International Association of Hydrogeologists
the World-wide Groundwater Organisation
South African National Chapter

12th International Symposium on Managed Aquifer Recharge

STELLENBOSCH
SOUTH AFRICA
28 APRIL-2 MAY 2025

ASCE
AMERICAN SOCIETY OF CIVIL ENGINEERS

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PROGRAMME & ABSTRACT BOOK

12th International Symposium on Managed Aquifer Recharge | STELLENBOSCH SOUTH AFRICA 28 APRIL-2 MAY 2025

ISMAR12 WELCOME

Dear Delegate

This week marks a historical week in groundwater history for IAH MAR Commission and South Africa with the opening of the 12th International Symposium of Managed Aquifer Recharge. It is fantastic to welcome the world all to Africa and to South Africa and see each other face-to-face. The hard-working Local Organisation Committee under the watchful eyes of the IAH South African Chapter, invite the world to the lovely venue here in Stellenbosch, South Africa.

I would like to welcome our distinguished keynote speakers Adam Hutchinson of USA, Ricky Murray of South Africa and Peter Dillion of Australia.

Our exhibitors made great effort to bring us the latest technologies and information. From academic and research institutions, industry, and consultancies. I would like to invite our delegates to support our exhibitors as they are supporting ISMAR12.

This Symposium is sponsored by great organisation which makes this symposium possible. All your contributions are noted with great appreciation, especially the student support. The Water Tasting on Tuesday afternoon will be a “happy” event, do not miss it.

The Symposium Theme “From Theory to Implementation and Operation” places the focus on the latest research, implementation of MAR sites and the practicality of operating MAR schemes.

This is the time to share and learn from each other. This is a gathering of world minds and experiences. Let’s, use this opportunity. Our Scientific Committee developed the programme in such a way that discussions are instigated. There is plenty of time after each Oral presentation and lunchtime to discuss the presentations. The Pre-symposium workshops are complemented with the In-symposium workshops and Panel Discussions.

A special welcome to our neighbours here on the continent of Africa. Thank you for making the trip to the most southern point of Africa. Each one of us has something to learn but the world can learn from Africa as well. So please share your knowledge and experience from Africa.

Welcome to every one of you to ISMAR12, on behalf of the Local Organisation Committee.

Regards

Fanus Fourie

Chairman of the ISMAR12 LOC

Conferences Et Al
IN PERSON EXHIBITIONS HYBRID EVENTS

Event Organizer
Conferences et al - Deidre & Arnolette
www.conferencesetal.co.za

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IMPORTANT INFORMATION

Visit Stellenbosch (Tourist Info):
47 Church Street, Stellenbosch | Tel: +27 (0)21-886 4310 | info@visitstellenbosch.org

MediClinic Hospital (ER and after hour medical emergency)
Elsie du Toit Dr, Stellenbosch | Tel: +27 (0) 21 861 2000

Foreign exchange: ABSA Bank: Oude Bank Bldg, Plein Str

Travel X: 28 Bird Str, Stellenbosch

Conference Hotel and Venue: Techno Ave, Techno Park, Stellenbosch
Phone: 021 880 9500

ORGANIZING COMMITTEE

Fanus Fourie	IAH-SA - Chairperson
Kes Murray	WGA (Australia)
Nicolette Vermaak	CSIR- Scientific Committee Chairperson
John Okedi	University of Cape Town
Ricky Murray	Groundwater Africa
Reynold Chow	Stellenbosch University
Amy Allwright	Stellenbosch University (IAH-SA)
Kornelius Riemann	Umvoto
Awodwa Magingi	Department of Water and Sanitation
Ashton van Niekerk	Department of Water and Sanitation
Sumaya Clarke	University of Western Cape
Yazeed van Wyk	Water Research Commission
Philani Msimango	City of Cape Town
Daniela Benedicto van Dalen	Acacia Water (Netherlands)
Danita Hohne	GEOSS
Julian Conrad	GEOSS (IAH-SA)
Andrew Johnstone	GCS

SCIENTIFIC COMMITTEE

Nicolette Vermaak	CSIR (Chairperson)
Ricky Murray	Groundwater Africa
John Okedi	University of Cape Town
Kes Murray	Wallbridge Gilbert Aztec – Australia
Kornelius Riemann	Umvoto Africa
Awodwa Maging	Department of Water and Sanitation
Danita Hohn	Geoss
Reynold Chow	Stellenbosch University
Yazeed van Wyk	Water Research Commission

BRGM, the French geological survey, is France's leading public institution for Earth Science applications for the management of surface and sub-surface resources with a view to sustainable development.
Under partnerships with numerous public and private stakeholders, it focuses on scientific research, providing scientifically-validated information to support public policy development, training and international cooperation.

BRGM's action is in line with 6 major scientific and societal challenges:

- Geology and knowledge of the subsurface
- Groundwater management
- Risks and spatial planning
- Mineral resources and the circular economy
- Subsurface potential for the energy transition
- Digital data, services and infrastructure

BRGM has been working for more than 60 years in Africa and has gained a unique continental geological knowledge, especially in mineral resource assessment, groundwater resource management or industrial projects linked to natural hazards prevention, environmental protection and site studies.

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Protea Hotel, Stellenbosch, Winelands

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ISMAR 12 EXHIBITORS

ISMAR 12 thanks the following exhibitors for their support:

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AB PUMPS

12th International Symposium on Managed Aquifer Recharge | STELLENBOSCH SOUTH AFRICA 28 APRIL-2 MAY 2025

SOCIAL/ SPECIAL SESSIONS

Mon, 28 April	**@ 18:00**	Welcome Function – Protea Hotel (symposium hotel)
Tues, 29 April	**@ 11:00 to 13:00**	Workshop: Integrated strategies in design of new MAR schemes to minimise clogging - Declan Page
	@ 14:00 to 16:00	Workshop: Part 1: Overview of American Society of Engineers (ASCE) Standard Guidelines for Managed Aquifer Recharge Surface Spreading Facilities (ASCE/EWRI 69-19): Managed Aquifer Recharge Concepts and Planning - Adam Hutchinson and Mike Milczarek
Tues, 29 April	**@ 14:00**	Panel Discussion: MAR in Africa – SADC-GMI
	@ 16:00	Poster Session & Drinks
	@ 17:00	Water Tasting Event
Wed, 30 April	**@ 08:30 to 10:30**	Workshop: Recent advancements in MAR feasibility mapping - Catalin Stefan
	@ 11:00 to 13:00	Workshop: Part 2: American Society of Engineers (ASCE) Standard Guidelines for Managed Aquifer Recharge Surface Spreading Facilities (ASCE/EWRI 69-19): Design, O&M, Data Collection and Site Characterization Methods - Adam Hutchinson and Mike Milczarek
	@ 14:00 to 16:00	Panel discussion: Aquifer management, the microbiome and biosurveillance – from science to operations – BGRM
	@ 16:30 to 17:30	IAH MAR Commission AGM
	@ 18:30	Symposium Dinner – Smart Casual/Traditional (Coach departs at 18:00 for the dinner from the hotel.)
Thurs, 01 May	**@ 08:30 to 10:30**	Workshop Part 1: Analysis of implemented MAR scheme failure: selected global case studies - Constantin Seidl
	@ 11:00 to 12:15	Workshop Part 2: Analysis of implemented MAR scheme failure: selected global case studies - Constantin Seidl

SYMPOSIUM LUNCH

Tuesday:	Please join us for South African theme lunch in the Network/Exhibition Venue.
Wednesday:	Lunch will be served in the restaurant on the ground floor.
Thursday:	Lunch will be served in the Network/Exhibition Venue

FINAL ISMAR12 SYMOSIUM PROGRAMME

From Theory To Implementation And Operation

The following programme is final. The organizer reserves the right to make adaptions onsite if deemed necessary.
Symposium Hotel: Protea Hotel Stellenbosch and Conference Centre
Address: Techno Ave, Techno Park, Stellenbosch

The pre-symposium workshops and the symposium three day programme takes place at the hotel.

MONDAY 28 April 2025	
Venue 1	**Workshop 1: Achieving Successful Groundwater Recharge and Recovery Through Wells** - David Pyne
08:30 - 10:30	Workshop
10:30 - 11:00	**COMFORT BREAK**
11:00 - 13:00	Workshop
13:00 - 14:00	**LUNCH**
Venue 1	**Workshop 2: Technical solutions for IWRM by means of MAR schemes** - Enrique Fernández Escalante
14:00 - 16:00	Workshop
16:00 - 16:30	**COMFORT BREAK**
16:30 - 18:00	Workshop
Venue 2	**Workshop 3: Hydrogeochemistry and Managed Aquifer Recharge (MAR) - Speciation Modelling of Mixing Waters -** Corné Engelbrecht
08:30 - 10:30	Workshop
10:30 - 11:00	**COMFORT BREAK**
11:00 - 13:00	Workshop
13:00 - 14:00	**LUNCH**
Venue 2	**Workshop 4: MAR Scheme Design Considerations for Bore Recharge (Science meets Engineering)** - Russell Martin
14:00 - 16:00	Workshop
16:00 - 16:30	**COMFORT BREAK**
16:30 - 18:00	Workshop
18:00 – 19:30	Welcome Cocktail – Protea Hotel Stellenbosch

Lunch is included for all workshop participants taking place both in the morning and the afternoon.

TUESDAY 29 APRIL 2025	
Plenary *Magnifica 4*	**Opening Session**
8:30 - 8:45	**F Fourie, ISMAR12 Local Organising Committee:** *Welcome and Introduction to ISMAR12*
8:45 - 9:15	Opening Address:
	IAH-SA (Amy Allwright), IAH-MAR (Commission - Co-Chair: Enrique Fernández Escalante) and IAH (Vice President: Sub-Saharan Africa - Seifu Kebede Gurmessa)
09:15 - 09:45	**Adam Hutchinson, Keynote speaker:** *Managed Aquifer Recharge: Restoring Our Connection to Water and to Ourselves.*
10:00 - 10:30	**Ricky Murray, Keynote speaker:** *an overview of MAR in Southern Africa – lessons learnt*
10:15 - 10:20	**TDS Gold Sponsor Introduction**
10:20 - 10:30	**Symposium - General Event Guidelines**
10:30 - 11:00	**COMFORT BREAK**
Parallel 1 *Magnifica 4*	**MAR for water supply purposes - Domestic/Municipal, Agricultural and Mining** **Session chairs:** Fanus Fourie & Amy Allwright
11:00 - 11: 15	**77. D. McGibbon,** K. Riemann, K. Woolf, D. Allpass, and P. Marais: *Cape Flats Aquifer Management Scheme - Benefits of MAR for making the City of Cape Town a more resilient city (South Africa).*
11:15 - 11:30	**132. D. Gonzalez,** J. Guillaume, L. Peeters, P. Wyrwoll, J. Vanderzalm, and D. Page: *A Framework for Estimating Costs of Managed Aquifer Recharge for Different Scales and Conditions under Uncertainty.*
11:30 - 11:45	**76. J. Prinsloo,** K. Riemann, and D. Allpass: *Refurbishment of the Atlantis Water Resource Management Scheme - benefits of MAR in improving water supply resilience.*
11:45 - 12:00	**64. S. Belser,** and D Pyne: *Aquifer Storage and Recovery (ASR) Well Design in Salt-water Intruding Coastal Aquifers - a case study.*
12:00 - 12:15	**20. B. De La Loma González,** S. Espinosa, M. Minoves, and M. Ganzer: *Reclaimed Water for Managed Aquifer Recharge: A tool for water security in Barcelona.*
12:15 - 12:30	**148. N. Vermaak,** S.A. (Fanus) Fourie, E. Lukas, A. Lukas, and G. Tredoux : *The Impact of MAR and Recovery on the Langebaan Road Aquifer Unit, Western Cape, South Africa.*
12:30 - 12:45	**14. J. De Beer:** *MAR Develoment Using Infiltraiton Ponds in River Beds for Water Supply and Drought Relief to a Drought Prone Area.*

12:45 - 13:00	**107. D. Mulder:** *Managing Aquifer Sustainability through Resource Protection Zones: Application of fundamental hydrogeological principles for assessing the viability of Managed Aquifer Recharge (MAR) for a small town's water supply scheme*
13:00 - 14:00	**LUNCH**
Parallel 1 *Magnifica 4*	**Panel Discussion: MAR in Africa** **SADC-GMI**
14:00 - 16:00	Panel discussion
16:00 - 16:30	**COMFORT BREAK**
16:00 - 17:00	Poster Session in the exhibition venue
17:00 - 18:00	**WATER TASTING**
TUESDAY 29 APRIL 2025	
Parallel 2 *Magnifica 5*	**MAR Methods and technologies** **Session Chairs:** Kes Murray & Danita Hohne
11:00 - 11: 15	**1. N. Hartog**, G. Schout, S. Beernink, and L. Brokx: *Overlooked: Non-uniform flow distribution across wellscreens for ASR of fresh water in saline aquifers.*
11:15 - 11:30	**32. Q. Hull,** M. Milczarek, and J. Keller: *A framework for estimating costs of Managed Aquifer Recharge for different scales and conditions under uncertainty.*
11:30 - 11:45	**119. E. Fernández Escalante:** *Hydrogeological Studies to Determine a MAR Site Feasibility, Pragmatic Approach: Example for Santiuste Basin MAR site, Central Spain.*
11:45 - 12:00	**11. N. Sharma,** M.F. Alam, P. Pavelic, and A. Sikka: *Evaluating the Efficiency of Managed Aquifer Recharge Interventions in the Ganges Basin, India.*
12:00 - 12:15	**25. P. A. M. Doulkom,** M. Koïta, Y. Rossier, J.M. Vouillamoz, C.A. Biaou, F. Lawson, M.B. Kafando, O.R. Yonaba, and L.A. Mounirou: *Design and Implementation of High-potential MAR System*
12:15 - 12:30	**74. K. Woolf,** D. MiGibbon, K. Riemann, and D. Allpass: *MAR in the Cape Flats Aquifer: A case study on injection methods and borehole design.*
12:30 - 12:45	**114. S. Kreipl,** A. van Doorn, H. Merton, M.M.A. Groen, M. Bakker, and B.M. van Breukelen: *Utilizing Horizontal Wells for Aquifer Storage and Recovery: lessons from a pilot study on Texel Island, the Netherlands.*
12:45 - 13:00	**86. A.Hutchinson,** M.Becker and P. O'Connell: *Mounded or Clogged? Using fiber optic distributed temperature sensing to diagnose and monitor basin behavior.*
13:00 - 14:00	**LUNCH**

Parallel 2 *Magnifica 5*	**MAR Methods and technologies** **Session Chairs:** Ricky Murray & Awodwa Magingi
14:00 - 14:15	**70. T. Dorsch,** M. Hussein, and M. Al Dajani: *Key aspects of the Management of One of the Largest ASR Systems in the World.*
14:15 - 14:30	**137. M. van der Schyff,** T. Kanyerere, and S. Clarke: *Field Pilot Study on Enhancing MAR: evaluating activated charcoal's effectiveness for water quality in Atlantis.*
14:30 - 14:45	**118. E. Fernández Escalante,** S. Fernández Cordero, and N. Crespo Arribas: *Checking 20 Infiltration Methods to Determine an Accuracy Rangking Using a Digital Twin, Santiuste Basin, Los Arenales Living Lab, Spain*
14:45 - 15:00	**105. R. Glaude,** N. Simon, and S. Brouyère: *Quantifying Infiltration Rates within a Managed Aquifer Recharge Pilot Site using Distributed Temperature Sensing Technology.*
15:00 - 15:15	**2. N. Hartog,** G. Schout, and T. Sweijen: *Aquifer Storage and Recovery: Design considerations from science to practice.*
15:15 - 15:30	**78. S. Martos-Rosillo,** N. N. Fernández, J. Jódar, and C. Marín-Lachado: *Ancestral Nature-based Solutions for Managed Aquifer Recharge in Spain.*
15:30 - 15:45	**91. S. Sasidharan,** R. Goncalves de Souza Gomes, S. Kumar, E.J. Bertrand, B.S. Bracamontes, and T.T.M.E. Silva: *Multibeneficial Managed Aquifer Recharge: Integrating advanced monitoring and novel source water for groundwater sustainability.*
15:45 - 16:00	**104. R. Glaude,** S. Brouyère, S. Lacorte, A. Jurado, and E. Pujades: *Batch Experimenta: a tool to evaluate the fate of organig contaminants in MAR prefeasibility studies.*
16:00 - 16:30	**COMFORT BREAK**
16:00 - 17:00	Poster Session in the exhibition venue
17:00 - 18:00	**WATER TASTING**
TUESDAY 29 APRIL 2025	
Parallel 3 *Magnifica 3*	**Workshop: Integrated strategies in design of new MAR schemes to minimise clogging** - Declan Page
11:00 - 13:00	**Workshop**
13:00 - 14:00	**LUNCH**
Parallel 3 *Magnifica 3*	**Workshop: Part 1: Overview of American Society of Engineers (ASCE) Standard Guidelines for Managed Aquifer Recharge Surface Spreading Facilities (ASCE/EWRI 69-19): Managed Aquifer Recharge Concepts and Planning** - Adam Hutchinson and Mike Milczarek
14:00 - 16:00	**Workshop**

16:00 - 16:30	**COMFORT BREAK**
16:00 - 17:00	Poster Session in the exhibition venue
17:00 - 18:00	**WATER TASTING (***Magnifica 4)*

WEDNESDAY 30 April 2025	
Parallel 4 *Magnifica 4*	**MAR in relation to environmental, sustainability and climate change adaptation** **Session Chairs:** Kornelius Riemann & Daniela Benedicto van Dalen
08:30 - 08:45	**164. N. Devau,** G. Picot-Colbeaux, A. Manlay, V. Debois, P. Goderniaux, L. Jehanno, and B. Meire: *Is Managed Aquifer Recharge an Option to Tackle Dysfunction in Sewer Network Induced by Groundwater Flow Infiltration on the Urban Community of Lens-liévin (Northern France)?*
08:45 - 09:00	**158. K. Murray:** *A Case Study of MAR for Sustainable Mine Water Management in Southern Africa.*
09:00 - 09:15	**120. E. Fernández Escalante,** J.D. Henao Casas, C. Moreno de Guerra Per, M.D. Maza Vera, and C. Moreno Valverde: *Unmanaged Recharge of Aquifers from Transverse Structures in Spanich River Courses: a GIS-based comparison between intentional and unintended MAR figures.*
09:15 - 09:30	**106. E. van Houtte,** T. Rogier, J. van Eeghem, and J. Verbauwhede: *Water Recycling Combined to Managed Aquifer Recharge in the Dunes: long time experience at Koksijde (Flanders, Belgium).*
09:30 - 09:45	**66. A. González-Ramón,** A. Fernández-Ayuso, M. Rodríguez-Rodríguez, H. Aguilera, T. Zakaluk, N. Naranjo, C. Marín-Lechado, J. Jódar, and S. Martos-Rosillo: *Preliminary Hydrological Assessment of "Pesqueras" in Gredos Mountain Range (Spain) as Ancestral Artificial Recharge Systems.*
09:45 - 10:00	**100. J. Melady,** and R. Dougherty: *Managed Aquifer Recharge for Thermal Loading Mitigation and Enhancement of Instream Habitat.*
10:00 - 10:15	**18. L. R. Lazarus:** *MAR: A Vital Component in Designing Livable Urban Waterways for Environmental Restoration in Cape Town.*
10:15 - 10:30	**128. T. Mumberg,** L. Ahrens, P. McCleaf, and P. Wanner: *A Swedish Case Study on Tracing Per- and Polyfluoroalkyl Substances (PFAS) through a MAR System.*
10:30 - 11:00	**COMFORT BREAK**
Parallel 4 *Magnifica 4*	**MAR in relation to environmental, sustainability and climate change adaptation** **Session Chairs:** Philani Msimango & Andrew Johnstone

11:00 - 11:15	**30. M.B. Demlie,** and H. Msweli: *Assessing the Potential of Managed Aquifer Recharge from Treated Wastewater in the Greater Durban Metropolitan Region, South Africa.*
11:15 - 11:30	**101. V. Parry,** R. Schneuwly, K. Carden, H. Thouin, C.G. Bryan, N. Baran, C. Soulier, and G. Alexis: *Potential Bioindicators of Aquifer Health: a preliminary investigation at a Cape Flats stormwater infiltration pond.*
11:30 - 11:45	**6. T. Mathivha,** N. Vermaak, A. Magingi, and P.J. Oberholster: *Potential Ecological Impacts of Managed Aquifer Recharge on Wetlands in the Langebaan Road Aquifer Unit.*
11:45 - 12:00	**149. C. Cherubini,** M. Sufyan**,** G. Martelli, and D. Goi: *MAR as an Effective Climate Change Adaptation Mechanism: a case study in Friuli Venezia Giulia Region, Italy.*
12:00 - 12:15	**35. S.N. Singh,** V.M. Patel, and Y. Atterwala: *Managed Aquifer Recharge through Precast Modular Systems with High-performance Recharge Wells Using Johnson Screens and Rain Quantification Systems in Gujarat's Varied Terrain - Case studies.*
12:15 - 12:30	**157. T. Madlala:** *Isotopic Investigation of Groundwater-Surface Water Interactions in Managed Aquifer Recharge Systems: a case study of the Lower Berg River Catchment, Western Cape Province, South Africa.*
12:30 - 12:45	**111. B. Makhahlela,** V. Parry, R. Schneuwly, S. Fernandes, P. Msimango, K. Carden, H. Thuin, J. Harris, and C.G. Bryan: *Microbial Biodiversity and Geochemistry of the Atlantis MAR Site: Initial developments towards a biosurveillance toolkit.*
12:45 - 13:00	**129. N. Weisbrod,** T. Turkltaub, E. Bar-Zeev, and A. Furman: *Revisit the SAT: Can we improve its efficiency and operation?*
13:00 - 14:00	**LUNCH**
Parallel 4 *Magnifica 4*	**Panel discussion : Aquifer management, the microbiome and biosurveillance – from science to operations** **BGRM**
14:00 - 16:00	**Panel discussion**
16:00 - 16:30	**COMFORT BREAK**
	AGM
16:30 - 17:30	IAH MAR Commission Annual General Meeting
18:00 - 22:00	**Symposium Dinner in Stellenbosch** Busses depart from hotel for dinner venue at 18h00
WEDNESDAY 30 April 2025	
Parallel 5 *Magnifica 5*	**Quality and Clogging Issues: Predictions and Management in Basins and Bores** **Session Chairs:** Reynold Chow & Yazeed van Wyk

08:30 - 08:45	**156. V. Troelstra,** A. Störiko, and B.M. van Breukelen: *Pathogen Transport and Fate During Riverbank Filtration.*
08:45 - 09:00	**95. C. Engelbrecht:** *Injection Bore Clogging Prediction and Management: Case studies from Southern Africa and Australia.*
09:00 - 09:15	**31. M. Milczarek:** *Soil Aquifer Treatment, Pathogens and Organic Carbon Removal Revisited.*
09:15 - 09:30	**39. U.E. Bollmann,** C.N. Albers, T.M.M. Karlsson, J.H. Christensen, and A.R. Johnsen: *Stormwater Runoff in European Cities: Risk of urban groundwater pollution due to SUDS?*
09:30 - 09:45	**153. A. Hutchinson,** *Removal of Suspended Solids and Water Quality Improvements from Riverbed Filtration - Eight Years of Demonstration Testing in Orange County California.*
09:45 - 10:00	**145. D. Page,** J. Awad, J. Vanderzalm, G. Puzon, F. Mathes, M. Taylor, J.-W. Liu, G. Dojchinov, A. Warden, C. Turnadge, K. Barry, J. Wiley, R. Rojas, J. Wu, L. Ling, S. Currie, and J. Jaeger: *Cost Effective Clogging Management During Managed Aquifer Recharge.*
10:00 - 10:15	**124. L. Augustin,** and T. Baumann: *Monitoring Dynamics in River Water Quality and Quantity of the River Günz in Bavaria (GER).*
10:15 - 10:30	
10:30 - 11:00	**COMFORT BREAK**
Parallel 5 *Magnifica 5*	**Quality and Clogging Issues: Predictions and Management in Basins and Bores** **Session Chairs:** Reynold Chow & Julian Conrad
11:00 - 11:15	**26. D. Botha,** J.C. Truter, E. Bester, and G.M. Wolfaardt: *Engineered Fungal Biofilms in a Novel Biosensor for the Real-time Monitoring of Estrogenic Endocrine Disrupting Chemicals.*
11:15 - 11:30	**40. U.E. Bollmann,** T.B. Bech, N. Vermaak, A. Magingi, S. Clarke, C.K. Hansen, and J. Aamand: *Fate of Pathogens and Organic Micropollutants in MAR: Enhancing removal efficiency by reactive layers.*
11:30 - 11:45	**89. R. Nardacci,** M. Widdowson, C. Bott, C. Wilson, D. Holloway, and J. Sparks: *Investigating MAR Well Clogging Potential for Highly Purified Wastewater in a Deep Coastal Plain Aquifer.*
11:45 - 12:00	**131. A. Furman,** N. Katsevman, and N. Weisbrod: *Addressing the Soil Aquifer Treatment Bottleneck.*
12:00 - 12:15	**150. T. Pichler,** S. Koopman, and H. Prommer: *Molybdenum Mobility during Managed Aquifer Recharge in Carbonate Aquifers.*
12:15 - 12:30	**141. R. Martin:** *Clogging Indicators: Werribee ASR case study.*
12:30 - 12:45	**112. R. Schneuwly,** K. Carden, and C.T. Tanyanyiwa: *Natural Attenuation of Stormwater Contaminants During Infiltration and Storage in a Shallow Primary Aquifer.*

12:45 - 13:00	**60. M. Mokhethi,** L. Towers, A. Roychoudhury, and R. Chow: *Assessing the Risks of Emerging Contaminants from Treated Effluent as Source Water in Atlantis.*
13:00 - 14:00	**LUNCH**
Parallel 5 *Magnifica 5*	**MAR for water supply purposes - Domestic/Municipal, Agricultural and Mining** **Session Chairs:** Kes Murray & Amy Allwright
14:00 - 14:15	**22. D. Hohne,** F. Fourie, P. Lourens, and S. Esterhuyse: *A MAR Framework in the South African Context for Fractured Rock Aquifer.*
14:15 - 14:30	**42. M. Villagrán,** L. Piepers, K.H. Jensen, T.O. Sonnenborg, and M. Huysmans: *Can a Local Solution Have a Regional Impact? Evaluating the influence of weirs in agricultural drainage ditches in Flanders, Belgium.*
14:30 - 14:45	**4. A. Magingi,** F. Fourie, N. Vermaak, P.J. Oberholster, and T. Mathivha: *Assessment of Wetlands as an Indicator for MAR site seleciton in Langebaan Road Aquifer.*
14:45 - 15:00	**3. E.A.J. Derks,** and R. Dijksma: *Assessing Managed Aquifer Recharge by Indigenous Communities in Mountainous Watersheds of Oaxaca, Mexico.*
15:00 - 15:15	**23. A. Ross:** *Water Banking to Increase Water Security and Resilience to Drought.*
15:15 - 15:30	**127. T. Hanna:** *Critical Aspects of Well Design for MAR.*
15:30 - 15:45	**12. D. Benedicto van Dalen:** *Infiltration Water Quality Concerns and Policy Development of ASR Systems: a comparison study of three case studies in the Netherlands.*
15:45 - 16:00	**162. S. Brouyère,** S. Durieux, R. Glaude, P. Orban, J.-M. Comprère, and J. Derouane: *Managed Aquifer Recharge in WALlonia: the MARWAL project.*
16:00 - 16:30	**COMFORT BREAK**
	AGM
16:30 - 17:30	IAH MAR Commission Annual General Meeting
18:00 - 22:00	**Symposium Dinner in Stellenbosch**
WEDNESDAY 30 April 2025	
Parallel 6 *Magnifica 3*	**Workshop: Recent advancements in MAR feasibility mapping -** Catalin Stefan
08:30 - 10:30	**Workshop**
10:30 - 11:00	**COMFORT BREAK**

Parallel 6 *Magnifica 3*	**Workshop: Part 2: American Society of Engineers (ASCE) Standard Guidelines for Managed Aquifer Recharge Surface Spreading Facilities (ASCE/EWRI 69-19): Design, O&M, Data Collection and Site Characterization Methods -** Adam Hutchinson and Mike Milczarek
11:00 - 13:00	**Workshop**
13:00 - 14:00	**LUNCH**
Parallel 6 *Magnifica 3*	**MAR in relation to environmental, sustainability and climate change adaptation** **Session Chairs:** John Okedi & Andrew Johnstone
14:00 - 14:15	**113. A. Gutierrez,** B. Mougin, J. Nicolas, V. Bault, C. Lasher-Scheepers, P. Msimango, L. Fisher-Jeffes, and A. Ncube: *Near Real Time Groundwater Forecast for the MAR Projects of Cape Town, South Africa.*
14:15 - 14:30	**43. C. Stefan,** J. Glass, A. Conrad, R. Heim, A. Chkirbene, K. Khemiri, C.F. Panagiotou, T. E. Leitão, T.N. Martins, M.M. Oliveira, M. Horovitz, K. Alpes, S. Ghannem, R. Bergillos, and J. Andreu: *The MAR Agreements: A new governance approach for advancing the MAR implementation.*
14:30 - 14:45	**103. R. Murray,** *Kolomela Mine - ten years of borehole injection in a shallow unconfined aquifer for surplus mine water disposal.*
14:45 - 15:00	**51. M. Camporese,** R. Chow, A. Furman, B. Gatto, C. Lauvernet, C. Massari, and A. Szymkiewicz: *Aiming at Sustainable Aquifer Recharge to Enhance Resilience of Groundwater Services under Increased Drought Risk.*
15:00 - 15:15	**143. D. Page,** J. Vanderzalm, K. Barry, D. Gonzalez, J. Awad, and C. Seidl: *Lessons from the Rise and Fall of Managed Aquifer Recharge (MAR) in Langhorne Creek Region to Manage Drought Resilience.*
15:15 - 15:30	**139. T. van Dooren,** K. Raat, N. Hartog, and G. Zwolsman: *Optimizing MAR in Coastal Dunes by Extracting Brackish Groundwater: a field pilot in the Netherlands.*
15:30 - 15:45	**117. H. Ndakola,** and J. Okedi: *Groundwater Quantity and Quality Assessment for Aquifer Recharge in Ohangwena Region, Namibia.*
15:45 - 16:00	**54. M.F. Alam,** M.E. McClain, A. Sikka, and S. Pande: *Planning Sustainable and Equitable Managed Aquifer Recharge Interventions: An agent-based socio-hydrology approach.*
	AGM *(Magnifica 4)*
16:30 - 17:30	IAH MAR Commission Annual General Meeting
18:00 - 22:00	**Symposium Dinner in Stellenbosch**

THURSDAY 1 May 2025	
Parallel 7 *Magnifica 4*	**MAR for water supply purposes - Domestic/Municipal, Agricultural and Mining** **Session Chairs:** Julian Conrad & Nicolette Vermaak
08:30 - 08:45	**161. A. Palma,** and M.I. Victor Franco: *Managed Aquifer Recharge Plan for Mexico City.*
08:45 - 09:00	**98. L. Speijer,** M. Zawadzki, M. Maertens, W. Boënne, J. Dams, and M. Huysmans: *Sub-irrigation as Managed Aquifer Recharge Technique: The impact on groundwater levels and flow.*
09:00 - 09:15	**125. T. Baumann, a**nd L. Augustin: *Coupling Stormwater Protection and Water Suppl for Hop Gardens: first results from a pilot plant.*
09:15 - 09:30	**53. S.R. Dennis**, A. Johnstone, J. Tanner, R. Powell, and D. Diongue: *Managed Aquifer Recharge from Rooftop Rainfall Collection to Ensure Sustainable Off-the-grid Groundwater Supply.*
09:30 - 09:45	**34. L. Piepers,** M. Villigrán, J. van Orshoven, M. Huysmans, and J. Diels: *Assessing the Regional Impact of Weirs in Agricultural Drainage Ditches Using a Numerical Model: A case study in northeastern Belgium.*
09:45 - 10:00	**140. S.A. (Fanus) Fourie,** and D. Hohne: *The Design and Implementation of Aquifer Recharge Enhancement Schemes in South Africa*
10:00 - 10:15	**142. J. Vanderzalm** and co-author D. Page, S. Priestley, A. Deslandes, H. Groves, S. Kim, and C. Seidl: *Upper King River Managed Aquifer Recharge (MAR).*
10:15 - 10:30	**88. M. Faneca Sanchez,** J. King, G.O. Essink, and M. van der Vat: *Conceptual Design of a MAR System for a Brackish Aquifer in the Mekong Delta, Vietnam.*
10:30 - 11:00	**COMFORT BREAK**
Parallel 7 *Magnifica 4*	**MAR for water supply purposes - Domestic/Municipal, Agricultural and Mining, etc. and Awareness, Education and training on MAR** **Session Chairs:** Ricky Murray & Yazeed van Wyk
11:00 - 11:15	**28. D.L. Carnow,** and T.O.B. Kanyerere: *Using Digital Transformative Technologies to Detect, Screen and Remediate CEC's and POPS, Cape Flats Aquifer, South Africa.*
11:15 - 11:30	**58. P. Jokela,** J. Mäki-Torkko, and R. Rämä: *A 30-year-old Managed Aquifer Recharge Project for Drinking Water Production: Lessons learned.*
11:30 - 11:45	**52. M. Schirmer,** D. La Cecilia, and C. Moeck: *Large-scale and Long-term MAR Application of an Important Swiss Water Supply Company.*

11:45 - 12:00	**84. J. Okedi,** and K. Manoharan: *Building Resilience in Water Supply with Managed Aquifer Recharge with Recycled Wastewater - case of Paarl Town in South Africa.*
12:00 - 12:15	**5. R. Martin,** J. Frdelja, and D. Trigg: *Direct Harvesting of Roof Rainwater for MAR across New Urban Developments in Ballarat.*
12:15 - 13:00	**LUNCH**
Parallel 7 *Magnifica 4*	**Awareness, Education and training on MAR** **Session Chairs:** Kornelius Riemann & Philani Msimango
13:00 - 13:15	**5. D. Benedicto van Dalen** : *Oasis Flow: An assessment tool for municipal water footprint and Managed Aquifer Recharge across three European pilot sites - MARCLAIMED project.*
13:15 - 13:30	**81. P.S. Juuti**, R.P. Juuti , T.S. Katko, J.J. Hukka, and P. Dillon: *Engaging with stakeholders proved vital for uptake of Managed Aquifer Recharge in Community Water Supplies.*
13:30 - 13:45	**126. S. Hlahla,** A. Abrams, L. Grootboom, and K. Carden: *Developing a Local Implementation Guideline for Managed Aquifer Recharge in Combination with Blue-green Infrastructure.*
13:45 - 14:00	**62. E. Fernández Escalante,** H. Barbosa, and E. López-Gunn: *Co-managed Aquifer Recharge (CO-MAR): Evolution of the concept due to Spanish and Peruvian stakeholders participation.*
14:00 - 14:15	**V. Matta,** D. Duncan, E. Shaylor, L. Verstraete, and C. Stefan: *MAR in humanitarian contexts*
Plenary *Magnifica 4*	**Closing ceremony** **Session Chair:** Fanus Fourie
14:15 - 14:45	**Closing keynote: 67. P. Dillon:** *Testing the robustness of MAR policy settings for Water Supply Security under Climate Change.*
14:15 - 14:45	Symposium Presentation Prize Giving
	ISMAR13 Presentation
	Thank you notes and handing over to ISMAR13
THURSDAY 1 May 2025	
Parallel 8 *Magnifica 5*	**Suitability Mapping to Site Selection** **Session Chairs:** Danita Hohne & Daniela Benedicto van Dalen
08:30 - 08:45	**8. C. Stefan,** T. N. Martins, A. Chkirbene, K. Khemiri, C. F. Panagiotou, S. Ghannem, R. Bergillos, and G.Y. Ebrahim: *Guiding Principles for Geospatial MAR Feasibility Mapping.*
08:45 - 09:00	**97. A. Gutierrez,** J. Perrin, A Brugeron, Y. Caballero, A. Pécastaings, M. Boru, D. Deferso, N. Adela and A. Adugna: *Managed Aquifer Recharge Suitability Mapping in Eastern Ethiopia (Dire Dawa, Harar, Jijiga areas).*

09:00 - 09:15	**68. B. Vandala**, and G. Mahed: *Managed Aquifer Recharge Site Selection in the Nelson Mandela Bay Using Different Multi-criteria Decision Analysis Techniques.*
09:15 - 09:30	**44. T.S. Bording,** E.A. Auken, and P.K. Maurya: *Ground-based TEM for Efficient Pre-investigation of Managed Aquifer Recharge Sites.*
09:30 - 09:45	**75. P. Geldenhuys,** K. Riemann, J. Prinsloo, J. Weitz, E. Wise, and D. Allpass: *Proposed Expansion of the Atlantis Aquifer: An integrated approach combining geophysics and remote sensing investigations.*
09:45 - 10:00	**133. D. Gonzalez,** D. Page, and L. Peeters: *Managed Aquifer Recharge Opportunity Mapping in New South Wales.*
10:00 - 10:15	**37. D. Archer,** C.J. Truter, V. Rambau, P. Msimango, and G. Wolfaardt: *Exploring the Relationship between Effect-based Analysis, Emerging Pollutants, and Conventional Water Quality Parameters in a Threatened Coastal Aquifer.*
10:15 - 10:30	**115. N. Igwebuike,** T. Halihan, and T. Kanyerere: *Geophysical Applications in Managed Aquifer Recharge: insights from coastal and karst aquifer systems.*
10:30 - 11:00	**COMFORT BREAK**
Parallel 8 *Magnifica 5*	**Regulatory Lessons: Safe and Reasonable Requirements for Testing to Operating** **Session Chairs:** Nicolette Vermaak & Awodwa Magingi
11:00 - 11:15	**121. E. Fernández Escalante**, J.D. Henao Casas, and R. Calero Gil: *Water Quality from Spanish Managed Aquifer Recharge (MAR) Sites to Support National-scale Guidelines Avoiding Maximun Allowable Concentrations.*
11:15 - 11:30	**63. M. Sapiano,** E. Fernández Escalante, C. Schutz, and O. Gaerty: *Governance of Managed Aquifer Recharge: Insights from the European Union's regulatory framework.*
11:30 - 11:45	**21. D. Hohne,** F. Fourie, P. Lourens, and S. Esterhuyse: *Legislative Issues in South Africa for the Implementation of MAR Schemes.*
11:45 - 12:00	**163. G. Pico-Colbeaux,** N. Devau, M. Pettenati, and J.-C. Maréchal: *MAR's Strategy Back in France Following the Latest Consecutive Droughts.*
12:00 - 12:15	**57. F. Fourie, and S. Singh**: *The Artificial Recharge Strategy of South Africa: The ongoing cycle of research, knowledge generation and implementation.*
12:15 - 13:00	**LUNCH**
Parallel 8 *Magnifica 5*	**The Economics of MAR** **Session Chairs:** John Okedi & Kes Murray
13:00 - 13:15	**24. A. Ross:** *Benefits and Costs of Water Banking: An integrated water governance solution*

13:15 - 13:30	**134. C. Seidl,** D. Page, and S. Wheeler: *Managed Aquifer Recharge in Australian Water Legislation, Regulation and Policy: and anticommons problem?*
13:30 - 13:45	**92. Da. Mance,** B.H. Černeha, and Di. Mance: *Economic Institutional Mechanism Design of Managed Aquifer Recharge: Insights from the BLUE RECHARGE Project.*
13:45 - 14:00	**M. Arinaitwe,** and J. Okedi: *IOT-based Data and Analytic Hierarchy Process to Map Groundwater Recharge with Stormwater.*
14:00 - 14:15	**M.F. Alam,** P. Pavalic, J. Lautze, and A. Sikka: *Managed Aquifer Recharge to Co-manage Floods and Droughts: Transferring lessons from Asia to Africa.*
Plenary *Magnifica 4*	**Closing ceremony** **Session Chair:** Fanus Fourie
14:15 - 14:45	**Closing keynote: 67. P. Dillon:** *Testing the robustness of MAR policy settings for Water Supply Security under Climate Change.*
14:45 - 15:15	Symposium Presentation Prize Giving
	ISMAR13 Presentation
	Thank you notes and handing over to ISMAR13
THURSDAY 1 May 2025	
Venue 3 *Magnifica 3*	**Workshop Part 1: Analysis of implemented MAR scheme failure: selected global case studies - Constantin Seidl**
08:30 - 10:30	**Workshop**
10:30 - 11:00	**COMFORT BREAK**
Venue 3 *Magnifica 3*	**Workshop Part 2: Analysis of implemented MAR scheme failure: selected global case studies - Constantin Seidl**
11:00 - 12:15	**Workshop**
12:15 - 13:00	**LUNCH**
Plenary *Magnifica 4*	**Closing ceremony** **Session Chair:** Fanus Fourie
14:15 - 14:45	**Closing keynote: 67. P. Dillon:** *Testing the robustness of MAR policy settings for Water Supply Security under Climate Change.*
14:45 - 15:15	Symposium Presentation Prize Giving
	ISMAR13 Presentation
	Thank you notes and handing over to ISMAR13

FRIDAY 2 May 2025	
Field Excursions departing from the hotel. All delegates booked on the field excursions will receive the full itinerary of the excursion they selected. Pre-booking for the excursions, when registering to attend the symposium, is essential.	
Depart 08:00	**Field Excursion 1** The Atlantis Water Resource Management Scheme *Field Excusion Sponsored by EDRS*
Depart 08:00	**Field Excursion 2** The Cape Flats Aquifer Management Scheme
Depart 08:00	**Field Excursion 3** The Elandsfontein Phosphate Mine and Langebaan Road Aquifer MAR schemes *Field Excusion Sponsored by GEOSS*

Important: The programme may be changed by the organizers without prior notice.

ISMAR12 SYMPOSIUM PRELIMINARY POSTER PROGRAMME

28 April to 2 May 2025

	POSTER PRESENTATIONS
Slot	Poster information
1	96. **J. Myburgh**, P. Ravenscroft, and T. Bell: *Implementaton of Managed Aquifer Recharge for Sustainable Municipal Water Supply, Prince Albert, South Africa*
2	7. **C.F. Panagiotou**, J. Glass, and C. Stefan: *Assessing the Impact of Managed Aquifer Recharge in Akrotiri Coastal Aquifer (Cyprus) via Groundwater Modelling*
3	72. **T. Funiselo**, and T. Kanyerere: *Investigating Groundwater Hydrodynamics of Managed Aquifer Recharge System for Improved Sustainable Groundwater Supply, Limpopo, South Africa*
4	50. **A. Nicholls**, *Interpretation of groundwater modelling scenarios for Managed Aquifer Recharge, Langebaan Road, South Africa*
5	90. **K. Nkokou**, L. Baloyi, and G. van Dyk: *Managed Aquifer Recharge (MAR) for Rural Water Supply: Groundwater mapping for Carnavon*
6	36. J. Clearwater, V. Cypaite, and **K. Daines**: *Volsung: What Can Groundwater Modelers in MAR Applications Learn from the Geothermal Energy Industry*
7	82. **T. Mabula**, and K. Masindi: *Evaluating the Hydrogeological Environment of Johannesburg and Surrounding Areas for Managed Aquifer Recharge*
8	47. **Q. Nasson**, and T. Kanyerere: *Characterizing Palaeochannel Aquifer Systems to Support Groundwater Development for Improved Augmentation of Water Supply Systems, Western Cape, South Africa*
9	122. **H.E. Mapindani**, and T. Kanyerere: *Assessment of Aquifer Performance in Remediating Groundwater Contaminants, Polokwane Managed Aquifer Recharge Scheme, South Africa*
10	79. **N. Ndema**, S. Clarke, and T. Hlatywayo: *Evaluating the Possible Microplastic Contamination in a Managed Aquifer Recharge System*
11	61. **M. Sapiano**, C. Schütz, E. Fernández Escalante: *MARSOLUT-policy-brief: Essentials on Managed Aquifer Recharge for policy makers and water managers*
12	85. **H. Barbosa**, H. Casas, K. Schwartz, and M. Gilek: *Managed Aquifer Recharge Skewed Towards Technical and Physical Models: What does it mean in practice?*
13	73. **J. Jódar**, T. Zakaluk, A. González, and C. Marin: *Medieval System of Managed Aquifer Recharge in Sloping Aquifers of Sierra Nevada (Spain)*
14	94. **Di. Mance**, B.H. Černah, and Da. Mance: *Examples of Managed Aquifer Recharge Practices on the Croatian Coast*
15	**27. K. Masindi,** T.M. Mabula, Z. Khuzwayo, and L.K. Motaung: *Assessment of Potential Managed Aquifer Recharge Sites in Johannesburg, South Africa: A GIS and remote sensing approach.*

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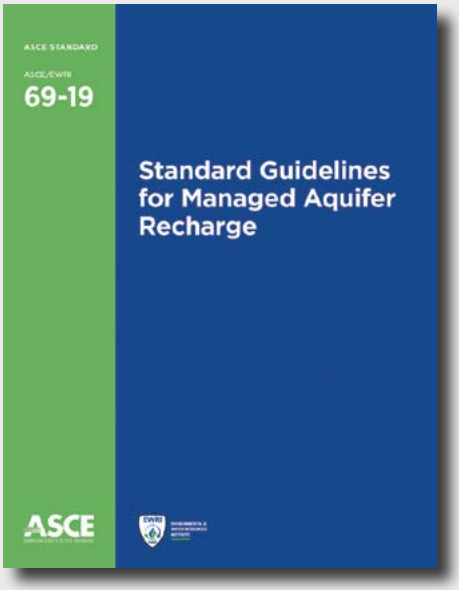
EWRI ENVIRONMENTAL & WATER RESOURCES INSTITUTE

ASCE Standards Order Form

Standard Guidelines for Managed Aquifer Recharge

ASCE/EWRI 69-19



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ASCE/EWRI 69-19, provides a thorough and up-to-date description of Managed Aquifer Recharge (MAR) projects. Ongoing demand for water supplies and the need for water storage have led MAR to becoming an increasingly important component for both storage and supply in regional water planning and management. Over the past several decades, much has been learned regarding how to design and implement a successful, cost-efficient MAR project and what pitfalls exist that prevent MAR success. With this standard, many water resources professionals can become aware of the benefits, techniques, standard practices, and applications of MAR.

The standard includes details on planning, design, construction, operation, monitoring, and closure of MAR projects, along with background information on groundwater and MAR concepts. It also describes the economic, environmental, and legal considerations, such as water rights, laws, and regulations, as well as field investigation and testing procedures that may apply.

The content of this standard has been designed to meet the needs of water resources planners and stakeholders during the initial evaluation and planning phases, along with the needs of engineers, hydrologists, and other professionals for standardization of MAR practices from conceptualization to operation.

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12th International Symposium on Managed Aquifer Recharge | STELLENBOSCH SOUTH AFRICA 28 APRIL-2 MAY 2025

Abstracts for Oral Presentations

Tuesday, 29 April 2025

Opening session:

Keynote 1:

REMOVAL OF SUSPENDED SOLIDS AND WATER QUALITY IMPROVEMENTS FROM RIVERBED FILTRATION – EIGHT YEARS OF DEMONSTRATION IN ORANGE COUNTY CALIFORNIA

Adam Hutchinson[1]

[1] Orange County Water District, California; Email: ahutchinson@ocwd.com

Abstract:

This keynote explores how Managed Aquifer Recharge (MAR) is more than a technical solution — it's a powerful tool for reconnection. Through global stories and personal experiences, the talk highlights how MAR helps restore our relationship with nature, renews our perspective on water as a resource, and strengthens collaboration across communities and agencies. Join us as we reimagine what's possible when we align innovation with nature's rhythms.

Keynote 2:

AN OVERVIEW OF MAR IN SOUTHERN AFRICA – LESSONS LEARNT

E.C. "Ricky" Murray

Groundwater Africa, Cape Town, South Africa; email: ricky@groundwaterafrica.co.za

Abstract

Research into the effectiveness and potential of MAR in South Africa took a leap forward with support from the Water Research Commission in the late 1990s and led to the Department of Water and Sanitation (DWS, formerly the Department of Water Affairs) developing a MAR strategy for the country. Prior to this, infiltration-enhancing schemes had been constructed throughout Southern Africa without monitoring systems to assess their effectiveness. With a change in water and environmental laws, an increasing water demand, and by popularizing the MAR concept, numerous feasibility studies have been undertaken, and a number of MAR schemes have been constructed.

In developing the DWS's MAR strategy, 10 "Success Criteria" were identified to guide feasibility studies in undertaking comprehensive assessments. In this presentation, examples from both feasibility studies and operational schemes are discussed to highlight factors that may have limited or enhanced their success. Essentially this is a presentation on lessons learnt.

These lessons are presented in relation to the 10 "Success Criteria": 1. The need for an MAR scheme; 2. The source water; 3. Aquifer hydraulics; 4. Water quality (including clogging); 5. The MAR method and engineering issues; 6. Environmental issues; 7. Legal and regulatory issues; 8. Economics; 9. Management and technical capacity; 10. Institutional arrangements.

Parallel Session 1:

1. MAR for water supply purposes – Domestic/Municipal, Agricultural and Mining

77. CAPE FLATS AUIFER MANAGEMENT SCHEME – BENEFITS OF MAR FOR MAKING THE CITY OF CAPE TOWN A MORE RESILIENT CITY (SOUTH AFRICA)

D. McGibbon[1], K. Riemann[1], K. Woolf[1], D. Allpass[2] and P. Marais[3]

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[2]City of Cape Town, Cape Town, Western Cape, South Africa
[3]Water and Wastewater Engineering, Stellenbosch, Western Cape, South Africa

Abstract

The City of Cape Town (CoCT) have diversified their municipal supply to include re-use, desalination and groundwater as a result of recent droughts and to build resilience against future uncertainty in the face of climate change and increasing demand. The Cape Flats Aquifer Management Scheme (CFAMS) forms one of the groundwater projects and includes both abstraction and managed aquifer recharge (MAR).

The Cape Flats Aquifer (CFA) is a coastal, unconfined, primary aquifer within an urban and peri-urban environment that is extensively utilised for agricultural irrigation. As such, it is well situated to take advantage of enhanced recharge using high quality advanced treated effluent. The MAR component of the CFAMS has a number of benefits that relate to water banking, increased yields, barriers to seawater intrusion (SWI) and contamination, and improvement of water quality/restoration of the aquifer.

We aim to present the design considerations associated with each of these MAR benefits. Due to the extensive use of the aquifer there is sufficient space available for water banking, however there is also a risk of flooding, particularly in the urban environment and therefore monitoring boreholes are used to control groundwater levels, preventing flooding and also minimising large water level fluctuations, reducing the impacts of biofouling. As there is competition for the groundwater, MAR is utilised to increase abstraction yields without detrimentally impacting existing users or the environment. Coastal unconfined aquifers are vulnerable to contamination from surface activities and also SWI from over abstraction or sea level rise, in this instance MAR is used to create barriers between contamination sources and abstraction wellfields or wellfields and the ocean. As no legislation for MAR exists in South Africa, international best practice was adopted ensuring high quality source water to minimise health risks, reduce clogging and improve water quality within the aquifer.

132. A FRAMEWORK FOR ESTIMATING COSTS OF MANAGED AQUIFER RECHARGE FOR DIFFERENT SCALES AND CONDITIONS UNDER UNCERTAINTY

Dennis Gonzalez[1,2*], Joseph Guillaume[2,4], Luk Peeters[1], Paul Wyrwoll[3,4], Joanne Vanderzalm[1], Declan Page[1]

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[2] Fenner School of Environment and Society, Australian National University, Building 48A, Linnaeus Way, Canberra, ACT 2601, Australia

[3]Crawford School of Public Policy, Australian National University, 132 Lennox Crossing, Canberra, ACT 2601, Australia

[4]Institute for Water Futures, Australian National University, 141 Linnaeus Way, Canberra, ACT 2601, Australia

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Abstract:

This study addressed the uncertainty surrounding cost estimation for Managed Aquifer Recharge (MAR) systems, a proven method for increasing drought resilience. The study developed a transferable financial cost assessment framework that incorporated time-varying costs, enabling the evaluation of MAR schemes across various operating scales and conditions. This framework's transparency is enhanced by a disaggregated cost analysis, which breaks down capital and operating expenses into their constituent parts, providing insight into the key cost drivers. The incorporation of time-varying costs allows for a more accurate representation of the costs associated with MAR schemes. This is particularly important for MAR schemes, where costs can vary significantly depending on factors such as opportunity costs of source water, aquifer storage losses and operational rules. The study's probabilistic approach captured the uncertainty associated with input parameters, allowing for a more comprehensive understanding of the costs involved. Global sensitivity analyses highlighted the most critical factors contributing to uncertainty that varied with scheme scales and operating conditions, enabling targeted efforts to reduce it. The methodology was applied to conceptual surface water infiltration and well injection sites in Australia's Murray-Darling Basin that demonstrated its practicality and provided insights into the factors influencing costs. Levelized costs of recovered water varied depended on the scheme's capacity, configuration and operating conditions. By capturing uncertainty, incorporating time-varying costs, and providing a transparent, disaggregated cost analysis, this study offers a robust foundation for evaluating MAR schemes. The approach can inform early planning and design stages, ensuring that potential storage losses and other critical factors are considered.

76. REFURBISHMENT OF THE ATLANTIS WATER RESOURCE MANAGEMENT SCHEME – BENEFITS OF MAR IN IMPROVING WATER SUPPLY RESILIENCE

J. Prinsloo[1], K. Riemann[1] and D. Allpass[2]

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[2]City of Cape Town, Cape Town, Western Cape, South Africa

Abstract:

The Atlantis Water Resource Management Scheme (AWRMS) is a mixed groundwater abstraction and managed aquifer recharge (MAR) scheme. A blend of treated effluent and stormwater is used as MAR source water, to recharge the Atlantis Aquifer (an unconfined primary sandy aquifer) which has supplied groundwater to the town for nearly 50 years. The AWRMS lost popularity in the year 2000, when the town was connected to the Western Cape Water Supply Scheme (WCWSS), and due to the relatively high maintenance and operational costs. The positioning of the town within the City of Cape Town (CCT) municipal area and the significant groundwater resource upon which the town was built provides a sensible opportunity for the CCT to improve its water resilience, particularly following the 2015-2018 drought. The supply capacity of the AWRMS is sufficient to be the standalone source of water supply for Atlantis and adjacent towns upon completion of the current MAR and abstraction infrastructure refurbishment initiatives. Atlantis has a current demand of ~6.7 million cubic metres per year (Mm3/a), once refurbished the scheme will be able to deliver ~9 Mm3/a. The refurbishment includes the re-drilling of production boreholes using modern materials and a standardised resource development approach, electronic monitoring and pump-control equipment with links feeding to a cloud-based decision support system and the expansion, lining and modernisation of key stormwater infrastructure to curb source water losses and treat detrimental water quality. Additional expansion initiatives include the construction of a 10 Ml balancing storage to improve the control of water supply and demand and the conversion of the supply pipeline which connected the WCWSS to a reverse flow line broadening the reach of the scheme to the greater City of Cape Town. The presentation will aim to provide an update on the progress made.

Key words: refurbishment, resilience, managed aquifer recharge

64. AQUIFER STORAGE AND RECOVER (ASR) WELL DESIGN IN SALT-WATER INRUING COSTAL AQUIFERS – A CASE STUDY

Stephen Belser, P.E.[1] and David Pyne, P.E.[2]

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Abstract

The southeastern United States has experienced a large influx of resettlement and population growth along its coastal cities. As a result, an increase in potable water demand has led to municipalities pumping the coast aquifers at higher volumes which is increasing the rate saltwater intrusion in these target aquifers. Public Service Districts have turned to both Reverse Osmosis (RO) for brackish and saltwater treatment and Aquifer Storage and Recovery (ASR) for storage and recovery to provide necessary current and future demand. Given the historical success of ASR wells application in brackish and high salinity aquifers the excess RO treated water can be stored in off-season months in ASR wells and recovered during peak demand. The benefits of combining ASR with RO treatment leads to a cost savings as well as flexibility for urban growth in their service districts.

This is a case study of two ASR wells for Hilton Head Public Service District in Hilton Head Island in South Carolina, USA. ASR Well #1 was constructed in 2012 and recognized as one of 29 MAR/ASR international sites by UNESCO3. ASR Well #2 is currently under construction. Both are located in the Middle Floridan Aquifer that is currently experiencing saltwater intrusion. This presentation will examine past the past success and planned future of ASR and how it complements District's long term 15 year water supply plan in relation to its RO plant production and existing water purchase agreements.

20. RECLAIMED WATER FOR MANAGED AQUIFER RECHARGE: A TOOL FOR WATER SECURITY IN BARCELONA

B. de la Loma[1], S. Espinosa[1], M. Minoves[2] and M. Ganzer[2]

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Abstract:

In recent years, Barcelona has faced extreme water scarcity, with the city experiencing one of the most severe droughts in decades. This crisis has forced the local water utility to release reclaimed (treated) water from the city's tertiary wastewater treatment plant into the Llobregat River to maintain sufficient flow for both drinking water intake and ecological needs. Despite this intervention being a clear success in terms of water availability, it has caused significant fluctuations in surface water quality, particularly in physico-chemical parameters and total organic carbon levels, complicating drinking water production. The MARCLAIMED project addresses this challenge by recharging excess reclaimed treated wastewater through infiltration ponds into the aquifer used by the city water utility's well fields. This natural filtration through the aquifer enhances water quality stability and further purifies the reclaimed water by reducing pathogens, nutrients, and organic contaminants.

The system, operational since April 2024, includes a 4000 m² decantation pond and a 5600 m² infiltration pond, with water quality monitored through 5 piezometers and 5 abstraction wells from the water utility, continuous CTD sensors and groundwater sampling every 6 weeks. Additionally, infiltration also takes place through a deep injection well, monitored via 5 piezometers and 3 pumping wells. Preliminary results show increased piezometric levels and groundwater conductivity that align with the recharged water quality. Over the course of the project, 1 Mm³/year of reclaimed water will be infiltrated, showcasing Managed Aquifer Recharge (MAR) as a safe, effective pre-treatment method for reclaimed water and a crucial tool for improving water security in the region. The aquifer recharge, available throughout the whole year and independent of rainfall events, raises piezometric levels creating a water buffer and making this coastal aquifer less vulnerable to overexploitation and saline intrusion, particularly during the increasingly frequent and severe droughts expected due to climate change.

148. THE IMPACT OF MAR AND RECOVERY ON THE LANGEBAAN ROAD AQUIFER UNIT, WESTERN CAPE, SOUTH AFRICA

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Key words: pilot injection; Langebaan Road wellfield; confined coastal aquifer; groundwater monitoring

Abstract

The Council for Scientific and Industrial Research conducted a pilot injection test in 2008 and 2009 at the Langebaan Road wellfield. The objective was to increase the volume of water stored in the confined layer of the Langebaan Road aquifer using excess winter water, so that it will be available in summer for the influx of tourists. Various factors cause the test to be considered unsuccessful and the recommendation was that injection is not the most optimal method of MAR for a confined aquifer in a coastal aquifer, based on how the aquifer responded. Evaluation of the long-term water level monitoring suggests that the test was successful. It did manage to increase the storage in the aquifer layer (measured by higher water levels) till the end of summer. This article will illustrate the importance of accurate, regular monitoring of water levels for determining the success of a MAR scheme and the use of water level data. This evaluation of the data will attempt to develop a method for using the water level data to measure the success of a Managed Aquifer Recharge scheme. It will also provide recommendations for the Managed Aquifer Recharge in South Africa (MARSA) project and the long-term planning of the Saldanha Bay Local Municipality, who must implement a MAR scheme according to their Water Use Licence conditions.

14. MAR DEVELOPMENT USING INFILTRATION PONDS IN RIVERBEDS FOR WATER SUPPLY AND DROUGHT RELIEF TO A DROUGHT PRONE AREA

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Abstract:

The Town of Calvinia, South Africa, is located in a drought prone region and relies heavily on groundwater as a water source. The town is mainly supplied by surface water with groundwater acting as a supplementary source when surface water supply becomes constrained. Nearly a decade of erratic rainfall patterns, coupled with a 5-year drought period has put the town's water supply under severe strain. This has resulted in limited recharge within the respective local aquifers leading to declining groundwater levels and decreasing regional borehole yields. This study, therefore, looks at the effectiveness of enhance recharge into the underlying aquifer by drilling infiltration boreholes near existing production boreholes.

The local hydrogeological setting comprises a fractured secondary aquifer hosted within shales intruded by younger dolerite sills and dykes. This aquifer contains known exploitable groundwater volumes with local groundwater recharge estimated at 4 – 8 mm/a. The electromagnetic (EM) geophysical survey technique was used to identify fractured zones in the underlying bedrock along seasonal drainage channels. This was used to delineate targets for infiltration boreholes and ponds allowing for water infiltration into the fractured aquifer near existing production boreholes, thereby enhancing recharge into the underlying aquifer. Six infiltration boreholes were successfully drilled, with subsequent constant infiltration testing to determine the feasibility of constructing infiltration ponds around boreholes in drainage channels. Infiltration tests indicated which boreholes will be most effective in recharging the underlying aquifer along with optimal infiltration rates. This study ultimately aids in understanding the effectiveness of using infiltration ponds for recharge of the local aquifer along with exploring the connectivity between infiltration and production boreholes.

107. MANAGING AQUIFER SUSTAINABILITY THROUGH RESOURCE PROTECTION ZONES: APPLICATION OF FUNDAMENTAL HYDROGEOLOGICAL PRINCIPLES FOR ASSESSING THE VIABILITY OF MANAGED AQUIFER RECHARGE (MAR) FOR A SMALL TOWN'S WATER SUPPLY SCHEME

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Abstract:

Following a nine-year drought in Sutherland, located in the Central Karoo of South Africa, a hydrogeological investigation was initiated to reduce the severe stress on the region's aquifer. Production boreholes were drilled alongside several managed aquifer recharge (MAR) boreholes to stabilize the town's water supply. The investigation aimed to reduce stress on the aquifer, where existing boreholes have shown deteriorating aquifer conditions relating to both yield and quality.

Historically groundwater management was limited to the existing production boreholes in town, therefore, a new groundwater supply network was established in a relatively untapped area within the local aquifer. This created an opportunity to delineate protection zones and develop a comprehensive groundwater management plan with a standard operating procedure, where Managed Aquifer Recharge (MAR) could serve as the turnkey solution for maintaining a healthy water balance within the source catchment area.

Parallel session 2:

2. MAR Methods and technologies

1. OVERLOOKED: NON-UNIFORM FLOW DISTRIBUTION ACROSS WELL SCREENS FOR AQUIFER STORAGE AND RECOVERY OF FRESH WATER IN SALINE AQUIFERS

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Abstract

Aquifer storage and recovery systems aim to efficiently recover sufficient of the stored water. When storing fresh water in brackish or saline aquifers, the density difference between the injected and native groundwater is known induce buoyancy flow in the aquifer that negatively impacts recovery efficiencies (RE's). However, pressure differences already occur in the well screen and in this study it is shown, through analytical and numerical analysis, that the density difference can induce non-uniform flow distribution across a well screen that may cause significantly lower recovery efficiencies (e.g. >20% difference in RE) than expected when only considering losses that occur in the storage aquifer. This negative offset can be particularly strong for ASR operation in aquifers with relatively favourable characteristics. Analysis shows that the degree in which non-uniform flow distribution across the well screen occurs depends mainly on the relative density difference and the injection pressure, which in turn is affected by injection and abstraction rates, well screen length and aquifer permeability. In addition to lower recovery efficiencies, non-uniform distribution of flow also results in higher flow velocities at the top of the well and therefore increased clogging risk by exceeding safe flow velocities across the well bore. Overall, this study shows that an assessment of the extent to which non-uniform flow across the well screen occurs for a planned ASR operation should be performed as a part of the ASR design to optimize performance and reduce operational risks.

32. COMPARISON OF SINGLE-RING CYLINDER INFILTROMETER WITH LATERAL DIVERGENCE CORRECTION AND DOULBE-RING CYLINDER INFILTROMETER AND LARGE-SCALE INFILTRATION TEST METHODOLOGIES

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Abstract

Prediction of achievable long-term infiltration rates is among the most important aspects in planning, designing, and managing groundwater recharge basins. The ASTM D3385-09 double-ring infiltrometer (DRI) method is commonly used and frequently specified by regulatory agencies to measure soil infiltration rates. There are two potential sources of error when converting DRI measurements to predict long-term infiltration rates: lateral divergence of water due to unsaturated flow, and the development of a hydraulic gradient during the short-term (i.e., over hours) measurement. In comparison, the single-ring infiltrometer with lateral divergence correction (SRI-LDC) method proposed by Bouwer and others (1999) provides a direct measurement and correction procedure to account for the influence of lateral flow and the hydraulic gradient on measured infiltration rates. We conducted co-located measurements using the SRI-LDC and the standard DRI methods. Depending on the soil texture, the estimated saturated hydraulic conductivity (Ks) from the DRI tests were three to six times greater than the SRI-LDC effective saturated hydraulic conductivity (Ke) measurements. In addition, we have conducted co-located SRI-LDC tests within long-term infiltration basins at various scales and found close agreement. Numerical simulations conducted in HYDRUS 2D/3D calibrated to the measured wetting front dimensions indicate the SRI-LDC measured Ke more closely matched the calibrated model Ks than the measured DRI Ks. Model results also demonstrate that increasing the size of the DRI outer ring from two times the inner ring diameter to four times only marginally improved the accuracy of the Ks estimate. Due to the relative ease of measurement, the ability to collect more data over the same amount of time, and the much greater accuracy in estimating long-term, large-scale infiltration rates, we recommend that the SRI-LDC method be adopted as a standard ASTM method for determining Ke and estimated long-term infiltration rates for MAR facilities.

119. HYDROGEOLOGICAL STUDIES TO DETERMINE A MAR SITE FEASIBILITY, PRAGMATIC APPROACH. EXAMPLE FOR SANTIUSTE BASIN MAR SITE, CENTRAL SPAIN.

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Abstract

In 2002 the Spanish Minister of Agriculture inaugurated the first MAR site at the Los Arenales aquifer in Castile and Leon, Spain. This site was born due to the request of farmers, who years before made associations to solve an overexploitation situation, and requested solutions to public authorities. The Spanish government asked previous feasibility studies to Tragsa Group and IGME, who provided a detailed knowledge of the aquifer, and recommended the implementation of the MAR site, specifying the successive construction of additional future elements too.

Nevertheless and despite the degree of detail of the feasibility studies, unexpected impacts happened, and technicians in charge met certain responses of the recharged aquifer, most of them due to the application of the "essay and error" method. Farmers and coverts had to face issues such as the flooding of crops in specific areas, payments to victims, infiltration rates below expectations and hydrochemical deterioration in certain spots, social conflicts, etc., and learnt plenty of lessons for successive improvement.

The stages of this preliminary feasibility study were nine.

- Technical, socio-economic and political pre-feasibility study.
- Hydrogeological study: This study has to combine and analyse the data with previous information and information generated during the study phase, relating to the geology, hydrology, geomorphology, topography, microtopography, pedology, climate, land use and essentially human actions of the área.
- Study of the lithology. Proposal for a new geological cartography.
- Determination of the 3D geometry of the aquifer.
- Geophysical prospecting campaigns.
- Study of the piezometry for a given period, and hydrogeological cartography using UNESCO standards.
- Determination of hydraulic parameters, flow velocity, equipotentials and flow lines.
- Hydrochemistry and quality studies in both, saturated and unsaturated zones.
- A specific study of the unsaturated body bacame complementary.

Some years after, different institutions have implemented new MAR constructions, but the initial "nine-stage recipe" was not enough to foresee subsequent impacts and risks, especially in the medium and long terms. Within this context, a new and more complete list of actions has been compiled, after long experience

and teamwork, proposing until 27 items. This presentation exposes the stages of the pioneer study, analyses the necessary components to implement and effective, safe, and sound MAR site, and proposes a consensual programme of action.

11. EVALUATING THE EFFICIENCY OF MANAGED AQUIFER RECHARGE INTERVENTIONS IN THE GANGES BASIN, INDIA

Navneet Sharma[1], Mohammad Faiz Alam[1], Paul Pavelic[2], and Alok Sikka[1]

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Abstract

Sustainable groundwater management is essential for securing drinking water and irrigation supplies in the Ganges Basin which supports about 43% of India's population and is facing multiple challenges including unsustainable water use, and climate change-induced variability. In response, the construction of MAR structures have become a priority of government agencies, NGOs, and the private sector to augment groundwater storage which supports ~ 70 % of irrigation in the basin. Over the past two decades, thousands of MAR structures have been constructed in the basin. This study evaluates the recharge efficiency of representative structures to help guide future investments in MAR. Fifteen recharge ponds with various MAR designs (e.g., recharge wells, recharge shafts, infiltration ponds and abandoned village ponds) — were selected for monitoring. Participatory water level monitoring was developed along with volume-elevation curves for the selected ponds, which were used to assess recharge rates. Infiltration tests and in-situ hydraulic conductivity measurements were also performed at all sites. Results show that the average recharge rates show high variability ranging from 29 – 166.7 mm day-1 with no clear correlation with the type of MAR design. The significant variation in recharge rates reflects the heterogeneity of the underlying soil, hydrogeological conditions, and groundwater levels, emphasizing the need to optimize MAR investments. The assessment using monitored recharge rates along with the number of MAR structures built under Government-led groundwater recharge initiatives shows that MAR has led to ~ 3-8% recharge increase at district scale. Converting unused ponds for MAR offers further potential to address groundwater depletion with co-benefits to increase baseflows to rejuvenate drying rivers/streams which is also becoming a priority for the government.

25. DESIGN AND IMPLEMENTATION OF A HIGH-POTENTIAL MAR SYSTEM

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Abstract :
MAR systems are currently expanding, with a view to securing water supplies, combating the effects of climate change and, more generally, helping to improve the quantitative status of groundwater bodies. Indeed, this technology is one of the many techniques used to manage water resources. Despite its development throughout the world, the problem of the efficiency of recharge and collection structures still remains. The aim of this work is to evaluate the efficiency of a number of designs in order to determine potential locations for infiltration basins and pumping wells, so as to set up an efficient system. For this purpose, a study area representative of the basement aquifers in the hydrogeological basin was delimited and reconstructed using the FEFLOW numerical flow model. A network of three to five infiltration basins (10m*10m) was set up in this 16 Km2 area. The distance between the basins varied between 10m and 500m, in order to assess their impact on the aquifer's potential. At the same time, a network of five pumping wells (350m3/h) was also installed, with intervals varying from 10 to 500m. The first scenario involved upgrading the infiltration basin system by category, while retaining the same pumping system. The second scenario consisted in keeping the same injection system and upgrading the pumping well system by category. The results show that the system of five basins placed in a cross with an equidistance of 500m offers a better design, as the effect of pumping is less perceptible. As for the network of three basins placed either parallel or perpendicular to the direction of flow, an equidistance of 50m between basins would be recommended. As for the injection wells, the ideal location would be between 10m and 100m, provided they are in the flow path of the water injected by the infiltration basins.

Keywords: Basement area, Design, FEFLOW, Infiltration basins, Pumping wells.

74. MAR IN THE CAPE FLATS AQUIFER: A CASE STUDY ON INJECTION METHODS AND BOREHOLE DESIGN

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Abstract:

In response to the severe drought experienced by the City of Cape Town (CCT) in early 2018, the Western Cape was declared a disaster area. The CCT initiated the New Water Programme (NWP) to augment its water supply through alternative sources, including groundwater. The Cape Flats Aquifer Management Scheme (CFAMS) was identified as a critical groundwater resource for both abstraction and Managed Aquifer Recharge (MAR). Given the Cape Flats Aquifer's (CFA) heterogeneous nature and the presence of semi-confining clay layers, injection was the most suitable MAR method. The selection process focused on three key components: borehole design, injection method (gravity vs. pressure), and geology. Analysis showed that while larger diameter boreholes could inject more water, the additional capacity was negligible compared to the cost increase. Therefore, a 304.8 mm (12") stainless steel borehole design was chosen as the optimal diameter, balancing recharge volume, space for downhole equipment, and cost-effectiveness. Two injection methods, gravity flow and pressure were tested. During testing, PVC pipes were installed to ~5 m above the screens and below the water level to reduce the cascading effect. For the pressure testing, the boreholes were welded shut to ensure no water escaped. Tests were conducted in areas with varying lithologies to assess impact of changes in lithology on injection yields. A constant head of 0.1 bar was maintained during the constant head testing to facilitate recharge and prevent flooding. Results indicate that injection under pressure achieved higher recharge volumes (0.6 – 2.7 Ml/d) and a greater radius of influence, particularly in areas with high hydraulic conductivity, along the coastline, where recharge volumes ranged from 1.3 – 2.7 Ml/d, compared to 0.7 – 0.8 Ml/d in lower hydraulic conductivity, further inland, where clay and peat layers are present. Tests confirmed the feasibility of MAR within the CFA, with pressure injection proving superior.

114. UTILIZING HORIZONTAL WELLS FOR AQUIFER STORAGE AND RECOVERY: LESSONS FROM A PILOT STUDY ON TEXEL ISLAND, THE NETHERLANDS

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Abstract

Pilot studies on Texel Island, the Netherlands, investigate the feasibility of using horizontal directionally drilled wells for Aquifer Storage and Recovery (ASR). In these pilot studies, surplus tile-drainage water from agricultural fields is collected in winter, treated for pesticides and nutrients, and pumped into a storage aquifer. This storage aquifer consists of fine sands with a low hydraulic conductivity of 5 to 10 m/d. It is confined by inhomogeneous leaky clay and sand layers at the top and bottom and has a thickness of 8 to 10 m. The horizontal well is positioned in the upper part of the storage aquifer (~ 14 m below ground surface) and has a screen length of 180 m. The native groundwater salinity is high, with a measured electrical conductivity of approximately 25 mS/cm (~16 000 ppm TDS). The tile-drainage water (electrical conductivity approximately 1.2 mS/cm) is stored until it is needed for irrigation during summer, when it is recovered through the same horizontal well. This presentation examines the potential of horizontal wells for ASR under difficult hydrogeological conditions – characterized by low hydraulic conductivity, low aquifer thickness, and high groundwater salinity – through a combination of numerical modeling and field data. Numerical models are used to assess the benefits of horizontal wells, such as less drawdown during pumping and reduced freshwater losses due to buoyancy effects. Field measurements are used to monitor the two year progress of the pilot studies: A network of observation wells measures hydraulic head and electrical conductivity at various depths in the aquifer. Borehole electromagnetics (EM-39) provide detailed vertical profiles of the freshwater distribution in the storage zone and electrical resistivity tomography offers 2D cross-sections of the shape of the freshwater bubble around the well. This combined approach provides a comprehensive evaluation of horizontal wells for ASR in these difficult settings.

86. MOUNDED OR CLOGGED? USING FIBER OPTIC DISTRIBUTED TEMPERATURE SENSING TO DIAGNOSE AND MONITOR BASIN BEHAVIOUR

A. Hutchinson[1], M. Becker and P. O'Connell

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Abstract

Degradation of spreading-basin infiltration is commonly attributed to (1) clogging of the basin floor or (2) mounding/perching of the water table below the basin. Mitigating the loss in infiltration rate requires knowing whether clogging and/or mounding is the culprit. Scraping, for example, will have no benefit if the groundwater is mounded below the basin. One way to know that the basin is hydraulically disconnected from groundwater is to observe that the vertical hydraulic gradient (Iz) below the basin relative to infiltration rate (qz). If the Iz is independent of qz, then the groundwater is disconnected from basin ponding, i.e. not mounded. If Iz is a linear function of qz, then saturated Darcy conditions dominate and the basin is likely mounded. Nested piezometers in or adjacent to the basin can determine Iz and water balance can determine qz. However, as we demonstrate in this field example, a basin may be dominated by both mounding or clogging in different portions of the basin. We show how infiltration rate monitoring using fiber optic distributed temperature sensing (FODTS) can help elucidate such complex behavior. FODTS measures temperature along a fiber optic cable that is installed horizontally and/or vertically in the basin. Diurnal heat fluctuation in the basin water is used as a tracer to measure downward migration of water at and below the basin. By combining these measurements of qz with piezometer measurements of Iz, we determined that our test basin was dominated by mounding or perching in one portion and clogging in another portion. Although determining sub-basin hydraulics requires additional effort, this knowledge is key for effective basin management. Decisions regarding flooding schedules, scraping, basin stage, and management of adjacent water resources cannot be made with confidence without this information. FODTS is an effective and mature monitoring tool that may offer valuable data beyond traditional measurements.

70. KEY ASPECTS OF THE MANAGEMENT OF ONE OF THE LARGEST ASR SYSTEMS IN THE WORLD

T. Dorsch, M. Hussein, and M. Al Dajani

Abstract:

In the Emirate of Abu Dhabi, United Arab Emirates, an Aquifer Storage and Recovery (ASR) system was implemented between 2008 and 2017. It aims at ensuring strategic storage of potable water for emergencies by storing excess water from desalination plants in the aquifer. The process involved the infiltration of water through surface basins and recovery through wells. During the aquifer recharge phase between 2015 and 2017, 7 MIGD of desalinated water were infiltrated for a duration of 27 months. This led to one of the largest stored volumes (5.8 BIG) of desalinated water in an ASR system in the world and has therefore significantly increased the security of water supply in the Emirate of Abu Dhabi.

The ASR infrastructure includes three schemes, each equipped with a pumping station, ground storage tank, and assembly lines. There are a total of 315 recovery wells, 164 monitoring wells, and 3 infiltration basins to support the project infrastructure. The recovery wells are equipped with special PVC screens (conical disc or wire-wrapped) and double filter packs for an optimized well efficiency.

Since 2022, one of the key aspects of the management of the three well-schemes is the existence of a preventive well maintenance program. The program's main activities are the execution of step drawdown tests and video surveys to identify wells which require well rehabilitation due to clogging problems. Moreover, riser pipes and submersible pumps are inspected to address potential corrosion issues.

Based on the results from this first well maintenance program, it can be concluded that, despite comparatively high costs, such projects are highly needed to keep the ASR system operational on a long term. A subsequent preventive well maintenance program including well rehabilitation will start in 2025

137. FIELD PILOT STUDY ON ENHANCING MAR: EVALUATING ACTIVATED CHARCOAL'S EFFECTIVENESS FOR WATER QUALITY IN ATLANTIS

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Abstract:

Managed Aquifer Recharge (MAR) was crucial for mitigating water scarcity and improving groundwater quality. This study examined the effectiveness of activated charcoal as a pre-treatment to enhance water quality before infiltration in MAR processes. Conducted in Atlantis, South Africa, where an existing MAR system was operational, the research provided insights into the remediation of key chemical parameters, including calcium, magnesium, and nitrate, with additional assessments of pesticides and pharmaceuticals forthcoming.

Activated charcoal was selected following column experiments comparing various treatment methods, including natural soil (control) and biochar, with activated charcoal showing superior performance. The pilot study involved installing an activated charcoal pre-treatment layer, with water quality monitored at depths of 30cm, 60cm, and 90cm to evaluate its effectiveness in the field.

Preliminary results indicated that activated charcoal significantly improved water quality, particularly in reducing nitrate concentrations and enhancing calcium retention. At the 90cm depth, calcium concentration peaked at 39.3 mg/L, demonstrating the charcoal's ability to adsorb and retain calcium over time. However, magnesium levels showed inconsistent results, with increases observed at 90cm. Nitrate concentrations were notably reduced, especially at deeper levels, underscoring activated charcoal's effectiveness in adsorbing this contaminant.

These findings suggested that activated charcoal was effective in enhancing water quality within MAR systems, particularly in calcium retention and nitrate reduction. The forthcoming analysis of pesticides and pharmaceuticals will offer a more comprehensive assessment of the system's efficacy. Overall, the results support the potential for large-scale implementation of activated charcoal as a sustainable and cost-effective pre-treatment in MAR systems.

118. CHECKING 20 INFILTRATION METHODS TO DETERMINE AN ACCURACY RANKING USING A DIGITAL TWIN. SANTIUSTE BASIN, LOS ARENALES LIVING LAB, SPAIN.

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Abstract

Hydraulic conductivity is one of the main variables to determine when conducting hydrological studies entailing groundwater resources and MAR. The present work helps to select the best method to estimate hydraulic conductivity in an intensely monitored area, comparing captured parameters under "hyper-controlled" conditions with the results of formulas of general acceptance available in the hydrogeological literature.

The workflow has been employed in Santiuste Basin, the Southernmost MAR site in the Los Arenales Managed Aquifer Recharge (MAR) Living Lab (Central Spain). Different sensors have gathered reliable data sets for about 15 years, providing valuable and accurate information. Direct measures of the real vertical (Kv), and horizontal (Kh) hydraulic conductivities, capillary tension, among other parameters, have been and compared using a "digital twin" with theoretical results.

A total of 20 formulas and methods have been applied, to address which theoretical formula better matches the hydraulic conductivities obtained in the field thanks to sensors, and study the environmental conditions influence on the efficiency of the MAR facilities under surveillance. The study also provides a list of the necessary data to be gathered in the field to repeat the calculation in additional sites.

Variations of up to three orders of magnitude have been spotted, depending on the applied formula. In general, Newman and Horslev methods have given the best results for the specific conditions of the site.

Keywords

Hydraulic conductivity; permeability, digital twin; managed aquifer recharge; artificial recharge; analytical equations; Los Arenales aquifer, Santiuste basin, ZNS stations.

105. QUANTIFYING INFILTRATION RATES WITHIN A MANAGED AQUIFER RECHARGE PILOT SITE USING DISTRIBUTED TEMPERATURE SENSING TECHNOLOGY

R. Glaude, N. Simon and S. Brouyère

Abstract:

Managed aquifer recharge (MAR) became a fundamental approach in sustainable groundwater management. In this study, we investigate the potential of the use of the DTS (Distributed Temperature Sensing) technology to assess the efficiency of MAR. An innovative approach that couples passive and active-DTS measurements along a Fiber Optic (FO) cable has been developed to quantify and evaluate the spatial variability of infiltration rates at the field scale. An infiltration test was performed in a small infiltration basin in the Geer watershed (Belgium) where a FO cable was buried within the basin sediments. Passive-DTS measurements allow for the monitoring of natural temperature variations at 10 cm depth along the FO cable. Since the injected water through the infiltration test was cooler than the ambient sediment temperature, a decrease of the temperature was measured over time along the FO cable at the beginning of the infiltration test. A heat transport numerical model was developed to interpret the temperature decrease induced by the water injection and estimate the infiltration rates at early infiltration stage (1.42X10-5 m.s-1). Then, an active-DTS test was applied by heating a section of the FO cable. The analysis of the temperature increase, resulting from the heat injection in the sediments, provided estimates of the infiltration rate along this specific section of the FO cable (3.79 X 10-6 m.s-1). This discrepancy is most likely attributed to the dynamics of infiltration rather than parameter sensitivity as higher recharge rates are observed at the start of the infiltration. The analysis of DTS measurements provides maps of the spatial variability of the infiltration rates along the FO cable at two different stages of the infiltration test. Findings highlight the potential of DTS based methods in accurately evaluating MAR rates throughout space and monitoring the temporal dynamic of infiltration rates.

2. AQUIFER STORAGE AND RECOVERY: DESIGN CONSIDERATIONS FROM SCIENCE TO PRACTICE

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Abstract

Across the globe, freshwater resources are increasingly under pressure, quantitatively by intensifying droughts and demand, and qualitatively by salinization and contamination. MAR techniques, such as aquifer storage and recovery (ASR), are well-positioned to play a vital role to sustainably increase water availability. However, it is known that ASR performance varies strongly with site-specific storage conditions. To facilitate site selection and optimal ASR design it is therefore crucial that the controlling factors of ASR performance, particularly its recovery efficiency, can be confidently anticipated and evaluated. The main factors known to affect ASR recovery efficiency are losses due to 1) dispersion, 2) displacement by ambient groundwater flow and 3) buoyancy flow. Here, we evaluated their impact of these factors by the adaptation and development of analytical solutions. Using Modflow-MT3DMS-Seawat simulations for a wide range of realistic field conditions we validated their accuracy and limitations of the analytical solutions for these different factors, both in separation and combined. Results showed that a simple, analytically derived, formula describing dispersion losses solely based on the dispersion coefficient (α) and the hydraulic radius of the injected volume (Rh) provided an excellent match for all conditions tested where $\alpha/Rh<0.2$. An expansion of the formula to include the development of recovery efficiency with subsequent cycles (i) was also derived and in keeping with simulation results.

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

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

78. ANCESTRAL NATURE-BASED SOLUTIONS FOR MANAGED AQUIFER RECHARGE IN SPAIN

S. Martos-Rosillo, N.N. Fernández, J. Jódar, and C. Marín-Lachado

Abstract:
Nature-Based Solutions for Water Management (WM-NbS) consist of a series of natural or nature-mimicking actions or processes that aim to improve water quantity and quality, reduce the risks of water-related disasters such as droughts and floods, and improve resilience, biodiversity and ecosystem integrity. If we want to find low-energy aquifer recharge systems that use local materials and can be categorized as WM-NbS, the ancestral Managed Aquifer Recharge (MAR) systems can inspire us. In Spain, aquifers have been intentionally recharged for more than a thousand years. The main ancestral MAR techniques are performed by infiltrating water through channels dug in the ground, unlined, in mountain areas, and in traditional irrigated areas, both on steep slopes with hard rock substrates, and in flat areas located on detrital aquifers of high permeability. The recovery and replication of these ancestral MAR systems and that of other systems, such as ecohydrological forestry oriented to aquifer recharge, in which forest density is optimized to increase recharge, constitute an opportunity to improve MAR in Spain, where traditional techniques using ponds and infiltration wells have not been successful. This paper will present the main results of the research that the Geological Survey of Spain (IGME-CSIC) is carrying out during the last 10 years on MAR systems that can be considered as Wm_NbS, such as the Water Sowing and Harvesting, the ancestral Agicultural-MAR and ecohydrological forestry oriented to aquifer recharge.

91. MULTIBENEFICIAL MANAGED AQUIFER RECHARGE: INTEGRATING ADVANCED MONITORING AND NOVEL SOURCE WATER FOR GROUNDWATER SUSTAINABILITY

Salini Sasidharan[1]*, Ruan Goncalves de Souza Gomes[1], Sumant Kumar[2], Ethan James Bertrand[1], Belen Sofia Bracamontes[1], and Thomaz Tomiatti Moura E Silva[1]

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Abstract:

This study explores the optimization of drywell-managed aquifer recharge (MAR) systems by integrating advanced monitoring technologies, numerical modeling, and innovative source water and energy sources to enhance groundwater sustainability. The research employs a comprehensive approach that combines empirical data from in situ sensors, soil hydraulic property measurements, and geophysical methods to better characterize subsurface heterogeneity and predict flow and contaminant transport dynamics from drywells. A key innovation of this study is the development of an Advanced Deep Vadose Zone Monitoring System, designed to continuously monitor soil moisture, temperature, electrical conductivity, redox potential, oxygen levels, and nutrient concentrations. This real-time data collection is integrated with numerical modeling tools such as HYDRUS and MODFLOW to simulate water flow and contaminant transport, providing critical insights into subsurface processes. The study also introduces an alternative, innovative source of water by collecting runoff from solar panels in an agrivoltaics system. This dual-purpose approach not only generates renewable energy but also captures and utilizes water for recharge operations, aligning with the Food-Energy-Water-Data-Ecosystem Nexus. This method enhances the sustainability of MAR systems by optimizing water use, improving groundwater recharge, supporting contaminant removal, and providing ecosystem services. By combining advanced monitoring, data analytics, renewable energy, and alternative water sources, this research demonstrates a multibeneficial approach to managed aquifer recharge. The findings emphasize the importance of understanding subsurface heterogeneity and optimizing drywell design for effective groundwater management. This integrated framework offers scalable solutions for diverse geological settings, addressing the challenges of water scarcity and enhancing climate resilience through sustainable groundwater practices.

104. BATCH EXPERIMENTS: A TOOL TO EVALUATE THE FATE OF ORGANIC CONTAMINANTS IN MAR PREFEASIBILITY STUDIES

R. Glaude, S. Brouyère, S. Lacorte, A. Jurado, E. Pujades

Abstract:
Contaminants of emerging concern (CECs) present in runoff water pose significant risks to water quality. Understanding the processes that control their attenuation is thus crucial for effective mitigation strategies. The research is motivated by the pre-feasibility study of Managed Aquifer Recharge (MAR) in a Cretaceous Chalk Aquifer in the Hesbaye region (in Belgium), aiming to assess the suitability of runoff water as a potential source for recharge. Specifically, the study evaluates whether the natural filtration capacity of Hesbaye loamy soils can sufficiently reduce the contaminant load present in runoff water to meet water quality standards. In this context, sorption and biodegradability of per- and polyfluoroalkyl substances (PFASs), alkylphenols and benzotriazoles present in runoff water are investigated through controlled batch experiments. Three batch reactors were set up with a water/soil volumetric ratio of 85:15 and were spiked with CECs at a concentration of 0.05 ppm. In each of these triplicates, synthetic water of similar chemical composition than the studied runoff water (major ions and DOC) was used. Three additional reactors were used as controls: one abiotic control to evaluate sorption of CECs on the soil, one biotic control for assessing their biotransformation, and the last one to assess the potential sorption of PFASs on the reactor glass bottles. Samples were collected daily the first week and then weekly from each reactor for 23 days and were analysed using liquid chromatography coupled to tandem mass spectrometry (LC-MS/MS). Results indicate variations in sorption capacities and degradation rates among different CECs, highlighting the complex nature of their interactions with soil and water matrices. Chemical modelling through PHREEQC allows the estimation of the sorption and biotransformation parameters for each studied chemical compound. These results will be beneficial for modelling the behaviour of runoff contaminants in the context of MAR systems.

Wednesday, 30 April 2025
Parallel session 4:
7. MAR in relation to environmental, sustainability and climate change adaptation

164. IS MANAGED AQUIFER RECHARGE AN OPTION TO TACLKE DYSFUNCTION IN SEWER NETWORK INDUCED BY GROUNDWATER FLOW INFILTRATON ON THE URBAN COMMUNITY OF LENS-LIÉVIN (NORTHERN FRANCE)?

Nicolas Devau[1], Géraldine Picot-Colbeaux[1], Adrien Manlay[1], Valentine Debois[2], Pascal Goderniaux[2], Lucas Jehanno[1], and Baptiste Meire[1]

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Abstract:

Groundwater infiltration in the sewer networks of the Lens-Liévin urban community, located in the north of France, locally led to dysfunction of this urban infrastructure. Technical options based on improving the pipe sealing cannot be used considering their costs. Overcoming this limit can be achieved by assessing if parasite water circulating in the sewer network, or groundwater pumped to prevent infiltration, can be used for managed aquifer recharge to improve locally water resource quantity and quality.

An innovative methodology divided in three tiers has been developed to conceive a multi-criteria scoring tool identifying the area of the Lens-Liévin territory where managed aquifer recharge using parasite water can be implemented. For each tier, literature data, field measurements and/or simulations results provided by a 3D hydrodynamic model of the chalky aquifer hydrosystem in transient state have been used to develop indicators. The first tier assessed where sewer network is vulnerable to groundwater inflow and what is the volume of parasite water circulating. Indicators developed in this tier are using information on groundwater table level and the altitudes of the pipes of the sewer network. Volume of parasite water was estimated by comparing daily water flow in sewer network during contrasted period (e.g. dry vs. wet). The second tier assessed the region of the aquifer where managed aquifer recharge will be more efficient to promote water resource in terms of quantity and quality. The third tier scored the infrastructures of managed aquifer recharge according to their capabilities to be deployed on Lens-Liévin territory.

This methodology allowed us to identify part of the Lens-Liévin territory where managed aquifer recharged using parasite water can be perform as well as the type of infrastructure that can be used. The next step is to perform prefeasibility study on each one of these sectors to design the infrastructure.

158. A CASE STUDY OF MAR FOR SUSTAINABLE MINE WATER MANAGEMENT IN SOUTHERN AFRICA

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Key words: Infiltration trench, dry well, geochemical modelling, Managed Aquifer Recharge, Mine Dewatering

Abstract:

A case study will be presented of the site investigations, trial and design process of a Managed Aquifer Recharge Scheme for Motheo Copper Mine, Botswana. Open pit mining extends below the water table, requiring dewatering for mining operations to occur safely. The objective of the MAR Scheme is to locally return excess water from open pit dewatering back into the aquifer, to support and maintain the local groundwater system. The hydrogeological setting and logistics favour shallow infiltration methods with dry well enhancements for the excess water, which have been trialled on site.

The selected method(s) of MAR were trialled on site during 2022 and 2023, to address operational and environmental knowledge gaps such as the potential for chemical precipitation and clogging, potential water quality changes due to mixing reactions, and spatial variability in infiltration rates due to subsurface conditions. Overall, the trial data and further site investigations were used to select suitable locations to implement MAR sites and inform MAR infrastructure designs for the full-scale implementation. A Management and Monitoring Plan for the MAR Scheme has been developed to facilitate operational controls and environmental management of the scheme, informed by hydraulic and chemical monitoring data.

This presentation aims to add to the growing list of case studies in Southern Africa and the rest of the world where MAR is used to more sustainably manage mine dewatering activities and impacts.

120. UNMANAGED RECHARGE OF AQUIFERS FROM TRANSVERSE STRUCTURES IN SPANISH RIVER-COURSES. A GIS-BASED COMPARISON BETWEEN INTENTIONAL AND UNINTENDED MAR FIGURES

Enrique Fernández Escalante[1,2*], **José David Henao Casas**[2], **Carlos Moreno de Guerra Per**[3], **María Dolores Maza Vera**[3], **and Carles Moreno Valverde**[3]

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Abstract

Conducting an accurate hydrological water balance at the regional and country-wide scales is paramount to assessing available water resources, and adequate allocation of them. One of the main components of these balances is the anthropogenic recharge of groundwater, intentionally, through managed aquifer recharge (MAR), or unintentionally, where infiltration from small dams and dykes in river courses play a substantial role.

In Spain, proper management of water resources is critical, due to the arid to semiarid conditions prevalent in most of the territory, and the relevance of water resources for maintaining a robust agricultural sector. Spanish previous work has estimated country-wide recharge from MAR at 150-280 Mm3/year. Recently, water authorities have pointed out that, according to hydrological water balances, the total volume from "unintended recharge" from watercourses may exceed 500 Mm^3/year.

This research aims to present a new inventory of transverse structures in Spain to estimate country-wide unintended recharge. The inventory, compiled by the Spanish Ministry for the Ecological Transition and the Demographic Challenge, has about 26,700 structures with detailed information. Structural data from the inventory has been crossed through map algebra with thematic layers, such as lithology, permeability, digital elevation model, average groundwater levels, etc., in a GIS environment. Infiltration from small dams and dykes in Peninsular Spain has been computed. The resulting volume of unintended recharge from transverse structures has resulted in about 800 Mm3/year (above official figures). This quantity can help close the hydrological balance at the national and river basin scales. Furthermore, this figure provides a difficult to obtain order of magnitude for anthropogenic recharge at a national level and remarks the crucial importance of the dykes for climate change *adaptation*.

106. WATER RECYCLING COMBINED TO MANAGED AQUIFER RECHARGE IN THE DUNES: LONG TIME EXPERIENCE AT KOKSIJDE (FLANDERS, BELGIUM)

E. Van Houtte[1], Rogier, T. [1], Van Eeghem, J. [1], and J. Verbauwhede[1]

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Abstract

In 2002 Aquaduin started reusing wastewater effluent for infiltration of an unconfined aquifer in its dune water catchment St-André at Koksijde. This enabled a reduction of groundwater extraction, not only in St-André, but also in another dune water catchment at De Panne, resulting in higher groundwater levels.

This presentation and paper want to highlight the different aspects and achievements of this water recycling combined with the MAR project.

This combination has enabled sustainable groundwater management of the dune aquifer, enhancing the natural values of the area (Van Houtte et al., 2021). Around the infiltration pond, wet grassland emerged and typical plants like orchids and Parnassia are back.

A sustainability rating was performed (Zheng, Y. et al, 2021) and the Aquaduin MAR system was rated good with a value of 2.8 (-5 being 'debilating' and +5 'restorative').

It also proved a robust combination to cope with the longer drought periods that recently occurred. Infiltration helped maintain groundwater levels high enough to ensure extraction and thus providing drinking water to residents and tourists, especially in summer (Van Houtte et al., 2021).

In the next decades, due to climate change, even more heat waves, extreme precipitation and longer droughts are expected but Aquaduin is prepared. The expected sea level rise, increasing the risk of seawater ingress, is monitored carefully but also here the Aquaduin MAR system is considered to be a preventive action.

As temperature plays an important role in our scheme (Samanta et all., 2020) the infiltration capacity will increase in summer seasons. This will compensate for the expected increase of demand in warmer summers. The lower infiltration capacity in winter, due to lower temperatures, was addressed by implementing subsurface infiltration since 2014. Infiltration boxes of the type used to store rainwater were placed in a trench one meter below surface. The advantages are multiple: no cooling when it is cold outside and low clogging risks. Aquaduin adjusts the volume fed to the subsurface system according to the season: less in summer and more in winter to compensate for the lower capacity in the open ponds. Aquaduin plans to automate the system based on the levels in the open pond.

The Aquaduin MAR project is economically feasible. In Zheng et al. (2021) a levelized cost and benefit cost rate (BCR) was calculated. The current cost is half of what Aquaduin needs to pay to import drinking-water from neighboring companies and this resulted in a levelized cost of 0,5 US$ per m³ recharged water and a BCR of 2,23.

The main aspect when drinking water is at stake is quality. The membrane treatment proved robust towards removal of bacteria, viruses and most of the micropollutants. The MAR system proved to be an extra barrier for microbiological issues and risks were mitigated varying the distance between the pond and the wells, thus the residence time.

66. PRELIMINARY HYDROLOGICAL ASSESSMENT OF "PESQUERAS" IN GREDOS MOUNTAIN RANGE (SPAIN) AS ANCESTRAL ARTIFICIAL RECHARGE SYSTEMS

Antonio González-Ramón[1]; Ana Fernández-Ayuso[4]; Miguel Rodríguez-Rodríguez[5]; Héctor Aguilera[2]; Thomas Zakaluk[1], Nuria Naranjo[1]; Carlos Marín-Lechado[2]; Jorge Jódar[3]; and Sergio Martos-Rosillo[1]

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Abstract:

This study presents a historical example of artificial recharge through infiltration ditches in a small watershed in Gredos Mountain Range (Spain). The so-called pesqueras stand out as a unique system for managed aquifer recharge, also known as water sowing and harvesting. The San Gregorio Gorge basin was comprehensively studied, including an inventory of 119 springs, detailed assessments, and mapping of four pesqueras (Poyos, Cardos, Lanchas and Toriles). Groundwater infiltrates into a hillside aquifer formed by weathered granite sands and clays. A subsequent hydrological analysis using precipitation data, hourly water levels, water temperature data and monthly water flow measurements collected during 2023-2024, as conducted to assess the basin's infiltration and runoff rates. According to this analysis the operation of infiltration ditches enhances the total aquifer recharge of the basin. The findings indicate that the ditches can divert flows up to 15 % of the area's total precipitation, recorded during the observation period at a meteorological station located at 667 m a.s.l. At the San Gregorio Gorge basin outlet, where the total discharge in 2023-24 (11 hm^3) was 70% of the area´s rainfall, pesqueras recharge have contributed 20% of this volume. Furthermore, these ditches could recharge significantly more if restored to their full capacity. Before widespread abandonment, and partial ongoing restoration during the last years the pesqueras were operational for 9 to 10 months each year. Finally, this research emphasizes this approach as an excellent example of Integrated Water Management and Nature-based Solutions in mountain regions generating social, economic, and environmental welfare.

100. MANAGED AQUIFER RECHARGE FOR THERMAL LOADING MITIGATION AND ENHANCEMENT OF INSTREAM HABITAT

Jason Melady, RG, CWRE and Ryan Dougherty, PE, RG, CWRE

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Abstract

Most rivers and streams in the Pacific Northwest of the United States (US) are listed as impaired waters under the US Clean Water Act (CWA) for excessive water temperatures that threaten Endangered Species Act (ESA) listed fish species. Water temperature total maximum daily loads (TMDLs) have been developed for many of these watersheds and thermal loading limitations have been put on dischargers and new surface water diversions to protect ESA listed fish. While numerous managed aquifer recharge (MAR) projects have been developed in the Pacific Northwest for municipal drinking water supply over the last 25 years, it has recently emerged as a tool for mitigating thermal loading impacts and enhancing instream habitats for ESA listed fish species by utilizing cool wintertime stored water as mitigation.

This talk will cover the extent and implications of surface water temperature impairments in the Pacific Northwest in the context of ESA listed fish species, public water users/dischargers, and climate change. The talk will then provide an overview of emerging applications of MAR as a tool for mitigating thermal loading impacts and enhancing instream habitats and discussing key project feasibility elements including hydrogeology, water quality and geochemical compatibility considerations, treatment requirements, facility design, and quantification of thermal benefits.

18. MAR: A VITAL COMPONENT IN DESIGNING LIVABLE URBAN WATERWAYS FOR ENVIRONMENTAL RESTORATION IN CAPE TOWN

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Abstract:

Cape Town's water shortage underscores the challenges of climate unpredictability and the growing demand for water due to urbanization and population growth. These issues highlight the pressing need for innovative water management strategies that balance social, economic, and environmental priorities. To address this, the City of Cape Town has committed to becoming a water-sensitive city by 2040, developing and adopting the Livable Urban Waterways (LUW) concept. This initiative, aligned with global efforts such as sponge cities and water-sensitive urban design, aims to build resilient urban water systems that restore ecological and environmental functions.

Managed Aquifer Recharge (MAR) plays a critical role in achieving the goals of LUW, offering solutions to mitigate flooding, improve water quality, and support urban ecosystems. The Sand River and Upper Elsieskraal River catchments in Cape Town serves as case studies where hydrogeological assessments were conducted to explore potential interventions. Findings revealed that enhancing groundwater-surface water interactions could transform the river system into a more functional LUW. MAR techniques, such as removing canal linings and re-establishing connections with floodplains, could promote aquifer recharge, reduce surface water quality variability, and sustain wetland areas during dry periods.

The LUW programme requires collaborative planning, robust conceptual hydrogeological models, and the integration of MAR strategies to enhance the urban waterways' capacity to manage flood risks, support ecological systems, and maintain water quality. This new approach to waterway management is essential for building sustainable, resilient urban environments.

128. A SWEDISH CASE STUDY ON TRACING PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS) THROUGH A MAR SYSTEM

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Abstract:

Managed aquifer recharge (MAR) is a cost-efficient technique to maintain and restore groundwater systems. Additionally, MAR can act as treatment step for certain contaminants [1,2]. In Sweden, MAR is used as pre-treatment in drinking water production to lower concentrations of dissolved organic matter in Swedish surface water as well as to maintain sufficient groundwater quantities. Stable water isotope ratios (d18O and d2H) are a widely applied tool to trace the fate of surface water infiltrated into groundwater or for determining the origin of groundwater when recovered downstream [3,4]. While stable water isotope ratios allow estimating the relative contribution of surface and groundwater to an aquifer, the fate of emerging contaminants infiltrated with the surface water is studied little. However, understanding the fate of contaminants of emerging concern such as per- and polyfluoroalkyl substances (PFAS) in MAR systems is becoming of concern due to stricter drinking water quality requirements. This study investigated the fate of PFAS and organic matter through a MAR system in combination with using stable water isotope ratios to track the relative contribution of the artificially infiltrated water to the natural groundwater system as well as seasonal variations. Ten years of 18O and 2H analyses have shown clear 18O and 2H seasonal variation in the surface water isotope ratios and thus allow for tracking of the artificially infiltrated water masses as well as indicate mixing and dilution by the natural groundwater. These results could be correlated with the different PFAS and organic matter composition profiles downstream of the MAR site, which aids future water resource planning at MAR sites especially when planning for expansion and operation schemes of the MAR system. This is especially relevant in cities facing population growth and thus increased needs for drinking water quality and quantity under changing precipitation schemes.

30. ASSESSING THE POTENTIAL OF MANAGED AQUIFER RECHARGE FROM TREATED WASTEWATER IN THE GREATER DURBAN METROPOLITAN REGION, SOUTH AFRICA

M.B. Demlie and H. Msweli

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Abstract

The Greater Durban Metroplitan Region produces an average of about 2.76 x10^8 m^3/year treated wastewater from 27 wastewater treatment works (WWTW) located across the Metropolitan Region**.** This treated wastewater is currently beng discharged into nearby rivers and streams and eventually joins the Indian Oean. However, this large volume of treated wastewater could be used to manage climate change and groundwater use impacts along the region's coast including water security challenges such as groundwater level declines, water quality deterioration and seawater intrusions. This paper presents the results of a preliminary research that investigated the potential of using the treated wastewater as part of climate change adaption and management of potential seawater intrusion in the region induced by groundwater use along the Indian Ocean coast. The study employed collection, analysis and interpretation of geological, hydrological, hydrogeochemical data, including the amount and quality of treated wastewater generated within the study area. The study identified the primary coatal aquifers made up of the Bluff, Berea, and the Harbour Beds Formations that have the potential to be used for managed aquifer recharge (MAR) using treated wastewater. These aquifers are mean hydraulic conductivities (K) 3.2,5 and 6.5 m/day, respectively. These aquifers receive an estimated mean annual groundwater recharge rate of about 12% of the mean annual precipitation (MAP = 935 mm/year). The depth to groundwater level varies across the area but generally varies from near surface to 20 m below ground level. The regional groundwater flows from west to east, toward the Indian Ocean. Based on factors, including the current rate of natural recharge, current groundwater abstraction, the potential need for MAR, the hydraulic characteristics of the aquifers, such as K, storage capacity and treated wastewater source for MAR (the infrastructure needed to transfer treated wastewater), five potential MAR sites have been selected within the primary aquifers. These are: i) Site 1 is located between Umhlanga Rocks and Tongaat, ii) Site 2 includes the area around Sea View, Woodlands, Mobeni Height, Joe Slovo and Lamont areas; iii) Site 3 is located around the uMlazi and Isipingo areas; (iv) Site 4 is located around the uMbogintwini and Amanzimtoti areas; (v) Site 5 is located within the Harbour Beds, stretching from the uMgeni River in the north through downtown Durban all the way to uMbogintwini in the south. Since a considerable amount of groundwater from these aquifers is being abstracted for various industrial and domestic purposes, MAR can be potentially applied to mitigate potential seawater intrusion along the Indian Ocean coast induced by pumping. The proposed source of treated wastewater for Site 1 and 6 would be derived from Northern WWTW, and for Sites 2, 3, 4, 5, 7 are from uMbilo WWTW, Southern WWTW, Isipingo WWTW, Amanzimtoti WWTW and New Germany WWTW, respectively. Though this study identified potential aquifer sites and sources of treated waste waters for MAR as a potential tool for climate change impact and seawater intrusion mitigation, improving the quality of treated wastewater to the standards required for MAR is essential. Furthermore, a detailed modelling and feasibility study across the area is recommended to come up with the most feasible and suitable sites for MAR using treated wastewaters generated across the Metropolitan Region.

101. POTENTIAL BIOINDICATORS OF AQUIFER HEALTH: A PRELIMINARY INVESTIGATION AT A CAPE FLATS STORMWATER INFILTRATION

Victor Parry[1], Rachelle Schneuwly[1], Kirsty Carden[1], Hugues Thouin[2], Christopher G Bryan[2], Nicole Baran[2], Coralie Soulier[2], and Alexis Gutierrez[2]

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[2] French Geological Survey (BRGM), Orleans, France.

Abstract:

The city of Cape Town has mobilized efforts to systematically exploit groundwater reserves, including through managed aquifer recharge with stormwater. Increasing urbanization results in polluted runoff that can contaminate groundwater; the City of Cape Town, UCT's Future Water Institute and the French Geological Survey (BRGM) have thus collaborated to examine aspects of urban water quality (contaminants of emerging concern and microbial biodiversity) in the Cape Flats Aquifer (CFA; South Africa) using analytical methods such as non-target screening (NTS) and high throughput sequencing. The latter technique generates large datasets ensuring good coverage of the microbial biodiversity and provides resolution to the genus level. This preliminary work was conducted at a stormwater infiltration site in Mitchells Plain within the CFA. Samples of stormwater and groundwater biomass were taken on site and analyzed using 16S rRNA gene sequencing. The results revealed that the biodiversity of the infiltration zone with 605 unique taxa was different to both the up and downstream parts of the aquifer as well as the stormwater, suggesting the community structure was driven by factors other than input of specific taxa from the stormwater. Furthermore, the study identified a correlation between geochemical factors, environmental conditions and the relative abundance of specific genera. For example, during dry spells, nitrate concentrations were higher, and groundwater had a greater abundance of *Omnitrophus* spp., which was absent in stormwater. This resulted in a hypothesis that *Omnitrophus* spp. dominance may be an indicator of a stable, undisturbed aquifer system. Overall, the study highlights the potential use of microbial bioindicators at MAR sites to improve groundwater quality monitoring. This has led to further ongoing research to i) better characterize microbial biodiversity and ii) understand the potential role of bioindicators in groundwater monitoring at two further MAR sites in the Western Cape.

6. POTENTIAL ECOLOGICAL IMPACTS OF MANAGED AQUIFER RECHARGE ON WETLANDS IN THE LANGEBAAN ROAD AQUIFER UNIT

T. Mathivha[1, 2], N. Vermaak[1, 3], A. Magingi[4], and P.J. Oberholster[1]

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Abstract:

This study evaluates the potential ecological impacts of Managed Aquifer Recharge (MAR) on the wetlands of the Langebaan Road Aquifer Unit in the Western Cape Province of South Africa, focusing on wetlands influenced by groundwater. An integrated methodology involving chemical and isotopic analyses is employed, with periodic collection of groundwater and surface water samples to measure physicochemical parameters, including pH, electrical conductivity, dissolved oxygen, and major ion concentrations. Stable isotope ratios (δ18O and δ2H) are analysed to trace the origins of wetland waters. Preliminary results indicate significant interactions between groundwater and surface water, with groundwater identified as the primary source for wetlands during dry periods, as evidenced by stable isotope signatures. Hydrochemical assessments reveal distinct seasonal variations influenced by factors such as seawater intrusion, calcrete presence, and seasonal dynamics. Notably, some wetlands appear to function as discharge points. The findings suggest that while MAR operations could enhance water availability, they also pose risks to wetland ecosystems. Concerns regarding excessive water injection and the consequent rise in the water table are critical, particularly given that some wetlands may act as discharge points. In these cases, careful monitoring of infiltration is essential, especially during the wet season, to prevent flooding and ensure ecosystem stability. Given the complex interplay of hydrogeological factors, a cautious approach to MAR implementation is warranted, highlighting the need for comprehensive impact assessments and the development of mitigation strategies to protect these sensitive environments. Meticulous planning and ongoing monitoring is recommended for MAR initiatives in this region. Further research is essential to deepen the understanding of groundwater-surface water interactions and to formulate targeted management practices for the sustainable utilization of the Langebaan Road Aquifer Unit Wetlands.

149. MAR AS AN EFFECTIVE CLIMATE CHANGE ADAPTATION MECHANISM: A CASE STUDY IN FRIULI VENEZIA GIULIA REGION, ITALY

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Abstract:

The Friuli Venezia Giulia (FVG) region in northeastern Italy has experienced an imbalance in the hydrogeological system over the years, resulting in the lowering of groundwater levels. Reduced and erratic precipitation patterns, rising temperatures, and increased abstraction have all contributed to the decline in piezometric levels in the Friuli Plain's phreatic aquifers. These changes in the hydrogeological system have resulted in a decrease in direct infiltration, and an increase in the surface run-off and evapotranspiration rate, thus affecting both the surface and groundwater resources in the region. The groundwater of the region is also polluted by nitrate content, whose concentrations in some parts of the region exceed the threshold value (50 mg/l as per Italian legislation) for potable use. To address declining water resources and improve underground storage of high-quality surface waters, three recharge sites (Carpeneto, Mereto di Tomba, and Sammardenchia), in the upper Friuli plain have been suggested for MAR practice. MAR potential in this pre-Alpine region is characterized by the availability of high-quality surface waters (primarily from rivers), a highly permeable thick aquifer system, and numerous existing structures such as pits and large-diameter wells. The present study aims to investigate the effect of MAR on groundwater levels and quality through an infiltration pond at Sammardenchia. Modflow is applied to simulate the aquifer's response to natural and artificial recharge through MAR by means of water from the nearby Ledra channel. The initial results show a positive effect of MAR on the groundwater levels at the local scale. The study further aims to simulate the solute transport and water quality changes resulting from the recharge operation, with the ultimate goal of predicting future hydrogeological variations in the aquifer system.

35. MANAGED AQUIFER RECHARGE THROUGH PRECAST MODULAR SYSTEMS WITH HIGH-PERFORMANCE RECHARGE WELLS USING JOHNSON SCREENS AND RAIN QUANTIFICATION SYSTEMS IN GUJARAT'S VARIED TERRAIN – CASE STUDIES.

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Abstract:

Gujarat, located in western India, faces significant challenges in water resource management due to its semi-arid climate, variable rainfall patterns, and growing water demands from agriculture, industry, and urban areas. Groundwater is a crucial lifeline for many regions in Gujarat, particularly where surface water is either scarce or unreliable. Over-reliance on groundwater extraction has led to alarming depletion levels, further compounded by climate change-induced variability in rainfall. Surface water resources, including rivers, lakes, and reservoirs, are increasingly stressed, making groundwater an indispensable resource for communities, industries, and agriculture. However, unregulated extraction and inadequate recharge methods are pushing many aquifers to their limits. To ensure the long-term sustainability of groundwater reserves, it has become essential to explore and implement strategies that augment aquifer replenishment while addressing local terrain and hydrological conditions.

Managed Aquifer Recharge (MAR) presents a promising solution to Gujarat's water challenges. By capturing surface water, including rainwater runoff, and directing it into aquifers, MAR offers a controlled method for increasing groundwater levels. This paper explores a cutting-edge approach developed by Furaat Earth Private Limited, which utilizes precast modular systems incorporating Johnson Screens for high-performance recharge wells. These wells are designed to channel harvested rainwater and surface water into the aquifers, mitigating the effects of groundwater depletion and providing a sustainable means of water resource management. This study focuses on the application of these systems in Gujarat's varied terrain, where conditions range from water-logged regions to arid zones, demonstrating the versatility and effectiveness of MAR in diverse environments.

Key findings from the project reveal:

1. Hydrological benefits of Managed Aquifer Recharge (MAR).
2. Improvements in groundwater quality and increased storage capacity.
3. Enhanced ecosystem resilience to climate impacts.
4. The synergy of MAR with rainwater harvesting as a strategy to combat groundwater depletion and over-extraction.

This research underscores the need for an integrated water resource management approach that addresses ecological, social, and economic dimensions, with MAR serving as a critical strategy for sustainable groundwater management in Gujarat.

Keywords: Managed Aquifer Recharge (MAR), Johnson Screens, High-performance recharge wells, Precast modular systems, Rainwater harvesting, Sustainable groundwater management, Gujarat terrain.

157. ISOTOPIC INVESTIGATION OF GROUNDWATER-SURFACE WATER INTERACTIONS IN MANAGED AQUIFER RECHARGE SYSEMS: A CASE STUDY OF THE LOWER BERG RIVER CATCHMENT, WESTERN CAPE PROVINCE, SOUTH AFRICA

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Abstract

The current study explored the interactions between groundwater and surface water within the context of Managed Aquifer Recharge (MAR) in the lower Berg River catchment, located on the west coast of South Africa. Stable isotopes of $\delta^{18}O$ and $\delta^{2}H$ were analyzed from water samples collected over two hydrological years, including wetlands, boreholes, rivers, and rain gauges. The study aimed to understand the possible recharge sources and their contributions to the groundwater system under varying hydrological conditions. Using stable isotope analysis and end-member mixing analysis (EMMA), recharge contributions from rainwater, surface water, and wetland sources were identified. The isotope results showed significant seasonal variability, with enriched $\delta^{18}O$ and $\delta^{2}H$ values in wet seasons suggesting direct rainwater recharge, while more depleted values during the dry season alluding to a complex interplay of evaporated surface water and groundwater mixing. Wetlands, often identified as transitional zones, were found to be significant contributors during certain periods, emphasizing their role in maintaining local hydrological connectivity. The end-member mixing analysis (EMMA) provided insights into the proportions of recharge sources. Results showed that surface water was a major contributor to groundwater recharge, especially during high-flow periods when river and wetland waters infiltrated the subsurface more effectively. Rainwater, though important during wet seasons, was not the sole contributor, as contributions from surface water and wetlands also played a critical role in maintaining groundwater levels. The calculated recharge contributions revealed variability across different locations and timeframes, emphasizing the complexity of recharge mechanisms in the region. These findings demonstrate the dynamic nature of groundwater-surface water interactions in semi-arid environments and highlight the importance of multi-source recharge in sustaining groundwater resources. These insights are crucial for optimizing MAR strategies in the Berg River catchment to enhance water security and ecological integrity of surface water systems amidst changing climatic conditions.

Keywords: Managed Aquifer Recharge, Isotopic Analysis, End-Member Mixing, Groundwater-Surface Water Interaction, Berg River Catchment, Wetlands, Water Recharge Dynamics.

111. MICROBIAL BIODIVERSITY AND GEOCHEMISTRY OF THE ATLANTIS MAR SITE: INITIAL DEVELOPMENTS TOWARDS A BIOSURVEILLANCE TOOLKIT

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Abstract:

Aquifers contain around 97% of all liquid freshwater on Earth and are one of the largest habitats for microorganisms (comprising ~25% of the total prokaryotic biomass). Aquifer ecosystems provide services that are of immense societal and economic value (water purification, active biodegradation of anthropogenic contaminants, nutrient recycling, mitigation of floods and droughts, support to dependent surface ecosystems). Thus, a healthy aquifer contains a functioning microbial ecosystem (microbiome) which contributes to and maintains water quality by removing, for example, nitrate and certain organic contaminants. This invisible biodiversity is of critical importance to successful aquifer management. Managed aquifer recharge (MAR) involves the mass input of exogenous water (either through infiltration mechanisms or via direct injection) into an established aquifer system. This may be, for example, treated wastewater or stormwater, and may involve the application of some form of wetland or other nature-based solution to further improve incoming water quality before it infiltrates the aquifer proper. This incoming water may nevertheless contain contaminants which may impact aquifer health and water quality, but also its own microbial community. In the continuity of a project conducted by the City of Cape Town, UCT's Future Water Institute and BRGM in the Cape Flats Aquifer (CFA) on the impacts of stormwater infiltration, a new project, MAReM, involving the same partners, aims to pursue the research on the impact of both stormwater and treated wastewater on aquifer microbial diversity and functions at the Atlantis city installation which has been running for 40 years. This project also aims to identify new management indicators, define education needs and deliver coherent educational material in relation to groundwater. Here we shall present the first results from samples collected up and downstream of Atlantis from a biological and geochemical angle as well as from the continued monitoring of the CFA site.

129. REVISIT THE SAT: CAN WE IMPROVE ITS EFFICIENCY AND OPERATION?

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Abstract

Soil aquifer treatment (SAT) is a subset of managed aquifer recharge (MAR), in which water quality and quantity are both challenges. In many cases, such as the Israeli case, SAT is used for tertiary wastewater treatment. On the one hand, the surface area available for SAT operation is becoming a limiting factor with population increase and lifestyle changes. On the other hand, the biogeochemical processes needed to achieve the level of degradation require time and specific operational schemes. Over the last several years, we have explored various methods and ideas, running experiments on different scales and analyzing data to confront this challenge. Data from numerous redox, oxygen, and water content sensors were collected and analyzed. The influence of seasonal and operational effects was compared. Columns experiments and modeling were conducted to explore the role of operational schedule (i.e., the length of wetting and drying cycles) on the biodegradation process. The idea of replacing silica sand with higher permeability yet with high porosity media is being explored on different scales. Active subsurface air injection was investigated on a laboratory scale to shorten drying periods and is currently being tested on the field scale. The usage of agricultural fields, specifically orchards, as an alternative area for winter flooding was also tested. This talk will briefly summarize our efforts to manage SAT under limited land conditions optimally.

Parallel 5:
4. Quality and Clogging Issues: Predictions and Management in Basins and Bores

156. PATHOGEN TRANPORT AND FATE DURING RIVERBANK FILTRATION

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Abstract

Riverbank filtration (RBF) is frequently employed for the production of drinking water through the subsurface passage of river water to an abstraction well. Due to the potentially contaminated nature of the infiltrating water, various physical, chemical and biological processes in the subsurface are relied upon to reduce the concentrations of contaminants. Concentrations of pathogenic microorganisms in river water fluctuate depending on water levels and source inputs. Given the variable nature of these input concentrations and the numerous factors influencing pathogen behaviour in soil, a solid understanding of the processes determining pathogen transport and fate is required to ensure the production of safe drinking water. Consumption of contaminated drinking water, even in trace amounts, can cause severe illness and, in some cases, lead to epidemics and fatalities.

Predictive modeling of pathogen transport and fate is essential for evaluating and mitigating the risk of pathogen presence in extracted drinking water. However, currently, the kinetic parameters used to describe the transport of pathogens at the continuum-scale tend to be descriptive rather than predictive. This research aims to advance the predictive modeling capacity of pathogen transport and fate in RBF systems. These models are crucial for evaluating and reducing the risk of pathogen presence in extracted drinking water. By developing and applying these models to existing and novel datasets, we seek to enhance the understanding of pathogen dynamics and contribute to safer drinking water production.

95. INJECTION BORE CLOGGING PREDICTION AND MANAGEMENT: CASE STUDIES FROM SOUTHERN AFRICA AND AUSTRALIA

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Key words: Injection bore, clogging, geochemical modelling, bore rehabilitation and cleaning, Managed Aquifer Recharge

Abstract:

Managed Aquifer Recharge (MAR) is increasingly recognised as a sustainable approach to water resource management in arid and semi-arid regions prone to water scarcity. However, one of the primary challenges associated with MAR is the risk of injection bore clogging, which can significantly educe the efficiency and lifespan of MAR schemes. This study explores the use of geochemical modelling for predicting and managing clogging issues in injection bores, with a focus on four case studies across Southern Africa and Australia.

Clogging in injection bores can arise from various processes, including chemical precipitation, biological growth, and physical blockage by fine particles. The interplay of these factors is highly dependent on the water quality and the geochemical characteristics of the aquifer. Geochemical modelling serves as a powerful tool to simulate these interactions, enabling the prediction of potential clogging scenarios under different recharge conditions.

This study highlights the application of geochemical modelling in assessing the risks associated with water quality, particularly in terms of mineral precipitation and dissolution, which are primary contributors to chemical clogging. By understanding the saturation indices of minerals like calcium carbonate, iron oxides, and silicates, it is possible to anticipate clogging before it occurs, allowing for proactive management strategies.

The management of clogging involves both preventive and remedial actions, such as adjusting the source water quality through the implementation of active- or passive treatment systems and scheduled injection bore cleaning and rehabilitation programs. The insights gained from geochemical modelling not only aid in these management efforts but also contribute to the optimisation of MAR systems, ensuring their sustainability and reliability.

In conclusion, integrating geochemical modelling into the design and operation of MAR systems is essential for predicting and managing clogging issues in injection bores, as demonstrated by various case studies. This approach ultimately contributes to the development of more sustainable MAR systems in diverse hydrogeological settings.

31. SOIL AQUIFER TREATMENT, PATHOGEN AND ORGANIC CARBON REMOVAL REVISITED

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Abstract:
The use of treated wastewater effluent for groundwater recharge has a long history worldwide. Multiple water agencies in the Southwestern USA have recharged treated wastewater effluent and/or effluent dominated surface water for decades. In Europe, hundreds of riverbank filtration systems, some for over a century, are used to pre-treat surface water, frequently effluent dominated for pathogen removal. Soil aquifer treatment (SAT) naturally occurs in Managed Aquifer Recharge (MAR) operations to remove bacteria, protozoa, and viruses and reduce organic carbon and nutrient concentrations via biogeochemical reactions in the vadose and saturated zones. Biodegradation is the most important SAT mechanism and removal efficiencies typically increase over time, making SAT processes sustainable and efficient. Numerous studies in a variety of aquifer materials indicate SAT removes pathogenic bacteria and larger organisms, such as protozoa, with the majority of removal occurring within one meter of the recharge source. Virus removal requires longer treatment path lengths due to the smaller size and need for deactivation; nonetheless, virus transport beyond 30 meters has typically not been observed. SAT commonly achieves 50% removal of dissolved organic carbon (DOC) within meters, with removal efficiencies increasing to 75% to 90% or more with time and distance. SAT removal of emerging contaminants is variable and dependent on biodegradability.
Recent regulatory changes regarding treated effluent MAR programs in some states within the USA fail to consider the efficacy of SAT in pathogen and organic carbon removal and have created unnecessary hurdles towards implementing new treated effluent MAR projects. This talk will review research and knowledge gained on SAT over the last 50 years.

39. STORMWATER RUNOFF IN EUROPEAN CITIES: RISK OF URBAN GROUNDWATER POLLUTION DUE TO SUDS?

U.E. Bollmann[1], C.N. Albers[1], T.M.M. Karlsson[2], J.H. Christensen[2], A.R. Johnsen[1]

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Abstract

Stormwater infiltration is implemented in sustainable urban drainage systems (SUDS) in many cities to cope with heavy rain events, as predicted in future climate scenarios. While it is an effective way of handling large stormwater volumes, that may otherwise cause urban flooding, it also increases the risk of fast infiltration of stormwater pollutants into the groundwater and thus into drinking water resources.
In the present study, we investigated the composition of organic micropollutants in various types of urban stormwater runoff from across Europe by suspect screening (high-resolution mass spectrometry, HRMS), as well as determined leachable pollutants in urban stormwater infiltration systems at 1 m depth. The results showed a variety of organic micropollutants, among them compounds from the wear of car tires, but also other persistent and mobile pollutants (PMT & vMvP) such as melamine and benzalkonium chlorides. Several compounds were also detected in 1 m depth and pose a risk of further leaching to groundwater aquifers.

www.D4RUNOFF.eu has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101060638.

153. REMOVAL OF SUSPENDED SOLIDS AND WATER QUALITY IMPROVEMENTS FROM RIVERBED FILTRATION – EIGHT YEARS OF DEMONSTRATION TESTING IN ORANGE COUNTY, CALIFORNIA

A. Hutchinson

Abstract:

Clogging due to the accumulation of suspended solids is a major constraint that limits the capacity of Orange County Water District's (OCWD) managed aquifer recharge facilities. To decrease clogging and increase system capacity, OCWD installed a Riverbed Filtration System (RFS) demonstration project in a controlled area of the Santa Ana River channel with a system capacity of 50,000 m3/day. The RFS consists of tile drains located at depths of approximately 1 meter below the riverbed surface. Surface water is spread and recharged in the channel and subsequently captured by the tile drain system and sent to a downgradient groundwater recharge basin. Water quality and operational monitoring data from an eight-year period shows that the RFS is highly effective, removing an average of 97 percent of suspended solids in the recharge water, and produces other water quality improvements. The improved water quality has essentially doubled the recharge capacity of the receiving recharge basin. Modeling suggests that expanding the RFS to full-scale will significantly increase recharge system performance. Work is proceeding on developing the design of the full-scale system in the Santa Ana River channel.

145. COST EFFECTIVE CLOGGING MANAGEMENT DURING MANAGED AQUIFER RECHARGE

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Abstract:

The wide prevalence of clogging experiences in MAR schemes across Australia has led to this national study which aims to improve our current knowledge about clogging risks and identify integrated strategies to address clogging of MAR schemes. For this, three operational MAR sites (surface infiltration: Lockyer Valley, recharge weirs; injection bores: Aldinga, aquifer storage and recovery (ASR) and Langhorne Creek, ASR) and a treated wastewater (TWW) disposal infiltration scheme (Jurien Bay) that is vulnerable to clogging in the same manner as TWW infiltration basins for MAR were investigated. Clogging was observed across all study sites, despite variations in water sources (recycled and natural waters), employed MAR techniques (injection and infiltration) and aquifer characteristics, leading to a substantial reduction (up to 50%) in scheme capacity. Further, while clogging in some study sites appeared to develop gradually over long periods, in others, it occurred within the same recharge cycle, highlighting the variability of clogging processes in MAR schemes. From analysis of clogging management at the study sites, three generalized strategies for clogging management were identified:

- Design strategies: Target aquifer and system engineering
  Highly transmissive limestone aquifers have been directly or indirectly targeted in three of the four case study sites.
- Pro-active strategies: Water quality and pre-treatment
  While various rehabilitation measures that can yield excellent results exist, ensuring that recharge water meets the appropriate water-quality targets through adequate pre-treatment is a key factor in ensuring successful and sustainable long-term MAR operations.
- Re-active strategies: Water budgets and scheme remediation
  Where the rate of recharge is known, clogging can be managed. When this rate declines to a constant fraction, α, of the initial rate, 25%, a remediation method should be triggered to restore recharge rates and prevent long term decline of scheme capacity.

Outcomes from this study highlighted that clogging management is fundamental to the scheme's success and an operational monitoring program is required to understand the impacts of their operations on recharge and recovery of an adequate quantity and quality of water.

124. MONITORING DYNAMICS IN RIVER WATER QUALITY AND QUANTITY OF THE RIVER GÜNZ IN BAVARIA (GER)

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Abstract:

Managed aquifer recharge (MAR) projects have the potential to reverse the trend of declining groundwater levels worldwide (Jasechko et al., 2024). When river water is used for MAR, this is simultaneously an adaptation strategy for the imbalanced landscape water regime. However, using river water makes it inevitable to improve the understanding of dynamics in river water quality and quantity and the associated quality risks.

We monitored the Günz River in Bavaria, Germany, for 17 months with high temporal resolution. For this, a cost-effective open-source monitoring kit was developed and complemented by chemical analysis of water samples in the laboratory. A watershed risk assessment was conducted to understand and evaluate input sources and anthropogenic influences. Daily, seasonal, and yearly fluctuations were observed, as well as changes during high flows. Defining critical constituents in conjunction with the hydroclimatic situations helped to generate treatment and monitoring recommendations.

Based on the monitoring results and the risk assessment, we concluded that the Günz river water is suitable for infiltration throughout the year. During floods, a dilution of major ions and artificial sweeteners was observed, while some pesticides increased in concentration. Most other contaminants were below the detection limit at all times. Turbidity, which can act as a carrier for pollutants, increased sharply in response to local precipitation. Removing suspended solids is a necessity to prevent clogging in infiltration systems, and additionally reduces the concentration of hydrophobic contaminants. The comparison with surrounding groundwater revealed similar chemical compositions, which reduces the risk of negatively influencing groundwater quality and the geological matrix during infiltration. Our data set covers the full dynamics of the river and provides key parameters that can be measured quickly and used to confirm the chemical status of the water prior to infiltration. The watershed risk analysis helps to identify and remediate risks that might occur during flooding events.

26. ENGINEERED FUNGAL BIOFILMS IN A NOVEL BIOSENSOR FOR THE REAL-TIME MONITORING OF ESTROGENIC ENDOCRINE DISRUPTING CHEMICALS

D. Botha, J.C. Truter, E. Bester and G.M. Wolfaardt

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Abstract

The presence of emerging contaminants such as endocrine-disrupting chemicals (EDCs) in water resources is a global concern, with reported persistent and rising concentrations in surface- and groundwaters. Endocrine-disrupting chemicals (EDCs) are known to be bioactive and interfere with the vertebrate endocrine system which regulates hormone synthesis, transport and degradation. Although analytical chemistry can detect for single chemical contaminants, it does not address the possible biological activity of the chemical cocktail of hazardous chemicals potentially present in environmental samples. Effect-based methods (EBMs) address this shortcoming by accounting for chemical-chemical interactions and assessing acute or chronic exposure risks to ecosystem and human health. Both analytical chemistry and EBM techniques, however, require an advanced skill level to conduct with other added financial costs. Deployable automated biosensors functioning as EBMs could provide a solution to EDC screening, bridging the resource and human capacity gaps. Within this study, we developed a fluorescent yeast estrogen screen (fYES) strain, *Saccharomyces cerevisiae* SC-ERCIT, to respond in a dose-dependent manner to the presence of estrogenic EDCs. A low-cost, deployable biosensor device was subsequently designed to allow for inline exposure to and monitoring of environmental samples. By exploiting the biofilm growth mode of this organism, the designed reactor sensor system was applied to detect the presence of estrogenic EDCs under continuous flow conditions, allowing real-time and online monitoring of water source quality. The sensitivity, specificity, response time and limits of detection (LoD) and quantification (LoQ) of the constructed yeast strain showed promise under static and continuous flow conditions for future *in situ* applications. This will include assessing not only the quality of groundwater directly as part of Managed Aquifer Recharge (MAR), but also the sources like treated wastewater that could possibly feed MAR resources.

40. FATE OF PATHOGENS AND ORGANIC MICROPOLLUTANTS IN MAR: ENHANCING REMOVAL EFFICIENCY BY REACTIVE LAYERS

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Abstract

The use of lower-quality water for MAR may be necessary in areas experiencing water scarcity, but it also increases the risk of polluting groundwater aquifers with organic micropollutants and pathogens originating from households, industries and alike. To mitigate this risk, reactive layers might be incorporated into the infiltration path to facilitate the removal of pollutants by both sorption and degradation.

In our conceptual laboratory experiments, we used 40 cm saturated sand columns fed from the top with artificial wastewater containing a variety of micropollutants and pathogens. The goal was to assess the effects of biochar or compost reactive layers on micropollutants and pathogen removal under aerobic and anaerobic conditions. Increased removal of some, but not all micropollutants was observed in columns with reactive layers under both aerobic and anaerobic conditions. As expected, the increased organic material content of the reactive layers caused higher micropollutant sorption. Additionally, the reactive layers also induced higher biological and chemical activity and increased degradation of some organic micropollutants. The sand columns primarily acted as a filtration mechanism for pathogens, with cell size influencing leaching. No significant effect of the reactive layer on pathogen removal was observed. The results show that the choice of reactive layers must be tailored to the specific pollutants in the source water, as different layers influence the removal in various ways.

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89. INVESTIGATING MAR WELL CLOGGING POTENTIAL FOR HIGHLY PURIFIED WASTEWATER IN A DEEP COASTAL PLAIN AQUIFER

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Abstract:

At the Hampton Roads Sanitation District (HRSD) SWIFT Research Center (SRC) in Virginia (USA), engineers are implementing indirect potable reuse and MAR via deep injection well (~430 meters) into the Potomac Aquifer System (PAS). The SRC implements a carbon-based advanced water treatment process on 3,790 m3/day of wastewater effluent followed by MAR with the goals of securing water supply, reducing effluent nutrient loads, and mitigating land subsidence and salt-water intrusion. The SRC has been operating since 2018 and in that time there have been challenges with well screen clogging of the original recharge well, necessitating the construction of a new and updated well in 2022. Evidence of clogging potential of recharge water has been observed via the loading of solids to wellhead bag filters. This work focuses on three approaches to determine the status and cause of clogging: 1) tracking well performance with step injection/withdrawal pump tests, 2) applying machine learning models to the analysis of specific injectivity, water quality parameters, and SWIFT process treatment variables, and 3) analyzing materials from recharge water captured by 1 μm bypass filters. Standardized step injection/withdrawal pump tests indicate a loss of specific injectivity over the past year. Historical data analyses of injectivity also identify inflection points where there were decreases in injectivity. Machine learning techniques, including principal component analysis, and a decision tree model with SHAP dependence were applied to numerous SWIFT water quality parameters (i.e. dissolved oxygen, total organic carbon), influent water quality parameters (i.e. total nitrogen, pH), and SWIFT process treatment variables (i.e. chemical doses) to determine which, if any, variables impact injectivity. Finally, composition and structure of solids on a 1 μm bypass filter were analyzed using ICPMS, SEM, and XRD. Work continues, but preliminary results suggest trace iron, organic matter, and dissolved oxygen interactions may contribute to injectivity decline.

131. ADDRESSING THE SOIL TREATMENT BOTTLENECK

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Abstract

Soil aquifer treatment (SAT) is a subset of managed aquifer recharge (MAR) in which water quality is of significant concern and equals, if not exceeds, that of quantity. In many cases, such as the Israeli case, SAT is used for tertiary wastewater treatment. The infiltration process is conducted intermittently to allow oxygen penetration to the shallow subsurface in a diffusion-dominant process. This primarily supports aerobic bacterial degradation of residual carbon and nitrogen compounds and maintains reasonable ORP values to prevent manganese leaching from the vadose zone. While the resulting water quality is high and typically suitable for unrestricted irrigation, the water quantity process is inefficient, as the infiltration surface area is used only for a fraction of the time, normally about 40%. A new 600-square-meter pilot-scale experiment aims to allow continuous water infiltration while maintaining aerobic conditions in the upper meter of the subsurface. This is done by active intermittent air injection (see Figure 1). We will present both technical considerations and preliminary results (for the hot season), comparing conventional SAT with the new Air-SAT process and comparing the effectiveness of the process at different locations in the SAT basin and their proximity to the air injection infrastructure. This talk will focus on the biogeochemical aspects of the new experimental facility.

150. MOLYBDENUM MOBILITY DURING MANAGED AQUIFER RECHARGE IN CARBONATE AQUIFERS

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Abstract:

During the operation of managed aquifer recharge (MAR) systems in the carbonate aquifers of the Floridan Aquifer System, oxidized injectants extensively trigger pyrite oxidation. This was observed to coincide with the release of molybdenum (Mo) into the recharged water, which could have severe consequences for water safety and aquifer management. Surprisingly, although Mo is a chalcophile element, it was not found in pyrite or any other sulfide mineral. Instead, sulfurized organic matter was identified as the most likely primary host for Mo. A conceptual model was formulated Based on field observations and laboratory-scale experiments. According to this model, the injection of oxygenated water causes the oxidation of pyrite in the aquifer matrix, and the associated release of protons induces the dissolution of dolomite as a buffering reaction. This enhances the accessibility of the injectant to sulfurized organic matter contained within dolomite, which causes the release of Mo. Subsequently, a reactive transport model was developed and calibrated, constrained by a comprehensive set of hydrogeochemical observations from a MAR site in Orange County, Florida, to investigate and quantify the processes that affect the mobility of Mo after its release. The results showed that kinetically controlled dolomite dissolution buffered the acidity produced during pyrite oxidation. The latter process led to the release of Mo, which was partially attenuated by the adsorption of Mo on mineral surfaces and its capture by iron sulfides. The results also showed that the release of Mo could be prevented by maintaining the near-neutral pH of the native groundwater. This could be achieved by deoxygenating the injectant, thereby eliminating pyrite oxidation or boosting the intrinsic buffer capacity in the injectant. Ultimately, Mo should be included in managed aquifer recharge risk assessments in areas prone to Mo contamination, such as carbonate aquifers.

141. CLOGGING INDICATORS WERRIBEE ASR CASE STUDY

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Abstract

Managed aquifer recharge is being adopted across multiple industry sectors to address water scarcity challenges posed by climate change and groundwater overexploitation. Managed aquifer recharge systems will invariably experience clogging of some type, and to some degree, during their operational life, significantly impacting on the operational performance of the system. Clogging can manifest in a variety of different ways, physical, mechanical, biological, or geochemical processes. Operation of a successful and sustainable managed aquifer recharge system requires understanding of the potential interactions between the clogging types so that the root cause rather than the symptoms are addressed. Once the root cause of the clogging is understood mitigation approaches either through engineering design or operational management practices can be employed. The Werribee managed aquifer recharge system uses the method of aquifer storage and recovery through multiple bores. The source water for the Werribee system is salt reduced treated wastewater, where following storage in the deep confined aquifer, is recovered for reuse and distributed via a third pipe for non-contact reuse by households and industry. The Werribee aquifer storage and recovery system has undergone multiple cycles of recharge and recovery as part of commissioning ahead of full operation. This paper presents the approaches used to identify clogging during the commissioning phase of the Werribee aquifer storage and recovery system.

112. NATURAL ATTENUATION OF STORMWATER CONTAMINANTS DURING INFILTRATION AND STORAGE IN A SHALLOW PRIMARY AQUIFER

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Abstract

One of the five commitments made by the City of Cape Town in its Water Strategy is that of becoming a Water Sensitive City (WSC) by 2040. The concept of a WSC is a holistic urban water management approach which aims to increase water supply from within the city, increase urban water resilience, and improve the liveability of urban waterways. In a WSC stormwater is seen as a resource which should be protected, cleaned, and utilised. Stormwater harvesting through managed aquifer recharge (MAR) and storage in the Cape Flats Aquifer (CFA) is one way to achieve this. There are around 200 detention ponds (dry depressions designed to attenuate floods) overlying the CFA and it has been proposed that retrofitting these with blue-green infrastructure (BGI) could enable dispersed stormwater harvesting via MAR. Studies have shown that coupled with seasonal abstraction, stormwater MAR in the CFA may reduce flooding risk, and that the retrofitting of a detention pond in Mitchell's Plain increased stormwater infiltration by 118%. Lowering of the water table (increased abstraction scenarios) would further increase infiltration. In shallow groundwater with limited vadose zone thickness, however, urban stormwater contaminants pose a potential risk to groundwater quality. This research highlights results from column experiments on contaminant removal during soil filtration under saturated and unsaturated conditions that relate to the field study at the retrofitted detention pond in Mitchell's Plain. The column experiments demonstrated that 75 to 99% of metals and phosphate were removed during infiltration of synthetic stormwater through 0.5 m soil depth. Nitrogen species transformation occurred during infiltration, and total nitrogen removal improved under saturated conditions and with the presence of biodegradable organic carbon in the synthetic stormwater. This has implications for understanding nitrogen and organic carbon load limits to protect groundwater quality when implementing stormwater-linked MAR to improve water security.

60. ASSESSING THE RISKS OF EMERGING CONTAMINANTS FROM TREATED EFFLUENT AS SOURCE WATER IN ATLANTIS

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Abstract:

Managed aquifer recharge (MAR) using treated effluent and stormwater (TES) is a valuable strategy for ensuring the sustainability of urban aquifers used for potable water supply in water scarce regions. However, the use of TES in MAR raises safety concerns due to potential exposure to emerging contaminants (ECs). In thisstudy, we aim to assess the impact of TES on groundwater quality in the Atlantis Aquifer, by quantifying the presence and spatial distribution of various ECs. Twenty samples, including MAR source water, groundwater, and surface water, were collected and analysed for 289 compounds. Preliminary findings show that 120 different compounds, including pharmaceuticals, pesticides, disinfection by-products (DBPs), and industrial chemicals were detected. Groundwater receiving natural recharge had the fewest detections, while MAR source water had the highest, followed by groundwater impacted by MAR, indicating that ECs are added to groundwater through MAR. The presence of a few compounds in naturally recharged groundwater suggests a baseline level of contamination, likely from atmospheric deposition and agricultural runoff. A three-tiered health risk assessment showed that less than 10% of detected compounds in each tier have risk quotients (RQs) exceeding 1, indicating that the majority of compounds do not pose a health risk. The spatial distribution of ECs and low exposure risk suggests attenuation of certain compounds, including DBPs, select pharmaceuticals, and pesticides within the aquifer. However, to evaluate the aquifer's capacity to attenuate ECs, long-term monitoring data of conventional water quality indicators will be analysed. The outcomes of the study will guide the development of an EC monitoring framework for the scheme, which can also be adapted to the country’s other MAR schemes in development.

1. MAR for water supply purposes – Domestic/Municipal, Agricultural and Mining

22. A MAR FRAMEWORK IN THE SOUTH AFRICAN CONTEXT FOR ROCK AQUIFERS

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Abstract

A MAR frameworks are created to assist in the development of MAR schemes. The framework needs to provide a set of standards that needs to be followed to make the projects practical and cost-efficient. Internationally MAR Frameworks consist of four parts (source of water, implementation, use, and monitoring) which can be subdivided into various options to ensure the success and feasibility of the MAR scheme. In the last decade, efforts in South Africa were made to improve MAR schemes in fractured rock systems. Efforts focused on adapting frameworks to local conditions and addressing specific challenges. Some key developments include design, implementation, and monitoring data. Simplified design and implementation: Designing a system/s that is more user-friendly by ensuring it is low maintenance and still add value to the system, for example, making use of rainwater to ensure a good quality of water is being used. Monitoring and data collection: The design of a monitoring network or the monitoring itself does not always take place, but the schemes are designed to recharge water supply schemes and restore the water levels. The success of the implemented scheme can only be determent by monitoring various benchmarked parameters. Other areas to be addressed in the future include education for the people on how the schemes operate and community awareness on the precious resource, especially with more declining rainfall and the consideration of other water sources to be introduced into fractured rock aquifers.

42. CAN A LOCAL SOLUTION HAVE A REGIONAL IMPACT? EVALUATING THE INFLUENCE OF WEIRS IN AGRICULTURAL DRAINAGE DITCHES IN FLANDERS, BELGIUM

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Abstract:
Belgium, particularly the region of Flanders, is characterized by low-lying, flat terrain where agricultural drainage is essential for managing excess groundwater. However, during severe drought periods in 2011, 2017–2020, and 2022, groundwater levels decreased significantly, affecting nature, agriculture, and drinking water supplies. In response, several managed aquifer recharge (MAR) systems have been implemented to increase groundwater recharge. One key method involves the installation of weirs in agricultural drainage ditches to slow down drainage and increase groundwater levels. This strategy has been implemented in the Dommel Catchment, located in the Province of Limburg, where 11 weirs have been operational in drainage ditches since 2015. To evaluate the influence of these weirs on groundwater levels, a coupled groundwater-surface water model (MIKE SHE – MIKE+) was developed and calibrated. This model quantified the extent of the weirs' impact on groundwater levels and helped estimate their effect on the catchment's overall water balance. Furthermore, the model allowed for scenario analysis, enabling comparisons between different numbers and locations of the weirs within the catchment. This study is part of a larger research initiative focused on evaluating various modelling approaches (MIKE, Analytical Elements Method and MODFLOW) to understand the impact of weirs in agricultural drainage ditches. The objective is to identify the strengths and limitations of different models, to optimize strategies for managing groundwater on agricultural landscapes facing increasing water scarcity and climate-related challenges.

4. ASSESSMENT OF WETLANDS AS AN INDICATOR FOR MAR SITE SELECTION IN LANGEBAAN ROAD AQUIFER

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Abstract:

Managed Aquifer Recharge (MAR) has been proven to be effective in improving water quality and storing water for later use. South Africa has used MAR for many years mainly to get more water into aquifers for community water supply. In a research study, Managed Aquifer Recharge in SA focusing on assessment of Langebaan Road aquifer and Atlantis aquifer which are both located in the West Coast, South Africa; nine (9) wetlands located in Langebaan Road Aquifer Unit (LRAU) were assessed and quarterly monitored from March 2022 to March 2024 to provide a baseline on ecological state and guide an environmental monitoring protocol. The wetlands were further evaluated using both sediment column tests and chemical analyses to provide an indication of potential MAR sites and possible methods that can be used for piloting of MAR in LRAU. This paper highlights the use of the Wetland Classification and Risk Assessment Index (WCRAI) to obtain a baseline of wetlands in LRAU; the quarterly chemical analyses conducted on groundwater and surface water, the criteria used to select wetlands for sediment column testing and the results obtained are presented in maps, tables and graphs.

The findings from the sediment column tests conducted on four wetlands suggest that wetlands located on the Berg River floodplain have a low infiltration rate than those located further away; this provides an input into the different methods that can be applied across LRAU. The variation in chemical analyses and WCRAI results can be attributed to seasonal dynamics. The recommendations on selection of MAR sites within LRAU and possible MAR methods were deduced from the results obtained from the aforementioned integrated methodology applied. The complexities highlighted are an indication that in LRAU, different MAR techniques can be implemented with different monitoring procedures to minimize impact on the environment.

3. ASSESSING MANAGED AQUIFER RECHARGE BY INDIGENOUS COMMUNITIES IN MOUNTAINOUS WATERSHEDS OF OAXACA, MEXICO

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Abstract:

Groundwater is a crucial resource, relied upon by 80% of the global population. However, declining groundwater levels worldwide, driven by extreme weather events such as droughts, and increasing demands, pose a significant challenge. A low-cost, low-tech solution known as Managed Aquifer Recharge (MAR) has been implemented by indigenous communities in mountainous watersheds of Oaxaca, Mexico, to address this issue. Effective MAR strategies are site-specific and require a thorough understanding of the local groundwater system. In the Valles Centrales region of Oaxaca, Mexico, there is limited data on the groundwater dynamics within these mountainous watersheds, which is required for a more comprehensive understanding of the system to assess the effectiveness of MAR interventions.

The primary MAR strategy in the study area involves the use of infiltration reservoirs. Data collection focused on spatial mapping of aquifer dimensions, properties, and water levels, alongside temporal monitoring of MAR structures and abstraction wells. Results indicate that the groundwater flow system is predominantly controlled by elevation gradients, with a negative correlation between storage capacity and elevation. While the infiltration reservoirs exhibit water level reductions primarily due to evaporation, they do not show significant infiltration. Nevertheless, these structures are effective in conserving water and mitigating rapid surface runoff.

From a quantitative perspective, it is recommended to allocate water to infiltration wells located in lower-elevation areas, where greater storage capacity is available. However, further research is necessary to evaluate the potential impacts of this approach on water quality.

23. WATER BANKING TO INCREASE WATER SECURITY AND RESILIENCE TO DROUGHT

A. Ross

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Abstract:
Fluctuations in water availability put pressure on ecosystems, agriculture, communities, and utilities. Groundwater provides a reliable and stable source of water supply in dry years. Water banking enhances long-term water security and resilience by depositing water underground when it is plentiful and withdrawing water when it is scarce. Water banking provides water resource management, environmental and economic benefits. Water banking reduces aquifer depletion and evaporative losses in dams and maintains environmental flows in connected rivers. Water banking can improve water quality by retention and breakdown of pollutants and enables water entitlements to be allocated to their most valuable economic uses spatially and through time. Despite the high potential benefits there have been few reviews of the implementation of water banking. This review of the global implementation of water banking schemes for irrigation, municipal water, and environmental management will assess the services and benefits that water banking schemes have provided including improved volume and timing of water supply, water flow regulation and water purification. The review will include analysis of physical, socio-economic and institutional settings and factors that maximise benefits of water banking at different scales and conditions that may hinder the implementation of water banking. This broad assessment is expected to reveal opportunities for rapid implementation of water banking in Australia and other regions, as well as long term opportunities requiring more complex arrangements, including basin scale negotiations across jurisdictions. This review will add to the growing information about economic and environmental benefits of water banking and will reduce uncertainty about physical and economic viability of water banking applications. The review will be followed by preparation of selected water banking projects for implementation.

127. CRITICAL ASPECTS OF WELL DESIGN FOR MAR

T. Hanna

Abstract:
The design of wells used for Managed Aquifer Recharge (MAR) have many similarities to production wells, however wells used for injection and extraction require additional design considerations for their successful long-term operation. Inefficient wells used for MAR are more expensive to own, operate, and require more maintenance resulting in downtime, and in some cases are not able to meet the project goals. One of the biggest challenges for MAR system is clogging of the well and lost efficiency. Water quality needs to match that of the aquifer and materials used in the construction of the well should be selected to not introduce materials into the aquifer that will increase the rate of clogging. The well equipment selected needs to be resistant to corrosion so that the recharge water chemistry and/or biological corrosion agents do not cause aquifer degradation due to physical clogging and chemical reaction with the aquifer materials and water in the aquifer and well maintenance and rehabilitation. Filter pack selection of size and material for production efficiency and bacteriological resistance to fouling is important and can aid in well development and well efficiency. It does not matter what you use for well construction materials if you do not properly develop the well it will be inefficient and have more maintenance issues over its life, resulting in a well that is expensive to own.

12. INFILTRATION WATER QUALITY CONCERNS AND POLICY DEVELOPMENT OF ASR SYSTEMS: A COMPARISON STUDY OF THREE CASE STUDIES IN THE NETHERLANDS

Daniela Benedicto van Dalen, Hans Merton, and Sophie Luijendijk

Abstract:
The availability of freshwater for agriculture is under increasing pressure due to climate change. In the Netherlands, drought and salinization—particularly in coastal areas—are becoming pressing concerns. Aquifer Storage and Recovery (ASR) offers a promising solution to meet irrigation demands during the (dry) growing season. To explore ASR's practical potential, Acacia Water and its partners are testing pre-infiltration treatment to remove contaminants in three demo sites: Texel, Boskoop and Termunten. In gricultural systems, nutrients and pesticides are the primary contaminants of concern, with pesticides posing the greatest health risk. Early pilot results indicate that these contaminants can be effectively removed using technologies such as slow sand filtration (SSF), granular activated carbon (GAC), and iron-coated sand filters (ICS). On January 1st, 2024, the new Environment and Planning Act (Omgevingswet) came into force in the Netherlands regulating the management of a healthy physical environment. As part of its implementation, all 21 waterboards have established new regulations (Waterschapsverordeningen). However, these regulations do not yet adequately address ASR practices. As a result, waterboards have adopted varying guidelines and contaminant thresholds for water infiltration, resulting in inconsistencies in how ASR permits are handled across regions. The pre-infiltration water treatment has shown positive results in all 3 demo sites, removing pesticides and pesticides. The presence of PFAS in the infiltration waters is also analyses for one of the demo sites. The outcomes of these studies will support policy development and promote best practices for ASR, contributing therefore to environmental security. Looking ahead, it will be crucial for policymakers to adopt an integrated approach, that evaluates the environmental benefits of ASR more holistically, avoiding conflicting standards between surface water and groundwater quality. ASR acceptance and success will depend on the creation of a clear and supportive policy framework.

162. MANAGED AQUIFER RECHARGE IN WALlonia: THE MARWAL PROJECT

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Abstract

Among all effects induced by climate change, the increasing occurrence of extreme hydrological events is of particular concern in some regions of the world. Specifically, the repetition of summer and winter droughts these last years have caused a diminution of groundwater levels in the major aquifers of Belgium and significant reductions of base flows. Such observations reflect a decrease in natural infiltration of meteoric waters and an increase in groundwater withdrawals, especially to meet agricultural water needs.

Public authorities of the Walloon Region of Belgium have implemented a Regional Water Resources Management Plan aimed at implementing a series of actions and measures to secure drinking water supply and protect water resources. In this context, the MARWAL project consists of a feasibility and pilot study to assess to what extent Managed Aquifer Recharge (MAR) constitutes an appropriate response to securing Wallonia's groundwater resources both from a technical, financial, and regulatory perspective.

In a first step, international benchmarking has been carried out to identify managed aquifer recharge systems most frequently implemented in environmental contexts similar to those met in Wallonia. On the basis of this information, a cartography of the potential for managed aquifer recharge has been established, mainly by cross-referencing geological contexts, available sources for recharge water and the strategic status of a number of priority catchment areas.
The second part of the study aims to precisely assess the MAR potential in the Hesbaye chalk aquifer in the Liège region, with a view to setting up a first pilot project. This phase of the investigation is based on a more detailed analysis of land use and hydrogeological conditions prevailing in the groundwater basin and advanced characterisation of available water sources from both a quantitative and qualitative point of view.

The objective is to present the project and results obtained so far.

Parallel session 6:
7. MAR in relation to environmental, sustainability and climate change adaptation

113. NEAR REAL TIME GR OUNDWATER FORECAST FOR THE MAR PROJECTS OF CAPE TOWN, SOUTH-AFRICA.

A. Gutierrez[1], B. Mougin[1], J. Nicolas[1], V. Bault[1], C. Lasher-Scheepers[2], P. Msimango[3], L. Fisher-Jeffes[3], and A. Ncube[3].

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Abstract

The water supply of the City of Cape Town is highly dependent on surface water and highly sensitive to drought. Since the 2015-2018 drought period, there has been a significant drive to identify and operationalize alternative water sources for the City of Cape Town such as the development of managed aquifer recharge (MAR) projects of Cape Flats and Atlantis. This has necessitated the equipping of existing monitoring points in order to monitor the behaviour of groundwater before and after the implementation of the MAR schemes. A new tool developed by the French Geological survey was implemented to enhance the information acquired by the monitoring points in a short-term predictive assessment of groundwater situation.

The Cape Flats Aquifer Management Scheme will rely on MAR for emergency supply and long-term resilience. Five MAR wellfields will inject advanced treated effluent thereby improving the groundwater yield and quality for abstraction from seven wellfields.

The Atlantis MAR scheme, operational for 40 years, is a water recycling scheme in the sandy aquifer. Treated domestic effluent (from maturation ponds) is blended with urban storm-water runoff and discharged into recharge basins in the coastal dune area.

In the frame of a project funded by the French Agency for Development, the MeteEau Nappes tool was set up for the City of Cape Town for two monitoring stations, one in each scheme. The tool reads in near real-time data of all the parameters needed to run a lump model calibrated on historical data. The model then displays forecasted series of water level for the next 6 months associated with various return periods.

Due to its simplicity of use, the MeteEau Nappes tool is an appreciated forecasted tool for decision-making. In the management of a MAR scheme, it may be an interesting monitoring tool to control injection and discharge operations.

43. THE MAR AGREEMENTS: A NEW GOVERNANCE APPROACH FOR ADVANCING THE MAR IMPLEMENTATION

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Abstract:

Arid and semi-arid regions are increasingly grappling with water supply shortages, a problem expected to intensify due to the impacts of climate change. To address this challenge, the paper introduces a new governance approach for advancing the implementation of managed aquifer recharge (MAR): the MAR agreements for benefits sharing. The approach is centered on a participatory and comprehensive methodology to assess and enable the feasibility of MAR as a key climate change adaptation measure. The main components of the methodology include: 1) Designing and demonstrating a broader feasibility mapping framework that combines aquifer-dependent service demand, hydrological assessments of conventional and non-conventional water sources for MAR, and GIS-based multi-criteria decision analysis; 2) Creating a general, stakeholders-centered framework for participatory governance; 3) Assessing the reliability, vulnerability, and resilience of MAR through web-based numerical modelling; 4) Involving a broad range of stakeholders in a participatory, multi-actor process to ensure diverse societal engagement; 5) Establishing location-specific, binding or non-binding and agreements for MAR implementation. The paper will present the results from the AGREEMAR project with successful application and demonstration of the approach at different scales across four case studies in Spain, Portugal, Cyprus, and Tunisia. The resulting solutions are anticipated to help close gaps in the hydrological cycle, ensuring optimal water availability for domestic use, food security, and the protection of natural ecosystems throughout the Mediterranean region and beyond.

103. KOLOMELA MINE – TEN YEARS OF BOREHOLE INJECTION IN A SHALLOW UNCONFINED AQUIFER FOR SURPLUS MINE WATER DISPOSAL

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Abstract

In 2014 Kolomela Mine, one of Ango American's iron ore mines in South Africa, started injecting surplus water from the mine dewatering program into a nearby unconfined aquifer. This is the first mine in South Africa to use this approach for environmental reasons, and it has continued, successfully, to this day. The injection boreholes, scattered around a riverine depression, are generally shallow (~20 m deep) and target alluvial gravels, weathered calcretes and permeable zones in the various deposits that overlie the banded iron formations, lavas and quartzites in this complex geologic terrain. The water table is shallow (~7 mbgl), and injection rates are managed to ensure water levels do not rise to ground level. To date the maximum injection rate has been 2.2 million litres per day, fluctuating around the need to dispose surplus water whilst ensuring water levels remain below ground level. By the end of 2023, 2.34 million m^3 had been injected into this shallow aquifer, and in so doing the mine had met the government's environmental requirements which does not allow surplus mine water to be discharged onto the ground. This paper presents the initial feasibility study, engineering design and challenges, the phased expansion of the scheme and the nine years of operational data, including injection rates, water levels, injectant water quality and receiving aquifer water quality.

51. AIMING AT SUSTAINABLE AQUIFER RECHARGE TO ENHANCE RESILIENCE OF GROUNDWATER SERVICES UNDER INCREASED DROUGHT RISK

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Abstract:

Future climate, population growth, and land use changes will likely worsen water security risks globally. Increasing drought severity and frequency, as seen in Europe and South Africa, threaten access to water for human consumption, irrigation, industry, and ecological needs. To address this grand challenge, groundwater is undoubtedly the most effective method for water storage, as it is less prone to evaporation than surface reservoirs and offers better quality due to its natural filtration. This is particularly crucial in arid regions experiencing reduced snowfall and rainfall. However, unsustainable land use and climate change have reduced groundwater recharge, while increased withdrawals for irrigation and drinking water, along with pollution from agriculture, are putting significant pressure on aquifers. Here, we present the first results of our research project AQUIGROW (sustainable AQUIfer recharge to enhance resilience of GROundWater services under increased drought risk), which aims to: 1) identify groundwater recharge fluxes and quality in aquifers used for irrigation and drinking water in Europe, Israel, and South Africa, 2) identify challenges in sustainable aquifer management under current and future land use and climate conditions, and 3) develop tools and solutions to enhance recharge and improve water quality. In particular, we will discuss how advanced hydrological models can be used in conjunction with managed aquifer recharge (MAR) techniques to address water-related threats in different climates, co-develop water management approaches, and balance demands for water abstraction, environmental flows, and agriculture.

143. LESSONS FROM THE RISE AND FALL OF MANAGED AQUIFER RECHARGE (MAR) IN LANGHORNE CREEK REGION TO MANAGE DROUGHT RESILIENCE

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Abstract

In the Langhorne Creek region of South Australia, vineyards have since the 1850's relied on multiple sources of water including regular surface flood irrigation, surface water diversions from the Angus and Bremer Rivers and groundwater, to manage water security. However, the introduction of pumps to extract groundwater since the 1950's, when electricity first became available, caused groundwater levels to severely decline and salinity to rise.

The use of Managed Aquifer Recharge (MAR), a promising technique for groundwater management, was introduced in the 1980's and increased dramatically as part of an adaptation strategy in the region. By 1987 the first water management plan was also adopted, and water meters were required on all bores. These innovative policies coupled with huge increases in the prices of winegrapes motivated many vineyards to use excess surface water for MAR to increase the amount of usable groundwater. Many privately owned pipelines were installed nearby to Lake Alexandrina.

However, the millennium drought from year 2000-2010 resulted in record low inflows to Lake Alexandrina and by 2007 the salinity of the lake's water was unacceptable for irrigation. During this period, use of groundwater and MAR again increased briefly. In 2009, a larger 42 km shared pipeline scheme to draw water from the River Murray above Wellington was built. This secured access to reliable, low salinity water at a time when water quality in Lake Alexandria was not suitable for irrigation. This also connected water users to the active water market in the Murray-Darling Basin enabling trade within and between hydrologically connected systems. This is now a dominant source of irrigation water for the region displacing locally led MAR solutions.

Insights from the specific regional experiences of water management in Langhorne Creek explain why MAR has declined despite the pressures of climate change.

139. OPTIMIZING MAR IN COASTAL DUNES BY EXTRACTING BRACKISH GROUNDWATER: A FIELD PILOT IN THE NETHERLANDS

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Abstract
Faced with climate change and population growth, Dutch drinking water utility Dunea is looking for additional water resources to secure drinking water supply. An option is to enhance the existing managed aquifer recharge (MAR) system in the coastal dunes by extracting underlying brackish groundwater. This provides an additional drinking water source and can simultaneously protect existing freshwater extraction wells from salinization. To test this concept in the field, a three-year pilot commenced in January 2022 at Dunea's primary drinking water production site Scheveningen.
In the first pilot phase, groundwater was extracted continuously for 1.5 years from the brackish transition zone (85-105 meters below sea level) with multiple well screens placed in a single borehole. The hydraulic effects and the dynamic distribution of fresh, brackish and saline groundwater were monitored with a dense network of piezometers, hydraulic head loggers and geo-electrical measurement techniques. The field results revealed a growth of the freshwater reserve on a local scale. During the second pilot phase, fresh groundwater was extracted from the freshwater lens (60 meters below sea level). This resulted in salinization by upconing, as anticipated. To revert the salinization, brackish groundwater was extracted again. Subsequently, fresh and brackish groundwater were extracted simultaneously. The deep extraction of brackish groundwater prevented upconing, thereby protecting the fresh groundwater extraction well. The extracted brackish groundwater was desalinated and, together with the fresh groundwater, incorporated in the regular drinking water production process.
From the extraction experiments, we derived further insights into upconing, downconing, and stabilization of the fresh/brackish interface, and its relation to pumping regimes. These will be further used to develop practical guidelines for coastal MAR. Moreover, the feasibility of upscaling and replicating the concept of brackish groundwater extraction to optimize MAR and to increase the availability of fresh groundwater in coastal areas is reflected upon.

Acknowledgements
This project is financed by EU LIFE19 CCA/NL/001222 – LIFE_FRESHMAN

Keywords
Brackish groundwater extraction, drinking water production, field pilot, coastal dunes, freshwater lens, managed aquifer recharge

117. GROUNDWATER QUANTITY AND QUALITY ASSESSMENT FOR AQUIFER RECHARGE IN OHANGWENA REGION, NAMIBIA

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Abstract:

Surface water scarcity and excessive groundwater use are critical issues, particularly in arid and semi-arid regions. As a result, Artificial Recharge (AR) has emerged as an effective strategy to address these challenges by injecting water into aquifers through boreholes, thereby reducing evaporation and utilizing the aquifer's porous media for water conservation and decontamination. Additionally, integrating Geographical Information Systems (GIS) with numerical modelling is essential for evaluating aquifer recharge potential, identifying suitable recharge sites, and assessing the impacts on groundwater levels and contaminant movement. This study focuses on the Ohangwena region in northern Namibia, an area characterized by water scarcity due to uneven rainfall distribution and growing demand, leading to aquifer depletion from over-pumping. While the western part of the region has access to surface-sourced potable water, the rest relies on groundwater. The objectives of the study were to evaluate aquifer recharge potential by identifying potential recharge sites, assessing the impact of AR on groundwater levels, and examining the movement of contaminants associated with runoff within the aquifer system. GIS was used to identify suitable recharge zones, MODFLOW to evaluate the effects of surface runoff on groundwater levels, and MT3DMS to assess contaminants dispersion. The GIS assessment showed that 80% of the region is classified as having high recharge potential, while the remaining 20% is categorized as very high recharge potential. The results from modelling showed increased groundwater levels due to AR, with the highest recharge observed at specific wells. The contaminant analysis indicated decreased concentration over time and distance, emphasizing the need for water quality testing before AR implementation. The study demonstrates the viability of AR using surface runoff for long-term groundwater management in the Ohangwena region, highlighting the importance of careful assessment and management of groundwater resources for sustainable water supply.

54. PLANNING SUSTAINABLE AND EQUITABLE MANAGED AQUIFER RECHARGE INTERVENTIONS: AN AGENT-BASED SOCIO-HYDROLOGY APPROACH

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Abstract:

The feedback between human and water systems, where changes in water availability influence human decisions and vice versa may result in unintended and negative externalities. These may include the phenomenon of supply-demand feedback, i.e. increasing water demand in response to measures enhancing water supply such as Managed Aquifer Recharge (MAR), thus nullifying the expected benefits from increased supply and further increasing vulnerability. Conventional hydrological models inadequately address these human-water feedback, typically treating the human elements (e.g., cropping and irrigation decisions) as exogenous scenarios. This paper introduces an agent-based sociohydrology model explicitly designed to simulate the supply-demand phenomenon resulting from human–water system feedback in response to MAR interventions. The developed model integrates a spatially explicit hydrological model with an agent decision-making module, simulated using rules derived based on household surveys and observed data. The model is applied to the case study area of the Kamadhiya catchment in the state of Gujarat, India, simulating the decisions of 38,447 farmers in response to the intensive development of rainwater harvesting structures, specifically check dams (CDs), to recharge groundwater. The simulations illustrate the unfolding of phenomenon of supply-demand feedback in the catchment, aligning with the observations in the area. The results show that the perceived increase in water supply, from enhanced recharge from CDs, has led nearby farmers to increase their cotton and wheat cultivation areas by 11.9% and 36.1%, respectively. About 54% of additional recharge is used for irrigation expansion, reducing groundwater levels by 1 meter. The results further show how unequal resource distribution among farmers, based on land size, can result in "success to the successful" dynamics, where larger (wealthier) farmers benefit the most from MAR interventions (such as CDs). These findings underscore the need to critically understand human-water feedbacks that lead to unintended consequences and inform future investments in MAR interventions.

Thursday, 1 May 2025
Parallel session 7:
1. MAR for water supply purposes – Domestic/Municipal, Agricultural and Mining

161. MANAGED AQUIFER RECHARGE PLAN FOR MEXICO CITY

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Abstract

The Managed Aquifer Recharge Plan (MARPMEX) for Mexico City focuses on identifying and analysing potential sites for MAR using recycled water and runoff. The document compiles historical and technical information on managed aquifer recharge, highlighting previous studies in Mexico City that cover topics ranging from hydrogeochemistry to the evolution of groundwater quality. One of the key elements is the use of a Geographic Information System (GIS) that enables the mapping and management of sites identified as suitable for recharge. The GIS was developed from multiple geospatial and field data sources, providing a solid foundation for analysis and decision-making. This system facilitates the integration of information on lithology, hydrological basins, extraction wells, and dams, among other factors, to assess the feasibility of recharge sites. The MARPMEX also includes a detailed description of the availability of surface and groundwater resources, as well as an inventory of existing hydraulic infrastructure, such as wastewater treatment plants.

98. SUBIRRIGATION AS MANAGED AQUIFER RECHARGE TECHNIQUE: THE IMPACT ON GROUNDWATER LEVELS AND FLOWS

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Abstract:
The region of Flanders (northern part of Belgium) experienced low groundwater levels during the intense summer droughts in 2018-2020 and 2022, threatening groundwater dependent ecosystems and water supply. Due to climate change, these periods of intense droughts are expected to become more frequent. Therefore, drought adaptation measures, including managed aquifer recharge, are being implemented. In the agricultural sector in particular, the practice of subirrigation is a novel technique which partly recharges the groundwater system. Subirrigation is a reversed drainage system where at approximately 1 meters below surface a network of permeable pipes infiltrate water for the dual purpose of irrigation and groundwater recharge. The infiltrated water can originate from sources such as treated wastewater, canal water and stormwater. Subirrigation can be considered as managed aquifer recharge practice since substantial volumes of the infiltrated water is recharging the groundwater system. Two case studies in Flanders (Belgium) investigating the impact of subirrigation on the groundwater system are explored. A first field experiment is located in Kinrooi (North-Eastern Flanders) in which an existing subirrigation system supplied with treated wastewater has been operational since April 2022. A groundwater flow and transport model is created to investigate the impacts on the groundwater system in terms of groundwater levels and flows. Preliminary results indicate local increases of groundwater levels up to 30 cm. The second case study consists of a regional study in the Nete catchment (Northern Flanders) in which the impacts of potential implementation of subirrigation in the region is examined. Here, the option to use canal water to supply subirrigation systems in the region is currently explored in terms of quantity and quality effects on the groundwater system. A regional groundwater flow model is set up to investigate potential impacts on groundwater levels and fluxes in different agricultural fields.

125. COUPLING STORMWATER PROTECTION AND WATER SUPPLY FOR HOP GARDENS: FIRST RESULTS FROM A PILOT PLANT

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Abstract:

Climate predictions for alpine forelands indicate accelerated warming leading to extreme precipitation events, flooding, and decreasing groundwater recharge. From a long-term perspective, droughts will become a new standard and will challenge the water supply for drinking water and irrigation. The BMBF-funded project Smart-SWS aims at one possible adaptation strategy: combining flood protection and drought prevention by infiltrating excess stormwater into shallow aquifers. A GIS-based multi-criteria decision analysis (Augustin and Baumann, 2024) identified 35% of the area in southern Bavaria as suitable for this co-management scheme. We are now implementing Smart-SWS in the Hallertau, Bavaria, Germany. The hop gardens in the Hallertau are among the largest suppliers of breweries. The cultivated area has doubled since 1950, and the demand for irrigation (up to 170 mm/a) has put the shallow aquifer under stress. While groundwater levels have been declining for the last decade, there have been several severe flooding events revealing insufficient protection. Our setup consists of a stormwater retention basin, a monitoring and processing unit (to remove fines and contaminants), an infiltration well, and a downstream monitoring well. The hydrochemical conditions are monitored from basin to well with conventional and spectroscopic sensors which are complemented by lab analyses. Model results show that the infiltration during one flood event provides enough water to irrigate 5-10 ha of hop gardens. At the same time, the efficiency of the flood retention basin is significantly increased. The predictions of the chemical quality of the surface water derived from a catchment risk analysis were confirmed by analyses during the June 2024 flooding event, which showed that the surface water is in a better state compared to groundwater.

53. MANAGED AQUIFER RECHARGE FROM ROOFTOP RAINFALL COLLECTION TO ENSURE SUSTAINABLE OFF-THE-GRID GROUNDWATER SUPPLY

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Abstract:

Rainwater harvesting and managed aquifer recharge (MAR) ensures sustainable yields from aquifers where abstraction may exceed normal recharge. This paper describes the mathematical simulation of a case study to determine the long-term yield from the aquifer to ensure a sustainable water supply. The proposed MAR will be through infiltration galleries recharging aquifers, effectively utilizing rooftop runoff. This system captures rainwater that falls on roofs, directing it into specially designed infiltration galleries that recharge the aquifer. Infiltration galleries are designed to ensure the majority of the rainfall roof runoff enters the aquifer and during extreme events excess discharges into the catchment. The design takes into consideration soil parameters to ensure optimal sizing of the infiltration galleries. The design often includes a series of trenches or pits that increase the surface area for absorption and is also dependent on the size of the roof and rainfall. This paper investigates the possibility of moving Rhodes University off-the-grid in terms of reducing municipal water supply and supplying the whole campus via groundwater abstraction. The campus is situated in the headwaters of a catchment with quartzitic and shale aquifers. The average recharge of the aquifer is estimated as 5% of the mean annual precipitation which is around 700 mm/a. A groundwater model was used to determine the sustainable yield of the aquifer before the introduction of artificial recharge through the infiltration galleries and thereafter linked to a rooftop runoff model to recharge the aquifer. Modelling results showed a promising increase in the sustainable yield under the assumption that the operation of the infiltration galleries are effective. MAR ensured that the Rhodes University water demand would not impact on the multiple other users in the aquifer.

34. ASSESSING THE REGIONAL IMPACT OF WEIRS IN AGRICULTURAL DRAINAGE DITCHES USING A NUMERICAL MODEL: A CASE STUDY IN NORTHEASTERN BELGIUM

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Abstract:

The Flanders region in Belgium is increasingly affected by extreme hydrological events, with periods of summer drought alternating with intense rainfall. Simultaneously, groundwater drainage persists due to the year-round use of agricultural drainage ditches. To address this issue, the Flemish government developed an integrated approach to improve groundwater recharge. A major aspect of this approach involves placing weirs in agricultural drainage ditches to raise drain levels and reduce groundwater drainage. Farmers adjust the weirs, lowering them as necessary during the growing season to avoid crop damage and prevent soil compaction during field activities caused by waterlogged conditions. During winter, when there is no risk of waterlogging, the weirs are raised to store more excess rainfall. Although, these weirs have been installed at many locations in Flanders, little is known about their impact on the groundwater. A study site in Northeastern Belgium, at the source of the Dommel River, was selected to investigate this impact. Since 2015, local farmers have been working with adjustable weirs along the Dommel River and its tributaries. The study area is located on top of the Campine aquifer characterized by a stack of sandy layers serving as a potential groundwater reservoir. In a first step, a groundwater flow model was developed using MODFLOW6 and calibrated with in-situ measurements. Agricultural drainage ditches including weirs have been conceptualized using the drain package. The model was used to assess the spatial impact of the existing weirs and gave insights in their required configuration for a maximized groundwater storage impact. The second part of this study aims to compare these results to other modeling approaches, including MIKE-SHE and Analytic Element Method. A comparison of different modeling techniques in relation to weirs improved our understanding of the necessary measures for the effective implementation of this under-investigated MAR strategy.

15. THE DESIGN AND IMPLEMENTATION OF AQUIFER RECHARGE ENHANCEMENT SCHMEMES IN SOUTH AFRICA

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Abstract:

The drought of 2014-2021 exposed the vulnerability of the water supply system at many of the local municipalities in the Karoo towns in South Africa. The rainfall has changed over the last few years with longer periods of low to no rainfall, lower rainfall intensity, flash floods and higher temperatures. This change put the groundwater resources under pressure when average rainfall is between 150mm and 300mm an annum. Some of the towns water levels in their aquifers decreased to such an extent that aquifers could not supply groundwater anymore. The impact on the environment of the drought resulted in very low vegetation cover and carrying capacity for animals on the farming community. The barren soils resulted in more surface runoff and less recharge to the groundwater. This further impacted this farming community's livelihood with fewer jobs available and an increase in poverty specifically for the farm workers. The aquifer recharge enhancement schemes aim to capture stream runoff through boreholes into infiltration infrastructure and add streamflow retention structures like gabions (rock filled wire baskets) to slow down the flow to enhance the infiltration to the aquifer. The gabions would be built by the community which will result in temporary income for the community. The increased recharge and slower flow would benefit the environment with the regrowth of the vegetation and increase the carrying capacity of the land. More people would be employed and receive a permanent income. Key lessons were learned during the design and implementation of various aquifer recharge enhancement schemes in the karoo. The design process and factors to consider during the implementation will be presented in the paper.

Key words: Process, design, implementation

142. UPPER KING RIVER MANAGED AQUIFER RECHARGE (MAR)

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Abstract

The Northern Territory, Australia, colloquially termed the "Top End," experiences distinct monsoonal wet and dry seasons, often leading to a seasonal reliance on groundwater. The Top End hosts numerous productive aquifers, including the Tindall Limestone Aquifer which are utilised for agricultural irrigation (mangoes and melons). Climate change is driving the need for improved water security and thus adoption of new water management tools such as MAR. MAR has the potential to provide ongoing water security to existing agricultural water license holders as well as protect cultural and environmental flows to the Katherine River.

MAR in the Top End still faces several technical and policy barriers. Barriers include limited hydrological information (e.g. sustainable yields of monsoonal rivers), hydrogeological information (e.g. sufficient aquifer storage), economics (e.g. benefits and costs of MAR in the Top End), and policy challenges (e.g. regulatory complexity). All these barriers will need to be overcome when developing a pioneering Top End MAR scheme.

The Upper King River MAR investigations aim to test the technical feasibility of a pilot MAR scheme in the Katherine region. Drawing together the expertise of involved organisations in a multi-disciplinary approach, the upper King River MAR investigations exemplify a coordinated and innovative approach to explore MAR as a novel water management tool in the Top End.

The study is currently in the later stages of field investigations with a primary focus on characterisation of surface water, hydrogeological assessment, flows and quality in the upper King River and assessment of legislative, regulatory and policy limitations for development of a pioneering MAR scheme for agriculture in the Katerine, NT region. The hydrogeological assessment is informed by new understanding gained through a drilling program, the use of environmental tracers to inform groundwater modelling and development of a conceptual MAR scheme.

88. CONCEPTUAL DESIGN OF A MAR SYSTEM FOR A BRACKISH AQUIFER IN THE MEKONG DELTA, VIETNAM

Marta Faneca Sanchez, Jude King, Gualbert Oude Essink, and Marnix van der Vat

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Abstract:

The Mekong Delta is facing severe challenges due to the changing climate and the socio-economic developments. Freshwater availability is one of the critical resources being affected in terms of quality and quantity, conditioning in turn the food production and drinking water supply in the delta. The intrusion of saltwater in the surface water is expected to increase in space and duration in the coming decades, therefore, water supply companies are evaluating alternatives to increase their volumes of freshwater in a sustainable manner. Their aim is to overcome the months of the year that surface water is saline and therefore cannot be used. Being the groundwater also brackish to saline in some areas, they are considering Managed Aquifer Recharge (MAR) methods to create freshwater reserves in the aquifer. The design of MAR systems and specifically Aquifer Storage and Recovery (ASR) systems through wells in a saline environment is still a challenge. In this study we developed a density dependent groundwater model using a parallel implementation of MODFLOW/SEAWAT with iMOD-WQ (Verkaik et al., 2021). The model was used to evaluate uncertainties and identify the performance of different potential conceptual designs for the ASR system. We considered a range of scenarios to cover different options for the design, but also assessed uncertainties both of parameters as well as of model concepts and software solvers. This modelling study clearly demonstrates the impact that choices in grid, solvers, model parameters, and model concepts have on the results. It also gives insights on recovery efficiency differences depending on the conceptual design and the infiltration-recovery schemes that are defined.

28. USING DIGITAL TRANSFORMATIVE TECHNOLOGIES TO DETECT, SCREEN AND REMEDIATE CEC'S AND POPS, CAPE FLAT AQUIFER, SOUTH AFRICA

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Abstract:

Managed Aquifer Recharge (MAR) has emerged as a crucial water management strategy to mitigate water scarcity in semi-arid regions like South Africa. By using recycled water to replenish groundwater reserves, MAR offers a sustainable solution to water supply challenges. Various sources of treated water are injected in the MAR scheme. The scheme is situated in a highly urbanised unconfined system known as Cape Flats Aquifer. Some contaminants are removed during the MAR process. However, limited knowledge exists on how contaminants of emerging concern (CEC's) and Persistence Organic Pollutants (POP's) are removed before and after MAR processes. Therefore, this study explored the use of digital transformative technologies to detect, screen and remediate CEC's and POPs, and tested the remediated water in compliance with international guidelines for drinking water. Water samples were collected at wastewater treatment plants (WWTP) and surrounding surface and groundwater bodies and analysed using liquid chromatography and mass spectrometry. Preliminary results revealed that CEC's (sulfamethoxazole, diclofenac and carbamazepine) were distributed from WWTP to landfills subsequently found at high concentrations in surrounding streams and groundwater due to insufficient removal during treatment processes by polarity and biodegradative resistance. Laboratory and field scale experiments suggests anoxic environments (low BDOC (<0.5mg.l BDOC)) were optimal in removing CEC's through sorption and attenuation processes compared to sub-anoxic and anoxic environments (BDOC >2mg/l). A threshold of <0.30 mg/l DOC was determined to be too low to
effectively promote CEC attenuation however, the presence clays produced effective sorption. In conclusion, BDOC is a driver of both microbial activity and redox states thus should be utilised in designing performance-enhanced MAR systems that efficiently removes CEC's and POP's during MAR. SANS 241 and WHO do not provide targets regarding CECs and POPs, this study recommends/informs the initiative or basis of including targets in existing water quality standards and guidelines.

58. A 30-YEAR-OLD MANAGED AQUIFER RECHARGE PROJECT FOR DRINKING WATER PRODUCTION: LESSONS LEARNED

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Abstract
Managed aquifer recharge (MAR) is used for the removal of natural organic matter from surface waters in drinking water treatment in Finland. A typical MAR plant includes infiltration of surface water and withdrawal of water from wells a few hundred meters downgradient. In Finland, drinking water is produced in over 25 MAR plants. Tavase Ltd. was founded in 2002 by municipalities to construct and operate a MAR plant (production 62,000 m^3/d) to provide drinking water. There are more than 300,000 inhabitants in the owner municipalities. Before the company was founded, a general plan for regional water acquisition was made in 1993, and geophysical and hydrogeological studies, as well as economical calculations, were conducted in 1994 – 2002. Tavase Ltd. implemented the required environmental impact assessment process leading to further infiltration and tracer trials in 2009 – 2010 and revisions for the design of the MAR plant during following years. The operation permit process was started in 2003 followed by several intermediate actions and decisions, and the final decision was declared by the Finnish Supreme Administration Court in 2024 with indications that further investigations are needed.
In Finland, MAR is applied primarily at Quaternary glaciofluvial eskers, which have good infiltration properties. These eskers attract also other interests: centres of population, recreational areas or nature conservation sites. Operations in, or in the neighbourhood of, these areas are subject to scrutiny and official approval, and they are of interest to the formation of public opinion. There is a need for a multidisciplinary MAR project management.
This paper aims to present experiences and recommendations dealing with MAR design, novel MAR technology, hydrogeological studies, environmental requirements, plant operation, project management, interaction with permit authorities, stakeholder relations - including shareholders and public relations -, and communication. These findings will benefit other MAR operators, MAR plant owners and regional water supply planners.

52. LARGE-SCALE AND LONG-TERM MAR APPLICATION OF AN IMPORTANT SWISS WATER SUPPLY COMPANY

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Abstract

For our urban study site belongs to an important water supply company in Northern Switzerland which supplies drinking water to more than 200,000 people. Without large-scale (about 95,000 m3/day) managed aquifer recharge (MAR), it would not be possible to extract high quality drinking water in this area surrounded by old land fill site, industry, traffic ways and urban settlements. An additional factor at this site is the complicated geology with a thick porous aquifer but an underlaying fractured unit which carries numerous contaminants. We used stable water isotopes, chlorinated solvents, dissolved gas concentrations, and 3H and tritiogenic 3He concentrations to assess water flow paths and mixing between artificially infiltrated surface water and groundwater. Especially, the recent developments of portable field-operated gas equilibrium membrane inlet mass spectrometer (GE-MIMS) systems provide a unique opportunity to measure dissolved gas concentrations, such as 4He with a high temporal resolution at relatively low costs. Although the GE-MIMS are not capable of providing apparent water ages, 4He accumulation rates are often obtained from 3H/3He ages and it has been shown that non-atmospheric 4He concentrations determined in the laboratory (e.g., by static (noble gas) mass spectrometry) and by field-based (GE-MIMS) methods closely agree. This agreement allowed us to establish an inter-relationship between 3H/3He apparent water ages and the non-atmospheric 4He excess (e.g., calibrating the 4He excess in terms of residence time). In addition to these studies, we investigated if microplastics (MP), a contaminant of growing concern, which is found in the water used for MAR might be a threat for the drinking water supply. We found that the MP (analytical precision of >20 μm) is held back on the way from the surface water source to the abstracted drinking water.

84. BUILDING RESILIENCE IN WATER SUPPLY WITH MANAGED AQUIFER RECHARGE WITH RECYCLED WASTEWATER – CASE OF PAARL TOWN IN SOUTH AFRICA

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Abstract

South Africa is a semi-arid and water-stressed country often plagued with issues of water scarcity. The Western Cape province experienced a long dry spell between 2015 - 2018 leading to the possibility of municipal water supplies being cut off, an event popularly referred to as 'Day Zero'. The impact of the drought in this period underscored the risk of over-reliance on surface water. This study investigated the potential for transition to groundwater with Managed Aquifer Recharge in Paarl (a town in the Western Cape Province with a population of about 300,000). An integrated model was used to investigate the possibility of injecting treated wastewater into the subsurface (i.e., from two membrane bioreactor wastewater treatment plants), and then abstracted as groundwater for reuse. The study determined that the system could meet about 5.8% of Paarl water demand whilst maintaining sustainable groundwater levels. If some decrease from the initial groundwater table is allowed, the system could meet up to 9.6% demand. In drought conditions, the system could meet demand up to 24.1% for a limited period up to one year, but the abstraction would need to take a break for the subsequent 2-3 years, to allow for the groundwater levels to recover. In summary, the study determined that Managed Aquifer Recharge with treated wastewater can build resilience in water supply and mitigate water scarcity in South Africa.

140. DIRECT HARVESTING OF ROOF RAINWATER FOR MAR ACROSS NEW URBAN DEVELOPMENTS IN BALLARAT

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Abstract

Sustainability of water supplies in the face of climate change is of critical concern. This study outlines options to improve Ballarat's water security profile against different water sources and diversification of local supplies. While there is no immediate augmentation required for new water supplies in Ballarat, the current and future growth areas in the Ballarat West region offer the potential to test and implement new integrated water initiatives to support longer-term water needs. New Urban development in the Ballarat West region has commenced and will continue for the next 25 years. The project identified eleven preliminary concepts incorporating managed aquifer recharge and evaluated these using a multi-criteria analysis approach factoring environmental, social regulatory, economic, and technical considerations. A short-list of four options were further explored weighing their advantages and disadvantages alongside the completion of a cost benefit analysis. This paper presents a summary of the high level options assessment and the cost benefit analysis. The study provides a direction for the types of MAR systems that could be implemented at the site and reasons for the selection. Scalability is a key criterion in presenting the options.

8. Awareness, Education and Training on MAR

5. OASIS FLOW: AND ASSESSMENT TOOL FOR MUNICIPAL WATER FOOTPRINT AND MANAGED AQUIFER RECHARGE OPTIMIZATION ACROSS THREE EUROPEAN PILOT SITES – MARCLAIMED PROJECT

Daniela Benedicto van Dalen, Alberto Dieguez Seoane, Sophie Hibben, and Sara Espinosa

Abstract

The OASIS FLOW tool is one of the digital tools within the MARCLAIMED project developed to assess municipal-scale water footprint performance in the context of Managed Aquifer Recharge (MAR). OASIS FLOW addresses the integration gap between groundwater resources management and municipal water demands, enabling a more precise evaluation of MAR's environmental and economic impacts on local water resources. The tool quantifies the benefits of MAR as Alternative Water Resources (AWR) across different sectors, including agriculture, industry, and domestic use, while incorporating future water stress scenarios driven by climate change and population growth. Aspects such as water cycle, aquifer typology and aquifer recharge rates, bring in more accuracy and hydrogeological characterisation to the models developed. By calculating a water scarcity indicator, OASIS FLOW facilitates comparison of the water demand for different scenarios and enhance informed decision-making on water governance at the municipal level. The development of all tools within MARCLAIMED, is being tested across three pilot sites—Barcelona (Spain), Comporta (Portugal), and Wadden Region (Netherlands)—each with unique hydrological setting – being Barcelona, Alcácer do Sal and Texel the targeted municipalities for Oasis Flow. These pilots also demonstrate the tool's interoperability with the other components of the project, such as PREDMAR for water availability forecasting, MARINSURE for assessing economic resilience, and RECOVER for tariff modelling. Together, these tools form a comprehensive decision-support system aimed at optimizing MAR performance, ensuring water security, and enhancing sustainable water management practices across Europe. Through these pilot sites, MARCLAIMED aims at quantifying MAR system performance through its different tools and advocate for the benefits of increasing water security, while supporting sustainable, data-driven best practices in water management.

81. ENGAGING WITH STAKEHOLDERS PROVED VITAL FOR UPTAKE OF MANAGED AQUIFER RECHARGE IN COMMUNITY WATER SUPPLIES

P.S. Juuti, R.P Juuti, T.S. Katko, J.J. Hukka, and P. Dillon

Abstract

For community water supply, MAR offers major advantages such as a planned overall system, good and homogeneous quality, almost stable temperature, and limited or non-use of chemicals. More recent issues relate to preparedness and security of supplies in crisis conditions such as nuclear fallout but also possible economic and social contradictions. Surface waters may encounter pollution risk, blue-green algae growth in warm periods, and increased turbidity. The first MAR trials in Finland were made in the 1920s, whereafter the interest in MAR and groundwater use declined. After WWII, groundwater use recovered, as did MAR since the 1970s. Sometimes large MAR projects have encountered public resistance due to ignorance of research results and spreading misinformation. After 40 years' work in the Turku region, a MAR project was finalized in 2012 whereafter no protest occured. A MAR planning in the Tampere region started 30 years ago. In 2024, the Supreme Administrative Court (SAC) rejected the smallest of three proposed recharge areas based on the seemingly controversial and problematic precautionary principle. Since SAC also bundled three recharge areas contrary to their decision in 2018, the entire project was subsequently rejected. Especially in large scale projects, strategic thinking is necessary to avoid potential bottlenecks. Although hydrogeological, economic and technical expertise is important, it alone does not help with institutional icebergs that hopefully could be forecasted and solved through co-planning efforts. Lessons of failed and successful projects are to be analyzed and used for future MAR projects. Forming relationships with all stakeholders will help inform knowledge and prevent polarization around misinformed concepts, and developing necessary partnerships will help run projects on a sustainable basis. Besides, proactive public relations, awareness creation and education will help in building trust and making informed decisions.

126. DEVELOPING A LOCAL IMPLEMENTATION GUIDELINE FOR MANAGED AQUIFER RECHARGE IN COMBINATION WITH BLUE-GREEN INFRASTRUCTURE

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Abstract

Existing water management practices in many South African cities are not resilient to climate change impacts, which combined with rapid urbanisation, have contributed to issues of water scarcity, flooding, and environmental degradation. A transition to more adaptive urban water supply, sanitation and stormwater management systems is necessary. Blue-green infrastructure (BGI), paired with managed aquifer recharge (MAR), can facilitate such a transition by addressing some challenges of conventional ('hard') infrastructure while improving groundwater infiltration. However, how such a transition can be implemented, integrated and managed within existing urban governance structures is not clear, particularly in under-resourced and inequitable settings. To provide such guidance, UCT's Future Water Institute developed an 'Implementation guideline for managed aquifer recharge in combination with BGI at local settlement level', funded by the SA Water Research Commission. The project used experiences on planning, designing and implementing BGI in sites of MAR from a stormwater retrofit case study in Mitchells Plain, Cape Town (the Pathways to Water Resilient South African Cities project). Although based on a case study, the guideline is generic and applicable to a range of BGI options associated with MAR. The document consists of six individual guidelines: 1. Scoping the local context (including local government priorities); 2. Encouraging civic engagement/organisation/coalitions and adhering to legislation, policies and programs; 3. Critical appraisal of planned implementation; 4. Facilitating engagement; and 5. Formalising local involvement. The guideline is meant for stakeholders involved in the design, implementation/construction, maintenance, management of MAR BGI, including local residents, residents' groups, consultants or interested stakeholders, city improvement districts, community-based organisations, or ward councilors. The presentation will focus on the processes undertaken to develop the guidelines and lessons learned, including how to communicate MAR science, and engage local residents to raise awareness, understanding and ongoing stewardship of such projects.

62. CO-MANAGED AQUIFER RECHARGE (CO-MAR). EVOLUTION OF THE CONCEPT DUE TO SPANISH AND PERUVIAN STAKEHOLDERS' PARTICIPATION.

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Abstract

Co-managed aquifer recharge concept was initially defined at the Los Arenales aquifer, Castilla y León, Spain, as a first row issue on governance and water security. It is based on the bottom-up participation of stakeholders in decision making regarding water management and conjunctive use of both, surface and groundwater, with a broader and broader attention on managed aquifer recharge systems.

The term has been applied in other irrigation communities in the world, with variations according to the nuance and idiosyncrasy of each respective sites. In this context, two observations are outlined: collective water management is a very highly effective measure for IWRM; and MAR is providing good results thanks to the collective effort of scientist/technicians, water authorities, end-users, Communities of irrigators, etc. (teamwork).

Monitoring from water authorities, local irrigators, stakehomers or "latents" from R&D projects) is proving to be an important measure indispensable for the concept evolution. Datasets allow reviewing many previous collective agreements and support new proposals for water authorities and regulators.

Co-MAR is evolving at the time it is being applied in new places, such as the Ica aquifer, in Peru, where the term has been deeply installed and implemented. Since its inception, several changes are taking place, especially in decision-making:

-The concept has consolidated as an adaptive complex system (CAS).

-The response to the overexploitation of the aquifer is working well, according to water level indicators and the changed rates on spatial patterns of groundwater pumping.

-New formulas for hard measures (concrete) are under permanent study, involving national, regional, local authorities, and user´s associations for improvements in the whole Co-MAR system.

-The concept Public-Private Partnership (PPP), modified to Public-Private People Partnership (PPPP) has had another derivative, becoming "People Public-Private Partnership" (PPPP´) due to a simple reason: "people are the most important into this CAS".

-In respect to "soft" measures (those which do not require important investments in infrastructure, e.g. the construction of a collective well, or the concentration of unconnected plots of land of the same owner) improvements are taking place. It is worth mentioning the "space of collaboration", based in the confidence for the fair use of (ground)water resources and organizational measures. This environment of trust has proven to enhance a direct influence on groundwater quality improvement, according to the samples collected in piezometers, and the dilution of "rural" pollutants thanks to MAR.

-The involved actors, despite eventually having opposite targets, play an important role for the sustainability of the system, according to the track of risks and impacts (monitored in the O+M programs).

-The degree of implantation of MAR technique is counting on a "contagious effect". Some nearby areas are seriously considering to replicate the model once they have realized it is working Well, e.g., in Castile and Leon, new permissions and allowance have been requested from the communities of users from the neighbour Medina del campo Water body. In Peru, actions in Ica start having replication in the Villacurí and Lanchas sectors of the aquifer.

- Economic indicators reveal a positive evolution.

Most of the initial key vulnerabilities of this “MAR social concept” identified in the presentation of the concept persist in both areas of study (Los Arenales and Ica Aquifers).

MAR IN HUMANITARIAN CONTEXTS

Jay Matta, David Duncan, Esther Shaylor, Lavuun Verstraete and Catalin Stefan (Dresden University)

Abstract

The lack of predictable rainfall is a major cause of water scarcity globally combined with population growth resulting in the World Economic Forum rating it as one of the most prominent risks of the decade to development. The question is then how we can more effectively harvest water within the landscape, particularly in semi-arid or arid zones, given often the episodic nature of rainfall events to contribute to communities becoming more climate resilient. Especially when these events result in rapid flooding, which is more often than not, considered a hazard rather than an opportunity to make water less scarce. The success or failure of implementing MAR will depend on the site-specific context with regards to knowledge on hydrogeology, climate and topography and also the overall objectives. This is very important to manage expectations in humanitarian settings where more often than not the hydrogeological setting of the respective camp or settlement is unknown. Indeed, due diligence should be done through a pre-feasibility study prior to progressing to feasibility, implementation and finally any operation and maintenance phases. For this reason, UNICEF's Office of Innovation (OOI) WASH Hub has decided to make MAR a key topic in their portfolio of potential innovations to assist in accelerating access to safe, sustainable and more resilient water supplies for communities impacted by prolonged water insecurity in arid and semi-arid lands through both groundwater mapping and monitoring. A MAR pilot study in a complex humanitarian context in Dollow in Somalia on the border with Ethiopia has been chosen following initial desktop studies. This abstract then seeks to outline how UNICEF is approaching building partnerships with both local stakeholders and experts in the field of MAR with the aims of: developing community-based climate resilient MAR infrastructure for water supply; community-based monitoring to allow sustained operation and maintenance; and developing a framework to allow scaling up to other countries where it operates.

Closing keynote:

67. TESTING THE ROBUSTNESS OF MAR POLICY SETTINGS FOR WATER SUPPLY SECURITY UNDER CLIMATE CHANGE

Peter Dillon[1], Dennis Gonzalez[2], Declan Page[2], Lei Gao[2], Sharon Megdal[3], Bridget Scanlon[4], John Ward[5], and Constantin Seidl[6]

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Abstract

Managed Aquifer Recharge (MAR) has been demonstrated through many welldocumented case studies to expand scarce water supplies and improve water quality. Similarly, MAR incorporating water banking has been shown to contribute to water supply security. Recovery entitlements are purported to be a major driver for MAR, and a unified set of parameters for accounting for recovery entitlements were published in 2022. These include anthropomorphic parameters such as maximum cumulative proportion of recharge that may be recovered and the maximum time period over which recharge credits may be recovered. Some parameters are governed by the hydrogeology, such as annual rate of retention of accrued storage credit and recovery efficiency in brackish aquifers. These are generally unknown at the start of an operation but become known through operational monitoring. In operational MAR projects, the interplay of these parameters in sequences of actual water availability and water demand have not been tested. This paper describes in more detail the water accounting procedures, simulates sites with long-term records in USA and Australia, using the recovery policy parameters currently in play, and identifies consequences of shortfalls in water supply. It then explores trends and correlations between supply and demand for these sites. This informs simulations with alternative candidate recovery entitlement specifications, to determine their influence on the incidence and severity of water supply shortfalls, especially related to climate change. This may also expose values for unmeasured parameters that accord with operational experience. The paper concludes with recommendations to policy makers on parameterization of recovery settings when uncertainties in climate change and recoverability of water from the aquifer are taken into account.

Parallel session 8:
3. Suitability Mapping to Site Selection

8. GUIDING PRINCIPLES FOR GEOSPATIAL MAR FEASIBILITY MAPPING

C. Stefan[1], T.N. Martins[2], A. Chkirbene[3], K. Khemiri[3], C.F. Panagiotou[4], S. Ghannem[5], R. Bergillos[5], G.Y. Ebrahim[6]

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Abstract

An abundance of studies is published on regular basis on mapping the spatial suitability of managed aquifer recharge (MAR) using a GIS-based multi-criteria decision analysis (MCDA). Such studies are apparently easy to conduct since they are based on easily-accessible datasets and the outcomes are presented in form of overview maps showing the regional MAR suitability potential. A recent review revealed major gaps in the methodological approach, which could explain the extremely scarce reporting on the practical usability of these maps. This includes: a) the use of generic terminology of "MAR suitability" without consideration of specific objectives and technology involved, b) selection of only readily available datasets, c) confusing MAR with natural groundwater recharge, d) reproducing previous studies that are conducted in completely different socio-environmental contexts, e) introducing a strong bias in criteria standardization and weighting, etc. To increase the reliability, acceptance and usability of MAR suitability maps, a set of guiding principles are proposed and validated at different case studies: 1) the MCDA process must consider not only the capacity of an aquifer to get recharged but also the availability of water for storage and the sector-specific demand for MAR; 2) selection of suitability criteria must reflect the site-specific conditions (project objectives, infiltration method, water source, etc.); 3) non-physical criteria (economic, social, legal etc.) shall be integrated in the geospatial analysis and the criteria selected shall appropriately describe the relevant MAR processes; 4) the methodology can be used to reproduce and discuss multiple scenarios, including seasonal variability of demand and water resources, future climate and human development, alignment of MAR to IWRM principles (economic efficiency, environmental sustainability and social equity), etc.; 5) (and the most important) the entire study must be conducted in a participative manner with permanent consultations with key stakeholders. The direct involvement of stakeholders is crucial as it will create a sense of shared responsibility for the feasibility maps and their future use, which can further increase the acceptance of MAR implementation.

97. MANAGED AQUIFER RECHARGE SUITABILITY MAPPING IN EASTERN ETHIOPIA (DIRE DAWA, HARAR, JIJIGA AREAS)

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Abstract

Groundwater constitutes a major water resource in Ethiopia: according to Kebede (2013), groundwater provides 90% of domestic supply (including the supply of fast-growing cities such as Addis Ababa, Nazret, Gondar, Awasa, Dire Dawa, etc.), 95% of industrial uses, and 80% of the total national supplies. However, these groundwater resources are not evenly distributed as the geological framework of Ethiopia is complex. Managed Aquifer Recharge (MAR) is seen as an appropriate tool for managing existing assets and augment water availability in stressed aquifers of Ethiopia. The country has a geo-climatic context favorable to MAR projects whereby groundwater shall be considered as a water bank recharged during surplus surface water periods (rainy season) and pumped during the dry season. However, it shall be stressed that successful MAR implementation is not feasible anywhere and it requires careful planning.

A scientific collaboration on MAR between the MoWE and BRGM has started in 2023 with the support of the French Development Agency (AFD). The main objectives of this collaboration are to develop a methodology for MAR suitability mapping at regional scale and then carry out pre-feasability studies in two favorable areas. This pilot project is located around the towns of Dire Dawa, Harar, and Jijiga (eastern Ethiopia), a region where groundwater resources are critical to meet the growing water demand linked to population growth and development. The MAR suitability mapping is performed using existing datasets within a multi-criteria analysis framework. The weighting of the criteria is determined via a pair-wise comparison (Saaty method). The main criteria are climate and precipitation, the proximity of runoff or watercourses, the proximity and depth of sufficiently porous and permeable reservoir layers, and the predisposition of land to receive MAR. The resulting map is then validated by field surveys.

68. MANAGED AQUIFER RECHARGE SITE SELECTION IN THE NELSON MANDELA BAY USING DIFFERENT MULTI-CRITERIA DECISION ANALYSIS TECHNIQUES

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Abstract

The Nelson Mandela Bay (NMB) recently experienced a severe drought where dam levels dropped to a record low of less than 10%, about 6% of which was dead storage. This resulted in an increase in the number of boreholes drilled across the NMB area. Unlike surface water, groundwater has a delayed response to droughts where groundwater levels continue to decrease beyond the drought period. Managed Aquifer Recharge (MAR) is proposed as a sustainable and effective solution for groundwater resource management and resilience to climate change.

This study presents MAR site suitability mapping using four different multi-criteria decision analysis (MCDA) techniques, which is the first step towards MAR implementation in fractured aquifers at the NMB. Soil texture, geology, vadose zone, water quality, slope and hydraulic conductivity are six effective criteria which were chosen based on their importance in MAR implementation in fractured aquifers. Data from various sources were collected, processed and reclassified according to the Boolean Logic, Fuzzy Logic, Weighted Linear Combination and Analytical Hierarchy Process (AHP) to produce suitable maps for MAR site selection. The final suitability maps were overlaid with a Land Use Land Cover map to exclude water bodies, built-up areas and farms. The final suitability maps show that 5.44% (53.02km2), 15.68% (152.73km2) and 13.57% (132.12km2) were suitable to very suitable according to the Boolean logic, WLC and AHP, respectively. The final overlays for all techniques indicate that suitable sites are located towards the south-eastern region of the NMB. The application of MCDA and integration with GIS proved to be effective at delineating suitable sites for MAR in NMB.

Future work should focus on fracture analysis to understand groundwater flow as well as hydrogeological modelling within the complex fractured aquifer systems of the NMB area.

Keywords: Managed Aquifer Recharge, Multi-Criteria Decision Analysis, Fractured Aquifers, Suitability Mapping, Drought Resilience, Nelson Mandela Bay

44. GROUND-BASED TEM FOR EFFICIENT PRE-INVESTIGATION OF MANAGED AQUIFER RECHARGE SITES

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Abstract

Geophysics has gained traction in pre-investigation of potential managed aquifer sites, especially in answering questions on how water moves from the surface into the subsurface. The size and suitability of a target aquifer, and the potential pathways that lead to the aquifer, can be estimated by geophysics. Traditional geophysical methods such as Electrical Resistivity Tomography (ERT) and ground-based Transient Electromagnetic (TEM) methods are suitable for this purpose, but the low data production rate is often a limitation.

Recognizing the need for more efficient exploration, especially in applications requiring shallower investigations (0 - 100 m), we've introduced a novel, compact TEM small coil setup. This rigid frame system is designed for rapid deployment and mobility in the field, enhancing the speed of dense data collection especially along long transects with >100 soundings possible pr day.

The system features small coils for both transmitter and receiver, 3x3 m, in rigid frames and in an offset configuration with 10 m separation. Both transmitter and receiver electronics are integrated into a compact unit, powered by two lightweight li-ion batteries. The system is controlled through a dedicated mobile application, available for both Android and iOS devices, allowing real-time monitoring of data, not requiring expert knowledge.

In the presentation we will present the technical details of the system and show examples of data compared to both towed TEM (tTEM) and ERT data.

75. PROPOSED EXPANSION OF THE ATLANTIS AQUIFER: AN INTERGARTED APPROACH COMBINING GEOPHYSICS AND REMOTE SENSING INVESTIGATIONS

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Abstract

The town of Atlantis is located along the semi-arid west coast of South Africa and is dependent on groundwater for its water supply. The Atlantis Water Resource Management Scheme (AWRMS) abstracts groundwater from the unconfined coastal Atlantis Aquifer via two wellfields (Witzand and Silwerstroom), augmented by Managed Aquifer Recharge (MAR). MAR is achieved by infiltration of treated domestic effluent and stormwater up-gradient of the Witzand Wellfield through two infiltration basins (Basin 7 and Basin 12). Additionally, treated industrial effluent is discharged into coastal basins down gradient of the Witzand Wellfield, superseding the need for a marine outfall while simultaneously maintaining a freshwater mound between the wellfield and coast. To facilitate the predicted future demand for the area of ~39ML/d by 2040, increased abstraction will be required. Several scenarios were considered through abstraction modelling to achieve this, with all indicating that the Witzand Wellfield yield would decrease within 3 to 4 years without additional MAR. Considering the effect of increased water abstraction and increased treated domestic effluent supply to the two basins, alternative approaches such as wellfield and MAR expansion were proposed to mitigate risk during high stormwater flows and down time in the production wellfield. By using 2D electrical resistivity tomography and borehole data, an improved basement surface was modelled. The basement surface combined with a high-definition Lidar digital elevation model and water level data enabled the identification of areas with increased aquifer thicknesses. The best-case scenario achieved entails the construction of an additional MAR basin and expanding the Witzand Wellfield. This would allow the AWRMS to achieve increased abstraction volumes from the wellfields and reduce the risk against climate change and water demand increase.

133. MANAGED AQUIFER RECHARGE OPPORTUNITY MAPPING IN NEW SOUTH WALES

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Abstract:

Effective management of groundwater resources is crucial for ensuring the long-term sustainability of ecosystems, agriculture, and urban water supplies, particularly in the face of climate change. As climate variability and extreme weather events become more frequent, the importance of managing groundwater resources to support resilient and adaptive water management systems cannot be overstated. In this context, the New South Wales (NSW) Groundwater Strategy in Australia aims to build community and industry resilience through sustainable groundwater use, including Managed Aquifer Recharge (MAR). This study assessed MAR opportunities across NSW, considering unconfined and confined aquifers, and uncertainty in input data. The results show that unconfined aquifers have significant storage potential, with 37 groundwater areas having > $1\times10^6 m^3$ of storage potential, 16 areas with > $50\times10^6 m^3$, and 11 areas with > $100\times10^6 m^3$, totaling $2{,}800\times10^6 m^3$ across 3,600 km^2. Confined aquifers also have substantial storage potential, with 18 areas having > $1\times10^6 m^3$ of storage potential, 7 areas with > $50\times10^6 m^3$, and 5 areas with > $100\times10^6 m^3$, totaling $6{,}000\times10^6 m^3$ across 21,000 km^2. The greatest storage potential is associated with large alluvial systems in the Murray-Darling Basin.

However, the full capacity may not be achievable due to various factors. The study highlights the need for further investigation, local-scale assessments, and policy development to realize the potential of MAR in NSW. This research found that many areas have a high reliance on groundwater during dry years, and some show evidence of resource stress, resilience, and sustainability issues. The sensitivities of factors like clay content, groundwater salinity, and aquifer thickness on MAR potential varied spatially. Site-specific investigations are needed to determine recovery rates, and the potential benefits of MAR include supporting town water supplies, agriculture, restoring depleted aquifers, and improving resource conditions.

37. EXPLORING THE RELATIONSHIP BETWEEN EFFECT-BASED ANALYSIS, EMERGING POLLUTANTS, AND CONVENTIONAL WATER QUALITY PARAMETERS IN A THREATENED COASTAL AQUIFER

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Abstract

The presence of emerging contaminants (ECs) in groundwater reserves is a growing concern globally. Despite this reality, limited data exists describing EC-associated biological activity in aquifers and the associations between EC burdens and conventional water quality parameters including chemistry and microbiology. The Cape Flats Aquifer (CFA) is subject to various sources of contamination (industrial, residential, and agricultural). To better understand the spatiotemporal patterns within this area, an extensive water quality index (WQI) was developed, incorporating 24 parameters measured over 98 boreholes within a five-year period (2018 – 2021, and 2023). Upon the identification of several contamination hotspots, a battery of effect-based methods (EBMs) were applied to screen groundwater for endocrine disruptive (i.e., estrogenicityand androgenicity), and aryl hydrocarbon receptor activation over two seasons. An in vivo fish embryo toxicity (FET) assay was furthermore applied to screen for embryotoxicity and teratogenicity. Analytical chemistry was performed in parallel with the EBMs to quantify a selection of ECs including pharmaceuticals, pesticides, and personal care products. A subsequent pollution source delineation principal component analysis (PCA) using the WQI parameters showed that a mix of agricultural, geogenic, and residential sources contributed to the poor water quality. Further information could be deduced with the incorporation of the EBMs data, where certain sites had significant endocrine disruptive potential. We conclude that caution should be taken when abstracting water from areas that were identified as pollution hotspots and that efforts should be taken in curtailing some of the activities contributing to the deteriorating groundwater quality. Finally, we show that EBMs can be a valuable tool in combination with traditional water parameters to provide a more comprehensive analysis of at-risk groundwater sources.

115. GEOPHYSICAL APPLICATIONS IN MANAGED AQUIFER RECHARGE: INSIGHTS FROM COASTAL AND KARST AQUIFER SYSTEMS

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Abstract
Managed Aquifer Recharge (MAR) is a critical strategy for enhancing groundwater resources. However, the approach must be cognizant of the geologic setting when selecting tools and methods. This study explores the application of geophysical techniques for MAR in two distinct geological environments: coastal and karst aquifers. In the West Coast Aquifer System of South Africa, geophysical methods such as Electrical Resistivity Imaging (ERI), Airborne Electromagnetic (AEM), Vertical Electrical Sounding (VES), and Magnetotellurics were employed to characterize subsurface lithology, delineate the freshwater-saltwater interface, and site proposed infiltration basins. These techniques provided crucial insights into the heterogeneity of the aquifer, the movement of the recharge front, and the potential for saltwater intrusion, ensuring the sustainable management of the aquifer. In contrast, the karst system of the Arbuckle-Simpson aquifer, Oklahoma, USA, is known for its complex, highly permeable structures and requires a different approach. Here, geophysical tools like the AEM and ERI were utilized to map subsurface cavities, conduits, and fracture zones, which are critical for understanding recharge dynamics. The high-resolution data obtained enabled the identification of preferential flow paths and the assessment of recharge efficiency. The lessons learned from these applications underscore the importance of tailoring geophysical techniques to the specific characteristics of the aquifer system. In coastal aquifers, the challenge lies in balancing recharge with the risk of saltwater intrusion, while in karst aquifers, the focus is on accurately identifying and managing complex subsurface features to optimize recharge. The study highlights the necessity of a geologically thoughtful approach to MAR, informed by detailed geophysical investigations, to conduct MAR effectively in diverse geological settings.

Keywords: Geophysics, Groundwater Resources, Infiltration basins, Managed Aquifer Recharge

5. Regulatory Lessons: Safe and Reasonable Requirements for Testing to Operating

121. WATER QUALITY FROM SPANISH MANAGED AQUIFER RECHARGE (MAR) SITES TO SUPPORT NATIONAL-SCALE GUIDELINES AVOIDING MAXIMUM ALLOWABLE CONCENTRATIONS

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Abstract

Most of the countries that have technical guidelines for artificial recharge or managed aquifer recharge (MAR) that include qualitative aspects are based on the establishment of standards or Maximum Allowable Concentrations (MACs). Therefore, they regulate the quality of the water percolated or injected into an aquifer, generally at national-wide scale. These limitations consider a very variable number of parameters (from four parameters in Spain to 156 in the USA), which apply to all aquifers inside the national territory, regardless the nature of the receiving medium, the depth of the water table, and additional key factors.

Eleven successful operational MAR systems in Spain have been studied, characterising the recharge water quality, and the result from the interaction processes. In most of the cases, a beneficial effect on water quality has been monitored for years; even though eventually do not meet standards regulated in different European countries.

The paper characterises the sites and their water quality and exhibits a generalised positive effect on each recharged environment, reducing the concentration of harmful elements, even when they remain above the legally established limits for some MAC-based European national guidelines.

It is concluded that regulations using MACs is not the most appropriate system to constraint the water quality in MAR systems, and that it is necessary to establish aquifer-wide limitations, even at local level. It is also advisable to water authorities the decision on granting allowances for MAR based on detailed studies, including risk/impact assessments, and avoiding rigid water quality standard limitations established at national level. Therefore, the excessive application of the precautionary principle, and the subjectivity of the allowance will be reduced.

This decision-making changes have been recommended to the drafters of the European guidelines for MAR document, including the monitored and intentional recharge (MIR) concept into groundwater hydrodynamic monitoring routines.

Keywords: Managed Aquifer Recharge (MAR), Monitored and Intentional recharge (MIR), Maximum allowable concentrations (MACs), regulations, MAR guidelines, water quality standards.

63. GOVERNANCE OF MANAGED AQUIFER RECHARGE: INSIGHTS FROM THE EUROPEAN UNION'S REGULATORY FRAMEWORK

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Abstract

"Artificial recharge" is recognized as a potential supplementary measure which may be adopted by EU Member States in fulfilment of obligations which emanate from the EU's Water Framework Directive 2000/60/EC (WFD), which mandates the prevention or limitation of pollutant inputs into groundwater and the prevention of the deterioration of its status, with the aim of achieving good quantitative and chemical status in all EU groundwater bodies. The WFD lays down a supporting framework towards this end, requiring that artificial recharge be subject to prior authorization, ensuring that the environmental objectives for both the source as well as the recharged, or augmented, groundwater bodies are not compromised.

The Groundwater Directive 2006/118/EC (GWD) expounds upon the WFD's "prevent or limit" objectives, establishing conditions for the management of hazardous and non-hazardous pollutants. Artificial recharge permitted under the WFD is exempt from these, provided that effective monitoring frameworks of the receiving (augmented) groundwater body are deployed. An analysis of the relevant regulatory provisions within these Directives through the EU-funded Marsol and Marsolut projects indicates that these constitute a sufficiently robust regulatory framework for safe managed aquifer recharge (MAR). The findings emphasize the importance of focusing on the quality of recharge water rather than its origin, the necessity of stringent quality control measures before water enters the MAR system and the critical role of permits based on comprehensive risk assessments of the entire MAR system.

This paper reviews the role of the EU's regulatory framework in supporting MAR as a scientifically sound, safe and sustainable groundwater management strategy.

*The MARSOL Project was funded under the EU's Seventh Framework Programme whilst the ARSOLUT Project was funded under the EU's Horizon 2020 Programme.

21. LEGISLATIVE ISSUES IN SOUTH AFRICA FOR THE IMPLEMENTATION OF MAR SCHEMES

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Abstract

Managed Aquifer Recharge in South Africa is part of the National Water Resource Strategy. It is part of the strategy to enhance water security, especially in the context of water scarcity and climate variability as the western part of the country is getting more arid. The legalisation on MAR should support the implementation of MAR schemes. The current legal documentation that can be used to address issues on MAR includes the National Water Act (1998) specifically referring to Section 21 which can give effect to Gazetted Regulations or Water Use Licenses. In the past decade, various regulations were used to legalise the construction of MAR schemes. Since in many cases, it was more for drought relief and not for future sustainable water supply a lot of rules/regulation were bent. But what counts for the one, counts for the other and in most cases Section 21 C&I regulations had to be bent to ensure any recharge takes place. Another issue that would need to be addressed is water quality. To what extent do we need to clean water before it is injected into the ground? Can EIA processes be made easier for the construction of specific MAR schemes, not only to ensure water for the client but also add water to the environment? Creating a thoughtful regulation specifically addressing MAR schemes could mean more water security for the near future. This paper will not only highlight lessons learned for current legislation but will describe the process to overcome challenges and provide guidance in future changes to elements in the legislation.

163. MAR'S STRATEGY BACK IN FRANCE FOLLOWING THE LATEST CONSECUTIVE DROUGHTS

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Abstract

France has long experience on Managed Aquifer Recharge (MAR). Many water supply facilities rely on this strategy, which was first deployed in the 1960s and is still in use today. A national inventory provided by BRGM identifies more than 78 installations, with 73% of them dedicated to the production of drinking water. Recharged volumes increased from 20-30Mm3/year in the 1960s to 36-46Mm3/year in the 1980s, to reach 115-125Mm3/year in the 1990s. Most of referenced MAR facilities are still functioning (66%). The long-term experience acquired from these previous MAR cases conduct to fewer smaller site deployments once a while on a case-by-case basis.

Over the last 15 years, the impacts of climate change have already been felt in France, with a rising of drought events (frequency and intensity). Since 2010, a rising number of water resources have shown alarming 'reinforced alert' and 'crisis' status, notably in 2017, 2019, 2022, 2023 and 2024. More than 90% of departments have decided to restrict water use by decree during a part of these years. Consecutive years of drought and restricted access to water resources act as lighthouse to highlight issues concerning water management. Many alternatives have been studied, including MAR strategy from catchment areas to catchment basins. Over the last 5 years, more than 10 MAR feasibility studies have been carried out throughout France for drinking water, industrial and agricultural uses, using i) data analysis and spatial multi-criteria analysis, ii) hydrogeological models and simulations of MAR scenarios and iii) experimental MAR pilots.

More than 10 MAR studies are currently under consideration. More than ever, coordination, knowledge sharing, previous experiences feedback, stakeholders' inclusion and training is needed to ensure that MAR can be a key strategy in France as an alternative solution to climate change adaptation!

57. THE ARTIFICIAL RECHARGE STRATEGY OF SOUTH AFRICA: THE ONGOING CYCLE OF RESEARCH, KNOWLEDGE GENERATION AND IMPLEMENTATION

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Abstract

In the 80's till the early 2000's many research projects focused on Managed Aquifer Recharge (MAR) and the testing of the various implementation scenarios. In July 2007, South Africa published the first "Artificial Recharge Strategy of South Africa (ARSSA)". Implementation of the ARSSA began in November 2007 to ensure sustainable groundwater use, protection and management. This was updated with Version 2 in 2010. The 7 themes that range from: Knowledge, Legislation and Regulation, Planning, Implementation, Management, Research and Strategy Implementation were subdivided into smaller activities.

Artificial recharge or managed aquifer recharge was a term that very few people had heard or understood. The correct order of implementation of the themes, time and budget spent played a major role in the roll out of the strategy. Developing communication material on MAR proved to be very successful when addressing the diverse sectors and knowledge needs. Awareness, a champion or driver and demonstration sites of artificial recharge were and still are the controlling factors for the success in implementation of an artificial recharge strategy. Numerous water supply schemes and users use artificial recharge, to secure their resource during drought periods, improve the water quality and to ensure that groundwater is available at a higher assurance level.

Key lessons were learned during the implementation of the above Strategies which are currently being incorporated in the development of ARSSA Version 3.

6. The Economics of MAR

24. BENEFITS AND COSTS OF WATER BANKING: AN INTEGRATED WATER GOVERNANCE SOLUTION

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Abstract

Water banking, a strategic approach to managing water resources, has gained prominence as a solution to address water scarcity, enhance supply reliability, and support environmental sustainability. Water banking provides an integrated water governance solution that improves water security for communities and farmers by storing water in aquifers using managed aquifer recharge and managing groundwater extractions to ensure that water supplies are available during droughts. This study evaluates the economic, social, and environmental benefits and costs of water banking in selected case studies with diverse biophysical and institutional contexts. The primary research questions address the economic impacts of water banking on agricultural productivity, urban water supply and impacts on streamflow and water dependent ecosystems in normal and dry climate scenarios. The study is adopting a mixed methods approach to the assessment of water banking combining cost benefit analysis (CBA) and multi-criteria decision analysis (MCDA) with hydrological modelling to assess changes in groundwater levels, water quality and streamflow. CBA provides quantitative economic assessment, which is ideal for comparing alternative sources of water supply while MCDA offers a more holistic view incorporating social and economic criteria and is often used in the assessment of environmental water banking. The study is expected to provide integrated quantitative assessments of benefits of water banking in different climate scenarios taking account of the diverse interests and objectives of stakeholders. This will add to understanding about the benefits water banking to water security and sustainable water management and contribute to the development of adaptive management frameworks to manage long-term impacts of increased groundwater use and climate change.

134. MANAGED AQUIFER RECHARGE IN AUSTRALIAN WATER LEGISLATION, REGULATION AND POLICY: AN ANTICOMMONS PROBLEM?

C. Seidl, D. Page, and S. Wheeler

Abstract

Managed aquifer recharge (MA) is widely regarded as a promising nature-based water management and water supply/storage tool. However, implementation of MAR has been slow, both globally and in Australia, with economic and legislative drivers identified as main impediments. Despite the Australian government viewing MAR for agricultural purposes as a key element in its efforts to tackle water scarcity and drought mitigation, there are only a few operational MAR schemes in Australia, mostly in municipal and urban settings. This paper explores whether legislation is an impediment to MAR implementation in Australia by reviewing state and Commonwealth water legislation, regulation and policy. We draw on more than 30 characteristics to score MAR regulation and legislation across the three domains of: 1) legislative conflicts, definitions and stand-alone MAR legislation; 2) licence characteristics; and 3) licence applications and conditions. We find that stand-alone MAR legislation, regulation and policy is either non-existent or in its infancy in all states but South Australia (SA) and Western Australia (WA). Water licence regimes in Australia prevent MAR as, although water physically changes from surface to groundwater, there is no legal way to convert recharged surface water to groundwater using existing transfer/trade or allocation mechanisms. Instead, the same volume would count as surface and groundwater extraction.

Even where legally possible, MAR scheme operation may require multiple different permits and licences. This imposes significant transaction costs through assessments and documentation for the approval process. This may constitute a tragedy of the anticommons problem: too many permits/licences are needed for scheme operation with associated complexity and transaction costs leading to an underutilisation of MAR. To encourage future MAR implementation, we propose: 1) additional research on economic benefits of MAR storage; 2) enshrine specific MAR licences in water acts and legislation; 3) simplify and make processes more transparent; 4) change existing permits to better reflect operations; and 5) remove legislative barriers to account for recharge and recovery volumes and to prevent double counting.

92. ECONOMIC INSTITUTIONAL MECHANISM DESIGN OF MANAGED AQUIFER RECHARGE: Insights from the BLUE RECHARGE Project

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Abstract:

The BLUE RECHARGE Interreg project, a collaboration between Italy and Croatia, examines regulatory, economic, and environmental frameworks essential for implementing Managed Aquifer Recharge (MAR). This research focuses on institutional mechanism design, exploring how regulatory frameworks impact the safety, operational efficiency, and environmental sustainability of MAR initiatives. These frameworks are crucial for transforming water from a hydrological common-pool resource, defined by rivalry and non-excludability, into a hydrological common good through sustainable replenishment practices. In Croatia's predominantly karstic coastal landscape, MAR addresses specific environmental challenges. Karst aquifers, characterized by high permeability and rapid groundwater flow, are vulnerable to over-extraction, leading to issues such as land subsidence and saltwater intrusion, especially along the Adriatic coast. MAR mitigates these impacts by replenishing groundwater reserves, creating barriers against saltwater intrusion, and stabilizing land surfaces. By capturing and storing surface water, MAR enhances the aquifer's capacity to ensure a reliable water supply during droughts and supports the ecological health of riparian habitats. Water management institutions can also regulate water as a private good, with controlled access and usage fees, or as a lumpy good, where agricultural producers pay lump sums for nearly unlimited use. MAR, by ensuring sustainable replenishment, balances these institutional frameworks, transforming water use into a common good model that promotes long-term water security and environmental stewardship. Innovative economic tools, like Blue Credits, incentivize sustainable water management, facilitating the integration of MAR into broader water resource plans. This analysis underscores that sustainable groundwater management in karst regions requires navigating complex trade-offs and opportunity costs, highlighting the necessity for balanced, adaptable solutions.

Keywords: institutional mechanism design, water scarcity, common goods, common pool resources, sustainability

109. IOT-BASED DATA AND ANALYTIC HIERARCHY PROCESS TO MAP GROUNDWATER RECHARGE WITH STORMWATER

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Abstract

The sustainable management of groundwater resources in developing countries is often challenging due to limited measurement and monitoring infrastructure. This study investigates the use of Internet of Things (IoT) technology, including low-cost sensors, to collect groundwater-level data and develop a model to map the recharge potential with stormwater to address these challenges. The research focuses on two stormwater ponds in the Mitchells Plain West Catchment of the Cape Flats Aquifer (CFA) in Cape Town, South Africa. A combination of Geographic Information System (GIS) analysis and Analytic Hierarchy Process (AHP) was employed to generate a groundwater recharge potential zone map. The stormwater ponds were classified within the excellent zone, demonstrating their potential for groundwater replenishment through infiltration. The unconfined aquifer was modelled in MODFLOW software in two layers based on subsurface geology, with hydraulic conductivities assigned to each layer to reflect the variation in soil composition. IoT-based groundwater level data was used to calibrate the MODFLOW numerical groundwater model, revealing that the integrating IoT systems enables the collection of accurate, high-resolution data essential for hydrogeological studies. The results confirmed the occurrence of groundwater recharge at the stormwater ponds, validating the effectiveness of the ponds for groundwater augmentation, especially during the winter months. The steady-state model calibration yielded a root mean square error (RMSE) of 0.65, while the transient model, calibrated using wet-season data, achieved an RMSE of 0.86. The study confirmed the reliability of IoT technology in addressing data scarcity, enabling the collection and processing of large volumes of high-quality groundwater data at a low cost. Furthermore, integrating GIS, AHP techniques and MODFLOW software provided a robust framework for mapping groundwater recharge potential, particularly in semi-arid urban areas facing increasing water demand and the impacts of climate change.

10. MANAGED AQUIFER RECHARGE TO CO-MANAGE FLOODS AND DROUGHTS: TRANSFERRING LESSONS FROM ASIA TO AFRICA

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Abstract

Underground Transfer of Floods for Irrigation (UTFI) is a novel MAR technique that targets aquifers with excess seasonal flows on a basin scale. By strategically installing groundwater recharge infrastructure across a basin, UTFI captures surplus floodwaters to replenish aquifers. This approach mitigates downstream flood risks—protecting lives and assets—while enhancing water availability for agriculture during dry periods. UTFI was successfully piloted in the Ganges basin, northern India, where upscaling efforts are currently underway. A multi-method approach was used to establish a proof of concept: initial UTFI suitability mapping was followed by field assessments to confirm high-potential areas, community and stakeholder engagement, and the establishment of a pilot site. Technical and modeling evaluations demonstrated that the pilot site recharged 30 to 60 ML of water each season, supporting the cultivation of 13 hectares during the dry season. When scaled, models showed that UTFI could reverse groundwater decline, and deliver additional co-benefits such as flood mitigation and enhanced groundwater availability during dry seasons to help build resilience and in climate adaptation.

A global UTFI suitability assessment identified high UTFI potential across various regions, including in Sub-Saharan Africa (SSA), where 462 million people live in highly suitable areas, alongside 88 million hectares of crop area and 28 major cities (pop. > 0.5 million). Given that floods and droughts account for 80% of mortality losses and 70% of economic losses related to natural hazards in SSA, UTFI offers a promising solution to co-manage these extremes. UTFI could provide a complementary way to co-manage floods and droughts in a number of river basins, while making agriculture more resilient to drought events through enhanced groundwater storage in conjunction with the development of groundwater irrigation in SSA. This paper will present insights and approaches for transferring the UTFI to SSA's river basins based on the experience of the Ganges basin for its potential adaptation in SSA's river basins to build resilience.

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Abstracts for Poster Presentations

96. IMPLEMENTATION OF MANAGED AQUIFER RECHARGE FOR SUSTAINABLE MUNICIPAL WATER SUPPLY. PRINCE ALBERT, SOUTH AFRICA

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Abstract

The picturesque Karoo town of Prince Albert, known for its harsh, dry conditions with limited rainfall and high summer temperatures, uniquely benefits from access to both groundwater and surface water. Managed Aquifer Recharge (MAR) studies conducted over fifteen years ago highlighted MAR's potential to sustain the town's water supply by using surplus surface water to replenish aquifers during dry seasons when groundwater is heavily relied upon. With funding from the Western Cape Department of Local Government, the Prince Albert Municipality has initiated the implementation of MAR based on historical feasibility studies done by Groundwater Africa and the Department of Water and Sanitation. The current project's first phase involved rehabilitating injection boreholes and installing the necessary injection infrastructure and monitoring equipment for future injection trials. Due to aboveaverage rainfall in the year preceding the planned trial, the aquifers are currently fully recharged leaving insufficient space for effective injection trials. A short injection test was conducted to calibrate equipment, with an extended trial being scheduled for the dry season when groundwater levels are expected to lower, allowing sufficient space in the aquifers for effective injection assessments. Additionally, a shallow injection trench was constructed in the overlying alluvium and connected to the injection infrastructure, enabling future injection into either the deeper fractured aquifer or the overlying alluvium. This will provide valuable data on the alluvium's capacity for artificial recharge in conjunction with injection into the fractured aquifer. The feasibility of in-channel modification and flood retention structures, to increase recharge to the underlying aquifer, forms part of the study. Effective collaboration between the hydrogeologist and engineering specialist is therefore critical. A cost-benefit analyses and comparison between the different MAR options will assist in decision making prior to implementation. The final design and extent of the MAR project can then be completed and implemented once the applicable water use licenses have been obtained.

7. ASSESSING THE IMPACT OF MANAGED AQUIFER RECHARGE IN AKROTIRI COASTAL AQUIFER (CYPRUS) VIA GROUNDWATER MODELLING

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Abstract

Managed Aquifer Recharge (MAR) systems are installed in coastal areas of Cyprus to address two main water-scarcity related issues, particularly the intrusion of seawater into the coastal aquifers and the overexploitation of the existing freshwater resources. Tertiary-treated wastewater is currently used to recharge the aquifer systems via infiltration ponds, whereas a complex of nearby wells is used to abstract groundwater for covering the water needs of agriculture and tourism sectors. According to estimates by the national water authorities, a significant increase of the available amounts of treated wastewater for MAR is expected in the coming years, accompanied by major changes in land use and economical patterns. This study focuses on developing a groundwater flow model to quantify the impact that these changes will have on the status of the aquifer system. Different scenarios are considered to assess the evolution of the piezometric levels and major pollutants, with special attention to a) the vicinity of the coastal line and b) the location where drinking wells are currently operating. The conceptual model was developed together with representatives of water authorities, taking into account the local hydrogeological conditions and different water fluxes interacting with the aquifer. For the numerical implementation of the model, multiple datasets were collected from the governmental authorities and remote sensing repositories for the period 2019-2023 and used to assign appropriate boundary conditions to a MODFLOW-based groundwater flow model. Steady-state simulations have been run to calibrate the spatial distribution of the hydrogeological parameters (i.e., hydraulic conductivity and specific yield), revealing the strong connection between the infiltration patterns and the aquifer response. The results of this analysis were discussed and validated during stakeholder workshops in the presence of representatives of local and regional water authorities.

72. INVESTIGATING GROUNDWATER HYDRODYNAMICS OF MANAGED AQUIFER RECHARGE SYSTEM FOR IMPROVED SUSTAINABLE GROUNDWATER SUPPLY, LIMPOPO, SOUTH AFRICA

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Abstract

The study investigates groundwater hydrodynamics, focusing on the geometric properties of subsurface flow and transport processes. Hydrodynamics examines the mechanisms of fluid movement within geologic formations through mathematical modeling, offering a comprehensive understanding of groundwater hydraulics and hydrology. The study aims to characterize the urban aquifer system, providing the necessary data to support more effective and sustainable groundwater management practices. The primary goal is to enhance knowledge of the hydrogeological characteristics of a Managed Aquifer Recharge (MAR) system, which is vital for sustaining groundwater supplies. The study takes the Polokwane Managed Aquifer Recharge scheme in Polokwane City, South Africa, as a case study. This scheme recharges groundwater with treated wastewater from the Polokwane wastewater treatment plant. After remediation by aquifer materials, the recharged effluents are abstracted via production boreholes. However, Polokwane's urban aquifer system's hydrogeological characteristics, particularly the hydrodynamics, remain poorly understood. Understanding groundwater flux and its exchange processes is crucial for improving management practices aimed at contaminant remediation and assessing how the aquifer system contributes to the overall water balance across seasonal changes. This is especially important locally in arid and semi-arid regions, where water shortages are exacerbated by industrial growth, population expansion, and extreme climatic events like droughts.

50. INTERPRETATION OF GROUNDWATER MODELLING SCENARIOUS FOR MANAGED AQUIFER RECHARGE, LANGEBAAN ROAD, SOUTH AFRICA

A. Nicholls

Abstract

Ever-growing water demand, climate change impacts, and rapid urbanization-related activities coupled with an increase in population and economic activities continue to threaten surface water sources globally and particularly in semi-arid environments such as South Africa. Managed aquifer recharge (MAR) is an engineering technology that stores water in the subsurface when such water is available or from various sources and abstracts such water when it is required to augment the conventional water supply system. Groundwater models or modeling scenarios for managed aquifer recharge have been used in various MAR schemes as management tools. However, the implication or interpretation of outputs from such models to inform practical actions remain a challenge. Hence, the current study aims to provide science-based interpretations from groundwater modelling scenarios to inform feasible actions required to set up MAR Scheme. The West Coast Aquifer system in the Langebaanweg area in South Africa was used as a case study. To achieve the study- aim, the following objectives were identified: 1) To describe the groundwater flow system in the study area using a site-specific conceptual model. 2). Apply a numerical model of groundwater flow to evaluate groundwater modeling scenarios, 3). Assess implications of different abstraction/injection scenarios to determine the feasibility of setting up the MAR scheme in the unconfined layer of the Langebaan Road Aquifer. Systemic and analytical reviews of previous studies and modern methods were evaluated to identify suitable methods to achieve each objective. It was hypothesized that the MAR scheme will increase the local groundwater table causing inundations on the surface i.e. groundwater flooding. However, using an integrated groundwater flow model, a suitable injection rate would be identified to recede the hypothesized groundwater flooding events to support the MAR scheme as a sustainable groundwater supply system as an adaptive climate change measure.

90. MANAGE AQUIFER RECHARGE (MAR) FOR RURAL WATER SUPPLY: GROUNDWATER MAPPING FOR CARNARVON

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Abstract

Investigating hydro-geophysics techniques to map groundwater for managing aquifer recharge. Water-stressed areas and depleting aquifers are driving research on investigating and mapping groundwater for managing aquifer recharge by using hydro-geophysics. This involves employing various geophysical methods to investigate subsurface properties, identify groundwater resources and understand aquifer characteristics (Earle,2019). The geophysical investigation is conducted at Carnarvon town, Northern Cape. Carnarvon is an isolated town in an arid environment with a low rainfall of 250 mm/annum (Frandsen, 2024). The temperatures range between 1 - 24°C in winter and 11 – 40°C in summer. The town, surrounding communities and farms are dependent on groundwater for farming and domestic use. The area belongs to the Ecca group of Karro Supergroup, dominated by shale and sandstones. The lithology was intruded by weather resistant dolerite dykes which formed the high lying areas of the Kareeberg Mountains with buttes and mesas (McCathy & Rubidge, 2005). Drill sites of the investigation were selected along dolerite dykes where the adjacent sediments were deformed and fractured to form a secondary or fractured rock aquifer (Esterhuyse, 2014). Managing aquifer recharge is a purposeful recharge of groundwater to build a long-term sustainability on groundwater resource by directing surface water into the subsurface (Meles, et al., 2024). Carnarvon town experiences a deficit water supply due to hot temperatures and low rainfall in summer. The dam which replenishes the town's dam experiences frequent aridity. During the season of little to no rainfall, aquifers only experience a recharge in winter due to decreased water usage. The use of Magnetic survey as a hydro-geophysics technique was used to map groundwater for managing aquifer recharge. A topographical survey was used to determine the difference in elevation of the site area. A magnetometer was used to collect total magnetic field to create a magnetic map. The results confirmed that the aquifer recharge is highly dependent on rainfall runoff and the river passing through the town. The integration between the elevation and magnetic survey made it evident that they are powerful hydro-geophysical techniques to determine aquifer characteristics, and they are recommended to detect potential areas for managing aquifer recharge.

36. VOLSUNG: WHAT CAN GROUNDWATER MODELERS IN MAR APPLICATIONS LEARN FROM THE GEOTHERMAL ENERGY INDUSTRY

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Abstract

In this article, we explore the potential application of the Volsung geothermal modelling software tool in Managed Aquifer Recharge (MAR) projects. Volsung, a reservoir modelling package designed for geothermal energy projects, is rapidly gaining popularity within the geothermal reservoir modelling community. It includes a reservoir simulator, wellbore model, and surface network model, capable of running fully coupled reservoir/wellbore/surface simulations. This integration allows geothermal operators to optimise field and plant operations using a single, cohesive workflow. The ability to run coupled reservoir, well, and surface network models, along with fast simulation times and a modern graphical user interface (GUI), makes Volsung particularly appealing to the geothermal energy sector. These features are equally beneficial for MAR applications. Volsung's core philosophy emphasises the use of internally consistent methods that are fast, stable, and user-friendly. For MAR projects, Volsung offers hydrogeologists and groundwater modellers the capability to model and visualize complex geoscience and reservoir engineering data, rapidly build and analyse 3D conceptual models, and test multiple scenarios using dynamic modelling that updates with new data inputs. At the same time, projects benefit from a reduction in both risk and cost through using the data and models for better well planning, flow simulations, improved reservoir estimation and monitoring, and informed operational decisions. This high-quality, robust modelling supports the entire lifecycle of a MAR project, from the phases of exploration and feasibility assessment to project development and operational management. Therefore, given the similarities in the underlying hydrogeological principles and physics of reservoir modelling in both geothermal and MAR applications, Volsung presents a valuable opportunity for MAR professionals to leverage state-of-the-art software tools, like Volsung, developed for the geothermal industry.

82. EVALUATING THE HYDROGEOLOGICAL ENVIRONMENT OF JOHANNESBURG AND SURROUNDING AREAS FOR MANAGED AQUIFER RECHARGE

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Abstract

The growing global population and climate change have put a strain on water resources worldwide. Metropolitan areas such as the City of Johannesburg were spatially centered around mining activities, with little consideration for the proximity of water sources, resulting in the need to share water resources with cities located nearer to those sources to meet the increasing water demand. The aim of this study is to assess the suitability of the hydrogeological environment of Johannesburg and the surrounding areas for managed aquifer recharge (MAR) practices, with the goal of using subsurface storage as an alternative water resource for domestic use to augment surface water supply. To date, the approaches employed in the investigation include an extensive review of published and grey literature containing geological and hydrogeological information. The geological framework has so far been verified through mapping the surficial geology of the Johannesburg area, where outcrop exposures are present. Aquifer tests such as slug tests, tracer tests, and electrical resistivity tomography surveys will be conducted to acquire information about the hydraulic properties of the aquifer. Physico-chemical and isotopic analyses will be carried out to understand the groundwater flow mechanisms in the aquifer. Preliminary findings indicate that the flow is fracture-controlled within crystalline rocks, with borehole yields ranging from 0.5 to 2.0 L/s. In this hydrogeological setting groundwater levels are shallow, ranging from 5 to 25 meters below the surface. Given the complexity of fractured crystalline rocks, integrated approaches are necessary to fully understand the hydrogeological environment and determine the suitability of a site for subsurface groundwater storage.

47. CHARACTERIZING PALEOCHANNEL AQUIFER SYSTEMS TO SUPPORT GROUNDWATER DEVELOPMENT FOR IMPROVED AUGMENTATION OF WATER SUPPLY SYSTEMS, WESTERN CAPE, SOUTH AFRICA

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Abstract

The proposed study aims to characterize paleochannel aquifer systems to support development of groundwater to augment water supply systems. Extreme weather events such as droughts have resulted in reducing surface water supplies, thereby encouraging the seeking of alternative water supply sources such as groundwater. Groundwater exists in different aquifer systems such as alluvial, basement, fractured rock, coastal, mountainous among others. Various techniques exist to explore the availability and quality of groundwater in such aquifer systems. These techniques have not been widely applied in paleochannel aquifer systems, hence, the focus of this proposed study. To achieve the stated objective of the proposed study: 1) Paleochannel aquifer systems will be identified and mapped for their spatiotemporal analysis: 2) Groundwater potential zones in such aquifer systems will be investigated; 3)Parameters and properties of such aquifer systems will be determined; 4) A hydrogeological conceptual model of groundwater processes (recharge-flow-discharge) will be developed to explain the groundwater balance of paleochannel aquifer systems in supporting water supply systems via potential managed aquifer recharge schemes. The Berg Water Management Area in Western Cape of South Africa will be used as a case study.

122. ASSESSMENT OF AQUIFER PERFORMANCE IN REMEDIATING GROUNDWATER CONTAMINANTS, POLOKWANE MANAGED AQUIFER RECHARGE SCHEME, SOUTH AFRICA

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Abstract

This study evaluates the effectiveness of aquifer systems in reducing pollutants within a Managed Aquifer Recharge (MAR) scheme, using the Polokwane MAR Scheme as a case study. The Polokwane MAR Scheme involves recharging an aquifer with treated wastewater effluent from the Polokwane wastewater treatment plant. The recharged effluent is later abstracted via production boreholes, naturally remediated by aquifer materials, and then further treated to meet drinking water quality standards before being supplied to the residents of Polokwane. MAR facilities are widely recognized as sustainable strategies for augmenting water supply globally. However, the use of reclaimed water in these systems can introduce contaminants into the aquifer. Identifying, categorizing, and characterizing these contaminants are crucial to understanding their behavior and the effectiveness of natural in-situ remediation processes. This study aims to thoroughly assess the ability of aquifer materials to remediate groundwater contaminants through a rigorous research process. A contaminant mass transport model based on a source-pathway-sink framework will be employed to evaluate the effectiveness of in-situ remediation technology. The findings of this study will provide scientific evidence for making reliable, evidence-based recommendations on MAR as a sustainable and safe alternative for urban water supply augmentation.

79. EVALUATING THE POSSIBLE MICROPLASTIC CONTAMINATION IN A MANAGED AQUIFER RECHARGE SYSTEM

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Abstract

Microplastics are plastic particles smaller than 5mm which have become a significant environmental concern due to their persistence and potential impacts on ecosystems and human health. The Cape Flats aquifer, a crucial water resource in Cape Town, South Africa, faces growing threats from various pollutants including microplastics. The City of Cape Town intends to use the means of Managed Aquifer Recharge to recharge the aquifer with the treated water from the Cape Flats WWTP to increase volumes of water being supplied to the city. This study aims to evaluate possible microplastic contamination and potential environmental and health impacts due to microplastics. The study will further recommend removal techniques that can be added as part of the treatment process at the WWTP before injecting the effluent into the subsurface. The results of the study will provide insight into the sources, distribution, and fate of microplastics in the aquifer. This will help in identifying the potential effects microplastics can have on the environment and human health as the water will be added to the city's supply. This study contributes to the limited knowledge about microplastics and the effects they may cause in the environment.

61. MARSOLUT-POLICY-BRIEF. ESSENTIALS ON MANAGED AQUIFER RECHARGE FOR POLICY MAKERS AND WATER MANAGERS

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Abstract

Water Management in Europe is facing an uncertain future, as established management frame-works are being challenged by the pressures resulting from climate change. Ensuring a high level of resilience in the water sector is increasingly becoming a priority for the EU and concepts have to be developed and implemented.

Despite uncertainties in global climate projections, the anticipated reduction of renewable fresh-water resources especially in Southern Europe can be as high as 50% until 2100, hitting regions that anyway already suffer from water scarcity and droughts. At the same time, large water quantities are lost to the sea as surface runoff and river discharge, discharge of treated and untreated wastewater, or discharge of excess water from various sources during periods of low demand.

Managed Aquifer Recharge is one of the tools which can support a move towards a more water resilient Europe, improving the quantitative (and qualitative) status of groundwater whilst enabling the reservoir capacity of aquifer systems to be exploited for balancing water storage between wet and dry periods.

Managed Aquifer Recharge may become an inevitable necessity moving forward and thus some elements of legal uncertainty require addressing. These relate mainly to (i) the lack of a formalized position with regards to the 'prevent and limit' concept, (ii) to judgements of the Court of Justice of the European Union and grey areas in the law, and finally (iii) to monitoring issues.

Careful and tailored design of MAR systems and monitoring of MAR sites is therefore crucial for performance evaluation and management of sites. However, water quality is still the key issue in implementing MAR systems, as the regulatory background is not well defined yet.

85. MANAGED AQUIFER RECHARGE SKEWED TOWARDS TECHNICAL AND PHYSICAL MODELS: WHAT DOES IT MEAN IN PRACTICE?

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Abstract

Managed Aquifer Recharge (MAR) is often promoted as a technology that aligns with sustainability goals in groundwater policy. This article analyzes three MAR pilot projects in Europe, including a case study in Los Arenales, Spain. Additionally, in-depth interviews were conducted. The aim of this paper is to better understand how MAR projects address the multiple dimensions involved in the long-term sustainability of operations and how numerical models contribute to this effort. The paper highlights a predominant focus on technical and physical modeling in MAR. This emphasis stems from the dominance of engineering perspectives, the demands of funders, and the pressure to deliver immediate, measurable results within limited timelines. The article argues that this focus on technical and physical modeling necessitates technical capacities and financial resources for operation, which may be lacking in practice, particularly after MAR pilot projects are concluded. This raises the question of why the focus on modeling persists in the MAR field, when groundwater managers increasingly recognize the critical importance of social and institutional dimensions. The adoption of socio-hydrological models could be a good way forward to complement and further develop long-term sustainability of MAR operations. It would provide a more diverse expertise on various sustainability-related dimensions. Thus informing more holistic MAR policies and practices for the long-term of these MAR projects.

Keywords: Managed aquifer recharge; models; sustainability; practice

73. MEDIEVAL SYSTEM OF MANAGED AQUIFER RECHARGE IN SLOPING AQUIFERS OF SIERRA NEVADA (SPAIN)

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Abstract

The acequias de careo are ancient water channels excavated during the early Al-Andalus period (8th-10th centuries) and used for the purpose of recharging the sloping aquifers situated within the watersheds of the Sierra Nevada mountain range (southern Spain). The water channels are maintained by the local communities and serve the primary function of collecting snowmelt and rainwater runoff from the headwaters of the river basins, subsequently distributing it to the upper parts of the slopes. This method of artificial aquifer recharge serves to extend the availability of water resources in the lowlands of the river basins during the dry season, when there is almost no rainfall and water demand is higher. This study examines the contribution of the Careo channels in the Bérchules and the Mecina basins, where several channels were gauged. The discharge data were then compared with those obtained from a semi-distributed hydrological model applied to each of the hydrological basins. The Careo recharge constitutes 52% and 32% of the total aquifer recharge (i.e., natural plus Careo recharge) for the Bérchules and the Mecina basins, respectively. The findings illustrate the significance of this ancient and effective channel system for recharging hardrock slope aquifers. The acequias de Careo represent a natural solution to the increasing scarcity of water resources and have contributed to the prosperity of the Sierra Nevada. The long history of the Careo recharge system, exceeding 1,200 years, indicates remarkable resilience, enabling adaptation and persistence through centuries of significant climatic and socio-economic changes. It is plausible that a similar recharge system could be implemented in semi-arid mountainous regions worldwide, potentially contributing to the alleviation of the adverse effects of climate change.

94. EXAMPLES OF MANAGED AQUIFER RECHARGE PRACTICES ON THE CROATIAN COAST

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Abstract

The Croatian coast, a popular tourist destination, experiences a significant rise in population during the tourist season, leading to increased water demand in the summer months. High temperatures and prolonged dry spells highlight the need for adequate water supplies and adaptation to climate change and its associated extreme events. Managed aquifer recharge (MAR) is increasingly recognized as a sustainable method for adapting to climate change and managing water resources effectively in the Croatian coastal areas. The challenge of water scarcity during summer is not new. The Croatian coast relies on karst aquifers, meaning freshwater is stored underground, with limited surface water availability. The Mediterranean climate is characterized by hot, dry summers with low precipitation. To address these challenges, it is crucial to examine existing successful MAR practices before implementing new projects. This work presents two examples of effective MAR practices on the Croatian coast: the Ponikve accumulation on the island of Krk and the MAR of the Gradole spring. The latter involves using water from the Butoniga reservoir, recharged through the Ponor Čiže sinkhole. These cases demonstrate how MAR can help maintain water availability during periods of high demand and contribute to the sustainable management of water resources in karst environments. By examining these examples, we highlight the potential of MAR to mitigate water scarcity issues in the region, ensure a reliable water supply during peak usage periods, and enhance the resilience of coastal communities against climate-induced water stress.

Key words: karst aquifer, extreme events, artificial recharge, sustainability, Croatian coast.

27. ASSESSMENT OF POTENTIAL MANAGED AQUIFER RECHARGE SITES IN JOHANNESBURG, SOUTH AFRICA: A GIS AND REMOTE SENSING APPROACH

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Abstract

Increasing population and low rainfall in semi-arid Johannesburg, the economic hub of Africa, exert immense pressure on the water supply of the city. More recently, Johannesburg has faced water restrictions, primarily due to low rainfall. The main purpose of the current research is to conduct a hydrogeological feasibility study to assess the suitability of managed aquifer recharge as an alternative water storage solution, particularly during dry seasons, given the increasing water demands in the Johannesburg area. This study utilizes GIS and RS tools to overlay land use/cover, geology, streams, and recharge estimates. The preliminary GIS results, based on catchment analysis using Digital Elevation Models (DEM) and hydrology tools in ArcMap, reveal the nature of the slope, which aids in classifying low-lying areas with a high potential for managed aquifer recharge (MAR). Further investigation into the drainage characteristics of these areas will allow for a better understanding of their storage potential within the aquifer. Unlike many studies where MAR sites are typically situated in sandy aquifers in coastal regions, identifying potential recharge zones in Johannesburg proves challenging due to its large, urbanized area and complex heterogeneous crystalline geology. The anticipated outcome of the study is a potential MAR map which includes a ranking of the quality of the source water and the suitability of the geological material to act as storage sites. The findings of the study are intended to provide the Johannesburg City water managers with a possible alternative for ensuring water security and increasing resilience in the city.

https://ismar12.org.za/