharged effluent and the native aquifer water were compared with those of chloride and carbamazepine, which are well known tracers in the Shafdan system.

The results of the research showed the ability to trace the recharged water and accurately quantify mixing ratios between different types of water using the H_2O isotopes. Increases in the heavy isotopic composition between the years 2012 and 2014 indicate a spreading of the new desalinated water body in the aquifer. The use of H_2O isotopes as a tracer for recharged water has an advantage over other tracers, due to their conservative behavior and the ability to predict their ratio in the water sources, the supplying system and in the effluent system.

THREE-IN-ONE USES OF A MANAGED AQUIFER RECHARGE SYSTEM: THE TRIPLETS IN LOS ARENALES (SPAIN)

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Keywords
Managed Aquifer Recharge, MAR, artificial recharge, groundwater quality

Los Arenales aquifer is a broad groundwater body that occupies 2,400 square kilometres and lodges 96 villages with 46,000 inhabitants in the provinces of Valladolid, Segovia and Ávila (Castilla y León, Spain). Managed Aquifer Recharge (MAR) activities began in 2002 in Santiuste area with a maximum recharged volume up to 12.2 hm^3 per year. After this successful experience, two more areas on the same aquifer developed their own recharging facilities: El Carracillo (5.61 hm^3/year) from 2004 and Alcazarén (3 hm^3/year) from 2012. Core usage of recharged volume is irrigation.

Within the two first aforementioned areas, Santiuste and Carracillo, a couple of stretches of the canal network has been designed to cover three functions in a row: decantation, biofiltration and restoration.

Santiuste recharging system has been operative for more than 12 years but from 2005 a WWTP by lagooning began to spill its effluent into the junction with the next infiltration canal. Therefore, the recharging volume from Voltoya River, with a high water quality (95%), began to be mixed up with the sewage (5%) into the immediate ditch. Hydrophilic plants in the canal bed help micronutrients absorption from water flow as their roots prevent clogging and increase infiltration. At the same time, the green cover is used as a fauna shelter. Parallel to the canal the water may enter an artificial wetland system where purification, infiltration and environmental functions follow. The existence of deeper and broader water bodies permit the development of other physical and biochemical processes that could not be achieved in the canal stream. This three-pond-group (Sanchón 1: 2,361 m^2, Sanchón 2a: 2,916 m^2 and Sanchón 2b: 13,000 m^2) is reconnected back to the main East infiltration canal when fulfilled.

In El Carracillo the second triplet consists in a 42 m^2 stagnation strainer-infiltration pond, a 50m-long-green-filter canal and a 420 m^2 artificial wetland. Complementarily, a near sandy meadow receiving occasional spillway flow from the last little marsh, acts as a spreading area for infiltration recharge. In this case water source comes only from Cega River.

Water quality analysis and groundwater level monitoring have been carried out in a series of sample points to test processes in these two triplets.

According to the datasets obtained by now, even though the scarce mixture of WWTP sewage, some chemical measurements show dissimilar behaviour in canal and ponds, indicating water content reduction that improves latter infiltration. The checked balance between water infiltrated and used by the plants in the ditches is positive for the aquifer yet. The presence of artificial wetlands in MAR facilities plays a very complementary role into general biodiversity.

Therefore, this open air interconnected schemes show an excellent opportunity for increasing MAR functionality in big systems where passive no cost natural processes can perform water quality improvement, clogging prevention and environmental services as much as their infiltration main goal. Its installation in lateral stretches as in El Carracillo can be implemented when lower quality spillways could be involved. These open air labs can be monitored for future design for secondary functions without compromising general recharging aim.

Transient flow modelling of an exploited aquifer in the city of Hanoi, Vietnam and simulation of managed aquifer recharge measures

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Keywords
Hanoi; groundwater depletion; groundwater model; managed aquifer recharge

During the last decades, urban development in Hanoi, Vietnam has caused a severe depletion of groundwater levels. The present study evaluates the actual situation and investigates the suitability of managed aquifer recharge (MAR) techniques to stop further decline of groundwater resources.

A conceptual and numerical groundwater flow model using MODFLOW-NWT was developed in order to understand the groundwater flow system and to suggest solutions for a sustainable water resource management. A transient flow model was built and calibrated for the years 2005 and 2006 and then validated with the year 2007. In order to counteract the groundwater depletion, three different predictive scenarios including MAR were built. The evaluation of MAR measures was done comparing hydraulic heads of the base case, which represents the actual situation without MAR, with the hydraulic heads obtained from the three predictive scenarios.

The results of the transient groundwater flow modeling show vast groundwater depletion cones in parts of the study area for the two years modeled indicating that groundwater is not sustainably managed. To combat groundwater depletion, wells were relocated from the main groundwater depression cones towards the river to induce further riverbank filtration as a first scenario. The resulting groundwater levels show an increase, especially in the depression cones (up to 15 m) as water abstraction was reduced in those areas. The second scenario includes the infiltration of surface water (mainly storm water runoff) into the upper (Holocene) and partly the lower aquifer (Pleistocene) via injection wells. As a result, a general increase of groundwater heads (1-3 m) in the study area can be observed. The third scenario combines the aforementioned two scenarios. The two years simulation already shows a high recovery of groundwater tables (2-6 m) throughout the study area and the major groundwater depression cones can be almost restored by applying MAR. Furthermore, a steady-state five year simulation shows that in the long-term, groundwater levels can be further increased (2-9 m).

The results of groundwater flow modeling supports that MAR can be a valuable tool to restore the groundwater balance and to manage the aquifer sustainable in Hanoi city. Nevertheless, further studies regarding the long-term application are required and the implementation of MAR should be accompanied by an integrated water management.

TYPES OF CLOGGING, DISTRIBUTION AND INTERACTION WITH GROUNDWATER QUALITY IN AN AQUIFER UNDER LONG M.A.R. PRACTICES. LOS ARENALES (SPAIN)

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Keywords
Managed Aquifer Recharge, MAR, artificial recharge, clogging, groundwater quality, multivariable geo-statistical analyses

Clogging is considered one of the major negative environmental impact caused and affecting the 'artificial recharge' devices. Consequently, several experiments aimed at the study of clogging have been accomplished in managed aquifer recharge (formerly known as artificial recharge) facilities within the framework of the EU founded DINA-MAR and MARSOL R&D Projects, related to management of aquifer recharge in the context of sustainable development. Since 2010 research is specially being conducted on the detection and distribution of physical, chemical and biological clogging processes and their synergistic combinations by means of sampling in 34 stations, visual inspection using magnifier and/or microscope, reaction to acid tests, biochemical analyses, radiometric images, photographs in the field and physical parameters determinations.

These activities have lead to a classification of these complex clogging processes, by binocular microscope, serial radiometric images taken at the infiltration ponds and canals of the main site used as an experimental laboratory where the project is developed: Santiuste basin, Los Arenales aquifer (Segovia, Spain), locations before studied and well known through other methods, such as chemical analysis, interaction models, sequential gauging tests, infiltration tests, etc.

On the one hand, clogging has been characterized as a process so five main types of clogging have been individualized in the MAR canals, with many different combinations: Areas with physical clogging processes, biological and biophysical, chemical, physical-biological and mixed plus synergistic mixtures.

On the other hand, Santiuste basin started its MAR activity in 2002, when the Spanish Ministry of Agriculture (MAPA) set up a groundwater quality monitoring network. Groundwater iso-contents cartographies have eventually been performed.

The article aims a new characterization of clogging processes in the area, developing distribution cartographies for the different clogging processes and combinations, and correlating the results by means of multivariable geostatistical analyses and calculations with the groundwater quality cartographies obtained by other procedures. That way, the different clogging processes are mapped by their nature in relation to the distribution of the major components of groundwater. The findings, in general, can be extrapolated to practical conclusions to other less known sites from the same aquifer and/or analogous scenarios. It also suggests a methodological proposal to correlate clogging and groundwater quality. The following results are worth mentioning:

-The clogging process is becoming more and more complex. New clogging combinations are appearing in the field and some areas are willing to enhance preferential clogging development.

-External processes bring multiple superimposed profiles and sand mobilized by the wind is fossilizing previous clogging profiles, which brings the necessity for frequently updated characterizations and increasing cleaning costs.

\- Iso-components cartographies match, frequently, the distribution of the characterized clogging typologies. The biggest congruency between clogging and specific components in groundwater has been correlated.

- The most important finding is possibly the bi-directional influence of MAR water in the groundwater and the opposite: groundwater has a direct action on clogging processes.
- The knowledge of the distribution of the incipient clogging processes allows improved designs and scheduled maintenance operations to become more efficiently and the application of the Best Technological Solutions for prevention, cleaning and maintenance.

Updated ASCE\EWRI Guidelines on Managed Aquifer Recharge

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Keywords
Standard Guidelines; Managed Aqufier Recharge; ASCE

Managed Aquifer Recharge (MAR) is becoming an increasingly important component in regional water planning and management. Project developers and stakeholders need standard guidelines for planning purposes while engineers, hydrologists and others use them to standardize their practices and safeguard project success. In 2001, American Society of Civil Engineers Environmental and Water Resources Institute (ASCE\EWRI) published the first Artificial Recharge of Ground Water standard guidelines as EWRI/ASCE 34-01. As more MAR projects were developed and constructed, it became evident that the original guideline needed to be modernized and upgraded to provide additional details on the planning, design, construction and operation of MAR projects. The ASCE/EWRI MAR Guideline Development Subcommittee was formed to update the guidelines. The process of developing the new MAR guidelines will be described, including the internal and public comment steps before the document is finalized. The final product will be based on consensus of the Standard Committee and the public, and then will be approved by the ASCE Codes and Standard Committee for publication. The contents of the draft guidelines will also be summarized. Once finalized, the new guidelines will be a useful tool to MAR project planners and design professionals.

Water Banking in Australia: Progress and Issues

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Keywords; water banking, integrated water management, adaptation, infrastructure, planning, water governance

Integrated management of surface water and groundwater through time can increase the efficiency of water use and help adaptation to climate variation and uncertainty by banking surface water underground and recharging aquifers during wet periods, and using an increased proportion of groundwater in dry periods. Water banking can be applied on a seasonal or inter-annual time scale. Banking water in aquifers reverses groundwater depletion, maintains flows of groundwater to rivers and improves water quality by leaching out pollutants. Methods of water banking can be divided into two broad types. Non infrastructure based methods include regulation of surface and groundwater allocations and usage over time, and land and water management practices that encourage water infiltration and aquifer recharge. There are a wide variety of Infrastructure based methods including infiltration ditches, ponds and basins and injection wells. Although the case for systematic water banking has been established in theory and the basic physical requirements exist in many regions of the world, the implementation of these techniques is relatively unsystematic, slow and unevenly distributed.

This paper summarises findings from an investigation of water banking in the Australian states. Opportunities for water banking have been pursued most strongly in the driest states; Western Australia and South Australia. Queensland has seen some local development of rural aquifer recharge and recovery. Water banking requires integrated surface water and groundwater planning. There is a trend in Australia towards better accounting for impacts of groundwater pumping on streamflow, rising water tables and saline intrusion. There has been less progress on accounting for the impacts of surface water diversions on recharge. There is still little or no systematic attempt to plan and manage surface water and groundwater storage and use at a regional scale over time. Some developments in water governance are needed to support the development of water banking. Current policies effectively subsidise surface water storage. Aquifer storage and recovery entitlements are not in place in some jurisdictions. Water for petroleum and gas, mining and forestry is generally managed separately from and poorly integrated with the national water management system. Despite these issues Australian experience demonstrates the utility of water banking and the prospects for further implemenation in Australia and elsewhere.

Topic M11: MAR in hard rock and karstic systems

Windhoek, Namibia: From conceptualising to operating and expanding a MAR scheme in a fractured quartzite aquifer for the city's water security

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Keywords
Fractured aquifer; hard rock; borehole injection; water banking

The City of Windhoek lies in the centre of Namibia some 700 km from the nearest perennial river. The concept of recharging the highly complex local quartztic aquifer was first considered in 1997 as an alternative to piping water from the distant Okavango River.

The aquifer was studied in detail to establish the flow mechanisms in this anisotropic, hard rock, faulted and jointed aquifer system. Four borehole injection tests were conducted and they provided the confidence to design and construct the scheme which included 6 injection boreholes with a recharge capacity of ~9 000 m^3/day. Borehole injection started in 2006 and continued until the targeted recharge area was full in 2012 (which was also aided by above average rainfall during this period). The scheme's success led to two expansion phases; the first resulted in drilling an additional 9 injection boreholes with a combined capacity of ~16 000 m^3/day and drilling 10 deep abstraction boreholes with the aim of being able to access a 200 – 300 m column of water in the aquifer. The second drilling phase is due to start in 2016 and will include drilling of an additional 7 deep boreholes to be used for abstraction and/or injection.

The source water is surface water from the city's supply dams and a portion of reclaimed water; both of which are treated to drinking quality standards prior to recharge.

This paper summarises the process of establishing the feasibility of recharging this complex aquifer; it presents operational data since the onset of full-scale borehole injection; the water quality of the injectant and receiving aquifer; management and operational issues; the economics of the scheme and alternative options; and the planned expansion of the scheme to utilise the storage capacity of the aquifer and maximise the water banking concept.

An account of Artificial Groundwater Recharge in an Overexploited Block with special reference to Kottukal Micro watershed, Kerala S.India

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Key words
Aquifer recharge, over exploited area, groundwater quality
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Land use practices are assumed to have important impacts on both the availability and quality of water resources. In Kerala the conventional homestead irrigation practices, rapid urbanization, industrialization along with natural topographic challenges etc leads to over exploitation and contamination of groundwater resources. The Groundwater Control and Regulation Act 2002 in Kerala had enforced the restricted use of Groundwater for irrigation and industrial activities in the over exploited areas giving thrust to groundwater conservation and recharge. This is particularly true in Kottukal micro watershed, which is a part of on over exploited block situated in the coastal sedimentary terrain. The watershed evolved from large scale neo-tectonic movement is hydro-geologically an unfavorable terrain but are engineered to suite artificial groundwater recharge for conservation and sustainability for domestic and irrigational needs. This paper evaluates the effects of terrain improvements adopted for irrigation in Kottukl micro watershed and its environmental consequences for domestic groundwater use. The long term trend analysis of hydrograph in the recharge area depicts a rising trend of 0.146 cm/yr and a falling trend of -0.136 cm/yr during the pre monsoon and post monsoon period respectively. But the discharge area indicates a falling trend of -0.122cm/yr and -0.102 cm/yr respectively during both seasons. This implies the planned groundwater recharge has more influence on the upper groundwater regime during the dry spells whereas the over conservation of groundwater along the stream results in reduction in stream discharge during monsoon and non monsoon periods. The water quality analysis during pre monsoon period shows that the stream water samples have slightly higher pH values indicating its alkaline nature. The EC in groundwater samples ranges from 67 to 131 mmohs/cm, and stream water samples ranges from 157 mmohs/cm to 224 mmohs/cm respectively. The range of EC values in groundwater and stream water are distinctly different suggesting a difference in hydro-geochemical behavior. An anomalous high EC value of 2500 mmohs/cm noted from one groundwater sample indicates that the SW side of the watershed is tidal prone. The low EC values and alkaline nature are significant throughout the watershed indicating shallow groundwater and stream water samples are fresh. The study indicates high coliform contamination of $\geq$ 1600MPN in 80 % of the water samples and elevated presence of Fe in 65% of the samples. The groundwater recharge measures adopted for irrigation had induced large scale biogenic contamination and impacted stream discharge due to over conservation of water resources within the same watershed.

An integrated modelling approach to the design of the Hinds catchments proposed regional scale MAR project

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Keywords
Managed aquifer recharge, Integrated modelling, New Zealand

Abstract
To support sub-regional water management planning and plan implementation requirements Canterbury Regional Council has developed an integrated hydrological model of the Hinds/Hekeao catchment in South Canterbury using the modelling software MIKE SHE™ (DHI).

The Hinds/Hekeao catchment covers roughly 1375 km^2, and is home to a large groundwater resource, hill-fed streams and more than 36 coastal spring-fed streams. Both the surface water and groundwater resources play a critical role in the area: providing drinking water, stockwater and irrigation, in addition to sustaining abundant biodiversity, cultural and environmental values. Across the Hinds/Hekeao area, groundwater levels and flows in the coastal spring-fed waterbodies are declining, reducing the biodiversity in spring-fed streams and the reliability of supply for abstractors. Declines are attributed to changing irrigation practices, increased groundwater abstraction, and piping of irrigation and stockwater distribution races thereby reducing recharge to groundwater.

The Hinds/Hekeao sub-regional water management plan seeks management options and allocation limits to help offset groundwater level and flow declines whilst meeting the environmental and economic requirements of the water resource. A key tool in this strategy is the use of catchment scale groundwater replenishment scheme (GRS). This process is beginning with an initial 0.5 m^3/s recharge basin trial. The final GRS seeks to utilise large-scale recharge basins in the upper catchment for storage and smaller infiltration rate galleries spread throughout the middle of the catchment at optimal locations to meet water quantity and quality outcomes. The final GRS design will be informed by the results of the trial and modelling.

To develop the GRS programme we utilised our integrated catchment model developed in support of the Hinds/Hekeao plan. We chose an integrated modelling platform as the modelled scenarios focused on the effects of land use changes on both surface water and groundwater, which are equally important to the plan outcomes. The model is a finite difference model that uses a 500 m grid area defined laterally by large, glacial-fed rivers, the coast and inland by the Southern Alps. The model is transient, calibrated to the 2009-2012 period and consists of:

- an evapotranspiration (climate) model utilising rainfall and evapotranspiration
- an unsaturated zone model calibrated against lysimeter data
- an overland flow model that routes the component of water not infiltrated or evaporated to the nearest river
- a river model calibrated against three rivers and six coastal streams
- a saturated zone model calibrated against 29 head elevation points using pilot point PEST.

We modelled two lines of GRS site scenarios, with results compared against the calibrated baseline model: the first looking at the operational effects of the MAR trial on groundwater levels in support of the trials resource consenting requirements. The second focusing on placement, timing and total volume of water required to meet the outcomes of the Hinds/Hekeao plan.

Optimal placement of the trial site in addition to the GRS design is key to the success of the program, our scenarios focused on these aspects. Initial GRS modelling used an operating window of nine out of twelve months, with operation ceasing when the source water is prioritised for irrigation and during the wettest period of winter. Results indicated initial site placement and timing would provide insufficient recharge to mitigate seasonal low flows caused by groundwater pumping for irrigation. Revision to scheme design has demonstrated that careful placement of larger the MAR basins and some localised operation during the irrigation season to benefit from operational mounding enables us to meet low stream flow requirements.

As the results of the trial are realised the model is updated and recalibrated, it will provide the community with a tool to help implement the GRS and develop a catchment wide approach to water management. The paper presents up to date results of the trial phase modelling.

Assessing infiltration rates and clogging impacts during recycled water managed aquifer recharge (MAR) in Floreat (WA) and Alice Springs (NT)

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Keywords
Soil aquifer treatment; infiltration gallery; clogging; infiltration rates; MAR;

Australia has tremendous potential for supplementing groundwater resources using managed aquifer recharge (MAR), with highly porous surface and shallow sub-surface sedimentary deposits of sand, gravel and limestone covering a large proportion of the Australian landscape. However, MAR is not without technological challenges and the presence of lower permeability, fine-grained sediments, such as silt and clay, and/or limited treatment of wastewater prior to recharge can promote clogging that is detrimental to the infiltration process. To gain a better insight into reductions in infiltration rates during MAR, two field investigations were carried out: (i) on MAR via an infiltration gallery located in predominantly medium-grained Aeolian sand deposits typical of the coastal plain of Western Australia at the Floreat Infiltration Gallery site; and (ii) on MAR via soil aquifer treatment (SAT) using recharge basins located within a mixture of fine- and coarse-gradient riverine deposits in Alice Springs, Northern Territory.

In 2013 it was demonstrated that an infiltration gallery constructed of Atlantis Flo-Tank® modules in Spearwood Sand can recharge the aquifer using secondary treated wastewater applied at an average rate of 4 m/d over a 5 month period. A total of 750 kilolitres was recharged to the Tamala Limestone aquifer over this period (average rate of 6.7 kL/d over a surface area of 1. 7 m^2). Whilst high rates of recharge to the aquifer were sustained over the entire duration of the field experiment, changes occurred spatially in gallery wastewater levels and soil moisture contents surrounding the gallery after 14 weeks, supporting the theory that heterogeneous clogging developed locally within the gallery.

With infiltration at the SAT site (NT) there were variable soil characteristics in five recharge basins overlying an alluvial aquifer. The hydraulic performance of each of the recharge basins was assessed using wastewater derived from two different treatments, initially Dissolved Air Flotation (DAF) and then later Dissolved Air Flotation and Filtration and Ultraviolet disinfection (DAFF + UV). A total of 2,580 ML (2.6 Mm^3) was delivered to the basins over six years, with infiltration rates in the five SAT basins, constructed in lower permeability sediments, varying from 0.2 to 1 m/d. Implementation of filtration as an additional pre-treatment step improved the quality of recharge water to the SAT basins resulted in at least 40% improvement in average infiltration rate in each of the five recharge basins.

Blending Stormwater and Treated Wastewater for Managed Aquifer Recharge to Support Irrigation Expansion and Economic Development

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Keywords
aquifer, groundwater, recharge, economics, wastewater, storm water,

Historically, the Northern Adelaide Plains region of South Australia relied solely on groundwater to meet irrigation demand using 13 to 16 Mm^3 (10,539 to 12,971 acre feet) per year depending on climate and crops. In 1998 the Virginia Pipeline Scheme was commissioned which currently supplies 17 Mm^3 (13,780 acre feet) of tertiary treated wastewater from the Bolivar wastewater treatment plant into the region to meet summer irrigation demand. Groundwater use has declined slightly over the past decade and typical use is now between 9 to 12 Mm^3 (7,296 to 9,730 acre feet) per year. The area immediately to the north of the major horticultural area on the Northern Adelaide Plains has suitable land for further expansion of horticulture but to date has no reliable source of water to support development. Proposed treatment plant optimization could provide up to a further 20 Mm^3 (16, 215 acre feet) per year of tertiary treated wastewater during winter but requires suitable storage. A proposal to store the winter volumes of treated wastewater from the Bolivar Wastewater Treatment Plant is currently under consideration by the South Australian State Government. Under the proposal there is 8 Mm^3 (6,485 acre feet) of treated wastewater available in winter for storage for the first stage of the project with the remaining 12 Mm^3 available in subsequent stages. Economic modelling has demonstrated that the most cost effective means of managing the water is via storage in the aquifer compared to above ground storage.

Growing global demand for food presents a large economic opportunity but requires greater certainty on the reliable supply of a suitable quality water. Managed Aquifer Recharge (MAR) presents opportunities to use water from all the available sources to maximise the horticultural productivity of the region. The majority of MAR systems aim to deliver a triple bottom line (economic, social and environmental) benefit but to effectively deliver on these objectives usually requires overcoming numerous challenges ranging from the physical aquifer characteristics for the storage and recovery of the water through to the various agendas of stakeholder groups.

One of the potential challenges for the operators of the system will be the delivery of a suitable quality of water for a price that is acceptable to the irrigators. Preliminary canvassing of potential demand in the preferred location has identified that users would be prepared to pay a fair price for a good quality secure water supply. The ambient groundwater in the aquifer at the preferred location is typically brackish to saline (3,000 to 6,000 mg/L). The salinity of the treated wastewater is reported to be ~1,000 mg/L and stormwater in the area is ~200 mg/L. Mixing of the treated wastewater with the high salinity ambient groundwater will present significant challenges to any operator to deliver a suitable quality of water to irrigators without initiating further costly treatment to reduce the salinity. The incremental cost associated with additional treatment such as desalination to reduce the overall salinity may make the unit cost of water too high for irrigators to take up for the types of crops grown in the area.

An economic assessment of an integrated water management strategy using the existing water resources in the region, rather than additional treatment such as desalination, has been completed. The assessment evaluates the unit cost of using MAR to supply either 8 Mm^3 (6,485

acre feet) per year of treated wastewater or 6 Mm^3 (4,865 acre feet) per year comprising equal parts of treated wastewater and harvested stormwater using economic values from a field scale wastewater MAR trial plus capital and operating costs for operational stormwater MAR systems. Cost ranged from AU$880 to AU$1550 per 1,000 m^3 (0.8 acre feet) however this does not include the environmental benefits that accrue by reducing the disposal of nitrogen, turbidity and coloured dissolved organic matter to marine outfalls, or the value of crop production that can be grown with irrigation supply as different levels of salinity. The expected environmental social and economic benefits plus operational challenges associated with a MAR system that blends the two water sources for storage in the aquifer during winter followed by recovery to meet summer irrigation demand are discussed.

Can village ponds be modified to mitigate floods and meet local irrigation demands?

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Keywords: floods; irrigation demand; groundwater depletion; piloting; Uttar Pradesh, Ganges river basin

Abstract Submitted for **Poster Presentation**. Possible Sessions to present could include:
M20. Flood water harvesting via MAR for agriculture / M7. Monitoring and management

Mitigating devastating floods that occur with regular occurence during the monsoon by storing this water in aquifers for utilization to meet irrigation demands during the dry season in the same river basin is a novel form of conjunctive water management referred to as 'Underground Taming of Floods for Irrigation' or UTFI (pronounced 'utify'). This study aims to set up and monitor UTFI pilot operations and to address the design and performance related issues such as clogging and geochemical/ microbial effects of the recharged water and groundwater which is recovered. This study also serves as a trial into the feasibility of upscaling the technique at the watershed/basin scale taking further account of social, economic and institutional issues.

After a detailed remote sensing based analysis of the entire Ganges Basin and field visits with support from local agencies a suitable site in the Ramganga sub-basin of Uttar Pradesh state in India was chosen for the piloting. This area is affected by both seasonal flooding from a nearby river and groundwater depletion. A community-owned village pond was modified and retrofitted with ten recharge wells to serve as a scientific trial and practical demonstration. Three piezometers were also installed within close proximity to the pond to monitor the effect of recharge on water levels and water quality.

The trial commenced as recently as September 2015 and is expected to run for several years. Initial monitoring results indicate that the groundwater level around the pond has improved due to the recharge augmentation. This will in turn provide more water for irrigational activities in the dry season. Salinity reductions in the groundwater have also been observed. This pilot operation is intended to be handed over to the local community in the future to be maintained and managed by them after appropriate training has been provided and local institutional arrangements finalized.

Characterization of the Yucatan karst aquifer, pollution scenarios and possible solutions

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Keywords
karst aquifer; pollution scenarios; integrated vulnerability maps; Yucatan

The Yucatan aquifer is a well-developed karst whose duality allows flow through both the karst matrix and conduit systems increasing pollution risks. Flatness of the area and karstic features as sinkholes do not allow the formation of surface flow, therefore rainwater which does not evapotranspirate infiltrates almost immediately directly into the groundwater.

New housing developments are supposed to include a sewerage system and waste water treatment plants, but more than 80% of the total population still remains without this sanitary service. By using rural septic tanks and latrines, waste water undergoes residence times of just a few hours, reaching groundwater very fast. Pollution is the main risk for the aquifer as it is the only source of fresh water but also acts as receptor for untreated waste water. This situation has turned the upper 15 meters of the groundwater underlying Merida city unsuitable for human consumption. This problem is expected to further increase due to an estimated population growth of 17 % for the Merida metropolitan area in the next 15 years.

Possible solutions should fit the natural and anthropogenic characteristics of the area in a physical and economic way. Intrinsic vulnerability maps with integration of anthropogenic factors (demographic changes, waste water generation/treatment, etc.) can serve as first step in order to determine protection strategies and evaluate attenuation/remediation solutions for endangered areas. While building of sewage systems is difficult and expensive (due to hardness of the limestone and low elevation gradients), adapted managed aquifer recharge techniques are considered to be a suitable option.

Combining aquifer storage and recovery with reverse osmosis (ASRO Westland)

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Keywords
Aquifer storage and recovery; ASR; brackish/saline aquifers; water quality; reverse osmosis

Coastal areas are marked by high freshwater demands, but yet a low freshwater availability. Use of the local eco-systems via aquifer storage and recovery (ASR) of temporary freshwater surpluses and reverse osmosis (RO) of brackish-saline groundwater are potential solutions for freshwater supply in coastal areas. Both techniques have their drawbacks, however, since ASR in coastal aquifers is marked by freshwater losses by buoyancy effects in the saline groundwater (water shortage remains), while RO is accompanied by a saline waste stream (unsustainable). In DESSIN we demonstrate that a sustainable and reliable freshwater supply can be achieved by combining both techniques in one system (ASRO).

At the Westland field site, the freshwater surplus of 270,000 m^2 of greenhouse roof is collected, filtrated, and injected deep into the target aquifer (23-37 m below sea level; 4000 – 5000 mg Cl/l) via a dedicated, recently developed multiple partially penetrating well. Upon storage, the water is recovered during springs/summers. Unmixed freshwater is recovered for direct use at the aquifer top. During recovery, the deep well of the system is used as a 'Freshkeeper' for interception of brackish-saline groundwater. This water is directly re-injected in a deeper aquifer (2014) or desalinated via RO for use as irrigation water (2015-2016).

The Westland ASRO demonstration shows the potential of dedicated ASR concepts in coastal aquifers to manage freshwater resources and enable a sustainable freshwater supply. Focus is now on enhanced production via RO and evaluation of the effects on the local and regional groundwater system.

Decentralised Stormwater Management: Focus on Infiltration over Street Tree Pits in Steindamm, Hamburg, Germany

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Abstract: Is it possible to treat rainwater onsite in order to recharge the aquifer and reduce the amount of runoff in a highly dense urban area? The aim of this study is to illustrate the possible application of a decentralized stormwater strategy whose purpose is to reduce runoff volume and to remove pollutants for aquifer recharge through engineered soil and urban trees. The present study comprises a description of the potential application of two of the existing system's standards on Steindamm, a high-density street in Hamburg, Germany. As such, a short overview of Hamburg's water cycles is deployed, followed by two adapted implementation proposals. The study results show that it could be technically feasible to implement the system. However, a pre-treatment strategy onsite is required to prevent groundwater contamination risks. Similarly, any pilot project should be closely monitored. Moreover, all the involved stakeholders need to be taken into account for further steps. Additionally, the system could be a cost-effective solution regarding stormwater detention, water quality improvement, and wetland habitat. The likely positive effects include increased groundwater infiltration and recharge; local flood control; stormwater runoff and flow rate reduction; cleaner air by vegetation provision; and improved street aesthetic appearance.

Groundwater modelling of the Coastal Aquifer of Santa Marta, Colombia, under different hydrological and pumping scenarios, including sea-water intrusion, artificial recharge and Interbasin transfer

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Keywords:

Sea-water Intrusion, Water Management, Sustainability, Recharge, Sewerage
M1. Integrated water management strategies

Santa Marta is a touristic city, located in the north of Colombia on the Caribbean coast; its population (2015) is about 600.000 inhabitants and is growing fast due to the work opportunities that the city gives to the nearby towns and complex population processes. During vacation season the city population grows about 50%.

The city is located next to the Sierra Nevada de Santa Marta, a huge coastal mountain range (5800 masl), with unusual climate behavior, with long dry seasons and short rainy periods.

The city's water demand is supplied mainly by Manzanares and Gaira rivers (short streams with high slopes), and from a small quaternary aquifer located bellow the city, with approximately an extension of 40 km^2 and average depth of 50 m. In dry seasons the rivers flow is not significant, and city water is supplied by direct pumping from the aquifer, as a consequence, near the coastal line, the aquifer drawdown causes sea-water intrusion.

In rainy season the main rivers discharge its flow to the sea; in order to avoid the waste of this scarce resource, in the 90's sustainable management studies were developed, those includes artificial recharge through small dams in the Manzanares River. This system works for nearly 20 years but due to climate change, river water quality deterioration, change in watershed soil use, and the stakeholder's lack of knowledge of this system importance, the artificial recharge stops working the last decade.

To pick up the past studies, a numerical density-dependent flow and transport model of the aquifer was implemented in FEFLOW, as a tool to be used by the decision-makers in order to achieve sustainable aquifer management. Various management scenarios are considered, such as extreme dry climate conditions (due to climate change in the area), interbasin water transfer and hydraulic structures in the rivers to increase the riverbed recharge (Artificial Recharge), as a well as wells optimum location.

This hydrogeological study is part of a more wide research for Santa Marta's water supply alternatives, which includes population grow dynamics analysis, anthropological studies (due to indigenous tribes in the Sierra Nevada de Santa Marta), rivers and basins hydrological modeling, distribution network modeling and evaluation of the sewage system.

Groundwater Quality Improvement due to Rainwater Harvesting in Costal Aquifers

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Rainwater harvesting works have been taken up under watershed development programm by various organizations in the western coast of Saurashtra region of Gujarat, India. The study has been conducted to monitor the improvement of groundwater quality in these watersheds. Three watersheds selected for study are *Bantwakharo, Mangrol* and *Kodinar*. Forty two wells distributed in treated and untreated areas of these three watersheds were selected for collection of pre monsoon (Pre M) samples were analyzed for quality parameters viz. total soluble salt content (electrical conductivity, EC), pH, carbonates ($CO_3^{- -}$), bicarbonates ($HCO_3^{- -}$), chlorides (Cl^-), sodium absorption ratio (SAR), residual sodium carbonate (RSC) and soluble sodium percentage (SSP) using standard methods. The results show that the soluble salt content (EC values) was decreased by 12 percent during post monsoon in treated watershed area while in case of untreated area it is decreased by 4 percent only. In case of pH negligible changes were observed in treated as well as untreated area of watershed in Pre M and Post M season. In Post M season the HCO_3 content in groundwater of treated and untreated watershed area were increased by 42.7 and 40.9 percent, respectively. The chlorides (Cl) content increased in all Post M samples for treated as well as untreated area. In post M the Cl content was increased in comparison to pre M samples by 55.82 and 44.41 percent in the treated and untreated area, respectively. The Na content was also increased in Post M as compared to Pre M in treated as well as in untreated area by 14.05 and 13.12 percent respectively. Similarly, SAR increased in post M season as compared to Pre M in all samples. The RSC content was decreased in Post M as compared to Pre M season in treated and untreated area by 23.18 and 8.97 percent respectively. The SSP values were decreased in Post M as compared to Pre M season. The results revealed that the groundwater recharge occurred due to watershed development works has improved the quality of groundwater in the region.

Keywords: Rainwater harvesting, Watershed development, Coastal aquifers, Groundwater recharge, Groundwater quality.

Identification of recharge area for potential flooding recharge in Leizhou Peninsula, Guangdong, China

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Keywords: recharge area; rainfall-infiltration; multiple methods; Leizhou Peninsula;
Abstract; author details; example; headings; layout; title page

Leizhou Peninsula experienced a severe drought in the spring and summer of 2015. Even though the drought was estimated to be at a frequency of once per 50 years, the damage and lost was not significant due to the irrigation system with water from the aquifers in the peninsula. Three aquifers were usually categorized as shallow upper aquifer of less 30 m depth, middle aquifer of 30-200 m depth, and deep aquifer of more than 200 m depth. As groundwater has been used in the past 30 years at an annual average rate of 700 million m^3, groundwater levels of both middle and deep aquifers decreased, particularly in the Zhanjiang City, causing subsidence, potential seawater and other environmental problems. Approximate 80% of annual rainfall of 1500 mm occurs in the rainy season from April to October. Flooding recharge in the rainy season was considered a solution to the depleting aquifers, and the identification of recharge areas was found be a key issue in the recharge practice.

Two campaigns of field survey to collect water and soil samples were carried out in April and July of 2014, and field measurement of soil hydraulic conductivity, K, by using inversed auger hole was implemented with one test per 200 km^2. Data of rainfall and water level of more than 30 years were collected to analyze the relationship between the rainfall and response of water level, and calculate in the recharge rate. Recharge areas were identified based on the above relationship, K, land use and topography of 90x90 m DEM (digital elevation model). Water samples from six wells were collected to measure ^{14}C, ^{81}Kr and ^{85}Kr, which could be used as additional evidence for identification of recharge areas as these areas should have young groundwater apparent age. One groundwater model based on MODFLOW was constructed to simulate the water level varied scenarios of flooding recharge.

The topic to be submitted: M23. MAR in depleting aquifers and protection of groundwater dependent ecosystems

Impact in the quality of surface and groundwater generated by the leachates at the Municipal Landfill Linares/Mexico

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Keywords: Leachate, Municipal Solid Waste, Landfill, Groundwater, Linares.

This research deals with the quality of natural waters affected by pollution from leachate generated in the Municipal Landfill of Linares, Nuevo Leon, Mexico. The Municipal Landfill of Linares has more than 17 years of service and receives more than 50 ton/day of municipal solid waste. Geological (geological structural profiles), hydrogeological (piezometric cards) and hydrogeochemical (water quality classification and determination of pollutants) methods was applied to identify external agents to the environment. A negative impact on the quality of surface water (dam El Cinco) and groundwater (wells) in accordance with national and international environmental standards were identified (NOM, WHO, EPA). The results reveal deficiencies in the management and final disposal of municipal solid waste (torn geomembrane) and null leachate management (oversaturation of the landfill). In particular, high concentrations of NO_3, Pb, Mn and Fe in groundwater and surface runoff were identifying, that generate a significant contamination of soil and water; aspect very important if people in the region consume contaminated water from groundwater wells, that can cause harmful health effects.

TOPICS: M1. Integrated water management strategies.

Infiltration Basin: an Alternative Recharge Method for El Paso's Managed Aquifer Recharge Program

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Keywords
Infiltration basin, managed aquifer recharge, reclaimed wáter, recharge rate, groundwater

Topic
M12: Bank filtration, infiltration systems, soil aquifer treatment

Since 1985 El Paso Water Utilities has operated a managed aquifer recharge system in order to restore depleted groundwater storage by using reclaimed water. The system started with injection wells with a pump for redevelopment in each well and later changed to infiltration basins. With continued drought, El Paso Water Utilities is planning to expand its Managed Aquifer Recharge (MAR) system. Concerns were raised regarding performance of the infiltration basin. This study will evaluate the movement of recharged water from the infiltration basin and its impacts on groundwater levels as well as water quality. The infiltration rate of the basin will be estimated based on field tests using a double ring infiltrometer and monitoring of recharge events. The water front will be monitored with moisture sensors and boreholes. The movement of recharged water in the vadose zone and mounding in the underlying aquifer will be simulated by using Hydrus 3D and MODFLOW models. By testing an array of recharge scenarios, this study will help us gain a better understanding of hydrological processes during the recharge phase like mounding in the aquifer, water losses through evaporation and vadose zones, and impact of soil properties on the infiltration as well as operational parameters such as recharge rate and duration. A comparison will be made with the recharge with injection wells in terms of recharge rate and mounding in the underlying aquifer. With model simulations the recovery of recharged water can also be evaluated. This study is anticipated to provide information and data needed for future expansion of the MAR program with infiltration basins as well as improving performance of existing infiltration basins.

Integrated Approach for Artificial Recharge to Ground Water in an Infrastructure Project, Haryana, India

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Keyword: runoff, rainfall, percolation pond, injection well, storm water

Abstract

The study area is fast developing as an infrastructure hub but the water resources, groundwater and surface water, are scares to meet the demand. The Sahibi River drains through the area but enroute to river Yamuna become biggest drain as wastewater enters into it. The integrated approach was implemented as part of Integrated Water Resources Development & Management for supplementing the water resources for an infrastructure project covering an area of 7.53 Sq Km. The implementation of MAR projects are mandatory under the urban by laws if the groundwater is to be developed to meet the water requirements. The average annual rainfall is about 444 mm spread over only 23 rainy days in a year. The hydrogeological and resistivity survey result shows that the unconfined fresh water aquifer is of limited thickness varying from 12m to 20m bgl. It is also observed that the saline-fresh interface occurs between the depth range of 16m-30m, therefore groundwater development needs to be done carefully to avoid up coning of saline aquifer. It is therefore pertinent that the fresh water aquifers are managed using MAR techniques as the development and recharge is to be confined within the thickness of the unconfined aquifer. Based on the prevailing hydrogeological conditions, it has been estimated that the sub-surface storage capacity of the project area is about 4.6 MCM and the volume of water which can be recharged in this storage capacity is 5.4MCM. In order to prepare the master plan, the area is divided into 5 zones(catchment) based on the surface slopes, directions and flow of storm water drains and existence of outlets for disposal of final storm water. The total annual rain water harvesting capacity of complete study area is worked out as Zone-I: 0.217 MCM; Zone-II: 0.197 MCM; Zone-III: 0.112 MCM; Zone-IV: 0.827 MCM; Zone-V: 0.449 MCM; totalling harvesting capacity as 1.80 MCM per annum. The integration of artificial recharge structures which are basically recharge trenches and shafts associated with recharge tubewells (totalling 120 structures) along with 17 percolation ponds will help in preventing the water logging and improve the recharge capabilities, thus reducing the wastage of storm water runoff which ultimately entering into the drain which carries waste water enroute and cannot be used at later stages.

Integrated Modeling Approach for Sustainable Water Resources Management: The Case of Mexico City Metropolitan Zone Aquifer

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Keywords
Groundwater flow modeling, Spatial Analysis

Topic
Modeling of systems that include MAR

Water supply is an issue of mayor concern for authorities of Mexico City and its Metropolitan Area: a megacity that houses more than 20 million inhabitants. Water demand is supplied with water imported from surrounding basins and local sources: springs located in south and west Mexico City, and Mexico City Metropolitan Zone Aquifer (MCMZA). After decades of continuous water withdrawal: scarcity, overexploitation, land subsidence, and alteration of the hydrological system are main features associated with water management and are limiting factors for its availability in the near future. Computer simulation is a valuable tool to predict the behavior of hydrological systems under different conditions of exploitation, to quantify the effects of induced recharge, and to assess the impact of climate change. On the other hand, Geographic Information Systems (GIS) is a convenient platform to process, integrate and analyze information available including results of simulations. Also it is possible to establish relationships among processes involved in water supply, even those of economic and social nature. In MCMZA mathematical and numerical models have been applied. Most simulations have been carried out to evaluate land subsidence and overexploitation; finite differences method is the technique mainly employed, commonly using Modflow package; least modeling work has been done to evaluate recharge areas. In this work we present a platform for integrated water resources assessment using groundwater simulation and spatial analysis; showing the results obtained for MCMZA. To this end, we constructed a geo-referenced database with physical and social data of the study area; then, we carried out groundwater flow simulation using finite element method, and finally we performed spatial analysis to assess recharge areas and identify areas for allocation of enhanced recharge.

Integrating suitable sites for managed aquifer recharge with drinking water demand in Costa Rica

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Keywords
MAR; Costa Rica; drinking water supply; site suitability; water demand

The Institute of Water Supply and Waste Water (AyA) supplies water to more than two million inhabitants all over Costa Rica, which represents more than half of the country´s population. The AyA manages Costa Rica´s water supply systems and calculates their water balance to assess and plan the incorporation of new water sources to the systems when they are required.
Suitable sites in Costa Rica for the managed aquifer recharge (MAR) type `spreading methods` were determined in a previous study based only on the intrinsic characteristics of the land (geology, terrain topography and top soil). In this work, the study is expanded to integrate the demand for water supply systems in order to include MAR as a new water source. Two case studies are presented and further characterized. The chosen water supply systems are Tamarindo and Flamingo, which are both coastal areas in the northern Pacific Region of Costa Rica where the water availability is lower in comparison to other parts of the country.
In a radius of 10 km of the two water supply systems, the results show that Tamarindo has 500 ha which have a good suitability to apply spreading methods and 2900 ha classified as moderately suitable and Flamingo has 400 ha which are classified as good and 3200 ha as moderately suitable.

Methodology for Identification of aptitude of basin-scale aquifer artificial recharge areas

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Keywords
Artificial groundwater recharge, Recharge methodology, Agricultural demand

Groundwater currently plays a fundamental role in satisfying water resource demands for agricultural development in Chile. However, the natural recharge of this resource is limited and depends on the seasonality of surface water. Hence, it is necessary to assess the artificial recharge of aquifers in basins with agricultural potential. Since artificial recharge is just recently being implemented in Chile, it is not yet a widespread tool for water management. Artificial recharge studies, pilot projects, and related experiences are still few in number. They are associated with pilot plans, and generally being developed by state agencies, such as the General Water Directorate, the Water Works Directorate, and the National Irrigation Commission.

One of the first steps for the development of artificial recharge pilot tests concerns the identification within a watershed of the areas with the most appropriate conditions for artificial recharge. This allows efforts to be focused on searching for the most favorable locations to develop preliminary studies.

This work aims to develop and validate a methodology to classify areas within a watershed into different aptitudes, so as to carry out artificial aquifer recharge. The strength of this methodology lies in that fact that it is based on data collections and/or data records of public agencies, allowing for a first approach without the urge to have field data. Once the watershed has been classified, field trips can be made to corroborate and validate in situ the approach obtained through computer work.

The methodology is based on a simple weighting of hydrogeological variables of the basin under study, which can be evaluated spatially through a Geographic Information System (GIS), showing areas suitable or unsuitable for artificial recharge. Hydrogeological variables include: 1) horizontal hydraulic conductivity, 2) proximity and connection to a water source or sink, and 3) water table depth which serves as an indication of the available storage volume. The methodology comprises spatially distributed variables, for each of which a set of values to quantify the ability/aptitude the methodology imposes on the overall aptitude of the site assessed. The overall aptitude value (AV) of an area is calculated as an average of all the variables. Hence, value 1 indicates an inadequate area while value 5 designates a very suitable area for artificial recharge.

The methodology has been used in five basins in Chile, with 3 areas per basin being selected to validate the methodology. Field work, such as construction of test pits, was carried out in each area for lithological characterization, measurement of the water table depth, and estimation of the infiltration capacity of each site. Based on the application and validation of the methodology, a specific site was selected to develop a pilot test (5 in total) within a particular land property.

The methodology enables the identification of potential areas for artificial recharge, serves as a preliminary screen from which further information must be collected to determine whether the selected areas actually have appropriate characteristics for the application of this technology. The methodology has worked well, since it has allowed for the identification of areas with better features for artificial recharge than others. The main problem of this methodology deals with the quality of the hydrogeological information available. The methodology is easily implemented through a GIS. Finally, one possible upgrade can be incorporating surface geology information to identify sector areas that are suitable for recharge through basins or wells.

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Aquifer Recharge

Multiple barrier processes for indirect potable reuse: a lab-scale study for the Metropolitan Area of Mexico City.

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ABSTRACT

The supply of reclaimed water for human consumption, called direct potable reuse, is a practice that although being necessary, has not been able to achieve a comprehensive acceptance. In some cases, potential consumers have rejected it as it occurred in the State of California, USA, and while in others it remains as a common practice for more than 40 years at Windhoek, Namibia, or recently implemented in India. Otherwise, technical knowledge exist to face the shortage of water for supply to the large cities, mainly when the water resource is groundwater and where aquifer recharge has wastewater reuse (treated or not), to irrigate large agricultural areas, as main infiltration component. This water supply option is called indirect potable reuse.

The major concerns about both types of reuse for human consumption are regarding: i) the uncertainties in the production of safe water. ii) What risks to human health could arise if an accidental failure occurs during the water purification process. In addition, iii) the investment needed these treatment options in order to have tested purification processes and be kept under continuous supervision with monitoring and security programs.

Nowadays, technological development allows for treatment processes able to reducing or remove pollutants, such as metals or organic compounds, at lower concentrations than the limits setting in drinking water regulations. Moreover, there are treatment processes able to reduce the presence of pollutants not yet regulated, such as compounds regarding with the consumption of drugs and the use of personal care products, of which it is still unknown what might be the potential health effects, mainly after prolonged drinking water consumption.

The Mezquital Valley is the largest agricultural extension in Mexico where the wastewater generated in Mexico City is reused for the irrigation of more than 80,000 hectares, for more than 100 years. This practice of reuse has led to recharge local aquifers, where the soil has served as a medium of treatment (Soil aquifer treatment, SAT), and which are the water resources to supply of more than 500,000 inhabitants in the region. Therefore, considering the increase of available groundwater and the growing of demand for drinking water in Mexico City, it is evaluating whether to import water from aquifers of Mezquital Valley to supply 6.5 m^3/s to Mexico City.

Wastewater without any treatment has been reused in the region, and some contaminants have been found in groundwater despite the natural soil barrier, such that several pollutants are present in concentrations above the limits setting in the regulations for drinking water. Furthermore, it has been found compounds not considered in the national regulations, and are not even in international ones, as so-called emerging compounds, which include drugs and substances for personal hygiene that are discharged to the drainage coupled with human waste.

Previous studies have evaluated the quality of the Mezquital Valley aquifers and recommended the treatment of groundwater with membranes (reverse osmosis or nanofiltration) coupled to a pretreatment. In this research, these recommendations are taken up and presents the results from a preliminary approach at laboratory scale to treat water, analyzing non-conventional groundwater quality characteristics with a multiple barrier system.

Water treatment experiments with synthetic water were performed, simulating historical mean concentrations found in groundwater from Mezquital Valley, which were documented in more than ten previous studies. Water treatment was studied at a pilot plant laboratory scale, with an advanced stage system that includes reverse osmosis (1-10 Å) and ozonation processes. Two stages were incorporated as a pretreatment system with a sequence of filtration (sand/gravel, zeolite, activated carbon) and subsequent ultrafiltration process (5μ) to feed to the membrane system.

Mean concentrations of 11 parameters were simulated in synthetic water; some of them were selected considering their importance for human health protection, and others due to their role in process control, although were also found in concentrations levels greater than drinking water national regulations. Parameters selected were those observed with historical mean and/or maximum concentration greater than the limits setting in drinking water regulation, they included metals (aluminum, arsenic, cadmium, manganese, iron and lead); basic parameters such as nitrates, fluorides, chlorides, sulfates and sodium; and pathogens including helminths eggs and fecal coliforms simulated as *E. Coli*.

The preliminary results obtained from the potabilization of synthetic water, with the proposed processes fitted in the pilot plant, indicate that the treated water complies with Mexican drinking water regulation (NOM-127) for all the parameters tested. Pretreatment processes leads to a 65% mean reduction of the initial metals content. The reverse osmosis membrane appears to be more efficient for both metal and salts concentrations, and leads to an additional improvement higher than 90%. Based on these preliminary results, it is concluded that the pre-treatment processes have an important influence on improving the removal of metals, while reverse osmosis enhance the reduction of the risks by nitrates, fluorides, chlorides, sulfates and sodium. However, additional tests are required in order to assess the effect of other compounds in removal efficiencies, for example organic matter and emerging compounds (endocrine disrupter's compounds such as Nonilphenol, Bisphenol-A, and Butyl benzyl phthalate) content in synthetic water. It will contribute to confirm that safe water is generated with the scheme of multiple barriers proposed, before carrying out tests on site at pilot plant scale with groundwater from Mezquital Valley.

Pilot test design for MAR projects in Northern of Mexico

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Management of artificial recharge of aquifers (MAR, for short) is defined as a set of techniques whose main objective is to allow a better exploitation of aquifers by increasing its resources and creating reserves, through a direct or indirectly intervention in the natural water cycle.

Mexican Official Standard NOM - 014 - CNA - 2007, Requirements for artificial recharge of aquifers with treated wastewater, establishes the requirements that quality water must to have, thus operation and monitoring systems used in artificial recharge. These requirements can be evaluated at the optimal site previously selected through the implementation of a pilot project, built to temporarily operate a system of artificial recharge, assessing their technical feasibility, by monitoring the behavior of the hydraulic variables and water quality related, and its possible impact to the aquifer.

This paper presents a general proposal for the implementation of a pilot project in free aquifers in arid, northern features; by infiltration ponds, through safe reuse of treated wastewater.

Methodology depends on the availability of water and its implementation is based on the availability of ground, hydrogeological features, and specific needs of the project, site characterization and socioeconomic conditions of the area where artificial recharge is planned.

This work establishes general guidelines that define the volume of water for infiltration, dimension of the infrastructure according to the characteristics of the aquifer, the hydraulic performance and system operation cycles. Has been planning a general design of monitoring drilling in the unsaturated zone, in order to assess the evolution of the flow and quality of water passing through a porous medium.

Problems of Artificial Recharge in Unconfined Aquifers – Examples from Germany and Syria

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Keywords
MAR, Storage and recovery, annual weather prediction, inundation

Abstract

Artificial recharge (AR) for managing the groundwater table in Hessische Ried in West Germany is carried out since the eighties of the last century. Irrigation takes place during the warm months in this area. In the past the drawdown of the water table in years with less rain was extreme and damages took place in houses as well as on streets. Water from the Rhine is processed to drinking water and used for recharge. After a successful trial the recharge takes place in the unconfined aquifer. Different recharge devices are used in defined areas during the winter months. Under normal circumstances the water table is well equilibrated. In cool summers irrigation is not necessary or only for some days. As there is no long term weather prediction, the management tries not to over-recharge the aquifer. The aquifer is effluent to the River Rhine and if at the same time the river has high water (highest level before flooding) groundwater flow inverts. In those years the groundwater accumulates inundations destroy the harvest.
Recharge of groundwater in Damascus Plain is also problematic due to uncertain rainfall condition during winter. Natural recharge of the aquifer is not from direct rainfall but depends on a Karst aquifer. The Alfigeh spring is the main water supply of Damascus. In years with high precipitation the run off reaches 50 m^3/s. 7.5 m^3/s are necessary to supply the city. In a first trial the surplus was used for artificial recharge. The supply wells were used for the recharge taking the water from the network. No extra installations were necessary. The problem is focused on years with high rainfall. The aquifer is recharged rapid and the water table rises up. The recharge in wells has led to floods in tunnels. SAR is an engineering problem. Modeling of the groundwater flow demonstrates that the recharge must be distributed in a broad area. Due to the good permeability of the aquifer and the steeper gradient of the groundwater the recharged water must be recovered from new wells in an area well defined. To catch the complete surplus flow, a new channel to the recharge area has to be constructed to protect the crystal-clear water for AR with no need of processing. Without a reliable weather forecast a good steering of SAR is difficult. Numerical modeling has to provide scenarios to optimize the process.

Quantification of recharge and assessment of region benefitted due to a check dam by numerical modelling

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Keywords
Groundwater; check dam; finite deference; simulation; particle tracking

Implementation of different methods of Managed Aquifer Recharge (MAR) improve the groundwater storage in aquifers that are under stress. Check dams are often used as a method of MAR to augment groundwater storage across non perennial rivers. The objective of this study is to assess the temporal variation in the quantum of recharge and the area benefitted due to a check dam across the Arani River, north of Chennai, Tamil Nadu by numerical modelling. Monthly groundwater level measurements from the wells surrounding the check dams and water level from the check dam were used to validate the simulated groundwater levels derived from finite difference method using MODFLOW in Groundwater Modelling System. Simulation of groundwater level was carried put in the model with and without check dam helped to quantify the recharge from the check dam. Particle tracking method was used to determine the region benefited due to the recharge from check dam. The model will assist in locating new recharge structures and to identify the height and distances between them to maximize the benefit with minimum cost.

Soil Moisture Retention in Gradational Burn Severity: Arizona Ponderosa Pine Forests

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The ponderosa pine forests of the Southern Colorado Plateau stretch across a 6,000,000-acre region of northern New Mexico and Arizona, playing a crucial part in the ecology and hydrology in this semi-arid climate. Their ability to properly regenerate can be severely affected by catastrophic wildfire. The Slide Fire of 2014 burned roughly 21,000 acres of ponderosa forest near Oak Creek, Arizona, of which roughly 35% percent was classified as high intensity burn by the USFS. The purpose of this study is to determine how forest-thinning treatments can reduce the risk of high intensity wildfire, which will help to secure the soil and its moisture retaining properties. Using time domain reflectometry, the percent soil water content across areas of low to high burn severity is being measured in thinned and unthinned areas of the Slide Fire in the Coconino National Forest. These sites will be compared with proximal control and treated sites in an unburned area that is part of a concurrent study on soil moisture retention in thinned and unthinned, unburned ponderosa forests in the Coconino National Forest. I am testing the hypothesis that forest restoration treatments can reduce high intensity wildfires that cause hydrophobicity, thereby hindering the ability of the soil to retain moisture.

Temperature measurements during Managed Aquifer Recharge for safeguarding subsurface travel times

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Keywords
Subsurface travel time, tracer, heat transport, Berlin, riverbank filtration, infiltration ponds

Subsurface travel time from the area of recharge to the abstraction during Managed Aquifer Recharge (MAR) is a critical parameter to ensure sufficient attenuation for hygienic parameters and other undesired substances. The city of Berlin (Germany) relies to approx. 70% on MAR derived water for public water supply. From a hygienic perspective a minimum travel time of 50 days is demanded by German directives. Many MAR wells in Berlin are situated in 20-100 m distance from the area of recharge, but subsurface travel times were not yet evaluated in detail for a large number of individual MAR wells. This study investigates seasonal temperature fluctuactions observed in recharge water and MAR wells as a proxy for cheap and reliable travel time control. It is envisaged to include water temperature measurements in the operational routine of the water works in order to safeguard subsurface travel times for wells with critical travel time.

This study focuses on two MAR types operated by Berliner Wasserbetriebe for drinking water production: i) infiltration ponds in Berlin-Spandau and ii) induced riverbank filtration in Berlin-Tiefwerder. Time series of conservative environmental tracers (Cl, Br, $\delta^{18}O$ and $\delta^{2}H$) are measured in source water and abstraction well(s) in a fortnightly interval. The non-conservative tracer water temperature is measured manually during sampling and with automatic data loggers. The transport of the conservative tracers is mainly controlled by advection and dispersion, while temperature (heat transport) is stored both in fluid and solid phases and is, besides advective and dispersive transport, subject to thermal conduction. This heat exchange between water and sediment matrix leads to an retardation of the heat signal relative to the transport of conservative tracers. This thermal retardation is determined by comparing the time shifts between the arrival of non-conservative tracer temperature and the conservative tracers at the point of abstraction.

First results show that temperature data can be used as a cost-effective proxy for reliable travel time assessment for different types of MAR.

Topics:

- M12. Bank filtration, infiltration systems, soil aquifer treatment
- M7. Monitoring and management

The Influence of Filtration Treatment on Soil Aquifer Treatment (SAT) Infiltration Rates and Water Quality

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Keywords
Filtration Treatment, Soil Aquifer Treatment, Secondary Treated Wastewater

The soil aquifer treatment (SAT) system of the Shafdan’s Wastewater Treatment Plant in Israel, involves infiltration of secondary treated Wastewater from the Dan Region's municipalities into a localized section of the costal aquifer via 110 hectares of infiltration basins. The SAT's capacity is limited by a restricted available area for infiltration basins, and seasonal limitations in recharge rates. Currently, adjustments should be made to accommodate predicted increases in recharged wastewater. Accordingly, the main objective of our study is to examine the effect of filtration pre-treatment of the recharged wastewater on the infiltration rates (IR) and water quality of the SAT. To follow this objective, long columns (3m high, 10”d) - designed to simulate the SAT’s top soil layer, were established. The pre-SAT filtration treatments consisted of: Rapid Sand Filtration (SF), Ultra Filtration (UF), Intermittent Sand Filtration (ISF) and unfiltered secondary wastewater (EFF) as control group. For each treatment, three columns were assigned. The recharge regime followed the 72 hour interval employed in the Shafdan's infiltration basins. Specifically, 5 hours of flooding, followed by three days of infiltration and drying. The result showed a high variability between the three replicates, despite the controlled conditions. Therefore a relative IR (RIR) was calculated by normalized the measured IRs by the IRs of each column. The RIR of the ISF and UF columns was higher than the control (i.e. the EFF). In contrast, the SF columns exhibited lower values of RIR. In addition, the filtration pretreatments improved the water quality.

Understanding Groundwater Recharge Dynamics of Anicuts in Hard Rock Areas in Rajasthan, India

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Keywords
Managed aquifer recharge, Water balance, Surface water-groundwater interactions, and Rainwater harvesting

Topic area of the Abstract: M9 - MAR in developing countries

Rajasthan is the largest state of India and 91% of the State's drinking needs and 60% of its irrigation requirements are fulfilled by groundwater. The groundwater is totally dependent on the limited monsoon period but plays an important role in the livelihood of village communities. In this study, a water balance approach is used in the Dharta watershed of the Udaipur district of Rajasthan, India that predominantly a hard rock area. The approach is used to estimate recharge from four anicuts (check dams) on ephemeral streams in the study. The study is being conducted under the Managed Aquifer Recharge through Village-level Intervention (MARVI) project, a project funded by the Australian Centre for International Agricultural Research. Area and volume-elevation curves were determined by level surveys and rainfall and water levels in these structures, and in adjacent wells, were monitored through the monsoon period to calculate runoff, recharge, spill and evaporation for each structure. For one structure, no spill occurred and the runoff coefficient derived was applied to the other similar sub-catchments to estimate flow and proportion of runoff harvested. During periods of no inflow and spill, the decline in the reservoir water level is attributable to the sum of recharge and evaporation losses. Elevations of ponded water and of groundwater in nearby wells were compared to determine the nature of surface water-groundwater interaction.

The water balance analysis of anicuts monitored during the 2014 monsoon season indicate that with a rainfall of approximately 580 mm and the total wet period of between 20 to 30 days, hydraulic loadings achieved were 2.8 to 5.7m, resulting in a preliminary estimate of total recharge of 308000 m^3 which is sufficient to supply supplemental irrigation for 77 ha, and thereby supports about 18% of the irrigated agriculture in this area. Calculations suggest that total harvested water averages approximately 47% of stream flow, but varies significantly between anicuts and that the evaporative loss is approximately 9% of the captured water. The results for the 2015 monsoon season also show similar trends of recharge and groundwater dynamics. The study demonstrates an important role played by anicuts in groundwater recharge, particularly in terms of additional groundwater recharge that is possible with anicuts and provides for the first time data on the performance of anicuts as MAR structures in hard rock areas of India.

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Using numerical modelling to investigate the behavior of the shallow quaternary aquifer in the west part of Damascus and possibilities to optimize this process

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Keywords

Artificial recharge, injection, numerical modelling, waterworks, Damascus

Supplying water for Damascus and its countryside represents a challenge for decision makers in the country especially in the dry season when the discharge of the karst springs reduces to less than 2m3/s. The water amount which is discharged from Alfigeh Spring reaches 284 Million m3 in a good rainy season while this amount reduces to less than the half in a dry year with an average of about 155 Million m3 for a moderate rainy season. The water surplus which goes in Barada River is measured by the water authority in Damascus with an average of 50 Million m3 between the years 2003-2011. Damascus water supply and sanitation authority applies since 1997 artificial groundwater recharge in some of its waterworks in Damascus Plain. The maximum amount which has been applied totally in these waterworks reached 6 Million m3 which was injected through the drinking water supply network. Two detailed investigations were executed on two waterworks in Damascus Area (Kattan et al., 2010) at the campus waterworks and (Abou Zakhem and Hafez, 2012) in Almazraa waterworks. These studies concentrated on the chemical changes which take place during and after the fresh water but the behavior of the aquifer, the maximum water amount which can be recharged and the natural groundwater recharge were not considered. This paper investigates the behavior of the aquifer under the artificial recharge injection process and after it. It takes into account the natural groundwater recharge in an average rainy season. The numerical modeling delivers information about the maximum water quantitate which can be injected using the first drilled two injection wells (I, II) and compares (after calibrating) this amount when all wells are used for injection. The results of the simulation for the first injection process show that injecting water in the two wells I, II leads to level arise of 6.5m and the injection process has an effective radius of 500m. The maximum amount which can be injected through the23 waterworks wells reaches two Million cubic meter while the amount which can be injected through the wells I, II is just 900 000 cubic meter. The alternative which can be used to infiltrate more amount of water is using infiltration tranches which enables much more infiltration in a wider space.

9th International Symposium on Managed Aquifer Recharge

Water recharge reduction in the Alto Atoyac subbasin, Oaxaca, by climate change, and identification of recharge zones

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Keywords

Water availability, groundwater, Impervious areas, Remote sensing.

This study analyze the climate change effects and the loss of water recharge areas in the availability of groundwater in the Alto Atoyac Sub-basin an area where the agricultural is the main economic activity and use the el 87.6% of the groundwater. Analyzing five climate stations for the period 1951-2010 was needed to evaluate the historical water recharge in the subbasin, the modeling was conducted in the HELP 3.95D code, with two different Global circulation models (GCMs), the GFDL-CM3 and HadGEM2-EN under the climate change scenario RCP-8.5, for the 2015-2039 and 2075-2099 period. The annual recharge average for the subbasin is 169 millions of cubic meters, which is reduced by 17.97% and 65.09% for the climate change scenario for the two different periods respectively. A remote sensing analysis whit LandSat imagery from 1979 to 2013 showed an increase of 135 km^2 of impervious areas, indicating a reduction of $2.65x10^6$ m^3 of fresh water. Were identified four zones with a high recharge ratio due their geological formations, soil permeability, depth of the water table, these sites are essential to propose strategies for local adaptation to ensure the availability of water resources in this sub-basin for future generations.

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Events

Technical trip

One of the major works referred to in the Water Sustainability Program of the Basin of Mexico is
The treated wastewater will be reused for irrigation of 80,000 hectares.

The plant will be equipped with a cogeneration system for the use of biogas produced in digestion, allowing maximum energy savings.
On Friday 24th, the meeting point will be at the main hall at 8:30
Departure time will be at 9:00, in order to return approximately at 19:00h
Please do not forget to wear long-sleeved shirt and protective shoes

Dinner

A splendid four-course meal will take place in the magnificent Main Hall at
Palacio de Minería house first Engineering University in México, on schedule from 20:00 to 23:00 h.

Turist trip

The archaeological site of Teotihuacan, is found in northeastern Mexico Valley.
Certainly it is essential to know the famous Pyramids of the Sun and the Moon which can be accessed to know a world wonder.
The meeting point will be the main hall and leave at 9:00, returning at approximately at 19:00 h.

Welcome ice breacker

On Monday the Study Case, Curse and workshop will be followed by an unforgettable icebreaker in the Autonomy Hall at Palacio de Minería on schedule from 18:00 to 20:00 h.

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The Sixteenth Biennial Symposium on Managed Aquifer Recharge planned for 2018 continues a long-standing series of symposia that originated in Arizona in 1978. The Fifteenth Biennial Symposium on Managed Aquifer Recharge was combined with the Ninth International Symposium on Managed Aquifer Recharge (ISMAR 9) held in Mexico City in 2016. The Groundwater Resources Association of California and the Arizona Hydrological Society have teamed up to hold the BSMAR event with the location alternating between California and Arizona. The 2016 event will be sponsored by GRA and be held in California in 2018. Please sign up for the GRA newsletter at the GRA website at www. Grac.org so you can receive updates on GRA events, including BSMAR 16.