8th International Symposium on Managed Aquifer Recharge (ISMAR8)

第八届国际含水层补给管理研讨会

Managed Aquifer Recharge: Meeting the Water Resource Challenge

人工含水层补给：迎接水资源挑战

BEIJING, P.R.CHINA | OCTOBER 15-19, 2013
中国 · 北京 | 2013年10月15日－19日

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Welcome

Welcome to the 8th International Symposium on Managed Aquifer Recharge. Thanks for all those who have helped to turn this initial proposal into reality.

Our world is facing the emerging challenge of climate change and water resource deficiency. Managed Aquifer recharge is an important way to expand water resource and improve water quality. Our team is committed to MAR research and is willing to cooperate with the peers worldwide. ISMAR8 provides a very important opportunity for such communication. Since the last symposium in 2010, new development of science knowledge in aquifer process, technology in water treatment, experiences in recharge projects have made great progress. Find out the all the new developments in Beijing!

Beijing is a charming city with long history, old tradition, new concept and modern constructions. Eastern and western culture is perfectly blended here. Beijing is expecting you. Delicious cuisine, harmonious atmosphere and beautiful scenery are waiting for you.

Wish ISMAR8 will bring fond memory to all of you. Beijing welcomes you!

ISMAR8 chair

Zhao Xuan

Xuan Zhao
Tsinghua University

Welcome

The IAH through its Commission on Managing Aquifer Recharge, the ASCE/EWRI through its Standards Committee for MAR and UNESCO through its IHP cordially invite all interested in managed aquifer recharge to attend ISMAR8 in Beijing.

The advances in scientific knowledge in aquifer processes, including clogging and water treatment, innovation in operational practices, and variety in design of projects and governance arrangements have grown enormously over the last three years, in addition to the global number and capacity of projects.

ISMAR8 is a special occasion to share this new knowledge in a country which is facing large water deficits and quality issues and is actively embarking on MAR as one of its strategies to meet its future demands for secure supplies of clean water. This will be a brilliant opportunity to learn about Chinese experience and from developing and developed countries alike, as groundwater replenishment very economically improves resilience in a changing climate with growing urban populations, and natural treatment systems are becoming recognised for mitigating greenhouse emissions.

Peter Dillon and Weiping Wang
(Co-chairs IAH Commission on MAR)

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(Chair ASCE/EWRI Standards Committee on MAR)

Alice Aureli
(Chief Groundwater Resources and Aquifer Systems Section, UNESCO IHP)

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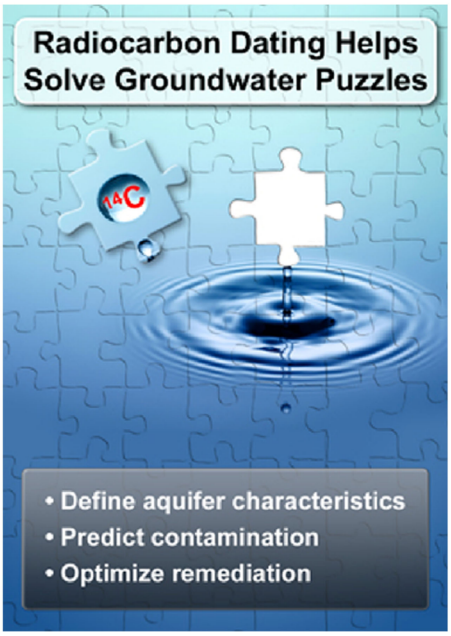

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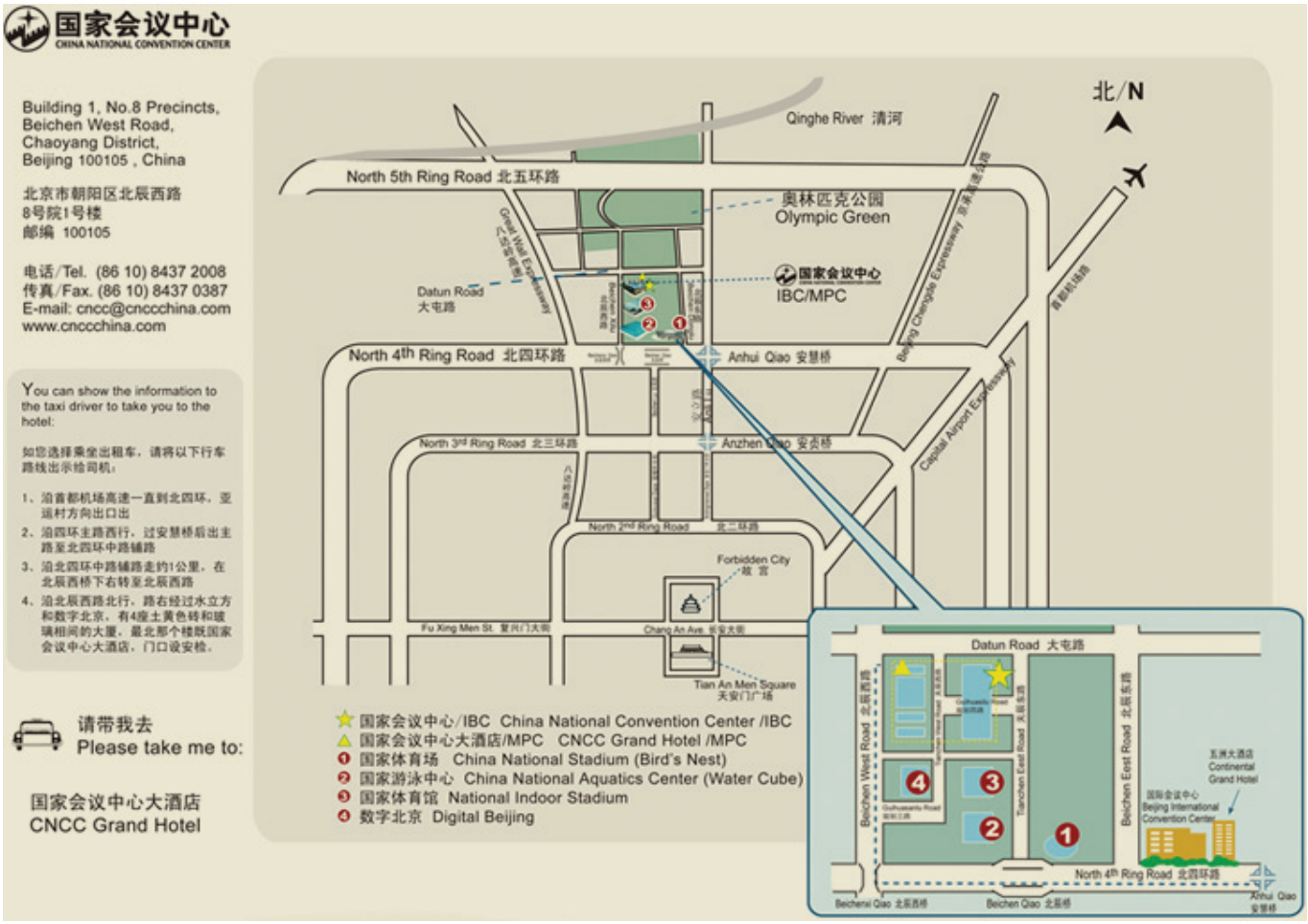
Conference venue

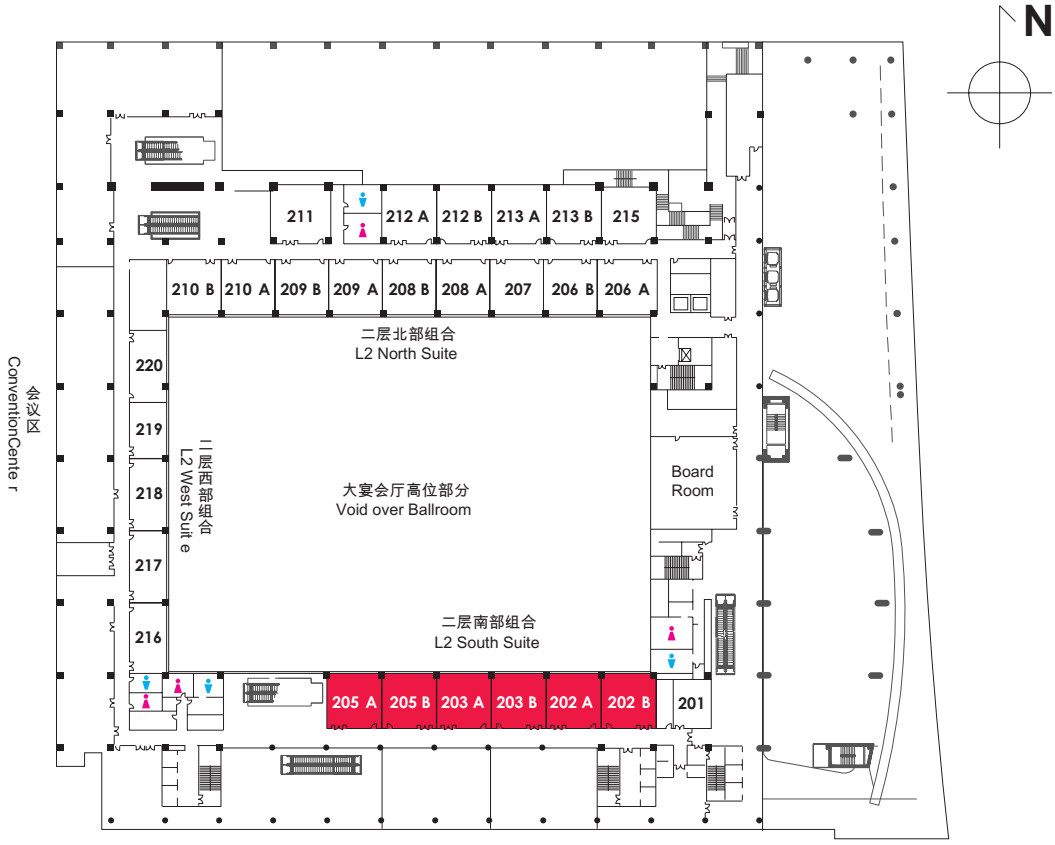
Ismar 8 will be held in China National Convention Center in Beijing, China. It specializes in staging national and international conferences, exhibitions, banquets, and other large events, with the world-class services and advanced AV facilities provided. It is located in the center of the Olympic commercial circle between Beijing's fourth and fifth ring roads. More than a hundred varied conference rooms could accommodate up to 20,000 people. The 6,400 sqm plenary hall is capable of caterring 6,000 delegates,

CNCC is conveniently located within a fascinating environment. There are dozens of hotels, restaurants, recreations and shopping centers around CNCC.



Floor Plan

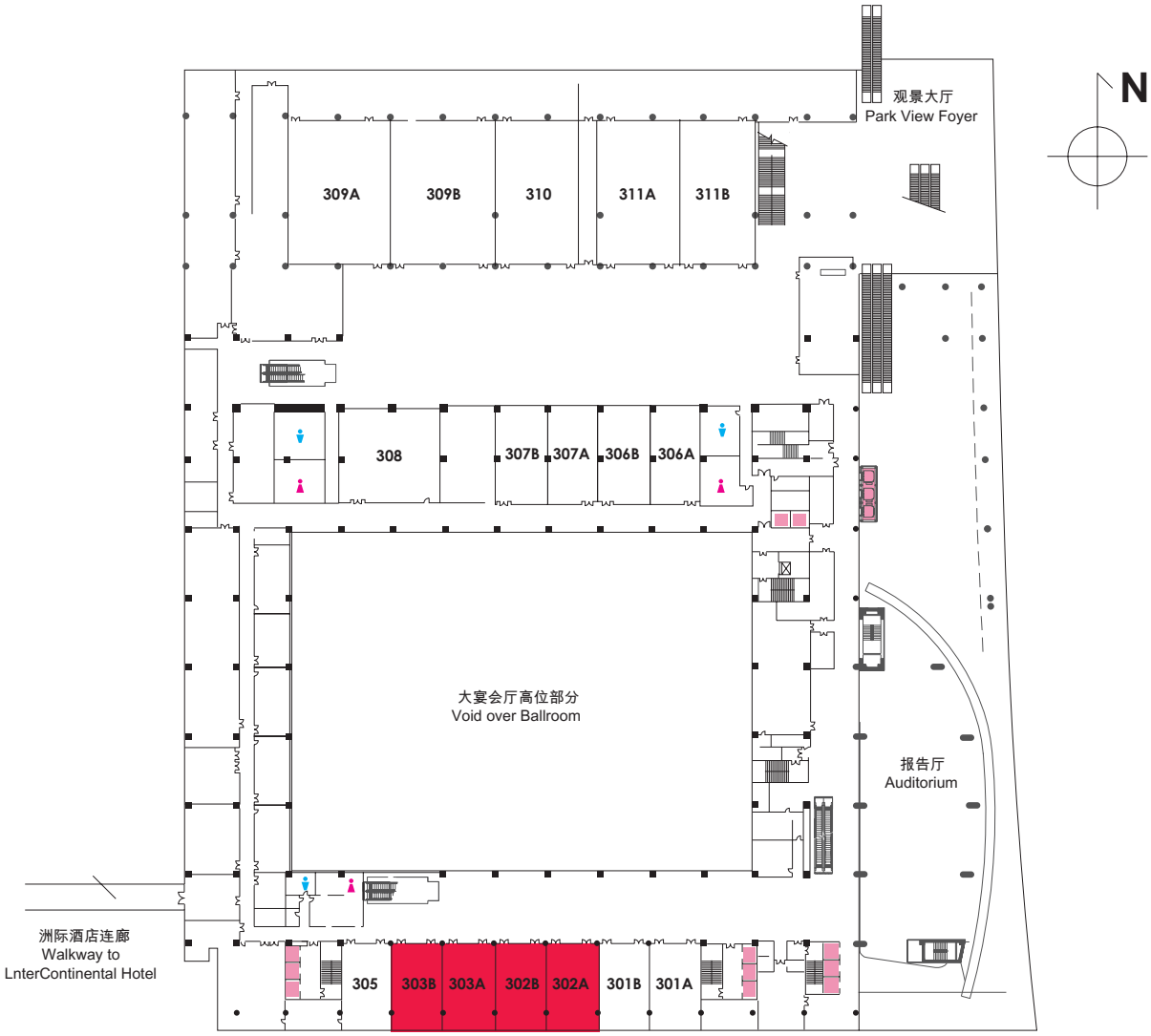
Tuesday, Oct.15 (Room 202A/202B/203A)



国家会议中心二层平面图
Floorplan of Level 2
China National Convention Center

Floor Plan

Tuesday, Oct.16 - Friday, Oct.18 (Room 302/303)



国家会议中心三层平面图
Floorplan of Level 3
China National Convention Center

General information

ISMAR SYMPOSIUM

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

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

ABOUT ISMAR8

This is the first time ISMAR will be held in Eastern Asia, making ISMAR8 unique and highly relevant to the developing world. It is a good opportunity to gain insights into the innovation of the Chinese water industry, water resources management and the varied MAR projects underway for those internationally and also nationally. It provides an excellent opportunity for communication on this topic in China whose diversified landscape and climate, varied culture, huge population and pressing water needs make managed aquifer recharge highly important.

Workshop 1

By Michael A. Milczarek.

State of the Art Techniques in Identifying and Characterizing Optimum Surface Spreading Groundwater Recharge Projects

Course Description

Successful site selection and design of surface spreading groundwater recharge operations are highly dependent on subsurface geologic conditions, source water quality, land availability and nearby land use. This course is designed to present, discuss and evaluate the best tools for site evaluation and subsurface characterization and the application of these tools for feasibility studies and recharge system design. A brief overview of modeling and monitoring tools will also be presented. A spectrum of case studies will be presented to illustrate the application of these tools and interpretation of data. Specific topics to be covered include:

- Defining recharge site goals and criteria for selecting an optimum recharge site
- Phased approaches to site characterization and site selection
- Near-surface field methods for hydraulic characterization
- Deep sub-surface field methods for hydraulic characterization and monitoring
- Modeling of recharge basin performance
- Integration of characterization, monitoring and modelling

Course Objectives

To provide participants with knowledge of the best tools and exposure to real-life conditions to ensure success in siting, haracterizing, designing and monitoring surface spreading groundwater recharge operations.

Who Should Attend

The course is designed for consulting and government scientists, engineers and managers who are or will be involved in groundwater recharge studies and operations. A background in the physical sciences or engineering is desirable.

Course Instructors

The course will be conducted by Michael A. Milczarek. Mr. Milczarek has 20 years experience in developing, implementing, and managing vadose zone, hydrogeologic and geochemical studies. He has actively managed or participated in over 25 groundwater recharge feasibility studies and conducted numerous vadose zone characterization and groundwater monitoring investigations. Groundwater recharge experience ranges from designing an innovative groundwater recharge/sediment removal riverbank filtration study, designing and implementing groundwater recharge feasibility studies for up to 100,000 acre feet per year of design capacity, designing and implementing investigations on stormwater capture and natural recharge processes in ephemeral stream channels.

Workshop 2

By David Pyne

Well Recharge: Science, Technology and Operational Experience, Aquifer Storage Recovery

Course Instructor s
David Pyne/USA* David is President of ASR Systems LLC, Gainesville, Florida, USA. He has pioneered the development of the science and technology for recharging aquifers through wells during the past 35 years and has directed or contributed substantially to the development of about half of the approximately 100 operating ASR wellfields in the United States. He is the author of the first book published on ASR, "Aquifer Storage Recovery: A Guide to Groundwater Recharge Through Wells (Second Edition, 2005)."

Description:
Topics covered will include review of the growing range of ASR applications and their prioritization to meet individual project needs; a recommended, phased approach to ASR project development; technical issues and solutions such as well clogging and redevelopment, pretreatment, post-treatment, interim recharge, cycle testing, target storage volume; design issues for ASR wells, wellheads and wellfields; water quality issues and solutions such as iron, manganese, arsenic, disinfection byproducts, hydrogen sulfide; economics of well recharge; regulatory issues and suggested solutions, and selected case studies.

Workshop 3

By Declan Page, Weiping Wang and Peter Dillon (CSIRO, Australia and Univ of Jinan, China)

MAR with Stormwater - water quality issues

Description:
Harvesting urban stormwater for storage in aquifers for reuse can have significant benefits for improving security of water supplies in semi-arid areas and managing a resource that is often wasted.

This is a half day workshop to cover the issues to be addressed to do this successfully for a range of uses such as public open space irrigation, non-potable 'third pipe' supplies to households and industry and for supply of drinking water. The workshop will draw on recent experiences and investigations in Adelaide, Jinan and New Delhi. The workshop will cover technical, economic, water safety and environmental matters. There will be an emphasis on water quality requirements including risk assessment and risk management plans. This will cover perspectives of Australia, China and India. Time for discussion will allow any other issues from elsewhere in the world to also be addressed.
The workshop program will include:

- Welcome – Weiping Wang and Peter Dillon
- Principles for management risks to human health and the environment in MAR Australia and India – Declan Page, Peter Dillon
- Aquifer considerations for changes in water quality – fate of pathogens, metal mobilisation – Saeed Torkzaban, Declan Page
- Practicalities of managing risk when urban stormwater is the source for recharge – Dennis Gonzalez
- Examples of stormwater harvesting investigations in Jinan and Adelaide and rainwater harvesting in India – Weiping Wang, Declan Page, Peter Dillon
- Discussion on water quality aspects – All attendees
- Water resources policy and planning issues and incentives – Peter Dillon
- Economic considerations and prospects for uptake elsewhere – Peter Dillon
- Questions and discussion – All attendees
- This workshop is run on behalf of the IAH Commission on Managing Aquifer Recharge, the Australian National Water Commission, the Goyder Institute of Water Research in South Australia, CSIRO Water for a Healthy Country Flagship and University of Jinan.

Workshop 4

By Jordan Clark

Application of Geochemical Techniques in MAR Studies

The objective of this course is to provide an overview of practical applications of environmental isotopes for evaluating and managing MAR operations. Topics include brief discussions of the fundamental principles of tracer geochemistry, sample collection and analysis methods, and case studies.

The main focus of the first section of the course will be practical applications of geochemical techniques for evaluating flow and transport near MAR facilities. This knowledge is needed to established hydraulic connections and travel times between the recharge location and production wells and to evaluate in situ biogeochemical reactions that change the quality of the recharged water within the subsurface. During the class, a number of different geochemical techniques including geochemical fingerprinting with stable isotopes of water and conservative ions, age dating with tritium and its daughter, tracer experiments with sulfur hexafluoride and isotopically enriched noble gases will be examined. The latter two techniques are used to determine groundwater ages. Knowledge of the spatial age distribution is critical for delineating flow paths and, in some case, can be used for numerical model verification.

The class will summarize detailed geochemical studies conducted at well characterized MAR operations including the Coastal Dunes of the Netherlands, the Orange County Water District, California, the Montebello Forebay, California, the Berlin Water Works, Germany, and the Bolivar ASR system, South Australia. Failures as well as successes of the geochemical studies will be discussed.

Course Instructor :

Dr. Jordan F. Clark is an professor in the Department of Earth Science at the University of California, Santa Barbara (www.geol.ucsb.edu/faculty/jfclark/). He is a geochemist by training and has been conducting hydrologic research using isotopic and tracer techniques for about three decades. During the last two decades, much of his research has focused on developing methods for evaluating flow and transport near MAR operations using geochemical approaches. Examples of this work were published in Ground Water (2004 issue #2) and Environmental Science & Technology (2005 issue #11).

Workshop 5

By China Geological Survey

Geothermal resource exploitation and recharge

Course theme

Methods of Investigation and Evaluation
Simulation Techniques for Development and Utilization
Reinjection Technology of Geothermal Waste Water
Technology of Development and Utilization of Shallow Geothermal Energy
Key Technology of Exploitation and Utilization of Hot Dry Rock.

Course Objectives

The course addresses the theme of technology development and utilization of geothermal resources, by discussing the key technologies for investigation, evaluation, simulation and recharge. , These technical methods are put forward will improve the level of development and utilization of the geothermal resources. They then require that a rational level of development and utilization of geothermal resources should be established.

Workshops

Course Description

Discussion is divided into three parts. The first part mainly focuses on hot dry rock resources, and the exploitation and recharge of hydrothermal type geothermal resources, including simulation and experimental methods of recharge. The second part addresses the latest progress of hydrothermal type geothermal resources, including their distribution and formation mechanisms. The third part mainly aims at shallow geothermal energy, the key technologies in the development and utilization will be discussed, and following specific examples, the status, potential and suitability will be analysed.

No	Title	Presented by
1	Hot dry rock resources in China	Wu Aimin
2	Geothermal reinjection tracer technique and reservoir simulation	Wang Guiling
3	The geothermal reinjection experiments in niutuozhen geothermal field of North China	Beijing Institute of Hydrogeology and Engineering Geology
4	Research on sustainable extraction-injection pattern of geothermal resources —— taking Xiongxian part of Niutuozhen geothermal field in North China Plain as an example	Beijing Institute of Hydrogeology and Engineering Geology
5	Geothermal resources Explotitation and recharge of Fuzhou city	Geological Survey of Fujian Province
6	Research on geothermal resources distribution and development of Shanxi province	Geological Survey of Jiangsu Province
7	Latest achievement of geothermal exploration in Haerbin urban district	Hydrogeology and Engineering Geology Prospecting Institute of Heilongjiang Province
8	Characteristics of sedimentation basin geothermal reservoir in east aera of Henan Province	Henan Institute of Geological Survey
9	Brief analysis on distributing characteristics of geothermal resources in Hubei Province	Hubei Province Geological Environment Terminus
10	Analysis on form,distribution and genetic model of geothermal resources in Sichuan Province	Sichuan Institute of Geological Survey
11	Distribution, Development and Utilization planning of high-temperature geothermal resource in western Sichuan	Sichuan Institute of Geological Engineering Investigation
12	Research on motion law and temperature of ground-source heat pump system recharge water in aquifer	Shenyang Center China Geological Survey
13	Key of aquifer's ground source heat pump engineering design in Jurassic,cretaceous red sand shale zone of weathering	Sichuan Institute of Geological Engineering Investigation
14	Research on suitable division assessment of ground-source heat pump system	Hainan Province Exploration Institute of Hydrogeology and Engineering Geology
15	Research on shallow geothermal resource in Changsha city	402 Geological Prospecting Party
16	Shallow geothermal resource and its utilization potential evaluation in Xining city	Qinghai institute of Hydrogeology, Engineering and Environmental Geology
17	Undetermined	Shaanxi Institute of Engineering Prospecting

Workshop 6

By Enrique Fernández Escalante; Christoph Sprenger & Adriana Palma

MAR to MAR-ket. Strategies to bring Managed Aquifer Recharge technique to the industry. Some examples for European countries developed by three EU founded projects.

Themes

This half day interactive workshop intends showing how some European, Israeli and Mexican Institutions are carrying out different techniques to involve industry in water management, most of them with an important D&TT (Dissemination and Technology Transfer) amount of activities and materials, taking notice of the importance of recharged aquifers for future industry advance in a broad range of branches.

Objectives

Different lines of action an examples will be provided, related to, at least, these industry sectors:
- Agro-industry
- Waste water treatment plants dealers
- Desalination agents
- Water bottled and refreshments companies
- Golf courses
- SPAs
- Specific governmental institutions

Each project will show their own strategy and lines of actions regarding MAR D&TT activities.

Description

The workshop is divided in four sessions. Each of them will be carried out by a representative of an European Union founded project, MAR-SOL and DEMEAU (FP7) and DINA-MAR (SUDOE). There is also an invited teacher to show the activities accomplished in another framework and another part of the world, providing an example for the South of United States and Mexico.

The workshop program includes:

SESSION 1:
1. Introduction. All attendees
2. Context. What is MAR to MAR-ket?. Enrique Fernández Escalante
3. MAR-SOLutions project. Strategies to bring MAR technique to industry. EFE / project coordinator/other project representative?.
4. DEMEAU project. How is MAR widespread in Europe & how can help industry and administrations to trust in MAR and in its benefits? Christoph Sprenger
5. Discussion – All attendees

Break- Networking

SESSION 2:
6. DINA-MAR project. Techniques applied to MAR on Dissemination and Technology Transfer, D&TT, & examples for activities & materials. Enrique Fernández Escalante
7. MAR to MARket out of EU. Example. Adriana Palma
8. Questions and discussion. Collective summary & photo. All attendees

Proposers:

- Dr. Enrique Fernández Escalante, with 23 years experience in hydrogeology, the last 14 dedicating most of his time to MAR projects and activities. Member of MAR-SOL project and coordinator of DINA-MAR. http://www.dina-mar.es/
- Dr. Christoph Sprenger, researcher in the Berlin Centre of Competence for Water (KWB), Watercycle Research Institute, leader ins. of Demeau project. http://demeau-fp7.eu/
- Dr. Adriana Palma. Teacher in the Autonomous National University of Mexico (UNAM), in charge of North Mexico projects. http://www.agua.unam.mx/jornadas2013/resultados.html

Keynote presentation
Wednesday October 16, 2013.

How to get more benefits from hydrogeochemical research in MAR systems, and how to make this more accessible for quasi everybody

Pieter J. Stuyfzand1,2
1KWR Watercycle Research Institute,PO Box 1072, 3430 BB Nieuwegein,Netherlands,
Email: pieter.stuyfzand@kwrwater.nl
2VU University, Amsterdam, Netherlands

Abstract
Hydrogeochemistry is mistaken by many people as kind of alchemy with a lot of fuzzy magic and witchcraft, producing fancy Stiff and Piper diagrams, uncontrollable model predictions and huge tables with hundreds of unpronounceable pollutants. In addition, there are,notwithstanding high costs of sampling campaigns, frequently doubts about the results obtained due to e.g. leaky risers, filtration bias, preservation problems and analytical errors.

Nevertheless, hydrogeochemistry is a key aspect of Managed Aquifer Recharge (MAR) systems for at least 3 reasons. Firstly, because it is essential part of any MAR feasibility study, in which the quality of source water and native groundwater needs to be tested, and the self-purification capacity of the target aquifer must be estimated. The second reason is, that the sustainability of MAR systemsdepends on both the leaching rate of reactive aquifer constituents and the accumulation rate of pollutants retained from the infiltration water. And thirdly, hydrogeochemistry helps the hydrologist to validate his flow model by depictingthe true spatial extension, age distribution and flow paths of infiltrated water.

In this contribution, it will be shown how to detect and reduce frequent errors in data acquisition, how maps produced by hydrochemical systems analysis reveal the most important patterns and processes, how to set-up and apply easy hydrochemical mass balances which identify and quantify processes while permitting the calculation of leaching rates, and how hydrochemistry can assist the hydrologist in understanding or visualizing groundwater flow.

Free downloadable Excel spreadsheet programs are demonstrated, which hopefully convince quasi-everybody of the benefits and accessibility of hydrogeochemistry in MAR (and other) studies.

About Pieter Stuyfzand
Pieter Stuyfzand has 35 years of professional experience in the fields of hydrogeochemistry and hydrogeology, with a focus on Managed Aquifer Recharge and systems analysis of coastal aquifers.

Pieter is full professor with a chair in (chemical) hydrogeology within the Amsterdam Critical Zone Hydrology Group, at the Faculty of Earth and Life Sciences of VU University Amsterdam. He is also employed at KWR Watercycle Research Institute (formerly part of Kiwa) in Nieuwegein (Netherlands), where he connects scientific work at VU University to applied research at KWR.

Keynote presentation
Wednesday October 16, 2013.

R&D activities of groundwater recharge by reclaimed water in Beijing

Dr. Jianlong Wang
Professor
Deputy Director
Institute of Nuclear and New Energy Technology (INET),
Tsinghua University ,Beijing 100084, P. R. China
Tel: +86 10 6278 4843
Fax: +86 10 6277 1150
Email: wangjl@tsinghua.edu.cn

Abstract:
Water shortage leads to increasing attention to managed aquifer recharge (MAR) by reclaimed water. The research and development of MAR in Beijing are introduced, with a novel MAR system (enhanced direct injection-well recharge, EnDir) suggested. The EnDir system can solve the problems of high cost in direct well injection and large land occupation in spreading basin. EnDir system was studied in both lab and demonstration. The characteristics and mechanisms of pollutant removal from reclaimed water were investigated.

About Jianlong Wang
Dr. Wang is a full professor and deputy director of Institute of Nuclear and New Energy Technology (INET), Tsinghua University. He worked at Leeds University (England) as a visiting professor from 1998 to 1999 and worked at Berlin Technical University (Germany) as a Humboldt Researcher from 2000 to 2002.
Prof. Wang's research focuses on water and wastewater treatment, environmental biotechnology and radioactive wastes management. He is particularly interested in the biological treatment of water and wastewater, the removal of toxic pollutants from aqueous solution.
Prof Wang received the following awards, including the National Science and Technology Advancement Award, the Natural Science Award of Ministry of Education, Beijing Municipal Science and Technology Advancement Award and the Natural Science Award of Chinese Academy of Sciences.
Prof Wang has published more than 300 papers in peer-reviewed academic journals.

Field trip

Saturday, Oct 19

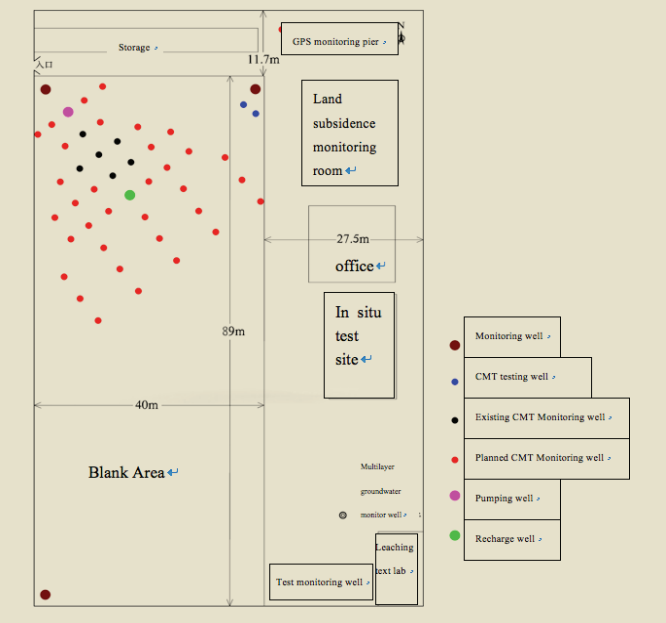
- AM Zhangjiawan Groundwater Science Observation Base
- PM Forbidden City

Zhangjiawan Groundwater Science Observation Base：

It is located in Zhangjiawan development zone in Tongzhou District in Beijing (Figure 1) with an area of 7800 m2. It was build in April 2008. It has land subsidence monitoring equipment, in situ leaching test site, leaching test lab, multilayer groundwater monitoring well, and three dimensional groundwater solute migration test site (Figure 2).

It includes:

1. Land subsidence monitoring equipment has 7 layer-wise mark, 5 groundwater observation holes and 2 pore water pressure observation holes, corner reflector, GPS mornitoring pier.
2. Multilayer groundwater monitor well is 311 m deep with 450 mm diameter. It uses Westbay layerwise mornitoring system produced by Schlumberger.
3. There are 12 mornitoring wells in three dimensional groundwater solute migration test site including 3 regular wells, 2 pumping-recharge wells, 1 test well and 6 CMT mornitoring wells.
4. Leaching test was operated in the middle of November. It could compare the concentration changes of NH4+、NO3-、NO2- in the soil after certain amount of water is irrigated and analyze the adsorption-resolution process in the migration process.



Forbidden City：

The Forbidden City was the Chinese imperial palace from the Ming Dynasty to the end of the Qing Dynasty. It is located in the middle of Beijing, China, and now houses the Palace Museum. For almost 500 years, it served as the home of emperors and their households, as well as the ceremonial and political center of Chinese government. Built in 1406 to 1420, the complex consists of 980 buildings and covers 720,000 m2 (7,800,000 sq ft). The palace complex exemplifies traditional Chinese palatial architecture, and has influenced cultural and architectural developments in East Asia and elsewhere. The Forbidden City was declared a World Heritage Site in 1987, and is listed by UNESCO as the largest collection of preserved ancient wooden structures in the world.

Schedule at a glance

Tuesday, Oct.15

08:00 - 16:00 **Registration**

10:20 - 10:40	12:30 - 13:30	15:20 - 15;40
Tea Break	lunch box provided	Tea Break

Room 202A, 202B, 203A

09:00 - 12:30 **Workshops**

08:30 - 12:30

State of the Art Techniques in Identifying and Characterizing Optimum Surface Spreading Groundwater Recharge Projects (Room 202A)
-By Michael A. Milczarek.

MAR with Stormwater – water quality issues (Room 202B)
-By Declan Page, Weiping Wang and Peter Dillon

Geothermal resource exploitation and recharge(Room 203A)
-By China Geological Survey

13:30 - 17:00 **Workshops**

Well Recharge: Science, Technology and Operational Experience, Aquifer Storage Recovery(Room 202A)
-By David Pyne

Application of Geochemical Techniques in MAR Studies(Room 202B)
-By Jordan Clark

MAR to MAR-ket. Strategies to bring Managed Aquifer Recharge technique to the industry. Some examples for Mediterranean countries(Room 203A)
-By Enrique Fernández Escalante christoph Sprenfer and Adriana Palma

Wednesday, Oct.16

08:00 - 16:00 **Registration**

10:20 - 10:40	12:00 - 13:30	14:50 - 15:10
Tea Break	lunch box provided	Tea Break

Auditorium, 3rd floor

08:30 - 12:00 **Opening ceremony**

Opening speech
Keynote presentation by Pieter J. Stuyfzand
Key note presentation by Jianlong Wang from INET,, Tsinghua University

Room 202, 203, 205

13:30 - 14:50 **Sessions**

1.Advanced methods for selection of aquifers, sites and methods(Room 202)

2.Mitigating geological problems using artificial recharge (Room 203)

3.Fate of pollutants of concern(Room 205)

15:10 - 16:30 **Sessions**

4. Advanced methods for selection of aquifers, sites and methods(Room 202)

5. Monitoring and modeling(Room 203)

6. Fate of pollutants of concern(Room 205)

Poster Area, 2nd floor

16:30 - 17:00 **Poster session I**

Function Room B, 1st floor

19:00 - **Banquet (Ticketing Event)**

Thursday, Oct.17

08:00 - 16:00 **Registration**

09:50 - 10:10	12:00 - 13:30	15:00 - 15;00
Tea Break	lunch box provided	Tea Break

Room 302, 303

08:30 - 09:50 **Sessions**

7.Management of clogging(Room 302)

8.Mitigating geological problems using artificial recharge(Room 303)

10:10 - 11:50 **Sessions**

9. Management of clogging(Room 302)

10. Integrated water resources management (Room 303)

Room 302

13:30 - 15:00 **Plenary session**

Plenary session of IAH Commission on Managing Aquifer Recharge organised ***by Peter Dillon and Weiping Wang***

Room 302, 303

15:20 - 17:00 **Sessions**

11. Geochemistry and hydrogeology in MAR; (Room 302)

12. Rainwater and stormwater harvesting via MAR ; MAR in conjunctive use of surface water and groundwater(Room 303)

Poster Area, 3rd floor

17:00 - 17:30 **Poster session II**

Friday, Oct.18

08:00 - 16:00 **Registration**

09:50 - 10:10	12:00 - 13:30	14:30 - 14:50
Tea Break	lunch box provided	Tea Break

Room 302, 303

08:30 - 09:50 **Sessions**

13. Cost effectiveness of MAR (Room 302)

14. Risk assessment and water safety plans (Room 303)

10:10 - 11:50 **Sessions**

15.MAR for drinking water quality improve-ment(Room 302)

16. Adaptation to climate change; Risk assessment and water safety plans (Room 303)

13:30 - 14:30 **Sessions**

17. Geochemistry and hydrogeology in MAR; Groundwater hydraulics and storage recovery(Room 302)

18. Recharge policies, standards and regulations; Community engagement and awareness; Waterbanks and groundwater user groups(Room 303)

14:50 - 16:20 **Sessions**

19. Other issues (heat pumps, geothermal injection, Rural water supplies etc. (Room 302)

20.Reclaimed water reuse via aquifer MAR in karst aquifers(303)

Saturday, Oct.19

Field trip

07:30	Pick up at Comfort Suites by Choice Hotels
07:45	Pick up at China National Convention Center Grand Hotel
08:00	Pick up at North Star Continental Grand Hotel
08:00 - 09:30	To Zhangjiawan Groundwater Science Observation Base
09:30 - 10:30	Visiting Zhangjiawan Groundwater Science Observation Base
10:30 - 11:30	To Forbidden city
11:30 - 12:00	Lunch box provided
12:00 - 16:30	Visit Forbidden city
16:30 - 17:00	Back to hotel

Detailed Program

Tues, Oct.15 (workshops)

Time	Room: 202 A	Room: 202 B	Room: 203 A
09:00 - 12:30	**08:90 - 12:30** State of the Art Techniques in Identifying and Characterizing Optimum Surface Spreading Groundwater Recharge Project Instructor: ***Michael A. Milczarek***	MAR with Stormwater – water quality issues Instructor: ***Declan Page, Weiping Wang and Peter Dillon***	Geothermal resource exploitation and recharge Instructor: ***China Geological Survey***
13:30 - 17:00	Well Recharge: Science, Technology and Operational Experience, Aquifer Storage Recovery Instructor: ***David Pyne***	Application of Geochemical Techniques in MAR Studies Instructor: ***Jordan Clark***	MAR to MAR-ket. Strategies to bring Managed Aquifer Recharge technique to the industry. Some examples for Mediterranean countries Instructors: ***Enrique Fernández Escalante, Christoph Sprenger and Adriana Palma***

Wed, Oct.16 (Opening and 3 parallel Sessions)

Opening Ceremony	
Time	Venue: Auditorium (3rd Floor)
08:30 - 09:20	Opening speech
09:20 - 10:20	Keynote presentation by Pieter J. Stuyfzand "How to get more benefits from hydrogeochemical research in MAR systems, and how to make this more accessible for quasi everybody"
10:20 - 10:40	Tea break & Network
10:40 - 11:20	Keynote presentation by Jianlong Wang, Tsinghua University
11:20 - 12:00	Discussion
12:00 - 13:30	Lunch box provided

Detailed Program

Three Parallel Sessions			
Time	Room 202 Advanced methods for selection of aquifers, sites and methods Moderator : ***Jim Lamoreaux***	Room 203 Mitigating geological problems using artificial recharge Moderator : ***Zhuping Sheng***	Room 205 Fate of pathogens in the aquife Moderator : ***Timothy Kevin Parker***
13:30-13:50	Towards successful aquifer storage and recovery (ASR) in coastal aquifers: use of ASR feasibility mapping and multiple partially penetrating wells ***Zuurbier***, Zaadnoordijk, Bakker, Paalman, Stuyfzand	Combining drinking water production with the world's most innovative coastal defence project.to keep dry feet - Insights on effects, interception measures and dynamic monitoring plan ***M. Hoogmoed MSc***, Drs. J.T. Buma, R. Caljé MSc., Drs. F. Schaars	Fate and Transport of Viruses in Porous Media: the Coupled Effect of System Hydrodynamic and Microscale Surface Heterogeneities ***Saeed Torkzaban***, Salini Sasidharan, Declan Page, Peter Dillon
13:50-14:10	An Advanced Multi-Disciplinary Approach for the Rapid Identification and Assessment of Managed Aquifer Recharge Options: a Case Study from the Darling Floodplain, N.S.W., Australia Ken Lawrie, Ross S. Brodie, ***Peter Dillon***, Richard McLoughlin, Kokpiang Tan, David Gibson, Jon Clarke, John Magee, Niels B. Christensen, Larysa Halas, Peter Somerville, Laura Gow, Heike Apps, Jo Vanderzalm, Declan Page, Ross C. Brodie, Stephen Hostetler, Jared Abraham, & Konrad Miotlinski	Hydrochemistry and stable isotopes during salinity ingress and refreshment in surface- and groundwater from the Arani–Koratallai (A-K) basin north of Chennai (India) ***Sprenger, C.***, Parimala Renganayaki, S., Elango, L., Schneider, M.	Fate of disinfection-by-products released into an anaerobic aquifer during managed aquifer recharge ***B. M. Patterson***, M.M. Pitoi, A. J. Furness, T.P. Bastow, A. J. McKinley
14:10-14:30	An Integrated Approach to Developing Hydrogeological Conceptual Models to Underpin Assessment of Managed Aquifer Recharge Options, Darling Floodplain, N.S.W., Australia Ross S. Brodie, Ken Lawrie, ***Peter Dillon***, Kokpiang Tan, David Gibson, Jon Clarke, John Magee, Niels B. Christensen, Larysa Halas, Peter Somerville, Laura Gow, Heike Apps, Jo Vanderzalm, Declan Page, Ross C. Brodie, Stephen Hostetler, Jared Abraham& Konrad Miotlinski	Aquifer Storage Recovery: An ASR Solution to Salt Water Intrusion at Hilton Head Island, South Carolina ***R. David, G. Pyne***	Natural Attenuation of Chlorobenzene at Different Temperatures during Groundwater Artificial Recharge ***Haiyang He***
14:30-14:50	In situ infiltration test using a reclaimed abandoned river bed: managed aquifer recharge in Shijiazhuang City, China ***Xiaosi Su***, Wei Xu, Shanghai Du	ASCE/EWRI Standard Guidelines for Land Subsidence Caused by Fluid Withdrawal ***Zhuping Sheng***, Devin Galloway, Keith Prince, Conrad G. Keyes, Jr. Jiang Li, Ben Willardson	Rapid Determination of Seven Selected Endocrine Disrupting Chemicals in Wastewater by Solid-phase Extraction and Ultra-performance Liquid Chromatography Tandem Mass Spectrometry ***Jianzhong Li***, Zhenyi Zhang, Lu Jiang, Xiang Liu

Detailed Program

14:50 - 15:10	Tea break& Network		
	Room 202 Advanced methods for selection of aquifers, sites and methods Moderator : ***Weixin Guo***	Room 203 Monitoring and modeling Moderator : ***Jordan Clark***	Room 205 Fate of pollutants of concern Moderator : ***David Pyne***
15:10 - 15:30	Advanced Aquifer Characterization for Optimization of Managed Aquifer Recharge ***Robert G. Maliva***, Rolf Hermann, Kapo Coulibaly, Weixing Guo	Effects of Reclaimed Water Use for Scenic Water on Groundwater Environment in a Multi-Layered Aquifer System beneath the Chaobai River, Beijing, China ***Fandong Zheng***, Licai Liu, Binghua Li, Yong Yang, Minli Guo	Combination of MIEX? Resin and ozonation for reduction of dissolved organic matter during aquifer recharge using municipal effluent ***Xue Zhang***, Xuan Zhao, Yutuan Gao, Meng Zhang
15:30 - 15:50	Modeling Studies of Aquifer Heterogeneity on ASR Recovery Efficiency ***Weixin Guo***, Kapo Coulibaly, Robert G. Maliva	Questioning the impact and sustainability of percolation tanks as aquifer recharge structures in semi-arid crystalline context ***Boisson A.***, Perrin J., Viossanges M., Kloppmann W., Chandra, S., Dewandel, B., Picot-Colbeaux, G., Rangarajan, R., Rana, N., Maréchal, JC., Ahmed, S.	Transport and fate of ammonium at a riverbank filtration site in Delhi, India ***Maike Groeschke***, Andreas Winkler, Gesche Gruetzmacher, Michael Schneider
15:50 - 16:10	The Freshmaker: enabling aquifer storage and recovery (ASR) of freshwater using horizontal directional drilled wells(HDDWs) in coastal areas ***Koen Gerardus Zuurbier***, Pieter J. Stuyfzand, Jan Willem Kooiman	10B-enriched boric acid, bromide, and heat as tracers of recycled groundwater flow near managed aquifer recharge operations ***Jordan Clark***	Influences of long-resistant pharma-ceutical compound in anaerobic digestion process ***YongSeok Cha***
16:10 - 16:30	Prediction of hydrogeological and environmental improvement by managed aquifer recharge in Xinjiang ***Ding Chen***, Zhenyi Zhang, Chenxi Zhao, Xiaoyu Wang, Jiaerheng Ahati, Xuan Zhao		Effects of nitrogen and Redox conditions on the removal of organic micropollutants during managed aquifer recharge ***A. F. Hamadeh***, S. K. Sharma, M.G. Taye, S. Bagchi and G. Amy
16:30 - 17:00	Poster session I (poster area of 2nd floor), see the list at the end		
19:00 -	Welcome Dinner (Function Room B, 1st floor) Ticketing event		

Thurs, Oct.17 (2 Parallel sessions)

Time	Room 302 Management of clogging Moderator : ***Yan Zheng***	Room 303 Mitigating geological problems using artificial recharge Moderator : ***Thomas M. Missimer***
08:30 - 08:50	Identification and management of clogging in a fractured rock aquifer during ASR operations ***Russell Martin***	Innovative design and indigenous technology for construction of recharge shafts in coastal aquifers of Bangladesh ***K M Ahmed***, S M M Alam, S Sultana, M M Hasan, S K Ghosh, M S Rahman, A Tuinhof
08:50 - 09:10	Characterization of Clogging of Moderate Clay Content Sandstone during Water Injection: Effects of Chemical and Hydrodynamic ***Saeed Torkzaban***, Svantje Treumann, Peter Dillon, and Joanne Vanderzalm	Freshwater storage in land reclamations; an integrated approach in an early desig phase ***M. van Ginkel***, Th.N. Olsthoorn
09:10 - 09:30	Management of Clogging in Small-scale Aquifer Storage and Recovery Sites in the Coastal Plain of Southwest Bangladesh ***S Sultana***, K M Ahmed, Mahtab Alam, Mahadi Hasan, A Tuinhof, J Oosterwijk, S K Ghosh, M S Rahman, P Ravenscroft, Y zheng	Enhancement of wadi dam recharge using dams coupled with aquifer storage and recovery ***Thomas M. Missimer***, Robert G. Maliva, Weixing Guo, Khan Z. Jadoon
09:30 - 09:50	The discrimination method of suspended solids clogging type in managed aquifer recharge (MAR) ***Yunqing Fang***, Xinqiang Du, Jiawei Hou	Assessing the impact of a check dam across a non-perennial river in southern India Parimala Renganayaki, S. and ***Elango. L***
09:50 - 10:10	Tea break &Network	
10:10 - 10:25	Practical criteria in the design and maintenance of Managed Aquifer Recharge wells and bores in order to minimize clogging impacts, obtained from three different operative sites in Spain ***Enrique Fernández Escalante***	A New Zealand approach to MAR for managing catchment-scale groundwater issues using induced infiltration through ephemeral river channels ***Bob Bower***, Brett Sinclair, Howard Williams
10:25 - 10:40	Riverbed clogging experiments at potential river bank filtration sites along the Ping River, Chiang Mai, Thailand ***Kewaree Pholkern***	Reducing the environmental impact of a shallow MAR site ***Sander de Haas***, Harry Rolf, Jos Peters
10:40 - 10:55	Maximizing Infiltration Rates by Removing Suspended Solids: Results of Demonstration Testing of Cloth Filtration ***Adam S. Hutchinson***, Greg Woodside	Near-stream Recharge to Protect Baseflows in the Upper San Pedro River, Arizona, USA ***Laurel J. Lacher***
10:55 - 11:10	Case study: recharge of potable and tertiary-treated wastewater into a deep, confined sandstone aquifer in Perth, Western Australia ***Karen Johnston***, Michael Martin	Managed Aquifer Recharge in California: Summary of Projects and Policy Issues ***Tim Parker***
11:10 - 11:25		Managed aquifer recharge: a potential component of water management in the syrdarya river basin ***A.Kh.Karimov***, V.Smakhtin, A. Mavlonov, V. Borisov, I.Gracheva, F. Miryusupov, A. Akhmedov; K.Anzelm, S. Yakubov , A.A.Karimov

11:25 - 11:50	Questions &Answers for the session	
12:00 - 13:30	Lunch box provided	
13:30 - 15:00	Plenary session of IAH Commission on Managing Aquifer Recharge organised by Peter Dillon and Weiping Wang (Room 302) Information sharing, announcing the release of the monograph on clogging, discussion about future directions for the Commission's activities and announcing ISMAR9	
15:00 - 15:20	Tea break & Network	
	Room 302 Geochemistry and hydrogeology in MAR Moderator : ***Pieter J. Stuyfzand***	Room 303 Rainwater and stormwater harvesting via MAR; MAR in conjunctive use of surface water and groundwater Moderator : ***Michael Milczarek***
15:20 -15:40	Quantifying nutrient removal during Aquifer Storage and Recovery (ASR) ***Joanne Vanderzalm***, Declan Page, Karen Barry, Peter Dillon	Towards Roof Runoff Replenishment of Groundwater in Jinan, China ***Weiping Wang***
15:40 - 15:55	Inorganic Solutes' Fate and Transportation During Groundwater Artificial Recharge ***Wenjing Zhang***	Development of a Flood Detention/Stormwater Capture/Aquifer Recharge Facility in a Semi-arid Environment ***Michael Milczarek***, Robert Rice, John Wallace, Cyrus Miller, Karen Riggs, Dave Goodrich, Lainie Levick
15:55 - 16:10	Trace element patterns and behavior in a long transect, from recharge towards recovery canal in Dutch coastal dunes, depicting 50 years of Rhine River infiltration ***Pieter J. Stuyfzand***	Origin, recharge mechanism and apparent age of shallow groundwater in the Ndop plain, North West Cameroon ***Mengnjo Jude Wirmvem***, Takeshi Ohba, Wilson Yetoh Fantong, Samuel Ndonwi Ayonghe, Justice Yuven Suila, Asobo Nkengmati
16:10 - 16:25	Aquifer Conditioning to Minimize Iron and Manganese in Recovered Water from ASR Projects ***R. David G. Pyne***, Richard K. Glanzman, Eric Odom	Integrated surface water and groundwater modeling for optimizing MAR structures in the Chennai region Bhola ,P. K., Zabel,A. K., Rajaveni, S. P., Nair, S., ***B. Monninkhoff***., Elango,L.
16:25 - 16:40		Beyond Sustainability: Using Managed Aquifer Recharge to Double the Yield of the Orange County Groundwater Basin Adam S. Hutchinson, ***Greg Woodside***
16:40 - 17:00	Questions & Answers for the session	
17:00 - 17:30	Poster session II (poster area of 3rd floor), see the list at the end	

Fri, Oct.18 (2 Parallel sessions)

Time	Room 302 Cost effectiveness of MAR Moderator : ***Sander De Haas***	Room 303 Risk assessment and water safety plans Moderator : ***David. Page***
08:30 - 08:50	Economic, social and environmental benefits of MAR in village scale interventions in rural India -Some insights from Gujarat and Rajasthan B. Maheshwari, ***P. Dillon***, S.R. Bhakar, P. Bhatnagar, S. Dave, Hakimuddin, H. Grewal, Y. Jadeja, , A.S. Jodha, R. Kookana, S. Oza, R.	Microbiological risks of recycling urban stormwater via aquifers for drinking in Adelaide, Australia ***D. Page***, D. Gonzalez, S. Torkzaban, K. Miotlinski, K. Barry, and P. Dillon
08:50 - 09:10	Waterbanking: benefits, barriers and ways forward ***Andrew Ross***, Muhammad Arshad	Setting water quality trigger levels for the operation and management of MAR systems ***Dennis Gonzalez***, Declan Page, Peter Dillon
09:10 - 09:30	Cost-Benefit assessment of community-led aquifer recharge: The case of Meghal river basin, Saurashtra, India ***Shilp Verma***, Sunderrajan Krishnan	The development, application and acceptance of environmental and health risk assessment methodology for MAR schemes in South Australia ***Peter Q. Newland***
09:30 - 09:50	Economic assessment of incorporating Managed Aquifer Recharge technique in water management. Results of a study carried out by means of an advanced Geographic Information System (GIS) for Spai ***Enrique Fernández Escalante***, Rodrigo Calero Gil, Mª Ángeles San Miguel Fraile, Fernando Sánchez Serrano	MAR with untreated river water: Clogging of basins and coliform removal rates ***Rico Bartak***, Thomas Grischek and Detlef Hoche
09:50 - 10:10	Tea break &Network	
	Room 302 MAR for drinking water quality improvement Moderator : ***Thomas Grischek***	Room 303 Risk assessment and water safety plans; Others: Adaptation to climate change Moderator : ***David. Page***
10:10 - 10:25	The study of how TOC changing and simulation forecasting under artificial recharge condition ***Haiyang He***	Geneva's artificial recharge system and the crisis management of the transboundary region's drinking water supply ***Gabriel de los Cobos***
10:25 - 10:40	Sprinkling infiltration and well infiltration in managed aquifer recharge for drinking water quality improvement ***Petri Jokela***, Esa Kallio	Risk assessment frameworks for MAR schemes in the UK ***Mital Nandha***, Paul Jeffrey, Mark Berry and Bruce Jefferson
10:40 - 10:55	Coupling Riverbank Filtration and Subsurface Iron Removal ***Thomas Grischek***, Johannes Ahrns, Matthias Kuehne1, Jobst Herlitzius	The crucial role of managed aquifer rechrage as an adaptation strategy for ground water sustaunability in the face of climate change in india ***R.C. Jain***

10:55 - 11:10	Lessons learned from large scale field testing of Managed Aquifer Recharge to improve water quality in coastal aquifers of Bangladesh ***K M Ahmed***, S Sultana, Mahtab Alam, Mahadi Hasan, A Tuinhof, J Oosterwijk, S Ghosh, M S Rahman, Y zheng, P Ravenscroft	The economics of groundwater replenishment for reliable urban water supply ***Lei Gao***, Jeffery D. Connor, and Peter Dillon
11:10 - 11:25		Water banks: Using managed aquifer recharge to meet water policy objectives Sharon B. Megdal, ***Peter Dillon***, and Kenneth Seasholes
11:25 - 11:50	Questions &Answers for the session	
12:00 - 13:30	Lunch box provided	
	Room 302 Geochemistry and hydrogeology in MAR; Groundwater hydraulics and storage recovery Moderator : ***Thomas Grischek***	Room 303 Recharge policies, standards and regulations; Community engagement and awareness; Waterbanks and groundwater user groups Moderator : ***Doug Bartlett***
13:30 - 13:50	Dissolved silica as an indicator of ASR efficiency in a chemically heterogeneous aquifer with similar source water and groundwater ***Marcia Schulmeister***, Sumrit Chusanathas, Aranya Fuangswasdi, Wasan Chansang, Theerasak Tangsutthinon, Kevin Bral, Noppadol Kornsilpa, Rungruang Lertsirivorakul	Balloting Process of Guidelines by Managed Aquifer Recharge Standards Committee of ASCE/EWRI Gordon McCurry, Peter Barkman, ***Doug Bartlett***, Zhuping Sheng and Dennis McGrane
13:50 - 14:10	Trapped gas bubbles around infiltration wells – Indications for potential impact on well performance ***Johannes Ahrns***, Ronny Groger, Jakob Ebermann, Thomas Grischek	MAR to MAR-ket. Dissemination and technology transfer criteria applied to Managed Aquifer Recharge. A strategic proposition and examples to transfer these techniques to industry ***Enrique Fernández Escalante***, Manuel López Hernández, Rosa Cordero Sánchez
14:10 - 14:30	Hydraulic characterization and recharge potential of weathered basement aquifer system of ibarapa area, southwestern nigeria ***Moshood N. Tijani***, Olarewaju A. Akanbi	Managed aquifer recharge: a potential component of water management in the Syrdarya River basin ***A.Kh.Karimov***, V.Smakhtin, A. Mavlonov, V. Borisov, I.Gracheva, F. Miryusupov, A. Akhmedov; K.Anzelm, S. Yakubov , A.A.Karimov
14:30 - 14:50	Tea break &Network	
	Room 302 Others (heat pumps, geothermal injection, Rural water supplies etc. Moderator : ***Elango lakshmanan***	Room 303 Reclaimed water reuse via aquifer; MAR in karst aquifers Moderator : ***Xuan Zhao***
14:50 - 15:10	Demonstration Program to Mitigate Drought and Flooding in the Northern Part of the Chao Phraya River Basin, Thailand, using ASR Methods – Part 2 ***Kevin Bral***, Sumrit Chusanathas, Aranya Fuangswasdi, Wasan Chansang, Theerasak Tangsutthinon,	A synergistic treatment hybrid of managed aquifer recharge-ozone for wastewater reclamation and water reuse ***Min K. Yoon***, Jerg E. Drewes, and Gary L. Amy

15:10 - 15:30	Noppadol Kornsilpa, Marcia Schulmeister Feasibility of aquifer storage and recovery of storm-water in a dunefield in western Saudi Arabia Oliver Lopez, ***Thomas M. Missimer***	Managed Aquifer Recharge with Reclaimed Water in UAE ***Mohamed Mostafa Mohamed***
15:30 - 15:50	Managed Aquifer Recharge as a key element in Sonora River Basin Management ***A. Palma,*** F. González, and C. Cruickshank	Study on Major Stress Factors and Vulnerability Assessment of Karst Aquifer ***Liankai Zhang***
15:50 - 16:20	Special issue of the Journal of the Spanish Geologica Survey, calle "Boiletin Geologico y Minero", dedic-taed to MAR by JOSE ANTONIO DE LA ORDEN	**Special session** Low tech application of MAR in rural water supply in developing countries By Rolf Harry

Sat, Oct.19 (Field trip)

Field trip	
07:30	Pick up at Comfort Suites by Choice Hotels
07:45	Pick up at China National Convention Center Grand Hotel
08:00	Pick up at North Star Continental Grand Hotel
08:00 - 09:30	From North Star Continental Grand Hotel to Zhangjiawan Groundwater Science Observation Base
09:30 - 10:30	Visiting Zhangjiawan Groundwater Science Observation Base
10:30 - 11:30	Zhangjiawan Groundwater Science Observation Base to Forbidden city
11:30 - 12:00	Lunch box provided
12:00 - 16:30	Visit Forbidden city
16:30 - 17:00	Forbidden city back to North Star Continental Grand Hotel, China National Convention Center Grand Hotel, Comfort Suites by Choice Hotels

LIST

Poster session I

Oct.16 (16:30-17:00) Poster Area, 2nd floor	
Title	**Author**
Artificial recharge in Crestatx aquifer (Majorca island, Spain) using springwater surpluses. Previous studies and design of the artificial recharge plant	De la Orden, J.A.
Integrated and preventive water management and forest ordenation techniques to mitigate climate change adverse effects	Enrique Fernández Escalante, Ignacio Prieto Leache, Jon San Sebastián Sauto
Managing the Water Buffer with 3R	Friedemann Scheibler
A methodological concept for the identification and subsequent development of potential bank filtration sites in India	C. Sandhu, T. Grischek, P. C. Kimothi, L. K. Adlakha, P. S. Patwal, D. Page and R. Bartak
Groundwater natural resources and quality concern in Kabul Basin Afghanista n	M.Hassan Saffi
Towards implementation of Managed Aquifer Recharge in Semi-arid areas of Nigeria: Possible contributions from large irrigation schemes	Sobowale A., Ramalan A.A., Mudiare O.J., Oyebode M.A.
Temporal-spatial variation of ecotoxicity and distribution of heavy metal in the hyporheic zone of Shima catchment, Dongguan, China	Lei Gao, Jianyao Chen, Zhiting Ke, Jiang Wang, Xueyun Yang, Yuta Shimizu
Applications of Managed Aquifer Recharge to Improve Groundwater Quality in the Khulna-Satkhira Coastal Belt of Bangladesh: Results and Findings	M M Hasan, K M Ahmed, S Sultana, M S Rahman, S K Ghosh, A Tuinhof, P Ravenscroft
Protection of Water Quality of Gaza Coastal Aquifer	Luay Froukh
Effect of silver nanoparticles on the performance of managed aquifer recharge: column study	S.K. Maeng, S.K. Sharma, J. Jeong, S. Chae, H.I. Park, K.H. Moon, J.C. Jeon
Improved Spring Water Yield via Artificial Recharge of Rainwater (Tanzania case study)	Harry Rolf, Sander de Haas and Hande Mwanjela
Experimental study of high sediment-surface water seepage to groundwater in the Nalingguole river	Jiawei Hou, Xinqiang Du, Yunqing Fang
Simulation of physical clogging at RBF sites using a laboratory channel experiment	M. Soares, T. Grischek, G. Gunkel
Development of Managed Aquifer Recharge in China	Yaqun Zhou, Weiping Wang, Qiang Huang, Qiaoyi Xu
Study on the Influence of Groundwater Source Heat Pumps on Groundwater Quality	Haiyan Deng, Weiping Wang, Yunfeng Pang, Bin Meng
Research on Index Scale Method for Suitability Division of Shallow Geothermal in Yinchuan City	Yangchao, Qianhui, Liuzheng, Hu zhiyong, LiuJun, Feng huanzhe
Removal of dissolved organic matter in municipal effluent with ozonation and soil aquifer treatment	Xue Zhang, Xuan Zhao, Meng Zhang
Managed aquifer recharge to mitigate fluoride contamination in groundwater in a part of southern India	L. Kalpana and Dr. L. ElangoPlease

Poster session Ⅱ

Oct.17 (17:00-17:30), Poster Area, 3rd floor	
Title	**Author**
Tailor-made high-frequency filter sand cleaner for high-capacity MARsbasin	T. Grischek, U. Feistel, W. Grunwald, T. Glettnik
Numerical assessment of community-scale managed aquifer recharge systems in south-western Bangladesh	Jessica Barker, Md. Mahadi Hasan, Clare Robinson1, Sarmin Sultan, Kazi Matin Ahmed
Combining geophysical and geochemical measurements for subsurface characterization at a full-scale aquifer recharge and recovery site	Andrew Parsekian, Julia Regnery, Alex Wing, Rosemary Knight, Jorg E. Drewes
MAR for Sustainable Water-Curtain Cultivation Method in Rural Area	Yongcheol Kim, Byungdae Lee
Management of groundwater quality at Spratly islands in context of climate change	Phan Thi Kim Van
Groundwater quality at southeast coastal zone in Vietnam	Phan Thi Kim Van
Using electrical conductivity measurements to monitor infiltration, recharge rates and clogging during managed aquifer recharge	Chloe Mawer, Rosemary Knight, Adam Pidlisecky, Peter K. Kitanidis
Development of numerical model evaluating withdrawal efficiency due to microbial clogging in riverbank filtration system	Heejun Suk, Sang-Eun Oh, Ha Kyoochul, and Kim Yongcheol
In-situ Test and Optimization of Saline Groundwater Restoration at the Lower Reach of Dagu River in Qingdao, China	Xilai Zheng, Yuhong Liu, Yang Wei, Lu Xia
Survival of Escherichia coli in Alluvial Aquifer Recharged with River water	Jeong-Ho Sohn and Yeonghee Ahn
A Case-Based Reasoning Application for MAR case-studies	N.Kukuric
MAR in Flanders (Belgium): Overview and Opportunities	Van Keer I., Patyn J., Bronders J. & Diez T.
Development of a catalogue on European MAR sites	F. Scheibler, M. Hernandez Garcia, E. Vilanova, N. Hartog, C. Sprenger & S. Hannappel
Effects of inorganic carbon limitation on nitrite oxidizing bacteria	Young Mo Kim and Kartik Chandran
Large diameter shallow wells in unconfined aquifer recharge: a new MAR integrated project in Treviso Province (Northern Italy)	Bertoldo Silvia, Busoni Simone, Pedron Roberto, Sottani Andrea
Scope for large scale application of managed aquifer recharge in Bangladesh for sustainable domestic , municipal and irrigation water supply	K M Ahmed, S Sultana P Ravenscroft, Albert Tuinhof
Modeling artificial recharge capacity of fractured hard rock under semi-arid conditions in Southern India: Implementing storage basin dynamics into MARTHE code	Picot-Colbeaux, G., Thiéry D., Sarah, S., Boisson, A., Pettenati, M., Perrin, J., Dewandel, B., Maréchal, JC., Ahmed, S., Kloppmann, W.
Key legal and regulatory Issues for sustainable Development of large-scale ASR in Korea	Jae-ho Choi, Nam-Sik Park, and Young-Gyoo Shim

Session I

Artificial recharge in crestatx aquifer (majorca island, Spain) using springwater surpluses. Previous studies and desing of the artificial recharge plant.

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In this paper we show an study about the possibilities of artificially recharge the Crestatx aquifer, in Majorca, using water surpluses from Ufanes de Gabellí springs. These springs are typically karstic, characterized by a very quick response to intense precipitation. Water flows drained are very high in very short time periods. The discharge pattern is very variable, depending on the rainfall pattern, but we can say that, as an average, there are 6 or 7 drainage episodes per year. Recorded water flows have been up to 30 m3/s.

Drained water is driven to the sea, a few kilometers downstream, by the Torrente de San Miguel. This makes very difficult to exploit the springs water resources, even more by the fact of in the river mouth there is a large wetland named Albufera de Alcudia, which is protected by the law. Nevertheless there is a possibility to use a part of the surpluses to make the artificial recharge of Crestatx aquifer.

In this paper, the first results of the artificial recharge feasibility study are shown, and too the first design of the future artificial recharge plant.

Keywords: Artificial recharge, Crestatx, Ufanes de Gabelli, Mallorca, suspended solids

Integrated and preventive water management and forest ordenation techniques to mitigate climate change adverse effects

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The effects of long term droughts may not be fought by means of specific and isolated actions, it is necessary an integral planning. On the other hand, the devastating capacity of high flow flood events and "gotas frías" is such that, once unleashed, it is impossible to stop their catastrophic effects.

Fortunately, it is viable to apply preventive techniques to mitigate risks and impacts. In Spain, where water resources are irregularly spread through the year, and where forecasts show a future scenario rather extreme, it is crucial to clarify at least the relationships between human activities and their impacts on the water cycle, increase the education of those involved in territory planning, improve water quality as well as its use in its circuit along the territory, and, urgently, transform any action into an opportunity.

Based on the principle of "prevention of damage from its origin", R&D projects carried out by Tragsa Group as DINA-MAR and GIAE have been developing lines of action to influence the causative agents for the last six years, proposing infrastructures and techniques spread throughout the whole water path, from the watershed top to the coast line. The cast of actions requires a comprehensive and panoramic view of the scenery, applying the premise of acting locally, but designing globally.

For prolonged drought periods, on the premise "the key is the storage", actions are based on the implementation of distributed managed aquifer recharge facilities, in order to promote the storage of water in the aquifers along the management chain.

In the case of extraordinary overflows, it is worth to remark forest management techniques in the upper drainage basin, creating retaining and diverting structures of high volumes of water outside the river beds, as: “boqueras” and “atochadas” (as complements to those located in rivers and streams), terracing the slopes, locating dams and dikes deducted by complex processes, implanting specific architectural elements in the cities, etc., with special attention paid to their design. An appropriate spatial planning is also needed, by means of new organizing techniques, urban planning and preventive measures in order to prevent extreme water related impacts.

It only seems viable to struggle against the undesirable effects of climate change by means of concatenation of integrated actions addressing each point where the natural environment is altered.

Keywords: Artificial recharge, DINA-MAR, GIAE, Managed Aquifer Recharge (MAR), climate change, drought, overfloods, preventive measures, palliative measures, risk, adaptation, impact.

A study on classification of groundwater aquifer using the principal component analysis in linpien basin, Pingtung, Taiwan

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The groundwater is mainly sources in Pingtung area; coastal area has great demand for aquaculture, especially in Linpien Township. The purpose of classification is to determine a hydrograph pattern that describes the water level trend over a 10 years period for each layer by adopting Principal Component Analysis (PCA) in interpreting the groundwater type in both time and space. The study conducted an analysis to understand the area distribution of various types of water level patterns and determine whether groundwater should be explored for utilization. To do so, groundwater data were collected daily from three Aquifer wells located at the Linpien River alluvial plain from 1999 to 2009.

The classification of groundwater hydrograph, total 19 stations, separate into two types that based on each aquifer by highest component loadings. Hydrographs of Type I indicate the pattern of fluctuations is strong similarity to the hydrograph in aquifer 2 and 3, the fluctuation is stable and trend is gradually descend at pass 7 years. The results indicate distinct explored in the region and depth. A type I is not be compare with type II on Aquifer 3.2, type I, not only present complex patterns since 1999, but also after 2005 the type change into ascend trend, and type II is stable and regular. Various factors influence groundwater dynamics, including topography, water movement, weather, and other human-related factors. The results indicate that the exploitation type must be in the coastal area, and the recharge area is located upstream, as described below. The groundwater source has almost been recharged entirely by rainfall near the proximal fan or in front of the mountain area, which is a recharge zone with a high infiltration rate. The lateral recharge of the mountain area is the source of the deep Aquifer (100 m to 250 m). Consequently, rainfall in the mountain affects the groundwater dynamics on the proximal fan and the deep aquifer, whereas the river affects the groundwater dynamics in the shallow aquifer. For example, in Shibupyi Station, where the river and the aquifer interacted, the water is obtained midstream and the level remains balanced with the groundwater until the river becomes the gaining river. In terms of the groundwater trend, aquaculture abstraction occurs frequently in the coastal area. Furthermore, complex groundwater fluctuations are observed in Aquifers 2 and 3.1, specifically in the Datan (2), Tungkang (3), Kangtung (3), and Chifeng (3) Stations. As a result, groundwater is gradually reduced during both dry and rainy seasons.

Key words: Classification of groundwater aquifer, Principal Component Analysis, Hydrograph pattern

A methodological concept for the identification and subsequent development of potential bank filtration sites in India

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Bank filtration (BF) is gaining awareness as a sustainable alternative to the direct abstraction of surface water for drinking in urban and rural India. However, interactions with Indian water supply ergana nt s have revealed the need for a scientifically based methodology to systematically select, investigate and evaluate potential BF sites. Such a methodology will serve as a tool to enable the development of new full-scale BF systems in India and to address the imminent threat to BF sites from monsoon floods. The methodological concept, based on hydrogeological investigations and evaluation of existing drinking water supply systems at Haridwar, Patna and Srinagar by the Ganga and Alaknanda Rivers is presented. The investigations included the BF site-selection based on visual reconnaissance surveys, construction of monitoring wells, field investigations, monitoring of faecal indicators, dissolved organic carbon (DOC), major ions and trace metals, and groundwater flow ergana . Relevant Indian socio-cultural and institutional aspects (large-scale bathing in rivers on religious occasions, capacity development needs of water suppliers, land acquisition for BF sites, legal aspects) are also included. The management of risks due to floods is derived from a risk-assessment of the BF sites in Haridwar and Srinagar. The risk-assessment is based on pathogen removal data collected from field studies and laboratory column experiments, travel-time of bank filtrate and technical deficits of BF sites in India. The development of the methodological concept has shown that BF is considered crucial to the removal of microbial pathogens due to high discharge of partially treated / untreated wastewater into rivers. Consequently a high removal of 3.5 log10 for E. coli was observed during non-monsoon and 4.4 log10 during monsoon, even for wells located only 15 m from the river. The relatively low DOC concentrations present in the abstracted water (0.2 – 2.8 mg/l), imply that conventionally ergana disinfection by chlorination will produce low numbers of disinfection by-products such as trihalomethanes. In the upper and middle course of the Ganga, the hydraulic conductivities of the aquifer are conducive for BF (0.004 – 0.000077 m/s), however the presence of confining clay layers can impede the hydraulic connection to the river especially in the middle and lower course of the Ganga due to increased deposition. Sufficient aquifer thicknesses (> 17 m) have been observed. However the drilling of boreholes for wells in the upper course of the Ganga (mountainous terrain) is difficult due to high-energy fluvial sediments. Additional geological interpretation of outcrops and geophysical methods can be of assistance in determining the aquifer thickness and material. Important considerations while selecting a potential BF site are sufficient year-round flows (changing distance between river channel and BF well, insufficient scouring during low flow periods, construction of new dams), locations of wastewater discharge points into rivers, protection of landside groundwater from contamination (pathogens, nitrate), high arsenic concentrations especially at shallow depths. At existing BF sites, the contamination of the production wells during floods through the direct entry of flood water has been identified as a main risk. Measures for improved risk-management of BF systems during floods are presented.

Managed Aquifer Recharge as a key element inSonora River Basin Management(M é xico)

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Arid regions frequently have competing urban supply and agricultural irrigation demands in excess of availablescarce water.This paper presents a Decision Support System (DSS) as an instrument to find the optimal scheme for water resources management from multiple suppliesusing managed aquifer recharge (MAR). The DSS capabilities are demonstrated through its application to the Sonora River Basin.

This Sonora River Basin watershed, located in northern Mexico, contains a wide variety of agricultural zones and many small towns along the river. The most important urban center is the city of Hermosillo, where there is a concentrated water demand for urban and industrial uses. Here, the scarcities of water demanded from urban areas, as well as water shortages and inefficient use of water (especially by the agricultural sector) are creating problems for water and food security to the region.

The DSSDincludes the hydrological modeling of the surface-water system, the groundwater-flow model, and the characterization of the water quality from various sources.

The results establish that the increasing volume of demand for water will be difficult to satisfy with the current supply-and-demand allocation schemes. Because alternative sources are needed to mitigate the differences between the supply and demand for water, MAR represents an option that could reduce this disparity and sustain the expectations of integral development of urban water supply and irrigation within this basin. This scheme also addresses potential improvements in water quality and helps palliateglobal climate change.

Keywords: Conjunctive use, groundwater, managed aquifer recharge, wastewater, climate change

Groundwater natural resources and quality concern in Kabul Basin, Afghanistan

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Historical groundwater level and water quality data from the Quaternary Kabul Basin aquifersystem were reviewed and compared with the Afghanistan National Groundwater Monitoringwell network, which has been operational since 2003. The results indicate that the Basin'sresources are now highly stressed and experience a water resources deficit. The Kabul Basin, especially in urban Kabul, is characterized by a scarcity of surface water, due to the extreme seasonality of precipitation. The Kabul River only flows for four months and is highly contaminated. Groundwater is, therefore, the major source of drinking water and has been crucial for the development of socio-economic growth and environmental security. Increasing human demand for groundwater resources has affected the aquifer system. The main impacts include: 1) drying-up of springs and karezes (qanats) due to water table decline; 2) increased waterlogging and salinisation in some areas; 3) serious deterioration of water quality; 4) depleted natural aquifer storage with time, and 5) unbalanced interaction between stream and aquifer (effluent and influent). Groundwater abstraction and recharge have remained steady since 2000 but, during this period, the water table has seriously declined due to overexploitation and low recharge and streamaquifer interaction has been disturbed. The discharge from springs and karezes has decreased. No new groundwater level equilibrium has been achieved; water tables have continuously declined and groundwater quality has deteriorated due to low recharge and over-exploitation. As a result, the majority of springs, karezes and shallow wells have dried up. The cessation of use of these features has merely led to the replacement of karezes and large-diameter shallow wells by deep boreholes. In the countryside, the drying-up of karezes, springs and large-diameter shallow wells severely restricts agricultural activity. Groundwater irrigation must be partially replaced by traditional or manual irrigation and rural water supply by drilled boreholes (which are expensive in terms of running cost and often of low productivity). This trend has affected socio-economic and environmental sustainability and has also caused displacement of inhabitants from the rural to urban areas. As Afghanistan's population continues to grow, there is increasing pressure to abstract more groundwater for various purposes, potentially resulting in further negative consequences for groundwater quality and quantity. In coming years, the majority of the Kabul Basin will become impacted by the gradual dewatering of the aquifer system. Therefore, the promotion and enactment of proper management strategies is a high priority. One of the most urgent and significant water resources management strategies for the Kabul basin (and other Afghan aquifer systems) may be the adoption of managed aquifer recharge (MAR) schemes.

Note: This abstract is based on the DACAAR report "Groundwater natural resources and quality concern in Kabul Basin, Afghanistan"

Key words: Natural groundwater resource depletion; water quality deterioration; overdraft; management aquifer recharge

Towards implementation of Managed Aquifer Recharge in Semi-arid areas of Nigeria: Possible contributions from large irrigation schemes

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The potential of managed aquifer recharge (MAR) implementation using return flows from surface irrigation schemes in semi-arid areas of Nigeria was evaluated using the Kano River irrigation Project as a case study. Groundwater recharge was evaluated daily for 3 years (2009-2011) using the water level fluctuation (wlf) method; 15 piezometers were installed randomly in five identified soil profile types (Pa3, Pal, Pl, Pab, and Pb) to monitor groundwater level changes on a selected 26.9 ha surface irrigated experimental farmland. Temporal and spatial analyses of recharge were done using a combination of Microsoft Excel® spread sheet and ArcGIS® 9.0 software. The groundwater recharge regime at the study site reveals high diurnal variations depending on season. Annual recharge range between 2, 907 mm and 4,770 mm on the farmland; while groundwater recharge was least in Pa3 soils, it was highest in Pl soils. Recharge occurrence range from 146 days (Pb soils) to 176 days (Pa3 soils) in a year. Groundwater recharges range from 17 mm/day (Pa3 Soil) - 32 mm/day (Pb Soil). Analysis of the data showed that about 8 mm of water is added to storage daily on the farmland; this addition has led to rising water levels in the area. The resulting waterlogging problems has implication for salt build up in the area and could be ameliorated by draining the farmland and releasing the water to the river system to increase the river flow and promote additional channel seepage in a systematic MAR implementation. This approach is a veritable solution for restoring the rapidly lowering groundwater level in the upper zone aquifer of the Chad formation which is located downstream of the Hadejia River; the Chad formation is the main source of water for urban and rural water supply in the downstream areas of the basin, however additional modelling studies and aquifer characterization are still required.

Keywords: Groundwater, Recharge; Irrigation; management

Temporal-spatial variation of ecotoxicity and distribution of heavy metal in the hyporheic zone of Shima catchment, Dongguan, China

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Water quality in Shima catchment has been significantly affected by discharge of industrial effluent and domestic wastewater. Chemical pollutants, especially heavy metals, severely have polluted river water and have been accumulated in the river bank. Those absorbed and accumulated heavy metals could be released from the soil/water interface to the river when acid precipitation occurs. The purposes of this study were to (1) analyze the polluted situation in terms of chemical parameters, (2) employ the LUMIStox (vibrio fischeri) to test ecotoxicity of river water and groundwater, (3) identify ecotoxicity variation in the process of aquifer recharge, (4) analyze toxicity on water extractable metal concentration of soil and (5) assess the soil pollution level. The results showed that elevated metal concentrations were detected in upstream water samples with moderate toxicity (38.35% inhibition) to vibrio fischeri, and both of them decreased from the upstream to the downstream in the dry season (February 2012) and were significantly higher than those of the groundwater samples. Low heavy metals concentration and inhibition of river water and groundwater samples were found in June 2012 after a heavy rainfall. These indicated that chemical pollutants were absorbed by soil in the hyporheic zone during the process of water/mass movement from river to the aquifer in Feb, and the heavy rain in June was the main factor for low concentration and inhibition. In rainy season, concentration and inhibition of heavy metals of river water were lower than those of groundwater in some sampling sites, which could be attributed to soil leaching when rainfall infiltration occurred from soil surface to subsurface. Positive relations ($p<0.05$ or $p<0.01$) between Zn, Fe, Mn and Ni concentration and inhibition in water samples were identified with correlation coefficients of 0.452, 0.567, 0.726 and 0.475, respectively. Heavy metals were supposed to be the main factor to result in the inhibition toward vibrio fischeri. Soil pollution of heavy metals including Cu, Ni and Zn was resulted from historical river-groundwater interaction and accumulation of heavy metals in aquifer. Most heavy metals were absorbed by soil particles rather land adsorbed on particles surface, as shown by low metals concentration and low or none ecotoxicity in the extracted samples with deionized water. Cd was heavily accumulated in soil and its concentration exceeded the background value in Guangdong province and reached the severe effect level. Heavy metals concentration of soil increased from the upstream to the downstream in Shima catchment, due partly to metals transportation by river water. This spatial pattern was examined to be controlled by the soil physical-chemical parameters, particularly soil particle size, soil organic matter content, pH and electrical conductivity. It was concluded that heavy metals in river water samples, were absorbed and adsorbed by soil in the process of river water-groundwater interaction, were yielding varied ecotoxicity to aquatic ecological system in both spatial and temporal scales.

Applications of Managed Aquifer Recharge to Improve Groundwater Quality in the Khulna-Satkhira Coastal Belt of Bangladesh: Results and Findings

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Seasonal safe drinking water scarcity is very severe in the Khulna-Satkhira coastal belt of Bangladesh. The occurrence of naturally brackish groundwater, vulnerability to climate change and sea level rise, and repeated contamination of surface water sources by both natural (e.g. cyclonic storm surges) and anthropogenic activities (e.g. brackish water aquaculture) are responsible for the increasing demand of fresh water in this region. To meet this ever increasing demand of fresh water, managed aquifer recharge has been tested as an alternative, cost effective and disaster resilient option to supply fresh water during the dry period. For piloting the technique, areas with no or very low densities of conventional safe water sources have been identified as primary sites by GIS analysis. Different physical, physico-chemical, hydrogeological, geochemical, social and economic criteria have been investigated in the field. Aquifer characteristics have been determined by exploratory drilling and grain size analysis. Finally two test sites have been selected based on a set of criteria. Four to six infiltration wells of 12 to 22 inches diameter have been drilled to a depth of 60 or 75 feet applying direct circulation rotary drilling method using locally available materials and drillers. Roof top rain water has been diverted and pond water has been pumped into the infiltration wells at two test sites after primary treatment in the filtration tank fitted with sand filter to remove turbidity and providing with a total head of about 3 feet. During the study period (monsoon 2011) a total of 392m³ and 827m³ of water have been infiltrated using gravity at Assasuni and Batiaghata test sites respectively. The initial electrical conductivity of the ambient groundwater were as high as 5.82 mS/cm and 1.79 mS/cm respectively while after infiltration the electrical conductivity has decreased to 0.82 mS/cm and 0.71 mS/cm respectively. The concentration of major chemicals of concern such as arsenic, manganese, chloride of the ambient groundwater was above the established Bangladesh drinking water standard. After infiltration, arsenic concentration substantially decreased from 0.1 to 0.01mg/l, manganese dropped from 0.63 to 0.15mg/l and 0.2 to 0.14mg/l and chloride concentration declined from 1324 to 500mg/l and 450 to 140mg/l at Assasuni and Batiaghata sites respectively. Though the quality and quantity of the source water is the main limiting factor, the findings of this study is very encouraging for water banking in shallow brackish aquifer to improve the groundwater quality and to ensure access to safe drinking water in the water stress coastal belt of Bangladesh particularly in the dry period.

Protection of Water Quality of Gaza Coastal Aquifer

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Groundwater is the only available water supply source within North Gaza. Excessive groundwater abstraction to meet the high increase in domestic and irrigation water demand has lead to groundwater depletion problems and degradation of water quality. Saline intrusion becomes one of the main threats to Gaza coastal aquifer. Gaza aquifer is subdivided into a number of sub aquifers separated by impervious and semi-impervious clay and silt layers. The lower clayey layers tend to be more thick and continues toward the coast and its thickness increases in the dipping direction to about 15-20 m thick and demolishes gradually to the east at a distance of 4-5 km. The lower sub-aquifers are confined whilst artesian conditions disappeared in the eastern parts where the aquifer becomes unconfined. The quantity of treated wastewater effluent that would be suitable for reuse is estimated to be 20 MCM by year 2020. The treated effluent reuse could therefore comprise around 36 percent of total water demand by 2020. The use of treated wastewater for irrigation and aquifer recharge will reduce the pressure on groundwater and reduce the gap between demand and resources and help to reduce the risk of saline intrusion in north Gaza. The quality of coastal aquifer is degrading due to increase in the salinity and nitrate concentration. This is due to reduction of rainfall floods and high abstraction of groundwater inside and along boarder of Gaza by the Israeli farmers This paper has investigated the potential of protection of Gaza coastal aquifer from saline intrusion through aquifer recharge scheme from the treated wastewater at Beit Hanon Treatment Plant. For this purpose a water balance model had been developed, the model indicated that there is potential to recharge up to 67,000 m3/day, the required area will be for recharge basin is around 84 dunums and recharge facility site area of 125x1000 m2 by the year 2025. The water quality of recharged water is expected to improve through infiltration process due to aquifer type (alluvial deposits). The study recommended to use the filtration basins with boreholes filled with filter matermaterial to connect basin with the aquifer.

Effect of silver nanoparticles on the performance of managed aquifer recharge: column study

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Managed aquifer recharge systems such bank filtration and artificial recharge and recovery have been recognized as an effective barrier in the multi-barrier approach for the attenuation of organic micropollutants such as pharmaceuticals and estrogens. However, there are only a few studies on the fate of silver nanoparticles during soil passage. It is also important to investigate the toxicity of silver nanoparticles during soil passage, as this issue has not been addressed in previous managed aquifer recharge studies. The goal of this study is to investigate the fate of silver nanoparticles during riverbank filtration. (1) To investigate the fate of organic matter characteristics during managed aquifer recharge using advanced organic matter characterization tools; (2) To investigate the effect of effluent organic matter on the fate of silver nanoparticles during soil passage; (3) To determine the reduction of toxicity determined by fluorescence producing bacteria (vibrio fischeri) via soil passage. Column experiments were then performed and fed with river water collected from Tancheon River in Seoul, Republic of Korea. This study showed that biopolymer fraction in bulk organic matter was effectively removed during soil passage.

Keywords: biodegradation, managed aquifer recharge, silver nanoparticles, toxicity.

Improved spring water yield via artificial recharge of rainwater (tanzania case study)

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Depletion of the Kwemakame spring fed rural water scheme in the Usambara mountains Tanzania is being investigated in a 'Village spring water supply research' project. Instead of infiltrating into the ground, most of the rainwater is running off over surface and is lost for the water scheme. In this pilot project surface runoff is harvested in earth dams and this water is being recharged slowly into the ground. This artificial recharge should boost groundwater and the yield of the downhill spring water intakes. Two pilots have been constructed to prove the feasibility and effectiveness. One of the pilots is described in this paper. To better understand the water system, the Dindira spring catchment was investigated by geophysical soundings, infiltration tests and four years of hydrological monitoring of rainfall, evapotranspiration, spring yields and groundwater heads. Working with the local community was a joy but it was also a challenge to properly organize good quality monitoring. Two recharge pilots were constructed in 2011 to test the feasibility of MAR. In pilot 1 the idea is to collect surface runoff in a hillside earth dam and to slowly release the water in a 7 meter deep (open) infiltration pit uphill from a spring water intake. Additional monitoring should prove the effectiveness of the recharge on the spring yield. So far, after one rain season, the results are disappointing: at first there was just too little runoff and once the rain came it was in a 59 mm rain storm. This caused a breach in the dam (through piping) and the sand filter behind the dam was flushed down into the infiltration pit. The dam was repaired and protected by clay. We decided to not reconstruct the sand filter but to leave the filter sand inside the infiltration pit. During the coming rainy season the system will be monitored to see how much runoff water we can collect in the dam and infiltrate in the pit and whether this will boost the spring yield. MAR could help to solve water shortages in spring fed rural water sources. As long as rain water is just running away unused, it makes sense to think of replenishing groundwater and feeding the springs. However, the Kwemakame case study raises some important questions: • What kind of (area specific) investigations are at least required to determine the feasibility of MAR? • Can earth dams be constructed and maintained sustainably? • Should infiltration pits be backfilled or is it preferred to pretreat the water in a sand filter (silt and clogging issues)? • Can MAR spring-replenishment be economically efficient for poor low-skilled rural communities? • Research like this brings high expectations for the local people. They just expect more water and it is difficult for them to accept failing plots in terms of water, regardless of the scientific lessons learned. How to cope with this social aspect of a MAR pilot project?

Assessing the impact of a check dam across a non-perennial river in southern India

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Check dams across non-perennial rivers are one of the methods of managed aquifer recharge to harvest excess rainfall runoff for increasing groundwater storage. Chennai is one of the 4th largest cities in India where the water supply is mostly met by drawing water from the surface reservoirs. About 1% of the city's water supply is met by pumping groundwater from the alluvial aquifers along rivers flowing north of Chennai. Over pumping from these aquifers has resulted in groundwater depletion as well as seawater intrusion and to overcome this problem check dams are being constructed across the rivers for storing the excess water during the monsoonal rains. The objective of this study is to assess the impact of a check dam across a non-perennial river, north of Chennai, Tamil Nadu, India. Water level in the check dam and groundwater level in the wells located around the check dam was measured once a month from July 2010 to July 2012. Surface water samples from the check dam and groundwater samples from the wells were also collected and tested for their electrical conductance and concentration of major ions. The groundwater table had increased by 1.5m after the construction of the check dam. Water stored by the check dam was generally fresh and with low ionic concentration. The geochemical signatures of the groundwater samples from the wells located within 1.5 km from the check dam were more or less similar to that of the water in the check dam. This similarity is due to the interaction of water in the check dam with the groundwater. It was also found that in Arani and Koratallai River, only about 7% and 8.5% of runoff is harvested respectively. Raise in water table due to the storage in the check dams is expected to push the seawater-freshwater interface by about 4 km to 6 km towards the sea. The managed aquifer recharge by check dams in this region had improved the groundwater quantity and quality with very minimal intervention to the existing hydrological scenario.

Keywords: Recharge structure; water management; groundwater; alluvial aquifers; Chennai; Tamil Nadu; India; water level; electrical conductivity.

Experimental study of high sediment-surface water seepage to groundwater in the Nalingguole River

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Due to the extremely arid climate in the western Qaidam Basin, the groundwater almost becomes the single water source for local residents and industrial production. As the largest river in the basin,Nalingguole River play an important role in solving the water resource among this area, which is the most important supply source of local groundwater. The suspended solids concentration of Nalingguole River is up to 1-2 million milligrams per liter .It is necessary to know the reliable information on the high sediment-surface water seepage to the groundwater, which is very important to reasonable and sustainable exploitation of the groundwater resources. In addition, the result will contribute to the study of artificial groundwater recharge clogging mechanism, prediction methods and processing techniques .The seepage capacity is usually through seepage tests to determine. However, previous experiments can not represent the natural flow, which has high sediment concentration. This study focused on the recharge of high sediment-surface water seepage to groundwater through seepage grooves in the indoor. Simulation experiments are divided into four groups:(1) Tap water is the source of water seepage test in the standing state,(2) the water, sediment concentration of 5000mg / l , is the source of water seepage test in the standing state,(3) Tap water is the source of water seepage test in the flowing state ,(4) the water, sediment concentration of 5000mg / l , is the source of water seepage test in the flowing state at different flow rate. The seepage rate and the quantitative recharge will be identified through many comparative experiments, which will provide a scientific basis for the determining of high sediment- surface river water to groundwater infiltration .

Simulation of physical clogging at RBF sites using a laboratory channel experiment

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Riverbank filtration (RBF) has been used for several decades in Europe, where river bed clogging is limited or regularly removed during floods. The turbidity of rivers in Europe is typically 20 NTU and below. In other regions, e. g. in Asia and South America, much higher turbidities are observed, especially during monsoon or floods, where it reaches values of more than 200 NTU due to local geological formations. Clogging has an enormous impact on river bed hydraulic conductivity and can reduce the specific capacity of production wells along the river bank and increase energy consumption. As there is limited information available on the practice of RBF along rivers with such high sediment loads, the nature and speed of clogging processes have to be studied under such conditions to enable the proper design and operation of well-functioning RBF water supply sites. Physical river bed clogging by fine particles can reduce infiltration rates in a very short period of time. Therefore, a channel experiment was conducted in the laboratory in order to investigate physical clogging effects as a function of flow conditions in the channel, grain size of the channel bed, infiltration rates and fine sediment concentration. First results show that with a turbidity of around 300 NTU, a flow velocity of 0.1 m.s-1 and Shields parameter of 0.05, a reduction of almost two orders of magnitude in K-values of the first 10 cm of sediment can occur in as little as 12 hours, during high infiltration rates and high flow conditions in the channel. A similar K-value reduction was also observed during low flow conditions (flow velocity of 0.006 m.s-1 and Shields parameter of 0.002) in the same period of time although the turbidity and high infiltration rates remained unchanged. Thus, infiltration of surface water with high turbidity seems likely to cause rapid river bed clogging if high abstraction rates are applied in the production wells, independent of flow conditions in the river channel.

Keywords: riverbank filtration, suspended sediment, physical clogging

Development of Managed Aquifer Recharge in China

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Development of Managed Aquifer Recharge in China Author: Yaqun Zhou1, Weiping Wang1*, Qiaoyi Xu1, Qiang Huang1 Corresponding Author Name: Weiping Wang Corresponding Author Affiliation: 1School of Resources and Environment, University of Jinan Corresponding Author Address: 336, Nanxinzhuang West Road, Jinan, China Phone: 13953162318 E-mail: stu_wangwp@ujn.edu.cn Abstract: China has a long history in managed aquifer recharge (MAR), the development divided into 4 stages based on the summary combined with typical MAR projects. The first stage is MAR applied in agricultural production. Such as Karez and Huantai transverse gallery were used to guiding groundwater or river water to irrigate crops in ancient China; the second stage is MAR applied in industrial production and alleviation of agricultural disasters, which has an obvious effect on water table recovery, energy conservation and consumption reduction, land subsidence control and augment of industrial water supply etc. Since 1960's, Shanghai conducted groundwater recharge with cooling water and tap water to recover water table and utilize aquifer to provide new "cool source" and "heat source" for factories. For another example, well-channel irrigation systems were popularized in North China to resolve problems of drought, waterlogging and alkali before 1990's. In Inner Mongolia, underground intercepting works were built to alleviate water shortage since 20th 70s; the third stage is MAR applied in ecological protection and augment of urban water supply. In Shandong Peninsula, many underground dams were constructed to prevent sea water intrusion. Furthermore, some reservoirs have turned form flood control and water supply type to integrated ecological type to alleviate the over-exploitation of groundwater, such as Wohushan Reservoir; the fourth stage is multi-source MAR. Stormwater, reclaimed water, mains water or even groundwater from other aquifers could be stored for MAR. Such as Gaobeidian groundwater recharge with reclaimed water trial project in Peking and karst aquifer recharge with treated roofwater in University of Jinan. In addition, geothermal reinjection and ground source heat pump are also effective use of MAR. Nevertheless, the system of MAR is defective, the study on water quality is lacking and the recharge rate of most projects is low etc. It is conclude that China has achieved a great effect on industrial and agricultural production, ecological protection, drinking water supply and urban reclaimed water reuse etc. However, there are still many issues. It is suggested to develop a feasible, convenient and economic technique of MAR fitting to local hydrogeological conditions, establish guidelines of MAR and management regulations together to make sure the MAR projects running successfully. MAR will make a great difference on improving potable water quality, alleviating geological hazards, long distance diversion, urban water supply and agriculture irrigation etc.

Keywords: MAR; stages in China; prospect

Study on the Influence of Groundwater Source Heat Pumps on Groundwater Quality

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Study on the Influence of Groundwater Source Heat Pumps on Groundwater Quality The groundwater source heat pumps have been accepted by majority of users with higher energy efficiency, lower operation cost and broad applicable scope. However, the influence of groundwater source heat pumps on groundwater quality hasn't been confirmed. Selecting Weifang region as the study area and choosing four groundwater source heat pumps works in Anqiu center hospital inpatient building, Weifang transit authority dormitory building, Weifang Chenlong hotel and Changyi Haojiachenghou residential building respectively as research objects on the basis of the regional application status investigation, the groundwater quality in the project area was observed and tested continuously. The changing trend of groundwater quality was analyzed by the software for mathematical statistic named SPSS, especially selecting the high-risk items of groundwater. The results show that the concentrations of TDS, nitrate nitrogen, ammonia nitrogen and some other indicators have changed. Groundwater quality changes more obviously when the open type groundwater source heat pumps are used, so it's important to make sure that the groundwater source heat pumps are closed completely. In addition, even if the system is sealed, the groundwater quality may also change beacuase that some substances may be taken into the aquifer from the upper layer because of the raised water level during the recharge in the area of deeper groundwater depth. Therefore, in the region, the groundwater source heat pumps are not completely free from contamination in the current technology conditions. So the government should forbid the application of groundwater source heat pumps in underground drinking water source protect areas and limit strictly in other functional areas such as the groundwater source of drinking water recharge areas in order to protect the groundwater environmental security. Acknowlegde Natural Scientific Foundation of China (412101125) for supporting.

Keywords: groundwater source heat pumps; groundwater quality; Weifang

Research on Index Scale Method for Suitability Division of Shallow Geothermal in Yinchuan City

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Index scale method is used for constructing judgement matrix in AHP. Using this method for the suitability division of shallow geothermal in Yinchuan City, according to the analytic hierarchy process (AHP) calculation ruler and calculation formula to calculate the weight value of groundwater heat pump in Yinchuan. The results can satisfy the (AHP) in consistency check. By Application of ArcGis mapping software to overlay each factor weight and its corresponding score multiplication value stack obtain the final comprehensive score, according to the comprehensive rating to merge partition, and ultimately the groundwater water source heat pump in Yinchuan suitability Division map.

Keywords: Yinchuan city; analytic hierarchy process; comprehensive weight; synthetical value; suitability division

Removal of dissolved organic matter in municipal effluent with ozonation and soil aquifer treatment

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The removal of dissolved organic matter (DOM) was investigated for municipal effluent treated by ozonation and soil filtration for aquifer recharge purpose. The DOM was characterized according to apparent molecular weight (AMW) using high-pressure size exclusion chromatography with organic carbon (OC), UV and fluorescent detectors. Based on OC detector, SE was mainly composited by humic substance (50.2%) and low AMW acids (45.4%), and the latter fraction was removed by 55% during ozonation. Most DOM (100% biopolymer and 58% humic substances) was removed by vadose layer, while further reduction was achieved during saturated soil layer. The removal ratios of total OCD peak area by the three treatment steps were consistent with those of DOC.

Based on UV detector, the aromatic DOM in SE is mainly composited with medium AMW 1.2-5.5 kDa (60.8%) and low AMW 0.4-1.2 kDa (38.5%) fractions. Ozonation effectively removed the large AMW (21.8-31.6 kDa) and medium AMW fractions by 100% and 65%, respectively, while the medium and low AMW fractions were further removed by 17% and 29% during SAT, respectively.

Fulvic acids was monitored using fluorescent detector at Ex=245 nm, Em=418 nm. The fulvic acids in SE were mainly composited with fractions of AMW 0.7-4.6 kDa (76.5%) and AMW <0.5 kDa (19.5%). Ozonation was effective in removing most fulvic acids by 88%-100%, except the fraction with AMW 0.5-0.7 kDa (41%). However, signal increased during SAT, especially for the fraction with AMW 0.7-4.6 kDa.

Soluble microbial products (SMPs) was monitored using fluorescent detector at Ex=280 nm, Em=358 nm. The SMPs in SE were mainly composited with fractions of AMW 0.8-4.1 kDa (52.1%) and AMW 0.4-0.8 kDa (33.8%). Ozonation was effective in removing most SMPs by 76%-100%, except the fraction with AMW 0.4-0.8 kDa (24%). SMPs with AMW of 0.2-0.8 kDa were further reduced during SAT by around 30%.

For the whole system, the reductions of total peak areas were 78.6%, 66.3%, 81.3% and 85.1% for OC, aromatic DOM, fulvic acids and SMPs, respectively. In the final effluent, the ratios of total humic substances, aromatic low AMW acids (0.4-1.2 kDa), SMPs with AMW of 0.4-1.1 kDa and fulvic acids with AMW of 0.5-4.6 kDa increased compared with SE, indicating such DOM was more resistant during the treatments.

Keywords: emission–excitation matrix (EEM); groundwater recharge; molecular weight distribution; municipal effluent; ozonation; soil filtration

Managed aquifer recharge to mitigate fluoride contamination in groundwater in a part of southern India

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Groundwater with fluoride content above the recommended limit of 1.5 mg/l is not suitable for human consumption as it causes dental and skeletal fluorosis. Fluoride contamination in groundwater is more pronounced in hard rock terrains of southern India and most of the local population depends on the groundwater for drinking. Considering this, a study was carried out in northwestern parts of Tamil Nadu state, with objectives of identifying the spatial and temporal variations in fluoride concentration in groundwater, relation between fluoride and rainfall recharge and predict the effect of managed aquifer recharge. Groundwater sampling was carried out from 40 wells for once in two months in 2011. This study reveals the presence of fluoride upto 4.3 mg/l in groundwater in 40% of sampling wells. High fluoride concentration is due to the geology of the area as groundwater occurs in unconfined condition in weathered and fractured parts of gneisses, charnockite and igneous intrusions which have relatively high fluoride bearing minerals. On analyzing the temporal variation in precipitation and fluoride concentration, it is clear that rainfall recharge is the major controlling factor of fluoride concentration in groundwater. This is evidenced by high fluoride concentration in groundwater of low and no rainfall periods and low fluoride in high rainfall periods, indicating the dilution of the groundwater with fluoride free, acidic rainwater. On examining the long term rainfall and groundwater level data, it is manifesting that the recharge of rainfall is from 1 to 12 %. Observation of groundwater level and fluoride concentration indicates 0.5 meter decrease in groundwater level increases 0.323 mg/l fluoride but 1.9 meter increase in water level has only 0.21 mg/l decrease in fluoride content. Hence higher groundwater recharge decreases the fluoride contamination but not very effectively because of the less recharge amount. Hence, in order to increase the quantity and duration of recharge, managed aquifer recharge methods like construction of check dams, subsurface barriers and percolation ponds are needed to be adopted. Groundwater flow was modeled by FEFLOW with the planned managed aquifer recharge structures and the prediction promises the improvement of groundwater potential. Increased groundwater recharge will dilute the water and makes it suitable for drinking. Hence by managed aquifer recharge groundwater potential will be increased as well as dilution of fluoride rich groundwater will be possible and so the socio economic status of the residents will be improved.

Key words: Fluoride, Groundwater level, MAR, FEFLOW, southern India

Poster Session 2

Tailor-made high-frequency filter sand cleaner for high-capacity MAR basins

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Drinking water production in the waterworks Dresden-Hosterwitz, Germany, is based on riverbank filtration and artificial recharge of pre-treated river water. Two different types of basins are used. One type has a long and narrow geometry and an area of 2800 m2. In the late 80ies, a new technique for cleaning the upper filter layer was developed, called "FIREG" (filter regeneration) and later "KUROF" (Kurztaktoberflächenfiltration – short cycle surface filtration). The frequent cleaning of the upper filter sand layer ensures a high infiltration rate. Whereas the aim was to achieve an infiltration rate of up to 15 m/day, the present capacity is about 8 m/day. A tailor-made cleaning trolley was developed to run on rails (spaced at 8.4 m) mounted on the concrete walls of the basin. An 8-m long washing drum is used to lift and wash the upper sand layer. The washing depth can be set between 0 and 40 cm. The forward trolley velocity is between 0.1 and 1 m/min, the backward velocity (without washing process) is about 1.5 m/min. The main advantage is the proven high recharge velocity. Thus, a large volume of water can be recharged even with a limited available land area. Disadvantages are the relatively high maintenance costs for the trolley and control units especially during operation in winter, additional energy consumption and the production of wastewater from the washing process. The poster will provide details and an evaluation of the technique based on long-term experience with operation and maintenance, including cost issues.

Numerical assessment of community-scale managed aquifer recharge systems in south-western Bangladesh

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Communities in the low-lying Khulna-Satkhira coastal region in south-western Bangladesh currently experience severe seasonal water scarcity. In this region the groundwater is naturally brackish and traditional drinking water sources (e.g., ponds) are frequently contaminated from events such as cyclones and storm surges. Aquifer storage, transfer and recovery (ASTR) is currently being tested by UNICEF-Bangladesh, University of Dhaka and Acacia Water (Netherlands) as a cost-effective disaster-resilient water supply alternative for these coastal communities. Twenty test sites have been established where fresh water collected via rooftop rainwater harvesting and surface ponds is injected into shallow aquifers during the monsoon season and stored for extraction that occurs throughout the year. A numerical variable-density groundwater model of two main test sites was first developed in SEAWAT-2005 for model validation. At these test sites ASTR has led to a significant reduction in electrical conductivity and major dissolved species including arsenic and manganese in the shallow aquifer. Once validated the model was applied to examine the efficiency of the system for of a range of hydrogeological conditions (e.g. hydraulic conductivity, aquifer dispersivity, aquifer depth) and engineering design and operating parameters (e.g. layout of injection wells, length of injection wells, injection rate). The influence of seasonal hydraulic gradient variability and tidal water table fluctuations (pronounced at one of the test sites) on the system efficiency was also examined. As expected larger hydraulic conductivity and injection heads lead to higher injection rates, greater freshening of the aquifer and lower salt concentrations at extraction well. For aquifers with high dispersivity and/or heterogeneities mixing of the ambient groundwater with injected water may prevent salt concentrations at extraction well decreasing below drinking water standards. For the regional hydraulic gradients (0 – 0.005) simulated there was no significant difference in the quality of water at the extraction well. Finally, the application of non-dimensional numbers to assist in identifying suitable sites and optimizing operational conditions to maximize the success of a small-scale ASTR scheme was explored.

Combining geophysical and geochemical measurements for subsurface characterization at a full-scale aquifer recharge and recovery site

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Heterogeneity can play an important role in determining how water flows between the surface recharge zones and the points of groundwater extraction at Aquifer Recharge and Recovery (ARR) sites. Due to the one-dimensional nature of boring logs and drill cores, these investigation tools alone often do not provide the spatial coverage necessary to reveal complexity and heterogeneity of the aquifer. Here we present the results of a combined geophysical and geochemical investigation designed to reveal subsurface heterogeneity, likely flow paths and water travel time from infiltration to extraction. The direct current electrical resistivity geophysical method was used to image two-dimensional cross-sections of the subsurface in a semi continuous mode to reveal the structure and composition of unconsolidated sediments between existing borings and to assess areas of the ARR site that did not have direct measurements available. Geochemical measurements of bulk parameters (i.e. total organic carbon, cations, anions) and trace organic contaminants (e.g. pharmaceuticals, flame retardants) along various transects were used to estimate flow paths and travel times and assess the performance of the ARR site regarding water quality and quantity. Our results indicate that the subsurface is highly heterogeneous at our study site and that the coarse-grained sedimentary units are acting as the best conduit for transporting water are likely discontinuous. The electrical resistivity measurements indicate certain areas of the infiltration basins may have good hydraulic connections to the extraction wells, while other infiltration basins may be separated by fine-grained materials from their respective extraction wells. We compare the geophysical structure of infiltration basins that have high-observed infiltration rates compared to those that have low infiltration rates to explore what subsurface structures may be responsible for the difference. The geochemical results imply that the water recovery of at least one basin is limited due to the heterogeneous subsurface. We identified three wells abstracting water (>50%) that does not originate from the infiltration basins. However, significant water quality improvements are achieved within short travel times (<5 days) at this ARR site receiving riverbank filtered water for infiltration. These geophysical and geochemical measurements have important future implications for locating, design and construction of ARR facilities. We suggest that geophysical measurements, which can be made relatively quickly and cheaply compared to well installation, should be employed in the engineering phase of any ARR project to verify suitability of the subsurface for transporting water and to guide the placement of infiltration basins and extraction wells.

MAR for sustainable water-curtain cultivation method in rural area

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Over 100 km2 of rural area in South Korea is covered by water-curtain protected cultivation facilities, which use heat source in groundwater to keep warm inside of the green house during winter night by splashing groundwater inner roof of the green house. Those cultivation methods can produce various vegetables and fruits in winter, but induce groundwater level decline over a large area because it discharge the used groundwater to the stream via drain ditch. This study is to evaluate the underground circulating water-curtain cultivation method which injects the used groundwater through nearby injection well into aquifer. A test bed of water-curtain protected cultivation facility coupled with aquifer recharge for two 0.1-hectare green houses is installed at rural area of Nonsan, Chungcheongbuk-do, South Korea. There are equipped with one pumping well, one injection well of 15-m apart, one observation well between pumping and injection well, splashing system, recovery and storage tank, injection system and control 10-6 from pumping test and system. Hydraulic conductivity is estimated as 3.47 effective porosity, linear velocity, longitudinal dispersivity are estimated as 10-6 m/s, 0.8m, respectively, from dye tracer test. Separate 0.105 and 2.68 pumping-injection well system is found to be more effective in temperature and head recovery rather than single pumping-injection well system from the results of thermal tracer tests. The underground circulating system reduced groundwater level decline up to about 3m compared to non-circulating system and also raised temperature of injected cool water close to ambient groundwater temperature of 15℃ during migration from injection well to pumping well. The water-curtain protected cultivation facility coupled with aquifer recharge is evaluated to be energy saving, groundwater protecting and sustainable system for the protected cultivation facility in a cold area.

Management of groundwater quality at spratly islands in context of climate change

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This paper presents results on impacts of climate change to groundwater quality of the Project "Studying the impact of the sea level rise by global climate changes of Spratly archipelagos". Purpose of this Project is to evaluating impacts of sea level rise and proposing adaptive solutions for reducing the natural disasters. Viet Nam is one of the five countries which are most vulnerable to climate change and the Spratly islands is one of the first parts which can be affected by the climate change. Those effects can make enforceable problems, increasing and make danger for coastal areas of Vietnam: increasing the flooding risks, increasing the salt instruction and making coast line erode; changing the coastal ecology…that entire problems will directly affect the human life at the coastal areas of Vietnam. In this report we focus on groundwater quality at some islands of Spratly islands. The study area includes very small islands with their elevations are from 2 to 6 m a.s.l . The upper geological structure of these islands are the same: the surface layers are mainly composed of friable coral with osmotic rate 10-15 m/day and dewatering coefficient: 0, 3-0,5, that why the rain-water will be osmotic into the deeper layers, it only a bit can make small flow on the surface layer. The geology structure affects strongly the rain-water collection and accumulation. The hard coral structure can't osmotic and storage rain-water, only the friable coral sand and the crumbing coral have a certain porosity which can observer and accumulate rain-water. That why the ground water in the Spratly archipelago only can be found at the friable coral layer or weathering-coral have a big porosity, distributing from the surface to the depth of 6-8 m. The form of ground water occurs in the form of 'freshwater lenses', static water level fluctuates from 0, 4-1,5 m, depends on the season and tidal regime: Water level rise and drop according to the tide, the diphase is slower 40 minute (edge of island) and 2-3 hours (central of island). At the dead tide period, level of ground water always higher 5-10 cm than tide ones at maxim mum tide and 40 cm at minimum tide. Based on results of chemical and stable isotope analysis of water samples, hydrogeological and geophysical investigations characteristics of water resources and situation of groundwater quality at some islands of Spratly islands shown that: salinity in the groundwater is increasing and water type also changed. The authors also propose some adaptive solutions such as rain-water harvesting or infiltration galleries for protecting and managing water quality. Amount of rain-water will be harvested on each island around 100,000 – 120,000 m3/y, that is a very precious source as artificial recharge or supplying domestic needs on these islands.

Groundwater quality at southeast coastal zone in Vietnam

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This report presents results of the project "Adapting to climate change: Solutions for managing coastal aquifers in the context of climate change" in Ninh Thuan Provinces, Viet Nam. The purpose of this project is to evaluating impacts of sea level rise by climate change on coastal zone in Ninh Thuan, proposing solutions for managing aquifer recharge to improve groundwater quality in coastal zones. In this work, authors focus in change of groundwater quality in time and their causes . The coastal province of Ninh Thuan, due to its disadvantaged geographic location, unfavorable climate conditions and the limited social and economic development is among those more likely to be affected by climate change impacts such as sea level rise. One of the potential effects of sea level rise in these areas is the risk of saline water intrusion into fresh water coastal aquifers. Located in the driest part of Vietnam, Ninh Thuan has a tropical climate with 2 marked seasons: a short rainy season from August-September to November-December and a dry period in the rest of the year. The annual average precipitation ranges from 700 to 800 mm in the coastal area and gradually increases to more than 1,800 mm in the mountainous areas; the annual average evaporation is between 1670 and 1827mm, while average temperature is 27oC and air humidity is 71-75%. The geological setting of the study area, located mainly along the coastal zones of Ninh Thuan is characterised by a magmatic bedrock of Cretaceous age (granite, granodiorite and granosyenite) overlain by a Pleistocene-Holocene marine deposits of both terrigenous and calcareous type. Recent and ancient sand dunes also occur in the southern part of the Province (Lu Thien, Son Hai and Mui Dinh) as well as in the northern coast (from My Hoa to Vinh Hai). The hydrogeology is characterised by the occurrence of unconfined aquifers in loose sediment at different elevations (maximum elevation reached by the investigation was around 40 m a.s.l. – Tram Bang) exploited through both drilled wells (up to 28 m deep) and hand dug wells (the majority) with diameter ranging from 0.7 to 6 m and depths ranging from 3 to 9 m from ground level. To understand the hydrogeological asset of the coastal aquifers, hydrogeological and geophysical investigations as well as drilling exploratory wells and monitoring of groundwater physio-chemical parameters such as EC, pH, Salinity, TDS and Temperature were carried out. The results show that in the study area there are two types of aquifers: intergranular aquifers in the cover sediments (depth from 25 to 40 m): (Holocene (qh) and Pleistocene (qp) and fractured aquifers in the metamorphic bedrock. Water level, EC and Temperature changes in each of these aquifers were recorded with continuous monitoring devices. The transects for monitoring groundwater quality at these aquifers include 8 wells: NH1, NH3, NH4 and NH5 for the intergranular aquifers and NH2 for the fractured aquifer. Results of chemical and stable isotope analysis of water samples as well as monitoring data at a monitoring well network from 2008 to 2012) showed that the groundwater quality changes in time and this is more evident in the higher elevated area, salinity in the groundwater is increasing and water type also changes and the reasons cause these change and MAR is a chosen solution to resolve these problems.

Poster Abstract

Using electrical conductivity measurements to monitor infiltration, recharge rates and clogging during managed aquifer recharge

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The efficiency of managed aquifer recharge via recharge ponds is often compromised because of processes that occur within the unsaturated zone. Clogging, which occurs within the top ten centimeters to meter of the subsurface due to the influx of silt and nutrients that cause bacterial growth, limits the amount of water that can enter the subsurface. Once water does enter the subsurface, it can often stray from the desired path of vertical movement towards the storage zone due to low permeability heterogeneities, which causes the water to move horizontally. Better methods for monitoring the movement of water from the pond through the subsurface to the storage zone are necessary in order to make maintenance and operation decisions to ameliorate the effects of clogging and water loss. Traditional hydrologic methods typically cannot be implemented in-situ during recharge and do not provide data on the spatial and temporal resolutions necessary to make maintenance and operations decisions. Electrical resistivity imaging, however, can provide data at the resolutions necessary, in-situ, in real-time, during recharge. In this work, our goal is to obtain hydrologic information from electrical conductivity measurements to better monitor the unsaturated zone. First, we derive an equation for relating unsaturated recharge rates directly to electrical conductivity measurements using van Genuchten and Archie parameters. We use this relationship to also derive an equation for monitoring the clogging factor (the ratio of the hydraulic conductivity of the clogging layer to its thickness) in real-time using electrical conductivity and the same Archie and van Genuchten parameters. This monitoring equation allows for the effects of changing pond height and clogging to be separated from each other, better informing managers of what is affecting the infiltration rate. Wanting to simplify this relationship further and reduce the number of parameters necessary, we performed numerical experiments of partially saturating pore-scale structures and measuring their electrical and hydraulic conductivity over a full range of saturations. We find that we can relate relative electrical and hydraulic conductivity by a single parameter. This allows us to simplify the first relationship, relating recharge rates to the electrical conductivity, a new parameter, β, and the saturated electrical and hydraulic conductivities. We then aimed to take away the need for the saturated conductivities, as they are difficult to measure, and defined a new measurement of recharge efficiency, which is a measure of the percent of the maximum recharge rate that the current recharge rate is acquiring. This efficiency parameter then needs solely the β parameter discussed earlier, the current electrical conductivity value and the initial electrical conductivity value (presumed to take place when maximum infiltration was reached during the first few days of recharge). Each of these relationships provides a direct hydrologic measurement using electrical conductivity measurements without needing to solve the flow equations or invert the data hydrologically. This direct use of data means that it can be readily applied by MAR managers to better and more quickly inform their maintenance and operation decisions.

Development of numerical model evaluating withdrawal efficiency due to microbial clogging in riverbank filtration system

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In Korea, it was observed that withdrawal rate has been decreased since riverbank filtration has been operated for decade. We have tried to reveal the major process and mechanism causing this phenomenon. One way to investigate it is to develop numerical models which consider permeability change due to microbiological clogging and to perform numerical experiments. Numerical models has been developed by Lagrangian-Eulerian method to be called LECLOG which solves groundwater flow and transport equations considering permeability changes due to microbial growth. Here, microbial growth model follows two kinds of model which are macroscopic model of Clement et al. (1996) and Biofilm model of Taylor and Jaffe (1991). The developed numerical models compute microbial concentration and substrate concentrations such as dissolved organic carbon, dissolved oxygen, nitrate, iron oxide, and manganese oxide. Depending on the concentration of microbial concentration and substrate concentrations, microbial growth rate can be calculated and accordingly the reduction of porosity occupied by the microbes can be calculated. According to the porosity reduction, permeability will be decreased and thus withdrawal rate will be decreased with time.

In order to investigate the effect of dissolved organic carbon on withdrawal rate, numerical experiments was performed to calculate biomass concentration distribution and porosity reduction distribution cross riverbank to pumping well depending on three different dissolved organic carbon concentrations. Relevant numerical input parameters were adopted from Petrunic et al. (2005). From numerical results, the withdrawal rates can be decreased from 10 % to 25 % within 2 years depending on dissolved organic concentrations.

In-situ Test and Optimization of Saline Groundwater Restoration at the Lower Reach of Dagu River in Qingdao, China

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Groundwater is one of the most important water sources for irrigation and domestic water in Qingdao. Seawater intrusion occurred at the Lower Reach of Dagu River due to overexploitation of groundwater. about 13 km2 saline water remains on the north of the undersurface cutoff dam near the Ligezhuang Groundwater source. Based on the investigation of hydrogeologic condition, a groundwater monitoring net was set up to describe the fluctuation of water table, temperature and salinity. An in-situ test for saline groundwater restoration was carried out from September 18, 2011 to October 11, 2011. After 21 days' pumping and injection, the salinity of most saline water decreases to less than 1 g/l, but some saline water intrusion was found between the injection wells from the east part. At the same time, a variable density numerical model coupling the flow and transport equation is established. Tens of groundwater restoration schemes were simulated for the guidance of the field test and three schemes were further used to optimize the number, water flow and arrangement of pumping and injection well and structure. Key words: Dagu River; Restoration of saline groundwater; In-situ Test; Numerical simulation

Survival of Escherichia coli in Alluvial Aquifer Recharged with River water

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Aquifer in alluvial soil is a good source for drinking water. However, alluvial aquifer in estuary is susceptible to seawater intrusion. It is prone to be biological and chemical contamination as well, especially when cities and industrial complexes are located along the river that contributes building of alluvial soil. This study investigated survival of E. coli using laboratory-scale soil reactors that simulated alluvial aquifer of a managed aquifer recharge (MAR) system. The MAR system was supposed to use river water for recharge. The soil reactors were recharged with river water containing E. coli concentration similar to average concentration of total coliform bacteria measured for last 23 years. Recharged water was recovered periodically form the soil reactors and the recovered water was analyzed for E. coli concentration. The analysis results showed clear attenuation of E. coli. Survival of E. coli in the alluvial aquifer was affected by environmental factors such as concentration of dissolved total organic carbon, pH, salinity, and temperature.

A case-based reasoning application for mar case-studies

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A Case-Based Reasoning Application for MAR case-studies During a global enquiry on Managing Aquifer Recharge (MAR)s enquiry conducted by IGRAC (International Groundwater Resources Assessment Centre) and Acacia a several years ago (www.un-igrac.org/publications/155), information on circa 450 applications of MAR techniques worldwide was collected. Although used in reviewing and reporting process, this database contains much more information potentially useful for those in search for MAR experiences. Already at that time of enquiry, simple off-the-shelf CBR (Case-Based Reasoning) software was used to facilitate the search in database for similar MAR applications and experience that could be reused elsewhere. In general, the purpose of a CBR application is to retrieve information on existing cases that have highest similarity with a new defined case (a new problem), in attempt to (adapt and) reuse already available solutions for the new problem (the new case). Since no update was provided for the used CBR software it was operational just for a short period of time. In meantime, for a purpose of another project, a sophisticated CBR software application was developed to provide comparison among the cases, using the set of indicators derived from variables that characterize case-studies. The core of the application is CBR algorithm that compares and ranks the cases. In order to develop a specific CBR application for Managing Aquifer Recharge cases, the CBR algorithm needed to be adjusted and updated. Additionally, among the attributes that describe CBR cases, the search variables were selected, their ranges and similarity matrixes. The user of the application is very flexible in adjusting the default search structure and introducing own set of search criteria. The MAR CBR application will be launched in spring 2013 to make collected information accessible and to encourage the international MAR community to provide comments (on proposed search structure) and updates (new MAR cases!).

MAR in Flanders (Belgium): Overview and Opportunities

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In Flanders, households, industry, energy and agriculture consume significant amounts of water. On the other hand, as a consequence of the high population density, the water availability is rather low. This causes an imbalance between water demand and water availability. To protect groundwater resources for public water and to prepare for prospective water shortages in relation to changing climate scenarios. De Watergroep, a Flemish water company, aims to improve its water management. To evaluate the possibility for the application of Managed Aquifer Recharge (MAR) techniques, a literature study on existing MAR applications in Flanders was carried out, followed by a first screening of waterproduction sites of De Watergroep and potential aquifers. Although MAR techniques are already well established worldwide, in Flanders only at two waterproduction facilities (i.e. St. André1 and Grobbendonk2,3) MAR techniques have been implemented by means of infiltration ponds. At the St-André site, located in the Belgian dune area groundwater resources are optimised through re-use of highly treated wastewater. In Grobbendonk, water originating from the Albert Canal, connecting the city of Liege on the River Meuse with the harbour of Antwerp, is infiltrated after a process of pretreatment. The application of ASR was studied by means of two pilotprojects (Koksijde4 & Grobbendonk2). Because of respectively low hydraulic conductivities and clogging due to iron precipitation both sites did not become operational. Projects for the recovery of the piezometrie of deep groundwater through ASR, have been studied only in theory. On the basis of site specific data, hydrogeological conditions, production volumes and the presence of surface water, 6 waterproduction sites of the Watergroup out of 78 were selected for further research concerning the application of MAR. With respect to applicable MAR techniques, MAR techniques using temporary water storage in a riverbed (e.g. percolation tanks, underground dams, sand dams, recharge releases) are not relevant because in Flanders rivers drain the water table which is connected to the surface water level. Therefore, there is lack of space for underground water storage. Furthermore, in contrast to arid regions, the rivers contain water permanently. Rapid screening of the potential for MAR for existing waterproduction centres indicates that infiltration basins and riverbank infiltration are technically feasible. Injection techniques (ASR ASTR) are less preferable because the hydrochemistry of groundwater in areas where injection could be applied, gives rise to the formation of iron deposition.

Development of a catalogue on European Mar sites

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The EU-funded R&D project DEMEAU (Grant Agreement No.308339) addresses the fate of emerging pollutants in water and waste water treatment, e.g. Managed Aquifer Recharge (MAR). For MAR the objectives are to mobilize existing experience from different European study sites and to develop a systematic approach for the authorization of new recharge schemes in compliance with the European water and groundwater directives. The activities will cover the issue of infiltrating and injecting treated wastewater as well as developing guidance on optimum design and operation of infiltration facilities. In order to demonstrate the effects of typical existing European MAR systems onto groundwater availability and groundwater quality with specific focus on trace organics, a comprehensive relational database (catalogue) on European MAR systems was created to ensure efficient management of available data. By means of the built-in user forms, queries, and reports, database users are enabled to not only view and enter records but also to quickly process the data to extract needed information. In total, 59 different parameters were selected in order to describe about 270 documented MAR sites in 23 countries in Europe. These parameters were then divided up into four main groups (general information, technical data, hydrogeological parameters and monitoring activities) plus references. The database was created using standard software (MS ACCESS) and references were managed by open source software (JABREF). The compiled data on European MAR sites was taken from a variety of different source types, including scientific articles, books, PhD, diploma and master's theses, presentations, technical documents, reports from previous national and EU research projects, personal communication with specialists, operators and water authorities, community and operator websites, newspaper articles, and Google Earth (for geographic coordinates to create overview maps). On the basis of this database a classification system for the MAR sites found in Europe will be developed that can be used for deriving site-specific pre-requisites and design criteria as guidance for the authorization of for new sites.

Effects of inorganic carbon limitation on nitrite oxidizing bacteria

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Nitrite oxidizing bacteria (NOB) participate in nitrification by converting nitrite, the end product of ammonia oxidation, into nitrate. NOB gain energy from nitrite oxidation and fix carbon dioxide via the Calvin-Benson-bassham (CBB) cycle for cell synthesis [1]. Although, much is known about the nitrogen metabolic pathways and regulation of NOB, little work has examined the carbon cycle in these organisms. In high nitrogen loaded systems such as combined nitritation- ammonia oxidation (anammox) process, inorganic carbon (IC) limitation is a plausible scenario given mass transfer restrictions, but investigations into the impact of dissolved CO2 limitation have rarely been performed [2]. Since Anammox, ammonia oxidizing bacteria (AOB) and, NOB all rely on an autotrophic metabolism, a deeper understanding on how energy and carbon fixation pathways are linked can yield into a better control of the system and hence into stable nitrogen removal efficiencies. In this study, Nitrobacter winogradskyi Nb255 was selected as a model NOB to assess the impact of IC limitation on the biokinetics, metabolism and molecular responses related to chemolithoautotrophic nitrite oxidation. When the reactors were subjected to IC limitation (day 26-31, Figure 1), nitrite oxidation efficiencies were compromised. Nitrite effluent concentrations rapidly increased, resulting in maximum accumulation of 206 ± 11.0 mg-N/L after 3 SRTs, corresponding to a nitrite removal efficiency of 26 ± 4.0%. Simultaneously cell concentrations declined steadily to a minimum value of 3.3 x 109 cells/L, prior to re-introduction of CO2. After CO2 from air (day 32-50) was provided, a quick recovery was established yielding a stable nitrite oxidation performance (below 1.0 mg-N-NO2-/L) within 6 days (at 3 SRTs). Cell concentrations sharply increased up to 68 ± 16 % when compared to initial cell concentrations and finally recovered to a similar (not significant at α=0.05) cell concentration as measured before the limitation test (Figure 1). Similar studies with a mixed culture showed that IC limitation did not give a significant impact on NOB activity in a combined nitritation- ammonia oxidation (anammox) process [3]. Also, it was observed that IC limitation had a stronger effect on the nitritation than on the nitratation [2]. This suggests that continuously carbon-limited environments might present a suitable ecological niche for the nitrite oxidizing N. winogradskyi. In sum, IC limitation had an adverse impact on nitrite oxidizing performance, leading to cell washout by a decrease in cell synthesis rates. However, adaptation to IC limitation was not observed and nitrite oxidation recovered only after re-supplying CO2. These results provide insights into coupled N- and C- cycling in NOB and could help to interpret their dynamics in complex engineered biosystems where Anammox, AOB and NOB could compete under transient IC limitation. In parallel, in order to link between reactor performance and the molecular-level activity of NOB, functional gene expression will be determined by reverse transcription quantitative PCR (RT-qPCR) specifically targeting nitrite oxidation (nxrA) and carbon fixation (cbbLS) genes in NOB.

Large diameter shallow wells in unconfined aquifer recharge: a new MAR integrated project in Treviso province (northern Italy)

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According to European project LIFE FOKS - Focus on Key Sources, investigations were carried out between 2009 and 2012 on an historical solvent pollution of the aquifer in Treviso province (North-East Italy). Over the course of this study, wells and piezometers were drilled to implement an hydrogeological characterization and to monitor the contamination of the unconfined aquifer, through innovative methods. At the end of the project, the public administration decided to follow up the investigations, funding a pilot project involving the achievement of an integrated system for aquifer artificial recharge. This initiative leads to a further exploitation of already drilled wells, in order to increase the geological knowledge of the area and to manage the water resources, which are widely used both for irrigation and for drinking water use. The project, starting in 2013, concerns the injection into unconfined aquifer of surface water during the agricultural off-season, through the construction of large diameter shallow wells in the unsaturated zone. The expected objectives are about: 1. increasing the natural recharge during the autumn/winter period, when the surface water network can supply a considerable amount of water; 2. compensating the water withdrawal carried out in summer by existing deep wells: therefore, there will be no impact on the aquifer water balance; 3. mitigating the transport of the historical chlorinated solvent plume, favoring MNA processes in the areas upgradient the plume; 4. developing specific monitoring and numerical models in order to improve the aquifer parametrization and to optimize the operational management of artificial recharge in other work in progress sites. It should be noticed that since the 60s the water reservoir of the hydrogeological system in Veneto plain are gradually decreasing. Although this is an aquifer with a considerable capacity, the effects of groundwater drawdown are serious and well-documented. They depend on both global climate factors and anthropic factors (e.g. withdrawal increase, permeable surfaces reduction). The project is a synergy between the authorities responsible for irrigation network management and the groundwater control with the local government offices; also some private subjects have participated in the construction of the network and experimental data acquisition. Regarding the existing chlorinated solvents contamination, a detailed monitoring plan has been planned, with investigation of groundwater and surface water, in order to test artificial recharge long term effects. Chemical analysis, automatic level and multiparameter monitoring and, specifically, temperature measures will be carried out to study the effects of mixing surface and ground water. The site is set up as a pilot area where not only experimentation and research but also culture and dissemination will be promoted, in order to improve the sustainable use of hydrogeological resources. The results will be used to establish a regional scale protocol to manage aquifer recharge and monitor aquifer impacts.

Keywords: aquifer recharge, enhanced attenuation, monitoring and modeling, shallow wells, water management

Scope for Large Scale Application of Managed Aquifer Recharge in Bangladesh for Sustainable Domestic, Municipal and Irrigation Water Supply

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Groundwater is used extensively in Bangladesh domestic, municipal and irrigation supply, though millions of wells with different depth, capacity and pump types, and resulting in remarkable achievements in providing safe water and attaining food security over the last three decades. However, questions remain about the sustainability of the groundwater resource, particularly in areas of intensive exploitation for urban supply and irrigation. There is evidence of rapid depletion of groundwater resources in many parts of the country, particularly at Dhaka City and beneath the Barind Tract, and groundwater is evidently at risk in the coastal regions of the country. In each case, area-specific, managed aquifer recharge techniques can augment the aquifer Dhaka is the world's fastest growing megacity, in with a population of about 16 million. About 87% of the existing municipal supply, about 1800 MLD, comes from groundwater drawn from more than 600 wells installed in the two major aquifers. Water levels are declining at rates of 1-3 meters a year in the upper aquifer; and a large part has been dewatered, and hundreds of wells have been abandoned due to falling water levels. Abandoned wells can be used to recharge the aquifer after catching the rooftop rainwater. The Barind Tract in the relatively dry northwest of Bangladesh cultivation traditionally relied on rainfall. Over the last three decades, thousands of wells have been installed to provide dry season irrigation. The positive impacts of irrigation are visible, but there are serious concerns about its sustainability, and there is widespread evidence of declining groundwater levels. Here, recharge wells and check dams, and percolation ponds can be used extensively to augment the aquifer. In the arsenic and salinity affected coastal regions of Bangladesh, poor water quality in shallow aquifers is resulting in a shift to abstraction from deeper (150 - 350m) aquifers, raising fears of over-exploitation. Surface waters are not a year round alternative due massive saline intrusion of the tidal river system, but collection, treatment and injected recharge of the abundant monsoon flows can produce a sustainable source of water supply. Advantages and disadvantages of large scale managed aquifer recharge in the three areas will be highlighted, and the legal and institutional framework needed to protect the overexploited aquifers will be outlined.

Modeling artificial recharge capacity of fractured hard rock under semi-arid conditions in Southern India: Implementing storage basin dynamics into MARTHE code

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In the Maheshwaram watershed near Hyderabad, intensive groundwater exploitation for irrigation (>700 groundwater production wells) has resulted in aquifer over-exploitation and deterioration of groundwater quality. The watershed (54 km²) is located in a semi-arid hard-rock context, typical of the entire region with a 10-20 m thick weathered layer (saprolite). Maheshwaram catchment has been investigated through numerous studies (geology, hydrogeology, GIS, geochemistry…) over the last two decades. To face groundwater over-exploitation, managed aquifer recharge (MAR) is an attractive concept for groundwater augmentation and, eventually, for local improvement of groundwater quality. As a consequence, the number of recharge structures as percolation tanks, check dams, dugwells, is increasing all over India. A conceptual model and a numerical 3D MARTHE flow model have been elaborated as decision-making tools to simulate scenarii of natural and enhanced recharge through storage/infiltration basins (tanks) at Maheshwaram. To understand the capacity of MAR to improve the quantitative management of the aquifer at the watershed scale, a sophisticated groundwater balance calculation is implemented into the MARTHE code adapted for monsoon climate and semi-arid hard-rock context. This implementation includes the spatiotemporal evolution of the infiltration basin volume and geometry linked to topography, heavy rainfalls during monsoon, evapotranspiration, infiltration, runoff, and groundwater dynamics while respecting the hydraulic mass balance. Rain water is stored on the surface during the monsoon season due to artificial modifications of topography preventing runoff. Part of the water infiltrates into the soil (potential unsaturated zone) reaching and eventually raising the water table (saturated zone) whereas part of water is evaporated both during monsoon and dry periods. The 3D MARTHE model is applied to the Tummulur tank, a local scale study site, planned to be monitored over a total duration of 3 years. The model will then be upscaled to the whole Maheshwaram watershed for evaluating quantitative artificial recharge effects on aquifer flow at catchment scale. In a further step, the results obtained at local scale will be used to establish solute mass balances through a watershed scale 3D flow and transport model, in order to evaluate the beneficial or adverse effects of recharge scenarii onto soil salinization and fluoride accumulation.

Key legal and regulatory Issues for sustainable Development of large-scale ASR in Korea

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Aquifer Storage and Recovery (ASR) is considered effective in preventing water jurisdictional dispute, preparing water resources for disaster, securing drinking water resources, and so forth. In addition, it is plausible to say that economic viability of ASR can be matured to the level of commercialization if appropriate legal and regulatory systems are combined with an optimal arrangement of key technological consideration on top of profitable revenue stream. Recently, in Korea, a 5 year long national research project entitled to develop technology packages for practical use of both large-scale ASR and small-scale ASTR (Aquifer Storage, Transfer and Recovery) was initiated funded by Ministry of Land, Infrastructure, and Transport. While some of the technological aspects are scheduled to be validated by other participating professionals, in-depth discussion on the legal and regulatory issues related to successful development and operation of ASR in Korea is the objective of this study. Two major research tasks involved are benchmarking on the laws and regulations of those countries that already use or plan to use ASR, and comparing the benchmarking result with Korean ones based on key legal and regulatory issues. The proposed set of example issues to be discussed are in the form of questions as follows:

① How to secure the right on the injected water that needs to be guaranteed to injector?

② Surface water right and underground water right can be separated?

③ Can an exception be made in declaring Drinking water protection zones?

What's the reasonable level of regulation on the quality of injected water for improved economic feasibility?

Keywords : Laws, Regulations, ASR, ASTR

Theme 1: Applications of MAR in water resources management

Track 1.1: MAR for drinking water quality improvement

COUPLING RIVERBANK FILTRATION AND SUBSURFACE IRON REMOVAL

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Riverbank filtration (RBF) is a process during which surface water is subjected to subsurface flow prior to extraction from vertical or horizontal wells. The raw water discharged from the production well consists of a mixture of infiltrated river water and landside groundwater. At many sites, anoxic conditions and dissolution of iron and manganese are already present or would develop during RBF. Thus, iron and manganese removal is required as a further treatment step, making RBF more costly and representing a drawback that may limit its wider use an alternative to direct surface water abstraction and treatment. A coupling of RBF and subsurface iron removal (SIR) has only been done yet at Linz, Austria, and Boker Heide, Germany. To identify the optimal combination of both techniques and to define the limits of application, field site investigations are going on at RBF sites in Germany, Russia and Egypt. The scientific objectives include a better understanding of the hydraulics of reaction zones forming around wells under varying water levels due to the hydrologic regimes of rivers as well as of specific biogeochemical processes at RBF sites. Research results from a field experiment coupling RBF and SIR in Torgau, Germany show that coupling the two treatment techniques is possible. A new drinking water abstraction scheme is currently being constructed in the city of Khabarovsk, Russia, where SIR (the SUBTERRA method) is preferred over common above-ground treatment, given the extreme climate conditions in the Far East. Important advantages are low running costs due to the elimination of the above-ground filter systems, long lifetime of wells together with low costs for well maintenance and sanitation, no need for chemicals (e. g. for flocculation) and no costs for sludge disposal. Furthermore, the reaction zone acts as an additional barrier against harmful substances in the groundwater and bank filtrate. At the Tungus site near Khabarovsk, wells are being operated with an abstraction and infiltration rate of 150 m^3/h and unusually high well entrance velocities. In Egypt, further use of RBF depends on low-cost iron removal, as landside groundwater has high concentrations. The presentation will give an introduction to the technique of subsurface iron removal, highlight aspects of coupling with riverbank filtration, present results from the field studies and raise open questions to be addressed in the future. The advantages of subsurface iron removal and riverbank filtration as cost-effective and natural water treatment steps as well as their limitations will also be highlighted with respect to hydrogeologic conditions in Germany, Russia and Egypt.

Key words: River bank filtration, subsurface iron removal

THE STUDY OF HOW TOC CHANGING AND SIMULATION FORECASTING UNDER ARTIFICIAL RECHARGE CONDITION

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Artificial recharge using outside water is an effective method to solve the land subsidence and reserve water resources; however, artificial recharge could solve above environmental geological problems and also impact groundwater organic quality. Organic have characteristics of low concentration, high toxicity and hard degradation. So, to study how organic quality changed is very crucial under artificial recharge. The paper selects TOC (total organic carbon) to represent organic components to explore how they changed, because a single organic component is low concentration. Tap water as recharge water was taken to the fourth confined aquifer by well in the experimental site. Groundwater environmental quality assessment showed that TOC was higher than that in groundwater before recharge, so, potential pollution hazards needs experiment and simulation to explore. DO (Dissolved Oxygen), ions, TOC, temperature and microbe were monitored in two flow (parallel and perpendicular) paths during recharge experiment continuously. According to the concentrations of electron acceptors NO3-, SO42- changing could speculate that biodegradation occurred. The result of PCR-DGGE was to determine microbial community response law of natural biodegradation of TOC, it corroborates biodegradation occurred again during artificial recharge, and TOC, temperature and DO increasing is to make the microbial quantity and community diversity that means to promote biodegradation. The results show that DO,TOC increased and then deceased, because recharge water bringing DO,TOC to aquifer made them higher, microbial growth made them decreased, and microbial death. TOC transporting model was constructed in PHREEQC with data of TOC, electron acceptors, microbe, and then identification and authentication. According to revising different recharge amounts and forecast times, different forecast results were drawn to study TOC changing, the concentration of TOC is first increasing and then decreasing first and stable finally. Organic quality of groundwater after artificial recharge was to be evaluated that TOC of mixed water was not exceed, new groundwater can be used as reversing drinking water. The conclusions are these the microbial degradation of TOC occurred in artificial recharge process, microbial community diversity responses law of natural biodegradation of TOC; tap water as recharge water is feasible. The study of this paper could be used for the entire Shanghai artificial recharge project to provide technical support.

Key words: TOC; Artificial recharge; Simulation; Microbe.

LESSONS LEARNED FROM LARGE SCALE FIELD TESTING OF MANAGED AQUIFER RECHARGE TO IMPROVE WATER QUALITY IN COASTAL AQUIFERS OF BANGLADESH

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Large scale field testing of managed aquifer recharge to improve groundwater quality and thus to increase potable water access for rural communities in the hard to reach saline areas of the Khulna-Satkhira coastal belt of Bangladesh started in 2009 with two sites. The number of test sites has been increased 20 and all sites were monitored for water quality and quantity during in the 2012 monsoon. The objective of testing was to assess the impacts of injection of rainwater and/or treated pond water into shallow brackish aquifers at depths of about 35m below ground. Four to six recharge shafts of varying diameter and design were installed for infiltration via both by gravity and pumping plus gravity after pretreatment though sand filter. Electrical conductivity, pH, turbidity, temperature, arsenic, iron, total coliform and faecal coliform were monitored on a daily, weekly or monthly basis using portable meters, field kits and laboratory techniques. The amounts of infiltration, abstraction, rainfall and groundwater level were monitored on daily basis using flow meters and portable devices. Monitoring data from 20 sites show that significant volumes of water can be infiltrated into the target aquifers during the monsoon. Infiltration can continue during the dry period if the source pond is large enough and where there is no conflict with other uses. Out of 20 sites, groundwater salinity has reduced to acceptable levels, ≤2000 µS/cm, at 13 locations and local communities are using this water for drinking and other potable uses. Apart from salinity, iron concentrations have also reduced significantly at most sites. Arsenic concentrations were above 50 ppb (the Bangladesh standard) at some sites which has been reduced to acceptable levels. Faecal and toal coliform counts were mostly zero in abstracted water. Water quality is better in all respects than the most widely used water supply technology in the area, the pond sand filter. Communities have shown keen interest in collecting water from the test sites and at each site have formed a committee to oversee operations. At one site the user committee has taken over payment of the electricity bill through a nominal monthly contribution of Taka 10 per family. The sites are currently managed and operated by a full time site supervisor appointed through a partner NGO. This responsibility will eventually be handed over to the user groups after necessary capacity building. The sites are built to be resilient to cyclonic storm surges and are expected to continue providing safe drinking water even after major disasters like cyclones Sidr and Aila. However, this resilience is yet to be tested. Important lessons have been learned during the three years of field testing and technology can be up-scaled in partnership with government and non-government agencies and organizations engaged in water supply in the coastal area.

SPRINKLING INFILTRATION AND WELL INFILTRATION IN MANAGED AQUIFER RECHARGE FOR DRINKING WATER QUALITY IMPROVEMENT

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Abstract: There are 25 managed aquifer recharge (MAR) plants for drinking water quality improvement in Finland. The main objective is the removal of natural organic matter (NOM) from surface waters. A standard MAR consists of infiltration of water in an esker and withdrawal of water from wells downstream. The infiltrated water should have a residence time of at least around one month before withdrawal to provide time for processes needed to break down or remove NOM. Basin infiltration is used most often. A number of plants use sprinkling infiltration (SI) and well infiltration (WI). SI and WI can be attractive for areas not suitable for the construction of basins, e.g., eskers with slopes, and forest areas having recreational values with restrictions of tree cutting. Tavase Ltd. aims to construct a MAR plant (capacity 70 000 m3/d) to provide potable water for Tampere and Valkeakoski region in Southern Finland. The number of inhabitants in the region exceeds 300 000. Tavase Ltd. conducted extensive on-site tests. The objective was to study the applicability of SI and WI in the same area. Groundwater was pumped from two wells and led 1.5 km upstream to infiltration using a temporary, above ground pipeline. Infiltrated water flowed underground back to the wells for recirculation. The tests lasted for 308 days, and the maximum infiltration rate was 7000 m3/d. The tests were preceded by geophysical surveys, drilling and groundwater observations. Two separate sprinkling rakes were built with altogether 100 valves to ensure an even distribution of water. In addition, a smaller rake was built in a steep slope. Three infiltration wells (diameter 400 mm, depths 35–50 m) were constructed. Screens were placed in different depths: in the groundwater zone and the vadose zone. Different hydraulic surface loading rates were used for SI. Influence of sprinkling on the vegetation as well as possible signs of erosion and pooling were observed. Pumping rates into the infiltration wells were varied and water levels inside and outside the wells were monitored. SI worked well with all hydraulic loadings (0.03–0.17 m3/(m2h)). The design loading (0.07 m3/(m2h)) could easily be doubled. There was practically no erosion in the vegetated area and SI worked in the steep slope, too. Water travelled directly downwards to the groundwater zone, and there were no restricting soil layers. SI increased the growth of hay-type plants on the soil surface. This must be considered when planning SI. WI worked well in all wells. Infiltration rate of 7000 m3/d could be achieved in each well. When infiltration rate was increased, wells adjusted quickly to new conditions and the total rise of water level inside a well was only a few meters. In the neighbourhood, the elevation of the ground water table was around 2–3 m. Both SI and WI are suitable for MAR. Effects on the landscape are small compared to basin infiltration. For research purposes an advantage of SI is the possibility to study large areas comparatively quickly, because the equipment can easily be transferred. On the other hand, WI can also be used in areas having impermeable soil-layers. With WI, the quality of infiltrated water must also be considered.

IMPACT OF AQUIFER RECHARGE ON THE DRINKING WATER QUALITY OF MADURAI - CASE STUDY

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The aquifer is recharged through rainwater harvesting, percolation ponds, rechargeable water sheds, deepening the ponds, lakes, rivers and the available water is allowed to let into it. Thus the aquifer is refreshed with the water table and so the sources of drinking water have shown good quality in terms of its parameters and its status of palatable. The water quality index tested using APHA methods before and after the recharge has indicated that the impact of recharging the water table has substantially improves the quality of drinking water. The taste, TDS, Fluoride, Arsenic, Salts, have been restored to the normal level by the aquifer recharging. Interesting reports indicate in this study proves to be an eye opener for the water managers to manage the drinking water status through recharging aquifer in any parts of the globe.

Key words: Recharge, Aquifer, Drinking water, parameter, water quality.

Track 1.2 : MAR for rural and irrigation water supplies

DEMONSTRATION PROGRAM TO MITIGATE DROUGHT AND FLOODING IN THE NORTHERN PART OF THE CHAO PHRAYA RIVER BASIN, THAILAND, USING ASR METHODS PART 2

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The Chao Phraya River lies in a low alluvial plain and runs from central Thailand south through Bangkok and into the Gulf of Thailand. The Chao Phraya River Basin includes the major rivers the Ping, the Wang, the Yom, and the Nan, which feed into the Chao Phraya River from the north, draining the northern parts of Thailand. This river system forms wide alluvial valleys which are used extensively for agriculture. Rice is the primary crop in the northern part of the basin, and groundwater use is abundant. Annual rainfall in the Chao Phraya River Basin ranges from 1,000 to 1,400 mm with 90% occurring between May and October. This results in heavy flooding during most years, with the flood waters then having to travel south through population centers north and south of Bangkok. The effect of this was seen dramatically during the 2011 floods where large areas of urban populated land were under water in the Bangkok area. Additionally, groundwater is used in abundance in the river basin. Double, or even triple, crops of rice are farmed each year, resulting in seasonally or year-round depressed groundwater levels. The Yom River sub-basin is adjacent to the Nan and Ping River sub-basins; the surface water of both are controlled via large dams. A major dam was not constructed on the Yom River because of environmental and economic reasons. Instead, a major groundwater wellfield was developed to supply irrigation water throughout the year. Over 200 deep alluvial wells are pumped in the area, contributing to the depressed groundwater levels. An Aquifer Storage Recovery (ASR) test facility was constructed in the northern part of the river basin adjacent to the Yom River in the Sukhothai Province, near the City of Swankalok. The ASR test facility is completed into the Yom River alluvium and consists of two recharge wells; an upper aquifer well (35 to 44 meters screened depth) and a lower aquifer well (74 to 83 meters screened depth). A floating pumping station was constructed to obtain flood water from the Yom River and transport it to a small treatment system, ultimately to be used to pump, treat, and store the flood water in the aquifer. The ultimate ASR application is intended to benefit the area by increasing groundwater levels in the aquifer, and reducing the volume of flood water that would eventually flow south, through the populated areas north and south of Bangkok. Part 1 of the Sukhothai ASR test program included the siting and construction of the test facility, and complete commissioning. This was completed in 2010. Part 2 of the test program is ongoing and scheduled to be complete in about February 2014. This paper will present the test program details, including the facility design concepts, hydrogeological testing methods, and results to date. Testing challenges, such as adequate treatment methods prior to recharge, and alternative treatment methods, will be discussed. Part 3, future applications and benefits of ASR in the area that are being considered, will also be presented.

MANAGED AQUIFER RECHARGE AS A KEY ELEMENT INSONORA RIVER BASIN MANAGEMENT(MÉXICO)

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Arid regions frequently have competing urban supply and agricultural irrigation demands in excess of availablescarce water.This paper presents a Decision Support System (DSS) as an instrument to find the optimal scheme for water resources management from multiple suppliesusing managed aquifer recharge (MAR). The DSS capabilities are demonstrated through its application to the Sonora River Basin.

This Sonora River Basin watershed, located in northern Mexico, contains a wide variety of agricultural zones and many small towns along the river. The most important urban center is the city of Hermosillo, where there is a concentrated water demand for urban and industrial uses. Here, the scarcities of water demanded from urban areas, as well as water shortages and inefficient use of water (especially by the agricultural sector) are creating problems for water and food security to the region.

The DSSD includes the hydrological modeling of the surface-water system, the groundwater-flow model, and the characterization of the water quality from various sources.

The results establish that the increasing volume of demand for water will be difficult to satisfy with the current supply-and-demand allocation schemes. Because alternative sources are needed to mitigate the differences between the supply and demand for water, MAR represents an option that could reduce this disparity and sustain the expectations of integral development of urban water supply and irrigation within this basin. This scheme also addresses potential improvements in water quality and helps palliateglobal climate change.

Keywords: Conjunctive use, groundwater, managed aquifer recharge, wastewater, climate change

Track 1.3: MAR in conjunctive use of surface water and groundwater

BEYOND SUSTAINABILITY: USING MANAGED AQUIFER RECHARGE TO DOUBLE THE YIELD OF THE ORANGE COUNTY GROUNDWATER BASIN

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In the early 1900s, the people of Orange County, California did not know their limits. As the area transitioned from ranchland to irrigated agriculture, surface and groundwater supplies were rapidly used up. Groundwater overdraft, declining groundwater levels and seawater intrusion resulted. Out of this crisis, arose the Orange County Water District (OCWD), which was created by the State of California in 1933 to manage the groundwater supplies of basin. In 1936, OCWD started purchasing 10 km of the Santa Ana River channel in order to increase the recharge of surface water to the groundwater basin. This was the start of what is now an elaborate network of recharge facilities that can recharge Santa Ana River base flow, storm flow, imported surface water and recycled water. In addition, two seawater intrusion barriers were constructed to protect the groundwater basin from seawater intrusion and to maximize the use of storage. Now, over 100 years after Orange County exceeded its limits, it has developed a large managed aquifer recharge (MAR) system with multiple sources of supply that has more than doubled the sustainable yield of the groundwater basin. The application of MAR in other parts of the world can yield similar results as long as there is an integrated approach to water management and regulation, a sound understanding of watershed and groundwater basin hydrology, and broad stakeholder support.

ORIGIN, RECHARGE MECHANISM AND APPARENT AGE OF SHALLOW GROUNDWATER IN THE NDOP PLAIN, NORTH WEST CAMEROON

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Hydrological investigations to assess groundwater resources and develop sustainable management strategies require a variety of scientific information, including the origin, rate and mechanism of recharge and residence time. Shallow groundwater of unknown origin, recharge and residence time is a vital resource for sustenance to over 200,000 people in the Ndop plain (a semi-urban community in North West Cameroon). This study investigated 72 water sources for δ18O, δD, 3H and Cl- in order to provide a management tool for the valuable groundwater resource. The objectives were to determine groundwater origin and recharge mechanism, timing and rate of recharge, and apparent recharge period-residence time. The narrow range of δ18O (-2.69 to -4.11 ‰), d-excess (8.34 to 13.87 ‰) and 3H (2.4 to 3.1 TU) in the groundwater suggested a uniqueorigin and homogenous unconfined aquifer. Like surface water, a narrow cluster of groundwater on the Ndop Meteoric Water Line (NMWL) and Global Meteoric Water Line (GMWL) with a slope of 6.59 indicated meteoric origin, rapid recharge with an insignificant modification by evaporation during and after recharge, and one dominantrecharge mechanism recharge. A high mean d-excess of 11.81 ‰ in groundwater suggested that besides the Atlantic moisture, recharge was derived partly from inland recycled vapour under low relative humidity conditions. From the δ18O-altitude relationship, 80 % of groundwater originated from local precipitation at low altitude (<1,260 m) within the plain by direct diffuse recharge while 20 % was from precipitation in the surrounding high altitude (>1,449 m) through localised recharge or mixed with depleted inflowing streams and rivers from the high elevations. A homogenous cluster of δ-values in groundwater and surface water between May and June rains on the NMWL indicated a selective recharge during these months. Chloride mass balance showed that about 20 % of the 1,540 mm annual precipitation recharged groundwaterindicating high annual recharge. This high amount of recharge is suitable for development of the groundwater resource for agriculture. The >2.4 TU in groundwater suggested post-1952 recharge with an estimated mean residence time of 27 years. Groundwater is young and renewable. The similar isotopic range in the shallow groundwater of this study and some related studies in the tropical low-latitudes of West Africa suggested that modern rainfall recharge of groundwater in these tropical low-latitudes, with comparable climatic regimes and related moisture sources (the Atlantic Ocean) occurred through a similar mechanism and limited time of the year.

INTEGRATED SURFACE WATER AND GROUNDWATER MODELING FOR OPTIMIZING MAR STRUCTURES IN THE CHENNAI REGION

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Chennai is the 4th largest metropolitan city in India located on the Coromandel Coast of the Bay of Bengal. Water supply to the city is met from reservoirs and large amount of groundwater is also pumped from the bore wells located in the well-fields of Araniyar and Koratalaiyar river basin (A-K Basin) north of Chennai. Over pumping of groundwater from the well-fields to meet the demands of the fast growing city of Chennai as well as for local irrigational needs have led to significant seawater intrusion. To overcome this problem of seawater intrusion, as a measure of MAR several check dams has been constructed across the two rivers to increase the groundwater recharge. A total of 8 check dams have already been constructed which reduce the outflow into the sea. The water stored in each of these dams infiltrates into the underlying aquifers and increases the groundwater level. A major part of the EU funded project Saph Pani ("Enhancement of natural water systems and treatment methods for safe and sustainable water supply in India") commenced in 2011 and involves optimizing the MAR structures in A-K basin. Based on this project the present study aims at analyzing the effects of these and possible additional check dams to counteract the growing conflicts between different stakeholders in the region. Various researchers have questioned the efficiency of check dams in dry regions such as Chennai, where evaporation losses are substantial. These analyses have been performed by setting up a three dimensional unsaturated-saturated groundwater flow model for the alluvial aquifers in the A-K basin. The model was calibrated in transient state over a period of 15 years. Model stability and sensitivity analysis were conducted and a general water balance of the whole system has been studied. The model results show particularly strong dependencies between groundwater potentials and river recharge rates, from which it was concluded that the use of a dynamically coupled approach between the surface water and groundwater components is required to analyze the effect of potential measures within the basin. Further, the model was coupled to a hydrodynamic surface water model, also describing rainfall run-off processes. By this integrated model system, a detailed analysis of the interaction between the surface water and groundwater is being performed, focusing on a possible relief of the water stresses by optimized use of MAR structures as well as integrating a density -dependent relation between groundwater potentials and salinity. Initial results have shown that by introducing new check dams, additional infiltration can be generated along the rivers, which at least could support irrigation water demand for the surrounding farmers, especially during the dry season. Further analyses will prove, whether a significant contribution can also be achieved through the check dams over a larger area of the basin.

Track 1.4: Mitigating geological problems using artificial recharge - land subsidence, earth fissures, seawater intrusion

ASCE/EWRI STANDARD GUIDELINES FOR LAND SUBSIDENCE CAUSED BY FLUID WITHDRAWAL

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Land subsidence caused by fluid withdrawal, especially groundwater pumping, has been well recognized as one of the major geological hazards by hydrogeologists and engineers. In 1984, UNESCO published a guidebook on land subsidence to present data collected and the main results of hydrological studies, as well as to provide information on hydrological research techniques. After nearly 30 years of development; new technology and approaches have been developed to detect, monitor, and control land subsidence. Over-withdrawal of groundwater due to growing water demands continues to put more stresses on regional aquifers. More and more aquifers were also used for underground storage of recoverable water as an important component of managed aquifer recharge (MAR) projects. Water managers and planners, as well as hydrogeologists and engineers, need contemporary guidelines to better manage groundwater resources and reduce potential risks of land subsidence under new groundwater development scenarios. The ASCE/EWRI Managed Aquifer Recharge Standards Committee (MAR SC) reviewed the UNESCO guidebook and recommended the development of an ASCE/EWRI standard guidelines on the title of this abstract. A Land Subsidence Subcommittee (SC) was established to carry out the task. In this presentation, the authors will describe the process of developing the Land Subsidence guidelines. Based on consensus during SC meetings and teleconferences, SC members determined the details of what should be included in the guidelines, especially the new technologies and approaches that were developed after 1984 and significant new information of land subsidence found worldwide since 1984, and then assigned a lead author or authors to develop the major sections based on their interest, expertise, and availability. The SC members submitted contributions to the designated lead author for integration. The Corresponding Editor reviewed and modified the text for consistency with other sections and submitted the draft text to the MAR SC for web-based balloting through ASCE. If a section did not pass the ballot, it was revised by the editor and the section authors for re-balloting until it was approved or withdrawn. The MAR SC then sent a summary of the balloting and the resolutions reports with the draft guidelines to the EWRI Standards Development Council and the ASCE Codes and Standards Committee for approval. This was followed during a public comment period where those comments were resolved and approved by the MAR SC through a similar balloting process. The final Standard Guidelines was being processed and was based on consensus of the Standard Committee and the ASCE public, and eventually was approved by the ASCE Codes and Standard Committee for publication. The new guidelines will be a useful tool to water resources project planners and design professionals, especially in areas where aquifers are susceptible to land subsidence.

HYDROCHEMISTRY AND STABLE ISOTOPES DURING SALINITY INGRESS AND REFRESHMENT IN SURFACE- AND GROUNDWATER FROM THE ARANI-KORATALLAI (A-K) BASIN NORTH OF CHENNAI (INDIA)

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In Chennai (India) public water supply and agriculture depends on groundwater to various extends, but the valuable resource shows increasing salinity over the last decades due to seawater intrusion. Different managed aquifer recharge (MAR) structures, i.e. injection wells, infiltration ponds have been investigated over the last decades and found to be ineffective due to the lack of source water. The main MAR intervention in the basin are check dams constructed across the ephemeral streams.

This paper aims at identifying major hydrogeological processes which leads to salinity ingress in the main aquifer (A-K basin) and investigates the effect of MAR structures such as check dams on local and catchment scale. More than 20 groundwater samples and 10 surface water samples from the coastal aquifer and one newly constructed check dam were collected from October 2011 to November 2012 and analysed for major hydrochemistry and stable isotopes (δ18O, δD). Regional hydrochemistry is discussed by a combination of stiff diagrams, Cl/Br ratios, ion exchange diagram and stable isotopes (δ18O, δD). The identified hydrgeochemical processes were high saline evolution due to intensive seawater evaporation for commercial salt production, up-coning of saline water and typical ion displacement chromatography under refreshening and salinisation conditions. Stable isotopes give new insights on i) mixing processes of different end members ii) occurrence and degree of evaporation in ground- and surface water and iii) isotopical characterisation of groundwater recharge. Shallow fresh water samples show a depleted isotope signal and represents groundwater recharge which carries the depleted signal of winter monsoon rain of the study area. On a local scale, chloride and stable isotopes of water are used as tracers to indicate recharge and mixing of ambient groundwater with recharge water from the check dam. Water samples from the check dam show, as expected under the climatic conditions, a strong evaporative enrichment with time. Mixing of ambient groundwater with recharge water takes place from the beginning of the recharge period between November and January. It is concluded that recharge is limited or absent during later phase (February to April), which makes the check dam ineffective due to high evaporation losses. This adverse effect may be managed by opening the water gates of the check dam structure during time of low infiltration and high evaporation. Based on the results and available data from other sources a conceptual hydrogeological model is developed and gives an overview of major processes leading to salinity ingress and the role of MAR structures in this context. Water budget estimations for the A-K basin highlight the overall effect of MAR. Preliminary results show that MAR infiltration cannot compensate the high groundwater abstraction amounts and without demand side interventions the problem of salinity ingress will persist or may get worse.

AQUIFER STORAGE RECOVERY: AN ASR SOLUTION TO SALT WATER INTRUSION AT HILTON HEAD ISLAND, SOUTH CAROLINA, USA

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Public water supply wells in the Upper Floridan aquifer at Hilton Head Island, South Carolina, USA, have been failing due to salt water intrusion, caused primarily by industrial and municipal groundwater withdrawals at nearby Savannah, Georgia. To address this problem a pipeline has been constructed to import treated drinking water from the mainland; a reverse osmosis water treatment plant has been constructed on the island, treating brackish water from the Middle Floridan aquifer, and a deep Cretaceous aquifer well has been constructed supplying warm, slightly brackish water to a second RO plant. During 2010 an ASR project was initiated for Hilton Head Public Service District at the north end of the island. HHPSD has lost five public supply wells to saltwater intrusion and expects to lose the remaining seven wells within about 10 years. The purpose of the ASR well is to store drinking water during winter months when demands are low, available supply is plentiful, and the cost of imported water is reduced by about 50%. The stored water is then recovered to meet peak demands during summer months. The storage zone is the Middle Floridan Aquifer, which is present beneath the Upper Floridan Aquifer and is brackish. Work included completion of an ASR feasibility study; design of one ASR well, two monitor wells and wellhead facilities; obtaining required permits; construction of wells and wellhead facilities; cycle testing, and placing the facilities into operation. All work was completed within 23 months and the well was placed into operation during 2012. An excellent set of hydraulic and water quality data was obtained during the cycle testing program, confirming suitability of the Middle Floridan Aquifer for ASR storage. South Island Public Service District then initiated a separate ASR program at the south end of the island. Work underway includes construction and equipping of two ASR wells in the Middle Floridan Aquifer; one brackish water production well in the Middle Floridan Aquifer and five monitor wells. SIPSD has recently lost one Upper Floridan Aquifer public supply well to salt water intrusion and expects to lose two more by 2015, and all nine remaining wells within the next 25 to 40 years. The production well was intended as a backup reliability well in case of failure of the deep Cretaceous aquifer well, which supplies one third of the SIPSD annual average drinking water supply. The two ASR wells and the Middle Floridan Aquifer brackish water production well will provide needed system reliability at relatively low cost compared to other alternatives.

Key Words: aquifer storage recovery; salt water intrusion; Hilton Head Island

COMBINING DRINKING WATER PRODUCTION WITH THE WORLDS' MOST INNOVATIVE COASTAL DEFENCE PROJECT TO KEEP DRY FEET - INSIGHTS ON EFFECTS, INTERCEPTION MEASURES AND DYNAMIC MONITORING PLAN

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Since 1887, Dunea produces high quality drinking water using the dune area at Monster (Province of South Holland, the Netherlands). Annually, 8 billion litres of water is produced here using artificial recharge and recovery with shallow wells and infiltration lakes. The dunes are an important step in producing drinking water serving as an underground buffer, levelling fluctuating in temperature and quality and removing bacteria and viruses from the infiltrated water in a natural way. Since space is limited in the Netherlands, the drinking water production of Dunea is closely matched with surrounding land uses and natural constraints. This prevents groundwater nuisance, upconing and intrusion of salt water and in this case also movement of a nearby groundwater pollution. This is especially true in Solleveld where the dunes are fairly low and small; the coast is less then 350 metres from the recovery wells. The coast of Monster was identified as a weak link in the coastal defence of The Netherlands. Because of this, two coastal defence projects were carried out in 2009 - 2011. The first project involved creating an extra dune ridge in front of existing dunes. This leaded to intrusion of a large volume of seawater. Directly after completion, the Sand Engine was constructed. This hook shaped sand peninsula will supply the coast with sand for the coming decades due to erosion and deposition along the coast. These two major coastal defence projects would obviously influence the tightly balanced hydrological system of Solleveld. Without hydrological intervention, the drinking water production would no longer be sustainable in this area. To study the effects of these projects and to find a solution to combine coastal defence and drinking water supply, field research and effect modelling were used interactively. This paper will give insight in the challenges faced to protect the drinking water supply against salt water intrusion and groundwater pollution by presenting field research and groundwater model results. A study combining both resulted in the design of a system of 28 interception wells on top of the dunes. Since the morphology of the coast is very dynamic here, the measure is demanded to be very flexible to enable mitigation of negative effects of the coastal defence projects now and in the future. The accompanying monitoring plan focuses on both the effectiveness of the system and 'unexpected' effects. Since sea levels are expected to rise in the future, coastal defence projects will play an increasingly important role in coming decades. The insights presented in this paper might help you to face what can be your challenge in the near future.

Track 1.5: Rainwater and stormwater harvesting via MAR

FEASIBILITY OF AQUIFER STORAGE AND RECOVERY OF STORMWATER IN A DUNEFIELD IN WESTERN SAUDI ARABIA

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An average of only 50 mm of rainfall occurs in the hyperarid region of central Western Saudi Arabia. Typically, rainfall events produce extreme flash floods that convey large-volume flows within wadi channels from the upper drainage system to the lower basin or to the sea. Dams are used to trap some of this flood water and cause part of it to recharge the aquifer system underlying the wadi channel and the adjacent banks of the channel. While wadi dams do serve a useful function in trapping and storing stormwater, the quantity of stormwater that actually recharges the aquifer system is relatively small in most cases because the reservoirs are commonly lined with mud that is carried in the stormwater. The rate of recharge tends to lessen with time as multiple flood events create a thickening of the mud layer in the reservoir bottom above the underlying aquifer. Therefore, only a small percentage of the stored water recharges the aquifer and the remainder evaporates with no potential beneficial use. Also, the wadi dam/reservoir facilities are commonly located in areas remote to potential users of the water for municipal systems or irrigation.

A dam/reservoir system located in Wadi Al Murwani in Western Saudi Arabia was recently constructed and is expected to contain a maximum stored water volume of 150 million m3. A hydrologic assessment of a dunefield lying on the downstream was conducted to evaluate its potential use for aquifer storage and recovery of stormwater from the Murwani reservoir. An engineering investigation was also conducted to provide the preliminary design parameters for the ASR system. The dunefield is located about 45 km downstream of the dam and there is a 110 m elevation difference between the base of the dam and the upper level of the dunefield. Conveyance of the water from the reservoir to the dunefield storage site can be accomplished using a gravity feed without pumping. This design makes the recharge system extremely energy efficient.

Measurements of the dune sand properties showed that the mean grain diameter is 0.07 mm, the average porosity is 0.4, and the average hydraulic conductivity is 9 m/day. The study also revealed that the hydraulic conductivity exponentially decreases with increasing weight fraction of clay. The desert pavement sediments underlying the dune sand were found to contain a significant percentage of clay, thereby creating a basal confinement that will prevent significant vertical loss of stored water. A parallel study on the evaporation extinction depth within the dune sands yielded a value of about 1m, so the recharged water must be keep below this depth to avoid evaporative losses. To maintain the stored water within the groundwater system and to reduce horizontal storage losses, it will be necessary to construct slurry walls around the down-gradient perimeter of the storage sites within the dunefield.

Based on the field and laboratory investigations conducted and some preliminary engineering designs, it is feasible to convey and store stormwater in the Wadi Khulays dunefield for future use by growing coastal communities. The use of this source of freshwater would benefit local needs by use of a source that is less expensive to operate and has lower energy consumption compared to use of desalinated seawater.

TOWARDS ROOF RUNOFF REPLENISHMENT OF GROUNDWATER IN JINAN, CHINA

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Jinan is well known as the "Spring City of China". With the rapid urbanization and industrialization, Jinan faces the problems of water demand exceeding karst groundwater available, flooding resulted from increased surface runoff due to the urban expanding towards south mountains and steep topography and worse drinking water quality because of karst groundwater supply replaced by Yellow river water. Managed aquifer recharge is one of important measures to conserve karst groundwater and prevent an increase in stormwater runoff. The pilot project of managed karst aquifer recharge with roofwater through recharge well was done at the campus of University of Jinan, including 10 parts of capture zone of roof of teaching building, pre-treatment of a fine screening, a first-flush of 6mm removal device, a settling tank, a rapid zeolite material filter, calmed inlet, recharge well of 230m with subsurface storage of unconfined limestone aquifer, observation wells of two, and end use of drinking water and keeping spring flow etc. Based on continuous monitoring of roofwater quantity and quality of 28 indexes in study area from 2008 to 2012, variation of roofwater quality with time, rainfall intensity, cumulative rainfall and season were mastered. Concentration distribution probability of roofwater main pollutants was estimated and the source of contaminants in roofwater was analysed. In August 2011 we conducted 2 roofwater recharge tests separately, and 8 in flood season 2012. The total recharge amount has up to 254m3. From 2010 to 2012, we have carried on 45 times monitoring of injection well ambient indicators and monitoring wells successively. And the conclusion was that chemical dynamic change in groundwater was mainly affected by rainfall dilution effect. Measurement of water quantity and quality of each part of recharge system and aquifer was conducted during each rainfall event, parameters including pH; temperature, EC, dissolved oxygen, oxidation reduction potential, Na+; K+; Ca2+;Mg2+; Cl-, SO42-, HCO3-, NH4+N, NO3-N, NO2-N, Zn and Pb, and the results showed that ammonia nitrogen removal rate of regulating pool was 27.1%, and filter tank 92.9%. Compared with Drinking Water Standard and Groundwater Quality Standard III, we concluded that ammonia nitrogen removal effect of the project was good, but turbidity and nitrite were still exceeded. In 2011, interactions experimental simulation between recharge roofwater and aquifer on different groundwater and roof rainwater mixing ratios (9:1, 7:3, 5:5, 3:7 and 1:9) were done. By PHREEQC, results were obtained that rainwater recharging could strengthen minerals dissolution in the aquifer. Application of Australia aquifer recharge management guidelines, risk assessment of the project was done. The result showed that karst aquifer recharge with roof rainwater was overall feasible through deep wells. But pre-treatment filtering material need to be improved, other more, nitrite and turbidity should also be controlled. Finally evaluating engineering economic benefit of the project, including national economic and financial evaluation, the national economic, ecological and social benefit of the project was remarkable but it was not reasonable by financial evaluation. In summary, The MAR approach applied at university of Jinan is intended to pilot the wides application of MAR, particularly in the direct recharge area of karst groundwater.

Track 1.6: Reclaimed water reuse via aquifer

MANAGED AQUIFER RECHARGE WITH RECLAIMED WATER IN UAE

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United Arab Emirates relied on groundwater as the main source of fresh water for several decades in the past. This resulted in the deterioration of the non-renewable groundwater aquifers; and thus, desalination plants have become the major source of fresh water supply in UAE. More than 70 desalination plants have been built in the last two decades. A major concern, therefore, is the vulnerability of these desalination plants to pollution and emergency conditions. In emergency conditions, the maximum amount of stored water in reservoirs and distribution systems will be enough for only 48 hours. Currently, production of these plants exceeds national water demand and the surplus is used to recharge groundwater in specific locations. While production of desalination plants is constant, demand is continuously increasing and soon will exceed production and then new plants will be needed. However, construction of new desalination plants cannot continue forever. In the meantime, treated wastewater is normally unmanageably dumped into the desert or the sea. Therefore, the main objective of this paper is to develop an integrated approach to increase the national strategic groundwater storage through managed aquifer recharge of recycled water. This approach will include hydrogeological and environmental feasibilities of water recycling and must be appropriate, environmentally sustainable, technically viable, economical, and socially acceptable. The focus of this study will be on Dubai Emirate. Currently, about 50% of the half million cubic meters of sewage water generated every day in Dubai is already being reused after treatment in irrigation of farms, parks, and golf courses; while the rest is diffused after purification. The Hydrological feasibility will include identifications of the best geological layers to receive the injected recycled water; whereas environmental feasibility will include assessment of risks on the public health and the environmental. First, previous geological and geophysical studies conducted in the Emirate of Dubai will be reviewed to develop a hydrogeological conceptual model for the area. Based on this model, potential recharge areas will be identified. Then, a groundwater model will be developed and used to examine several scenarios of recharge in these selected areas. Characteristics of the recycled water will be used in this model. Possible physical, chemical, and biological processes that control the transport of the recharged water in the subsurface will be induced in the model. Potential risks of recharged recycled water on the quality of indigenous groundwater, public health, and the environment will be studied in this paper. Results of this study will assess replenishing the aquifers with 182.5 million cubic meters of sewage water generated annually in Dubai. If this water is wisely recharged into groundwater aquifers, it can help building a back-up reservoir to face potential threats of shortage in freshwater supply from desalination plants in emergency cases.

A SYNERGISTIC TREATMENT HYBRID OF MANAGED AQUIFER RECHARGE-OZONE FOR WASTEWATER RECLAMATION AND WATER REUSE

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The synergistic hybrid treatment process of a managed aquifer recharge combined with ozone (MAR-O3) was evaluated for wastewater reclamation and water reuse. Soil-column experiments were set-up to study bio-acclimation period, oxic (aerobic) condition and depth of MAR. Ozone process was optimized for lower ozone dose (0.5 mg/mg), prior to and after MAR, and N-nitrosodimethylamine/ ergana control. The bulk organic matter and trace organic contaminants (TorCs) were effectively removed during MAR-O3 treatment hybrid. The bulk organic matter analysis revealed that both MAR and ozonation reduce soluble-microbial (protein-like) products by greater than 50% while only ozonation reduces fulvic and humic substances by greater than 80%. Ozonation is an effective oxidation process for a vast array of TorCs, however it's selective toward recalcitrant TorCs (kO3 ≤ 10). Thus, removal of recalcitrant bulk organic matter and TorCs during ozonation was analyzed prior to and after MAR for possible enhancements. The attenuation of recalcitrant TorCs were shown to be greater in ozonated MAR effluent compared to MAR effluent, which the higher biodegradable dissolved organic carbon (BDOC) content during ozonation may be a contributing factor. A slightly higher ozone dose of 1mg/mg significantly reduced UV absorbance (< 0.03 cm-1), fluorescence (≤ 33%), DOC (< 2 mg/L) and total (Σ) TorC concentrations (≤ 27%), resulting in near drinking water quality. However, no significant improvement in the removal of Σ TorC concentrations as well as the individual TorC concentrations was observed for the range of ozone dose from 0.5 to 1.0 mg/mg. In addition, ozonation prior to MAR was superior for overall removal of DOC, while ozonation after MAR was more effective in reducing UV absorbance, fluorescence, and TorC concentrations. Therefore, implementing MAR prior to ozonation appears to remove the bioamenable compounds that react rapidly with ozone, thereby reducing oxidant scavenging (demand) and treatment cost.

COMBINATION OF MIEX® RESIN AND OZONATION FOR REDUCTION OF DISSOLVED ORGANIC MATTER DURING AQUIFER RECHARGE USING MUNICIPAL EFFLUENT

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A magnetic anion exchange resin treatment (MIEX®), which has been proved as effective in removing natural organic matter in water treatment plant, was investigated for its removal characteristics on dissolved organic matter (DOM) in secondary effluent. The DOM removal efficacy was compared between MIEX® and the commonly used ozonation (alone or combined), as the pretreatment of soil aquifer treatment (SAT) for aquifer recharge purpose. The DOM removal efficacy increased with the increasing of MIEX® resin dosage (5-20 mL/L), and a dosage of 5-10 mL/L was suggested for the SAT pretreatment. Under this dosage, 30% DOC was removed from secondary effluent, which was much lower than that found with drinking water resources. The aromatic DOM with apparent molecular weight (AMW) ranging 2-5 kDa was preferentially removed by MIEX®, specifically the aromatic proteins. Differently, ozonation preferentially destroyed larger AMW (>10 kDa) DOM, specifically fulvic and humic acid-like materials, which supported the better performance and complementary effects when combined the two technologies. The DOM removals of SAT were significantly improved with the help of pretreatments (MIEX®, ozonation, and combined MIEX®/ozonation). The DOC and UV254 values were reduced by 40-77% in SAT combined with pretreatments, compared with 20-30% reduction achieved by only SAT. Fluorescent matters were reduced by around 50% by SAT and MIEX/SAT, while higher reductions of 76-84% were achieved in SAT with pretreatment of ozonation and combined MIEX/ozonation. Different modes were identified using high performance size exclusion chromatography with multi-wavelength UV detector: ozonation helped improve the SAT efficiency on removing DOM of 1.7-5.3 kDa, whereas MIEX® treatment attributed to the removal of small AMW (0.5-1.7 kDa) DOM responsible for the absorbance peak at 300 nm. Based on these results, DOM removed by MIEX® treatment is complementary with those removed by SAT and ozonation, and the highest DOM removal was found in combined MIEX®/ozonation/SAT.

KEYWORDS: emission–excitation matrix (EEM); groundwater recharge; molecular weight distribution; municipal effluent; pretreatment; magnetic anion exchange resin.

Theme 2: Design and construction of MAR

Track 2.1: Advanced methods for selection of aquifers, sites and methods

PREDICTION OF HYDROGEOLOGICAL AND ENVIRONMENTAL IMPROVEMENT BY MANAGED AQUIFER RECHARGE IN XINJIANG

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Managed aquifer recharge (MAR) is the useful tool to allocate water resource and improve hydrogeological and environmental conditions in arid regions. Water shortage and salinization are the common problems confusing several administrative regions in Xinjiang, and have become an issue of great concern recently. In this study, the data of aquifer properties and groundwater quality by previous geological survey and the data of reclaimed water quality supplied by municipal sewage treatment plants from typical arid regions of Xinjiang was collected and analyzed. Different types of MAR were compared and the optimized ones were selected by predicting the hydrogeological and environmental improvement using an assessment model in consideration of dynamic groundwater quality. The result showed that the corresponding MAR could be the solutions for typical arid regions of Xinjiang. The effects of MAR depend on both the original hydrogeological properties of aquifer and the quality of reclaimed water. This mode should be further studied so that cost-effective MAR could be widely applied in arid regions of Xinjiang.

ADVANCED AQUIFER CHARACTERIZATION AND MODELING FOR THE OPTIMIZATION OF MANAGED AQUIFER RECHARGE

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Managed aquifer recharge (MAR) will play an increasingly important role in solving water scarcity. The performance of MAR systems depends primarily upon local hydrogeology. Greatest opportunities for improvement in the implementation of MAR systems lie in the targeted application of conventional and advanced technologies to improve aquifer characterization. Surface geophysics (e.g., VES, TDEM, and seismic reflection and refraction) can provide generally low resolution, but areal extensive data on subsurface hydrogeology. Times series of relative microgravity measurements have been used to map changes in both vadose and phreatic zone storage and to augment monitoring well systems. Surface nuclear magnetic resonance (NMR) has the potential to provide quantitative data on water-filled porosity and pore size distribution, which, in turn, can provide an estimate of hydraulic conductivity. Standard borehole geophysical logging techniques can provide coarse-scale data on aquifer heterogeneity. Advanced borehole logging techniques, such as NMR, microresistivity imaging, and gamma ray spectroscopy, have been used in MAR projects in the USA and UAE to provide fine-scale petrophysical data (e.g., porosity, porosity-types, pore-size distribution).

Groundwater modeling is used in MAR investigations to evaluate system feasibility and to optimize system design and operation. Opportunities to improve groundwater modeling exist through the application of advanced reservoir simulation platforms (e.g., PetrelTM) that allow for the processing and integration of available lithological, geophysical, and aquifer testing data, and their subsequent incorporation into groundwater flow models. Advanced groundwater modeling programs (e.g., Eclipse®) are available that can be used to simulate complex aquifers, such as dual-porosity systems and variable density.

Key words: Managed aquifer recharge, aquifer characterization, surface geophysics, borehole geophysics

TOWARDS SUCCESSFUL AQUIFER STORAGE AND RECOVERY (ASR) IN COASTAL AQUIFERS: USE OF ASR FEASIBILITY MAPPING AND MULTIPLE PARTIALLY PENETRATING WELLS

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Rainwater harvesting is an important strategy to cope with increasing shortages of fresh irrigation water in the Dutch greenhouse horticulture. Small- to medium-scale aquifer storage and recovery (ASR) is a suitable technique for seasonal storage of harvested rainwater in brackish to saline confined aquifers, without claiming large areas of valuable land. Freshwater storage in these aquifers can be inefficient due to ambient groundwater entering the well during recovery in consequence of lateral groundwater flow and buoyancy effects. A priori performance estimation and optimization of the injection and recovery scheme can prevent ASR failing and are recently studied in a large coastal greenhouse area.

Aquifer properties and various ASR operational parameters in the coastal study area (~500 km2) were processed in a Geographical Information System (GIS) to predict ASR performance using fully penetrating wells. Generated spatial performance maps predict significant spatial variation in ASR performance. This indicates that small-scale ASR using fully penetrating wells will fail in large parts of the study area, especially due to buoyancy effects. An optimized set-up with multiple partially penetrating wells in one borehole (MPPWs) is therefore introduced to inject freshwater primarily at the base of the aquifer, and recover this at the aquifer top.

Application of the MPPWs in a well-monitored field pilot firmly reduced the freshwater loss caused by buoyancy effects in a 28 m thick brackish sand aquifer. This successful small-scale ASR system was used to supply local greenhouses (2 ha) with irrigation water during the summer of 2012. The injection, storage and recovery phases were modelled using SEAWAT, using head observations and chloride concentrations for calibration of the model. The benefits of the MPPWs were quantified by modelling of a fully penetrating well at the same location, which was never able to recover more than 20%. The MPPW set-up, however, projected a long-term recovery efficiency of approximately 60%.

The lack of injection at the shallow wells primarily used for recovery prevented the formation of iron oxides which potentially sorb released (trace) metals. Cation exchange, on the other hand, repeatedly contaminated the injected water with sodium at the base of the aquifer. During the last stage of recovery therefore, arsenic and sodium were threatening the quality of the recovered freshwater, rather than chloride. This ASR study shows that there are significant benefits to the use of MPPWs for ASR concerning freshwater recovery in an area with large variations in aquifer suitability, but also that geochemical interactions within the target aquifer need specific consideration.

Keywords: Recovery efficiency, ASR feasibility mapping, well optimization, coastal aquifers.

AN ADVANCED MULTI-DISCIPLINARY APPROACH FOR THE RAPID IDENTIFICATION AND ASSESSMENT OF MANAGED AQUIFER RECHARGE OPTIONS: A CASE STUDY FROM THE DARLING FLOODPLAIN, N.S.W., AUSTRALIA

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In the southern half of Australia, recent droughts and predictions of a drier future under a number of climate change scenarios have led to the search for innovative strategies to identify more secure water supplies for regional communities and industries, while also delivering environmental benefits to threatened river systems. It has long been ergana n that one of the areas with the greatest potential to contribute water savings in the Murray-Darling Basin is at the Menindee Lakes Storages (MLS), located on the lower section of the Darling River in far western New South Wales. As part of a broader suite of scientific and technical investigations, the Broken Hill Managed Aquifer Recharge (BHMAR) project was tasked with assessing the viability of Managed Aquifer Recharge (MAR) and/or groundwater extraction options to secure Broken Hill's water supply, protect the local environment and heritage, and return up to 200 GL to the Basin. The project is funded by the Australian Government and managed through the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC). The project involved the initial assessment of a number of aquifers across a broad region (150km radius), followed by development of rapid assessment techniques to identify and assess potential MAR sites over a large area (>7,500 km2), of the Darling floodplain. Data acquisition included an airborne ergana nt s c (AEM) survey (31,834 line km), a 7.5 km drilling program (100 sonic and rotary mud holes), and complementary field and laboratory hydrogeochemical investigations. Critical to success of the project was the use of a multi-disciplinary systems science approach for the mapping and assessment of potential targets. These investigations completely revised our understanding of the age, stratigraphy, structure and mode of deposition of the Darling floodplain sediments, with practical implications for the hydrogeological conceptual model underpinning the assessment of groundwater resources and MAR options. The study identified an excellent aquifer (the Calivil Formation), with high storage capacity, very high transmissivities (up to 50 l/s), and significant volumes of fresh groundwater. The aquifer is sandwiched between variably thick clay aquitards, and can be ergana nt s as varying from a semi-confined to a 'leaky confined' system. The hydraulic properties make the Calivil Formation aquifer potentially suitable for groundwater extraction and/or aquifer storage and recovery (ASR), with excellent recovery efficiencies predicted. The integrated analysis has identified a range of possible conjunctive use options involving surface water, ASR, and groundwater extraction incorporating natural bank filtration at a number of sites near to existing infrastructure. Targets were ergana nt, and a pre-commissioning semi-quantitative residual risk assessment carried out for a priority site. Assessment of 12 hazard types included hydrogeological ergana , laboratory column clogging studies and geochemical assessment to assess source water treatment requirements. The study found that the residual scientific/technical risks for MAR at a priority site are low. It is our understanding that this is the first use of a multi-disciplinary systems approach ergana AEM for MAR identification and assessment. The project has developed multi-disciplinary methodologies and workflows that provide a template for future hydrogeological investigations and MAR assessments.

AN INTEGRATED APPROACH TO DEVELOPING HYDROGEOLOGICAL CONCEPTUAL MODELS TO UNDERPIN ASSESSMENT OF MANAGED AQUIFER RECHARGE OPTIONS, DARLING FLOODPLAIN, N.S.W., AUSTRALIA

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A multi-disciplinary, hydrogeological systems mapping approach has been developed to guide development of new geological and hydrogeological conceptual models, and provide a framework for understanding complex hydrogeological and hydrogeochemical processes. Integration of the 3D mapping with hydrochemical and hydrodynamic data provides critical new insights into surface-groundwater interactions and groundwater flow. Using this approach, it has been possible to develop a new understanding of recharge processes, and identify potential recharge and groundwater flow pathways. The new datasets, knowledge and hydrogeological conceptual models provide a reliable basis for the identification, characterisation and initial assessment of groundwater resources and MAR options.

To meet the challenge of rapid identification and assessment of potential MAR targets and groundwater resources over the relatively large study area (7,541.5 sq km) within relatively short timeframes (18 months), the only cost-effective method with the ability to resolve key features of the hydrogeological system in the 0-150m depth range was airborne electromagnetics (AEM). The SkyTEM system is a high-resolution helicopter-borne time-domain electromagnetic system, and was developed specifically for high-resolution groundwater and environmental investigations.

The SkyTEM survey, validated by borehole and ground geophysics and drilling, successfully delineated the key functional elements of the Darling Floodplain hydrogeological system, and identified potential groundwater resources, zones of river leakage, and a large number of potential MAR targets. The survey revealed significant heterogeneity in the sub-surface electrical conductivity structure, reflecting a complex geology. The survey mapped heterogeneity (and 'holes') within the near-surface aquifers and confining aquitards, while conductivity variations validated by drilling enabled five hydraulic classes (based on grain size) to be mapped within the main aquifers, as well as groundwater salinities.

Locally, pump and slug tests, and NMR data were integrated with the AEM data to produce maps of interpreted hydraulic conductivity and aquifer transmissivity. Previously unrecognised faults, and landscape warping and tilting are observed to disrupt hydrostratigraphic units. These data necessitated development of a completely new hydrogeological conceptual model for the study area. This model shows the importance of faulting and erosional 'holes' in aquitards for recharge models. Discrete vertical fault offsets up to 20m produce localised inter-aquifer leakage. Sampling of rainfall, river, lake, groundwater and pore fluids has provided a comprehensive hydrochemical dataset for the alluvial aquifers of the Darling River floodplain. Major ion chemistry highlighted a mixing signature between river waters, the shallow unconfined aquifer and the underlying semi-confined target Calivil aquifer. Hydrochemical analysis including fuzzy-k means (FCM) cluster analysis, integrated with conventional hydrochemical and hydrodynamic analysis also provides invaluable new insights into groundwater processes. Recharge is dominated by river leakage during high flows, when scouring of riverbank mud veneers allows infiltration.

In summary, the new hydrogeological conceptual model of the study area has enabled a number of MAR options to be identified and assessed. The integrated, multi-disciplinary approach provides critical insights for developing appropriate conceptual models for groundwater processes and dynamics. This approach provides an invaluable tool for the rapid identification and assessment of MAR options, particularly in shallow sedimentary systems.

IN SITU INFILTRATION TEST USING A RECLAIMED ABANDONED RIVER BED: MANAGED AQUIFER RECHARGE IN SHIJIAZHUANG CITY, CHINA

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In situ infiltration test using a reclaimed abandoned river bed: managed aquifer recharge in Shijiazhuang City, China Managed aquifer recharge (MAR) is necessary for water resources management in arid and semiarid regions. Infiltration rate is often a decisive limiting factor in site selection for MAR. In order to avoid scale effects in the application of infiltration rate parameters, the largest in situ infiltration test in China was undertaken between August 19 and August 30, 2009, to measure the infiltration rate of the field selected for MAR in Shijiazhuang City, China. The in situ test lasted for 10 days, and about 1.82×107 m3 of water was introduced into the infiltration field, and 87 wells for groundwater monitoring were selected around the infiltration field. Groundwater level variations were monitored during the test. Monitoring showed that the initial infiltration rate was 2.50 m/d, but 6 days later had decreased by 40% to about 1.5 m/d, and the value plateau at 1.4 m/d at last, approximately 10–15×108 m3 of surface water could be injected into the underground aquifer every year. Also, groundwater level variations showed that the groundwater level responding times and peak times are proportional to the distances, and that the enhanced ranges and rates were inversely proportional to the distances; from the slopes of linear correlation analysis, the northern part of the aquifer has the highest permeability, and the islet has the lowest permeability, as predicted, and the test result supplied a sound foundation for validation of the groundwater numerical simulation, which will be of benefit for future predictions of the response of the groundwater level to artificial recharge engineering. Finally, an artificial recharge plan was proposed based on the infiltration test results and the water source conditions, and unexpected pollution events could be treated in a timely manner, which would be useful for the development of MAR programs and management of local water resources.

Key words: Managed aquifer recharge, artificial recharge, in situ, infiltration test, groundwater level variation, water management

MODELING STUDIES OF AQUIFER HETEROGENEITY ON ASR RECOVERY EFFICIENCY

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Recovery efficiency is a commonly used metric for the success of aquifer storage and recovery (ASR) systems. It is defined as the ratio of the volume of recovered water to the volume of injected water. The recovery efficiency of an ASR system may be affected by a number of factors, including site hydrogeology, aquifer properties, well design, native water quality, and regional hydraulic gradients. Aquifer heterogeneity is one of the key factors that determine the amount of injected water that can be recovered at an acceptable quality.

All aquifers have some degree of heterogeneity, which if extreme can adversely affect the performance of ASR systems. For example, flowmeter log data from several very poorly performing ASR systems in South Florida indicate that the hydraulic conductivity values may vary by several orders of magnitude within the target storage zone, and that 90% of the flow may occur in 10% or less of the injection zone. The expansion of horizontal extent of the flow zones increases the probability that vertical conduits will be intercepted. Flattened injection water "bubbles" may also have larger contact areas with native water. Modeling results show that lower recovery efficiency may be expected from ASR systems that tap aquifers with a high degree of heterogeneity.

Dual-porosity conditions are often encountered in storage aquifers. Recovery efficiency is controlled by the flow and solute transport processes through and between both the porous matrix and fractures/conduits. Various cases of heterogeneity and their potential impact on ASR system recovery efficiency were studied using Eclipse®, which is an advanced, multiphase, dual porosity and variable density simulator. A dual-porosity scenario with a porous matrix, which contains 80% to 90% of the total porosity and a low hydraulic conductivity, and a low-porosity, high-conductivity fractured domain was simulated along with a case where highly conductive, thin layers are interbedded in less conductive, thicker layers. Results show that such systems can have relatively low recovery efficiencies when fresh water is injected into the native brackish water due to mixing and differential solute travel time. Buoyancy effects are more pronounced in the fractured domain than in a homogenous system. This resulted in a wider fresh water bubble in the shallower layers within the fractured domain. The simulation results suggest that recovery efficiency can be improved by setting extraction points relatively shallower than the injection point.

Detailed aquifer characterization to determine the type and degree of aquifer heterogeneity present can be used to better predict the performance of ASR systems and to optimize their design and operation.

Key words: aquifer heterogeneity, modeling, dual porosity, recovery efficiency

Track 2.2: Alternative recharge systems

THE FRESHMAKER: ENABLING AQUIFER STORAGE AND RECOVERY (ASR) OF FRESHWATER USING HORIZONTAL DIRECTIONAL DRILLED WELLS (HDDWS) IN COASTAL AREAS

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Freshwater supply in coastal areas worldwide is under pressure due to salinization, increasing droughts and/or increasing freshwater demands. Seasonal aquifer storage and recovery (ASR) of any freshwater surplus (for instance, rain-, surface- or recycled water) may prevent freshwater shortages in these areas during prolonged droughts. ASR is successfully applied worldwide in freshwater aquifers, but storage of freshwater in saline aquifers is troublesome however, mainly due to buoyancy effects. The conventional ASR set-up, which uses a single vertical well for injection and recovery, will generally fail in saline coastal aquifers. Recent development of horizontal directional drilled wells (HDDWs), however, may initiate successful ASR application in saline aquifers. During the construction of a HDDW, horizontal directional drilling (applied since the sixties) is used to insert a long horizontal well screen into an aquifer. A biodegradable drilling fluid consisting of polymers is used to lubricate the drilling, to dispose the cuttings and to provide borehole stability. Once the well screen is in place, a strong oxidant is used to break down the polymers to sugars, which are easily washed away. With the HDDW technology at hand, long horizontal wells can be installed at any desired depth in shallow coastal aquifers, for instance for extraction of fresh groundwater from shallow lenses. As fresh groundwater lenses in shallow coastal aquifers are often thin, freshwater extraction still remains limited. The Freshmaker concept protects natural fresh groundwater lenses by interception of upconing brackish water using a deep HDDW ('scavenger well'), while a second, more shallow HDDW ('ASR well') is used for artificial recharge and recovery of freshwater surpluses. The injected freshwater enlarges the natural fresh groundwater lens and is available for crop irrigation in the growing season. The use of HDDWs makes the technique applicable in thin aquifers, which is a prerequisite in many of the world's delta areas. The first Freshmaker is installed late 2012 in the coastal province of Zeeland (The Netherlands). Here, intake of fresh surface water from a local watercourse after prolonged rainfall provides the infiltration water for the ASR well (located at 7 m-surface level). On the same watercourse, extracted upconing saltwater from the scavenger well (~15 m-surface level) is disposed in dry periods when surface water is saline and intake is ceased. With this Freshmaker prototype, it is aimed to store approximately 5.000 m3 of freshwater, which is used for irrigation of an orchard of approximately 10 hectares.

Track 2.3: Cost effectiveness of MAR

ECONOMIC, SOCIAL AND ENVIRONMENTAL BENEFITS OF MAR IN VILLAGE SCALE INTERVENTIONS IN RURAL INDIA—SOME INSIGHTS FROM GUJARAT AND RAJASTHAN

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In two catchments located in the semi-arid States of Gujarat and Rajasthan, check dams, anicuts and infiltration basins have been installed over a period of 15 years in an effort to curb the steady decline in water table that has occurred since electrification of pumping and drilling of tube wells. In a 4 year ACIAR research project , now in its 2nd year, irrigation livelihoods were reported as improved by recharge enhancement measures, especially by farmers whose wells are in close proximity. However the increase in recharge overall was insufficient to do more than slow the depletion of the aquifer. This has consequences for the sustainability of agricultural production, for the availability and quality of water for drinking water supplies and for the time spent by women in obtaining water for their households. Due to the existing deep watertables, environmental effects of recharge enhancement are primarily to downstream ecosystems, but given the ephemeral nature of stream flow in recent memory, it is considered that environmental effects are small. In this study recharge may be enhanced by desilting streams upstream of existing checkdams, and discharge reduced by improving irrigation water use efficiency by conversion to dripper or sprinkler irrigation from the current flood irrigation. The options for the community in managing groundwater storage and community well being will be developed through studies on hydrology, agronomic practices, and surveys of schools and communities.

ECONOMIC ASSESSMENT OF INCORPORATING MANAGED AQUIFER RECHARGE TECHNIQUE IN WATER MANAGEMENT. RESULTS OF A STUDY CARRIED OUT BY MEANS OF AN ADVANCED GEOGRAPHIC INFORMATION SYSTEM (GIS) FOR SPAIN

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The article exposes the economic aspects considered along DINA-MAR project, from simple ratios to advanced proposals, related to the price of MAR water, in order to study the feasibility to implement new building works and provide a certain support to Spanish decision makers.

Initially are exposed investment ratios of building costs against storage volume, as well as mean life of the devices.

After that, there have been proposed two alternatives for decision-making, according to the origin of the water sources, either fluvial or sewage waters.

The first consists on a diversion of running water from a river, leading it to an adequate aquifer (underground storage). There have been taken into account different premises according to the available flow, easiness of application, suitability and feasibility studies and projects and theirs cost, including exploitation and maintenance costs.

The second consists on the employ of reclaimed water for managed aquifer recharge by means of a deep injection across boreholes and wells, generally located in the vicinity of the sewage treatment plants. Economic studies have considered flow availability, tertiary treatment, osmotization, insertion into aquifers, building work and conservation costs, plus studies and projects cost.

Taking as a starting point the maps of potential sites or "MAR areas" for Managed Aquifer Recharge in Spain Iberian Peninsula and Balearic Islands and the results of the economic studies, it is proposed a new specific mapping by total expected costs for all "MAR zones" (€/m3), depending on the device considered most appropriate for each case. It definitely represents a novel and unusual mapping.

COST-BENEFIT ASSESSMENT OF COMMUNITY-LED AQUIFER RECHARGE: THE CASE OF MEGHAL RIVER BASIN, SAURASHTRA, INDIA

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The Saurashtra region of Gujarat represents a semi-arid hard rock plateau in western India. Over the past three decades, the region has seen the development of thousands of decentralized water harvesting structures through spontaneous collection action by farmers and with support from the government as well as non-government and quasi-religious organizations. This development has transformed the hydrology and the agrarian economy of the region and promises to provide much needed security against frequent droughts while making water available in a more democratic manner across the numerous river basins.

Meghal is a small seasonal river (80 km long; 472 km2 catchment) that originates in Kanada hills and flows into the Arabian Sea. It has four tributaries: Lathodariyo, Vrajami, Meghal and Kalindri. The main monsoonal (kharif) crop is groundnut and the main winter (rabi) crop is wheat. More than a thousand water harvesting and groundwater recharge structures – tiny check dams, percolation tanks, recharge wells and boribandhs (sand-bag dams) – have been created in the small basin partly due to the broader recharge movement in Saurashtra; the government subsidy program for constructing check dams; and due to the intensive efforts of Aga Khan Rural Support Program, India (AKRSP-I). In order to understand the impact of this work, AKRSP-I partnered with the International Water Management Institute (IWMI) and INREM (India Natural Resource Economics and Management) Foundation.

This paper presents results from the multi-disciplinary study that comprised of a hydrological assessment, a socio-economic synthesis and institutional analysis. Specifically, the paper addresses the critical issue of attribution of agrarian growth to investments in water harvesting structures by offering a novel methodology that combines results from a simple hydrological model, understanding of agronomy and data from extensive village surveys. The study provides a first-of-its-kind quantification of the costs and benefits of community-led aquifer recharge efforts at the river basin scale.

Track 2.4: Innovation and integration in MAR

ENHANCEMENT OF WADI DAM RECHARGE USING DAMS COUPLED WITH AQUIFER STORAGE AND RECOVERY

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Wadi channel losses and ultimate recharge of the underlying alluvial aquifer is naturally limited by the flashy nature of flood events, the heterogeneity of the aquifer with the vertical hydraulic conductivity being low, and evapotranspiration losses of water from the vadose zone. Anthropogenic lowering of the water table also reduces the potential recharge by creating a thicker unsaturated zone that requires a greater frequency of rainfall events to achieve recharge.One method to enhance recharge is to slow the flow within wadi channels by placement of dam structures, thereby ponding water and increasing the vertical head gradient to create a more rapid rate of infiltration and percolation.

The effectiveness of wadi dams to enhance aquifer recharge rates is dependent on the connectivity of the reservoir bottom with the underlying aquifer. During the early life-cycle of a wadi dam, recharge rates can be quite high, especiallywhen the reservoir is partially filled with runoff occurring during moderate to low runoff rainfall events that do not transport massive quantities of sediment. Large-scale flood events occurring over a multi-year period tend to transport and deposit considerable quantities of muddy sediment into the reservoir. These muddy sediments reduce the vertical flow into the aquifer, thereby reducing the rate of recharge exponentially. Free-surface evaporation removes most of the water in the reservoir before infiltration and recharge can occur. With time, the rate of potential recharge will continue to drop unless the sediment in the reservoir is physically removed.

One method to maintain or increase the rate of recharge is to convey clean water from the reservoir into downstream wells, thereby causing artificial enhancement of recharge. A system can be developed that uses a tower in the reservoir that contains a series of gates to allow gravity flow of low-turbidity water into a pipe that feeds it into wells located downstream of the dam. Commonly, there are significant numbers of large-diameter existing wells in most wadis that are abandoned or unused and can be modified to receive the flow. This type of system is a low cost and low energy method which could greatly enhance recharge of wadi aquifers in mature wadi dam/reservoir facilities.

Key Words:aquifer storage and recovery, wadi aquifers, dams, recharge, groundwater modeling

FRESHWATER STORAGE IN LAND RECLAMATIONS; AN INTEGRATED APPROACH IN AN EARLY DESIGN PHASE

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A major part of the world population lives in densely populated coastal areas. Population growth, urbanization and economic development result in an increasing pressure on available space in these areas. Land reclamations are used more and more to meet this growing need. Safeguarding the freshwater supply on land reclamations is one of the major challenges. Water demand often exceeds the available resources in these original saline areas, due to saline groundwater, periods of drought and problems in water supply from the mainland. The sustainable use of available resources, reuse and strategic storage are important issues for the development of a robust water system on land reclamations. Land reclamations are constructed from scratch in the sea. This provides opportunities to construct the land reclamation in such a way that subsurface storage and recovery of freshwater is possible. All kind of subsurface freshwater storage is possible if future functions are taken into account in an early design phase (before the implementation of the dredging works). This requires an integral approach of the civil engineering design and the design of the water system and master plan. The central question is: How can we organize the subsurface of a land reclamation as optimally as possible for freshwater storage? This paper presents several options. Use is made of a combination of constructions and techniques and the geological and geochemical characteristics of the dredged material; such as the application of coarser and finer material, the density difference between freshwater and native saltwater, the use of clay bodies or geotextiles, construction of horizontal drainage during construction work, optimization of the material around infiltration and extraction wells, and under infiltration ponds. The master plan and future functions are taken into account in the civil engineering design to optimize future freshwater infiltration and groundwater use; such as the location of parks and urban areas, design of water system and drainage system. All kind of storage is possible, including seasonal storage of rainwater during the rainy season, storage of desalinated water during low demand periods and storage of treated waste water. The water can be used for different purposes, including for vegetation, irrigation, swimming pools, drinking water, industrial and household water, firefighting and calamities.

INNOVATIVE DESIGN AND INDIGENOUS TECHNOLOGY FOR CONSTRUCTION OF RECHARGE SHAFTS IN COASTAL AQUIFERS OF BANGLADESH

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Managed aquifer recharge (MAR) has great potential for groundwater banking in the coastal belt of Bangladesh, particularly along the northern fringe of the Sundarban mangrove forest in Khulna, Satkhira and Bagerhat districts. The shallow brackish aquifer of the area is overlain by a Holocene clay aquitard varying in thickness from 3 to 15m. Recharge shafts have been found to be the most appropriate method for groundwater banking in the area where the main target is to lower salinity in the target aquifer by infiltrating rooftop rainwater or runoff water from ponds. There is remarkable variation in the clay aquitard and target aquifer thickness which warranted site specific design. As this research has been the first of such initiative in the country, there was lack of local knowledge in drilling and completion of recharge shafts as well as infiltrating pretreated water to avoid clogging. This paper specifically focuses on drilling and construction methods whereas a compendium paper would focus on the issue of clogging control. Detailed site investigation including exploratory drilling and test well installation were carried out at each site for preparation of designs. Local drillers have been motivated to drill wells up to 0.10m diameter to a depth of 50m. Equipments have been modified for drilling recharge shaft using both direct circulation and percussion drilling. Mud pump is the only mechanical equipment used in the drilling procedure. Recharge shafts have been completed using various designs with 12 inch poly vinyl chlorine (PVC) casing and locally designed screen made of mild steel rod frame wrapped with chicken mesh, varying in diameter from 8 to 18 inches. Wells have been filled with sorted gravel of more than 2mm size. Local sands have been used outside the screen to fill the annular space. Backwashing have been used to remove finer materials present in the hole. Shafts have been drilled on the ground or up to 3m below the ground surface depending on method of infiltration. Clay and cow dung have been used as additives to water based drilling mud. Gravity or pumped gravity methods have been adopted for recharge at different sites depending on head difference between groundwater and recharge pond water. The wells have been protected by brick walls and connected to source water by PVC pipes. Recharge shafts drilled at different sites have been evaluated by series of well performance tests. Individual well performance varies from site to site, even within a site. Average infiltration rates vary from 1 to 10 m3/d. Infiltration rates for sites with elevated tank are higher (average 8 m3/day) than the sites with direct pond gravity infiltration (average 2 m3/day.) Head difference between the source water and water level in the aquifer has been found to be the most significant parameters in controlling the rate of infiltration. Presence of screen enhances infiltration rates whereas shaft diameter has relatively low influence on the infiltration rate. Larger diameter and more shafts area needed to achieve optimum infiltration rate in case of the relatively thin aquifers.

Theme 3: Governance of MAR

Track 3.1: Community engagement and awareness in MAR

CLASHING COALITIONS: A DISCOURSE ANALYSIS OF A MANAGED AQUIFER RECHARGE PROJECT IN FINLAND

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In Finland, managed aquifer recharge (MAR) is used as a water treatment method in community water supply. Two large-scale MAR projects have been delayed for years due to strong criticism and generally opposing public opinion (Jokela and Valtonen 2010). This paper analyses the case of the Turku region, situated in the coastal area of south-western Finland, where drinking water acquisition has faced big challenges due to the lack of a local fresh water source. The long distance water acquisition project started already in 1970. However, after several phases the production of artificial groundwater started in 2011. The raw water is taken from the river Kokemäenjoki and infiltrated through the esker of Virttaankangas situated some 70 km to north-east from Turku. The MAR project has faced strong criticism on behalf of local people from the municipalities situated around the esker.

The purpose of the paper is to increase understanding of community engagement in MAR projects. Analysed material consists of the arguments presented in newspaper articles by the opponents and defenders of the MAR project of the Turku region. Through the application of Hajer's (1995) discursive framework, the paper aims to search for the ways in which the arguments create and sustain the opposing or defensive discourses. Finding discursive coalitions that are formed around the MAR project will help us to understand the policy process and why particular stories come to gain ascendancy and others do not.

MAR projects in general and the project of the Turku region have been studied thoroughly from the perspectives of technical and natural sciences. However, it seems that the lack of technical and natural scientific knowledge cannot explain the project's difficulties and prolongation, but research on the dynamics of public opposition is needed in addition. In the case of Turku region it is argued that the project organization's engagement with the community was not strong enough to achieve a public acceptance. This paper will be a step toward social understanding about the MAR project of the Turku region and thus provide useful insight also for other large scale MAR projects.

Keywords: infrastructure projects, local government, civil society, discourse analysis, artificial groundwater recharge

MAR TO MAR-KET. DISSEMINATION AND TECHNOLOGY TRANSFER CRITERIA APPLIED TO MANAGED AQUIFER RECHARGE. A STRATEGIC PROPOSITION AND EXAMPLES TO TRANSFER THESE TECHNIQUES TO INDUSTRY

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Information and environmental education play a very important role in order to disseminate hydrogeology and, specially, managed aquifer recharge technique to the population as a whole.

The main purpose of the article is to describe briefly the state-of-the-art of the Dissemination and Technology Transfer activities (hereinafter D&TT). It is also intended to expose the lines of action based on proposals for information, training and dissemination strategies aimed at separated sectors of the population organised into homogeneous groups.

Some examples already tested in Spain are presented, not only activities, but also materials, most of them in the frame of DINA-MAR R&D Project. A vast group of actions are described with specific examples for activities and materials. Most of the results o previous research are applicable for countries where Managed Aquifer Recharge (from now on MAR) technique installation is progressively advancing, as Spain. Although it has hardly been implemented, counts on a huge potential.

To use MAR with to its full potential, all the sectors involved or interested, the industry and the whole population, must be aware of it.

The final and main aim of the article is to plan a strategy to bring hydrogeology and MAR to the industry, taking notice of the importance of recharged aquifers for future industry advance in a broad range of branches.

Keywords: Hydrogeology, MAR, Dissemination, Environmental awareness, Environmental education, Managed Aquifer Recharge, Technology transfer, D&TT strategies, Training, Industrial hydrogeology, MAR to MARket, MAR-SOL.

Track 3.2: Institutional innovation for MAR - waterbanks and groundwater user groups

WATER BANKS: USING MANAGED AQUIFER RECHARGE TO MEET WATER POLICY OBJECTIVES

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Arizona is a semi-arid state in the southwestern United States that has growing water demands, significant groundwater overdraft and surface water supplies with diminishing reliability. In response, Arizona has developed an institutional and regulatory framework that has allowed large-scale implementation of managed aquifer recharge in the state's deep alluvial groundwater basins. The most ambitious recharge activities involve the storage of Colorado River water that is delivered through the Central Arizona Project (CAP). The CAP system delivers more than 1850 million cubic meters (MCM) per year to Arizona's two largest metropolitan areas, Phoenix and Tucson, along with agricultural users and Native American tribes, but the CAP supply has junior priority and is subject to reduction during declared shortages on the Colorado River. In the mid-1980s the State of Arizona established a framework for water storage and recovery, and in 1996 the Arizona Water Banking Authority was created to mitigate the impacts of Colorado River shortages, to create water management benefits, and to allow interstate storage. The Banking Authority has stored more than 4900 MCM of CAP water, including 730 MCM for the neighboring state of Nevada. The Nevada storage was made possible through a series of interrelated agreements involving regional water agencies and the federal government. The stored water will be recovered within Arizona, allowing Nevada to divert an equal amount of Colorado River water from Lake Mead, which is upstream of CAP's point of diversion. Arizona's experience suggests that water banking could be a valuable mechanism elsewhere where the hydrogeology, water balance and water policies are suited. This paper draws out the key features of water banking in Arizona and discusses the potential transferability to other locations, including Adelaide, South Australia. The paper also explores the physical and policy settings that enable water banking to be an effective tool for meeting water management objectives.

Track 3.3: Integrated water resources management

MANAGED AQUIFER RECHARGE: A POTENTIAL COMPONENT OF WATER MANAGEMENT IN THE SYRDARYA RIVER BASIN

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Growing demand for food and energy increased competition for water between upstream and downstream users in the Syrdarya River basin. The change in the upstream reservoir operation from conjunctive irrigation/hydropower mode to exclusively hydropower generation reduced summer and increased winter flow of the river downstream. The result is the water shortage downstream of 2,000 -3,000 Mm3/year in summer and excessive, often unutilized, flows of the same magnitude - in winter. This paper suggests that the current practice of sequential in-channel reservoirs is not coping well with the needs of both - upstream and the downstream water users, and examines the alternative approach - managed aquifer recharge (MAR) - in the upstream Fergana Valley to adapt to new water management reality. Favorable hydrogeology conditions of the Valley allow benefits from MAR from local to regional scale – to be envisaged. The study follows a step-wise procedure of implementing MAR in the Fergana Valley, starting from the regional assessment of the MAR potential to testing MAR at pilot scale through field and modeling studies. The regional assessment shows that over 500,000 ha, or 55% of the currently irrigated land in the Valley, can be shifted from canal irrigation to conjunctive surface-ground-water irrigation. This will reduce the return flow to the river by 30% (or by 1,000 Mm3/year), and form free storages of 500 Mm3 in the command areas of main canals. Pilot field and modeling studies for Isfara and Sokh aquifers in the Valley support the results of regional assessment. The study suggest to combine MAR and conjunctive use of groundwater and canal water, with adaption of water saving irrigation technologies, which will allow maintaining good water quality, both, of groundwater and surface water. Overall, groundwater development for irrigation and MAR in the Fergana Valley may reduce winter flow of the Syrdarya River at the Valley outlet by 1,500 Mm3/year and consequently increase summer flow of the river to the same magnitude. The paper proposes a major shift in the focus of development projects in the Fergana Valley from rehabilitation of dense drainage systems to MAR, recovery groundwater storages for irrigation and introducing water saving technologies.

Keywords: managed aquifer recharge; hydropower- irrigation nexus, conjunctive water use; Syrdarya River

MANAGED AQUIFER RECHARGE IN CALIFORNIA: SUMMARY OF PROJECTS AND POLICY ISSUES

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California has been a leader in conjunctive water management and managed aquifer recharge for decades. Recently, as a component of the California State Water Plan Update 2013, a significant effort has been dedicated to developing a more comprehensive inventory of statewide groundwater resources management, groundwater monitoring, groundwater quality, change in groundwater storage and managed aquifer recharge. Approximately 90 managed aquifer recharge projects are currently active in the state; however, existing state law and policy includes no requirements for reporting conjunctive management and managed aquifer recharge program activities so the summary results are incomplete. As background, the state of California has inherit hydrophysical constraints amounting to water supply abundance in the north state and water demand exceeding supply in the south state, which were initially addressed in the last century with a series of dams, reservoirs and conveyance (canals and aqueducts) to move water from the north state to the water poor south. In the future, with a changing climate, the hydraulic infrastructure in place is based on the last 100 years of hydrology that was relatively wet. The existing hydraulic infrastructure is unable to address the forthcoming needs with the prediction of more extreme events occurring on less frequent intervals, concentrating storms geographically and chronologically and reducing the amount snowpack as a water reservoir. What has become clear is the need for an increase in managed aquifer recharge to address future climate change and build resilience and address uncertainties in water supply reliability. Some of the complicating policy and political factors include the northern Central Valley (Sacramento Valley) has generally abundant water resources but is reticent to send water south to the San Joaquin Valley and southern California due to concerns about losing water rights and other uncertainties. The southern half of the Central Valley (San Joaquin Valley), a key agricultural resource for the US and world with a desert climate relying on imported water, is chronically overdrafted with groundwater storage losses of some 60 million acre-feet over the past 50 years, and no solution on the horizon. The focal middle portion of the Central Valley is the Delta through which the statewide water conveyance system flows and has become a key constraint and legal battle to moving water south due to environmental species declines and aging infrastructure. Additional state Policy constraints include: • State agency mandates and coordination and need for alignment – no agency has mandate for all aspects, there are competing and overlapping agency charges • Cross State Conveyance – supplies in the north state and majority of demands in the south state • Water rights – groundwater recharge is not generally considered a beneficial use • Jurisdictional issues – legal question of aquifer storage space ownership • Water markets & transfers – need for streamlining environmental policies • Permitting policy – declaring drinking water a waste to regulate aquifer storage & recovery (ASR) • No statewide overarching policy on groundwater recharge and banking • The presentation will provide a summary of California managed aquifer recharge projects, policy constraints and some solutions in the works to address these complex issues.

REDUCING THE ENVIRONMENTAL IMPACT OF A SHALLOW MAR SITE

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PWN, a leading drinking water company in the Netherlands, delivers water to industries and consumers in the province North-Holland, currently 105 million m3 annually. Since 1957 PWN applies managed aquifer recharge (MAR) at two sites in a coastal dune area in the Netherlands. Pre-treated surface water from Lake IJssel and river Rhine is infiltrated in parallel recharge basins, mainly for natural disinfection, buffering and attenuation of water quality. After an average travel time of about 2 months the water is recovered using over 1.100 shallow wells. The aquifer consists of fine alluvial sands with thin layers of clay and peat and the extraction wells are around 10 m deep. In total about 36 million m3 water is infiltrated and extracted at these MAR sites. Both sites are located in the coastal dune reserve, a nature conservation (Natura 2000) area. Because of the ecological optimisation of the sites in the 1990's the MAR sites are integrated into their natural environment and host a rich flora and fauna wildlife. To secure the increasing demand for drinking water up to 2030, PWN started a research to further optimize the MAR sites, without harming their sensitive flora and fauna. The MAR areas consists of 24 well systems which are switched on and off according to the water demand. Calculations with the groundwater model indicate that unmodified operations in accordance with the current permit leads to a loss of groundwater dependent nature of 12%. Using hydrogeological models the influence of each individual well series on their environment (moisture sensitive vegetation) was determined. This depends on their location, their hydrogeological setting and the morphology of the area. In an area with high dunes, the groundwater table is already relatively deep and vegetation is not so much groundwater depended. So an increase in production capacity of a well system in such an area doesn't have a big influence. While an increased abstraction rate of a well system in a wet dune valley greatly affects the vegetation. So even though the actual change in groundwater level may be smaller than in the previous example, this well system has a greater impact on the environment. This has lead to a new sequence of pumping: first the well systems that do no harm the vegetation, then the ones that cause minor damage and in the event of high water demand also the systems that affect valuable vegetation. The effects of this optimised sequence of pumping on groundwater levels were determined using a groundwater model. The positive effects of this optimised sequence on flora were confirmed by a ecohydrological model. The new 'nature driven' sequence of pumping leads to an increase in the production capacity without the construction of new wells, mains or recharge basins. Even with an extra production of 6 million m3 per year the area with groundwater dependent nature increases with 7%, a significant improvement compared to a loss of 12% with unmodified operations.

NEAR-STREAM RECHARGE TO PROTECT BASEFLOWS IN THE UPPER SAN PEDRO RIVER, ARIZONA, USA

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The San Pedro River originates in Mexico and flows north through southeastern Arizona to its confluence with the Gila River, the primary drainage system in Arizona. The Upper San Pedro Basin (USPB) extends from Cananea, Mexico to Fairbank, Arizona and covers an area of roughly 4,500 km2, with altitudes ranging from 2,700 meters (m) in the south to 1,052 m at the north end. The Upper San Pedro River is characterized by interrupted perennial flow, and serves as a vital wildlife corridor through this semiarid to arid region. Over the past century, groundwater pumping in the USPB has depleted aquifer storage that supports baseflows in the San Pedro River. In 1999, the American Rivers organization drew attention to the threat to stream flows posed by groundwater pumping by including the San Pedro River on its "Most Endangered Rivers" list. In response to a subsequent Congressional mandate to cease groundwater overdraft in the basin by 2011, the United States Geological Survey (USGS) published a MODFLOW-2000 groundwater model of the USPB calibrated for the period 1902 to 2003. This USGS model served as the basis for predictive simulations for the period 2003 to 2111. Despite the fact that most agricultural water uses in the USPB were eliminated by the year 2005, the predictive groundwater simulations showed that anticipated population growth and associated groundwater development in the 21st century present a significant threat to the remaining baseflows in the Upper San Pedro River if current water use patterns persist. As part of a basin-wide effort to identify strategies for sustaining baseflows in the Upper San Pedro River throughout the 21st century, groundwater modeling was used to explore the potential impact of near-stream recharge on baseflows. Three sites in the United States portion of the USPB were identified for recharge simulations. Each simulated site covered 25 hectares (ha) and was located in model cells adjacent to the San Pedro River or its major tributary, the Babocomari River. Simulated recharge varied from 0.12 to 3.2 million cubic meters per year (MCM/yr) at each site over the period 2012 to 2100. The simulation results showed that ramping up recharge, as needed, to compensate for downward pressure on the water table from pumping, could sustain baseflows in the Upper San Pedro River at or above 2003 levels until the year 2100 with less than 4.7 MCM/yr. This study demonstrates that strategic near-stream recharge of treated wastewater, stormwater, and possibly imported water could be a viable tool for offsetting the detrimental effects of groundwater pumping on baseflows in the USPB.

A NEW ZEALAND APPROACH TO MAR FOR MANAGING CATCHMENT-SCALE GROUNDWATER ISSUES USING INDUCED INFILTRATION THROUGH EPHEMERAL RIVER CHANNELS

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Globally, the management of groundwater resources through stakeholder-driven planning processes is becoming more prevalent as an effective method to develop community-supported solutions. In New Zealand, the use of Managed Aquifer Recharge (MAR) to support better management of catchment-scale water demand and availability issues is being explored on the South Island's Canterbury plains. Over-allocated groundwater resources coupled with decreasing incidental recharge through a shift to more efficient irrigation systems have placed negative pressure on groundwater dependent ecosystems and returning baseflows to rivers and springs. A collaborative partnership between water users, regional government, and Golder Associates (NZ) Ltd was formed to actively engage and educate the public about groundwater issues and the use of MAR as a potential management tool. A MAR pilot project was undertaken where high quality, alpine-sourced water was routed to an ephemeral river channel for passive infiltration to targeted unconfined alluvial aquifers. The recharge was induced over a 4-day period derived from a flow released to the river channel of 10.3 metres per second. Of this flow, groundwater recharge was estimated to be 2.1 million cubic metres. In-channel gaugings coupled with real-time gauge station data were used to quantify infiltration rates and reach-based estimates of gains and losses. Groundwater monitoring was used to track both the connectivity (pressure) and storage response of the targeted aquifers. Water quality results indicate potential opportunities to help reduce elevated nutrient concentrations associated with increasingly intensive farming in the catchment. Additional testing of both river channel MAR and purpose built off-channel recharge basins are being pursued based on the project outcomes. Consultation through the planning process and with native Maori elders continues to ensure solutions are consistent and acceptable with cultural values and community goals. This approach reinforces the importance of education and outreach in the development of successful groundwater replenishment programmes.

Track 3.5: Recharge policies, standards and regulations

BALLOTING PROCESS OF GUIDELINES BY MANAGED AQUIFER RECHARGE STANDARDS COMMITTEE OF ASCE/EWRI

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Managed Aquifer Recharge (MAR) becomes more and more important in regional water planning and management. Standard guidelines are used by project developers and stakeholders for planning purposes and engineers, hydrologists and other professionals to standardize their practices. In 2001, ASCE/EWRI published the first Artificial Recharge of Ground Water (ARGW) standard guidelines (EWRI/ASCE 34-01). As more MAR projects were developed and constructed, it became evident that the original guideline needed to be modernized and upgraded to provide additional detail and case studies. The ASCE/EWRI MAR Standards Committee reviewed the ARGW guidelines and recommended an updated guidelines outline. A Standard Subcommittee (SC) was established to carry out the task. In this presentation, the authors will describe the process of developing the MAR guidelines. Based on consensus during SC teleconferences, SC members first determine the details of what should be updated, added, or deleted to each section and then assign a Corresponding Editor and editor(s) to the major sections based on their interest, expertise, and availability. The SC members submit contributions to the designated editors for integration. The Corresponding Editor will review and redistribute to the MAR SC for web-based balloting through ASCE. If a section does not pass the ballot, the corresponding editor with the section editors are required to prepare resolutions to address comments and suggestions and revise the section accordingly. The revised sections are then sent for re-balloting until it is approved or withdrawn. Once the draft guidelines is approved by the MAR Committee, a summary of the balloting and the resolutions reports will be sent to the EWRI Standards Development Council and the ASCE Codes and Standards Committee for approval. This will be followed by a public comment period where comments will be resolved and approved by the MAR SC through a similar balloting process. The final product is based on consensus of the Standard Committee and the ASCE public, and eventually approved by the ASCE Codes and Standard Committee for publication. The new guidelines will be a useful tool to MAR project planners and design professionals.

WATER RESOURCES POLICIES THAT HARNESS MANAGED AQUIFER RECHARGE FOR GROUNDWATER SUPPLY SECURITY AND WATER QUALITY IMPROVEMENT

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A framework for regulation of managed aquifer recharge (MAR) in urban and rural areas has been developed in Australia and is now implemented in water resources management regulations in two Australian states. This follows principles of robust separation of entitlements and allocations that have been successful in guiding rural water reform in Australia. The concepts are universally transferable in addressing water security while supporting water quality improvement. Four fundamental elements of MAR projects require consistent water resources management policies; source water harvesting, recharge, recovery and end use. These policy elements are discussed briefly. Particular attention is given to policies relating to recovery and transfer of rights to recover water, as these have potential to greatly expand the role and value of MAR. The role of aquifer characteristics in determining entitlements is mentioned. Pathways to implementation of such policies are summarised.

Track 3.6: Risk assessment and water safety plans

MAR WITH UNTREATED RIVER WATER: CLOGGING OF BASINS AND COLIFORM REMOVAL RATES

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The Dresden-Hosterwitz water utility operates five open recharge basins supplied with pre-treated Elbe River water in Germany. The quaternary aquifer comprises sand and gravel and has a thickness of 9 to 14 m. The infiltration of untreated river water and its effects on basin clogging and pathogen removal were evaluated within a risk based framework.

Column experiments were performed to simulate infiltration in the recharge basins. Separate soil core samples were collected from the bottom of the main recharge basin ("Doppstadt-basin") and the aquifer below. Three vertical profiles were evaluated, which ranged from coarse filter sand to sandy gravel, and separately installed in an experimental flow-through column set-up. Untreated river water was pumped continuously to feed the columns. Turbidity, total coliforms, E.coli and other physico-chemical parameters were measured in the inflow and outflow at various infiltration velocities and redox conditions.

The hydraulic conductivity of the filter sand decreased exponentially due to external clogging. After 14 days of infiltration there was a reduction in infiltration rate from 3 m/d to 1.0 m/d and hydraulic conductivity decreased by two orders of magnitude from 126 m/d to 4.0 m/d. Total coliforms and E.coli numbers decreased by 4.4 log10 units and >3 log10 units. The average bacteria counts measured after 2.8 – 4.4 m total filtration length were 5.7 – 16.1 TCC/100 mL and <1 E.coli//100 mL. E.coli removal was greater than total coliforms but E.coli counts in the river water were one order of magnitude lower than TCC. Mean turbidity was reduced from 14 NTU to 0.9 NTU after passing only 0.6 – 0.9 m filter sand.

Removal of turbidity and bacteria was found to be as effective as in the nearby bank filtration wells located ~ 50 m from the riverbank during mean flow. The infiltration of untreated river water into the recharge basins is not a risk in terms of E.coli and total coliforms contamination of the abstraction wells at 70-m flow distance or 4 – 5-day travel time. Redox conditions were found to affect removal of DOC by 15 % but had no effect on coliform removal.

Keywords: MAR, basin flooding, coliform removal, clogging

THE DEVELOPMENT, APPLICATION AND ACCEPTANCE OF ENVIRONMENTAL AND HEALTH RISK ASSESSMENT METHODOLOGY FOR MAR SCHEMES IN SOUTH AUSTRALIA

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A risk assessment methodology for the establishment of Managed Aquifer Recharge (MAR) schemes has evolved in South Australia (SA) over the last 6 six years. The methodology is based on the Australian Guidelines for Water Recycling: Managing Health and Environmental Risks, Phase 2 Managed Aquifer Recharge, 2009 (AGWR MAR) and has been led by the SA Environment Protection Authority (EPA) in close collaboration with the Department of Environment, Water and Natural Resources (DEWNR), Department of Health and Aging (SA Health) and industry.

Early schemes were not rigorously regulated however each of the state agencies has become involved because of their legislative responsibilities. DEWNR regulates water quantity, EPA water quality and SA Health the impact of use on human health. Most of the legislation was written prior to MAR practices taking place and has been applied adaptively. The risk assessment methodology follows a stepwise approach to examining the source water (including catchment risk assessment), the receiving aquifer and the end-use. The journey has been challenging and is far from over. Industry acceptance has not been smooth, adaption of regulation is ongoing, monitoring has not been consistent and unexpected technical issues and water quality challenges continue to arise.

MAR has been established in SA as a common practice over the last twenty years. Early Aquifer Storage and Recovery (ASR) schemes were supported and initiated by DEWNR (in various guises) to explore viability and recharge depleting aquifers. Large areas of the Adelaide Plains, across where the states capital sprawls are underlain by a tertiary aquifer system that lends itself well to MAR.The City of Salisbury embraced the emerging practice as a key part of its stormwater management practices. Commonwealth Scientific and Industrial Research Organisation (CSIRO) Land and Water proceeded with an extensive program of research and documentation of existing and emerging MAR practices. ASR of treated waste water was trialled and a pilot scheme established by SA Water which is now operational.

The majority of MAR schemes that were established proved successful and the number of schemes has continued to increase. This was boosted over the last ten years by federal government initiatives to promote the use of recycled water(water generated from sewage, grey water or stormwater systems and treated to standard that is appropriate for its intended use), funding support and an extended period of drought. The Australian Guidelines for Water Recycling: Managing Health and Environmental Risks 2006 were developed detailing a health and environmental risk assessment framework that could be applied to recycled water schemes. Subsequently three phase 2 documents were completed that included AGWR MAR.

The requirements for developers and operators have increased over time but actions such as stormwater catchment risk assessment are now embraced. Moves to make one agency solely responsibility has not been successful however there has been a collaborative effort to streamline the process and the risk assessment methodology is a key binding force.

Keywords: Managed Aquifer Recharge; Risk;Risk Frameworks; Hazard and Critical Control Point Analysis; Water Safety Plans; Australian Guidelines for Managed Aquifer Recharge

RISKASSESSMENT FRAMEWORKS FOR MAR SCHEMES IN THE UK

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Managed Aquifer Recharge (MAR) provides a potentially cost and energy efficient opportunity to enhance resource availability however the risk management of implemented schemes needs to be sensitive to local environmental & regulatory circumstances. In addition, treatment train options, aquifer characteristics and operational detail will shape the risk profile of a scheme. This paper reports a critical review of risk assessment methodologies and frameworks as a first step towards the development of an assessment framework suitable for MAR schemes in the UK. A literature review of academic as well as grey sources was used to collate detailed descriptive information about candidate risk assessment frameworks which were subsequently discriminated on the basis of their strengths and weaknesses in the context of the UK regulatory and operational environment. Classification of risks across the MAR process involved decomposing the process into functional components; pre-treatment, recharge, storage, recovery, and post treatment prior to final use. Each component presents a range of risks to different receptors. The pre-treatment, injection, storage and recovery stages mainly contribute an operational and environmental risk (which in turn poses a regulatory risk). The post treatment stage carries an environmental, operational, human health and regulatory risk. Our evaluation of the potential value of risk assessment frameworks currently used in the water industry was undertaken using a qualitative suitability index. A set of idealised risk framework performance metrics for the UK context provided a basis for comparison. Four candidate frameworks were assessed; Hazard Analysis and Critical Control Points (HACCP), the World Health Organisation's (WHO) Water Safety Plan (WSP) concept, a framework produced by the UK Water Industry Research organisation (UKWIR) and the Australian Guidelines for Water Recycling using MAR. Findings exposed significant differences in the relative value of these four candidate frameworks. The HACCP, WHO and UKWIR methodologies provide a well structured approach to identifying, prioritizing and managing hazards, assessing the risks and implementing appropriate mitigation measures. Both the HACCP and WSP approaches focus strongly on the risk to human health while the UKWIR framework additionally considers acceptability and regulatory standards. Whilst we found the Australian guidelines to be particularly effective in considering operational and environmental risk, we found the focus on potential hazards to be a possible distraction from more process oriented considerations. By forming a risk assessment around the processes rather than the potential hazards, a wider range of potential risks can be considered, for example pre-treatment can be treated as a separate component rather than just a preventative measure. This also encourages an iterative approach to ensure the influences of the components on each other have been accounted for once the risk management strategies have been decided. Our findings indicate that local regulatory, technology maturity, and competence considerations heavily influence risk framework choices. In comparing and contrasting such frameworks in terms of their suitability for adoption we have generated an analysis that will be of value to researchers and practitioners in other countries with developing MAR activities.

GENEVA'S ARTIFICIAL RECHARGE SYSTEM AND THE CRISIS MANAGEMENT OF THE TRANSBOUNDARY REGION'S DRINKING WATER SUPPLY

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The artificial recharge system of the transboundary Genevese aquifer has been operating successfully since 1980, thus allowing for groundwater levels that are sufficiently high to compensate for peak flows due to heavy pumping of the water, especially in the summer months when demand is greatest. While the aquifer provides around 20% of the total drinking water supply, for over 30 years the artificial recharge system has made it possible for 450 million metric cubes of water to be used. Although the system has demonstrated its worth since 1980 and has helped to offset the excessive use of the 1960s and 70s by raising the average water levels in the aquifer by more than six metres, the region is still subject to water supply problems. In 2011, several events took place at the local, regional and even international level which prompted the committee responsible for the use of the transboundary aquifer to tackle the water problem on the basis of two factors: - The drought of 2010-2011 which ravaged a large part of Western Europe and prevented aquifers from collecting precipitation which is essential for their recharge - The Fukushima accident of March 2011 caused a radioactive cloud to form which travelled across the globe, passing over Switzerland. The effects of the cloud could have suspended the use of Lake Geneva's water as a source of drinking water for a long time. This water generally accounts for 80% of the total amount of water distributed in the Geneva region. In the face of these potential problems, the role of the Genevese aquifer in the provision of drinking water and its artificial recharge are the subject of a strategic study on water distribution in crisis situations. Sound recharge management helps to limit the effects of prolonged drought as long as there is regular, optimised pumping throughout the region. A serious atomic crisis would prevent use of the lake water, however one could take advantage of the aquifer for a while, even outside of recharge. This would be true as long as this potential accident takes place during periods when artificial recharge has ensured high groundwater levels (end of spring, beginning of winter). The work done in this area also paves the way for the next operation which is scheduled to take place between October 2013 and March 2014. The need to change a major pipeline in the lake water network will oblige the managers to divert a part of the lake water network to the groundwater network. This will mean that the Genevese aquifer will be used to supply the bulk of the region's drinking water, increasing from 20% under normal circumstances to over 60%. Once again, the recharge system is going to be the key to the success of the operation; it must help to prevent the effects of possible overuse resulting from weather conditions which determine recharge. All of these factors will be discussed at greater length in the present article.

MANAGING MICROBIOLOGICAL RISKS OF STORMWATER RECYCLING VIA AQUIFERS FOR DIFFERENT USES

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A brackish limestone aquifer was investigated as a treatment barrier when assessing microbial health risk of stormwater harvesting systems. A MAR research site recharging urban stormwater in a confined aquifer was used in conjunction with a Quantitative Microbial Risk Assessment (QMRA) to assess the microbial pathogen risk in the recovered water for different end uses. The assessment involved undertaking detailed water quality monitoring of the aquifer at the MAR site. The results were then used in the QMRA which demonstrated that the recovered water met the Australian Guidelines for recycled water for different end uses (viral hazards > 1 × 10-6 DALYs).

Keywords: Urban stormwater, Managed Aquifer Recharge Stormwater Use Options, Pathogens, Drinking Water

SETTING WATER QUALITY TRIGGER LEVELS FOR THE OPERATION AND MANAGEMENT OF MAR SYSTEMS IN PARAFIELD, SOUTH AUSTRALIA

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Setting of critical control and monitoring point trigger limits for water quality in managed aquifer recharge (MAR) schemes ensures human health, environmental and operational risks are managed. Application of a transferrable methodology for selection of appropriate critical limits and setting of alert limits for MAR systems is demonstrated for a stormwater aquifer storage and recovery scheme in Parafield, South Australia. This is the first demonstrated application of an approach incorporating hazard analysis and critical control point principles for setting water quality targets in a stormwater MAR system based on Australian Water Recycling Guidelines and Australian and international drinking water guidelines. Salinity and Escherichia coli are used as example parameters but others follow the same principles. A decision tree was designed for systematic selection of relevant targets and setting of critical and alert limits. Up to 10 years of operational water quality data across the system were used for analyses. Comparison of injected and recovered water showed the aquifer was capable of at least one log10 removal of E. coli. A predicted E. coli reduction of 25% in the distribution pipeline following a change in operational procedures was calculated using a probabilistic model. Long term data were used to set alert limits for critical control and quality monitoring points in the system. Management actions following occasions where limits are not met are discussed.

Keywords: Aquifer storage and recovery, stormwater, critical control point, E. coli, risk-based

Theme 4: Operations and maintenance of MAR

Track 4.1: Fate of pathogens in the aquifer

FATE AND TRANSPORT OF VIRUSES IN POROUS MEDIA: THE COUPLED EFFECT OF SYSTEM HYDRODYNAMIC AND MICROSCALE SURFACE HETEROGENEITIES

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Groundwater may become contaminated with pathogenic microorganisms, especially viruses. An understanding and ability to predict the fate and transport of viruses in soils and aquifers requires knowledge of processes and interactions that occur at different spatial and temporal scales. Virus attachment is believed to be largely restricted to a minor fraction of the mineral grain surfaces having positively charged properties. Metal oxides are the most common sources of the surface charge heterogeneities. The objective of this work is to quantify the coupled effect of system hydrodynamic and surface charge heterogeneity on attachment rate of viruses. A systematic laboratory study was conducted with a wide range of flow velocities and fractions of the positively charged patches on the sand surfaces. Experiments were conducted in columns packed with the sand under saturated conditions. Values of solution ionic strength and pH were fixed at 7 and 10 mM NaCl, respectively and bacteriophages PRD1 and MS2 were used as conservative model viruses. Attachment and inactivation rate of attached viruses were determined by fitting breakthrough curves and elution experiments. At a given percentage of favourable sites on the sand surface, significant amounts of virus deposition were observed a the flow velocity decreased. These enhanced attachments were attributed to weak adhesive interaction of viruses with the unfavourable regions of the sand and mass transfer on those regions to the favourable sites. The experimental findings and discrepancy between theory and experiments will be presented and discussed.

Track 4.2: Fate of pollutants of concern in MAR system

FATE OF DISINFECTION-BY-PRODUCTS RELEASED INTO AN ANAEROBIC AQUIFER DURING MANAGED AQUIFER RECHARGE

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Laboratory and field experiments were undertaken to assess the fate of disinfection-by-products N-nitrosodimethylamine (NDMA) and N-nitrosomorpholine (NMOR) in aerobic recycled water that was recharged into a deep anaerobic pyritic aquifer, at nanogram per litre concentrations. Laboratory studies demonstrated a high mobility of NDMA and NMOR in the aquifer with retardation coefficients of 1.1 and 1.2 respectively, suggesting the disinfection-by-products would travel un-retarded through the aquifer along with the recharged recycled water. Laboratory column studies were able to demonstrate that the anaerobic conditions of the aquifer were suitable for the biodegradation of NDMA and NMOR, with first-order degradation half lives of 25 to 150 days for NDMA and 40 to 45 for NMOR. Additional 14C-NDMA microcosm studies showed NDMA degraded faster under aerobic conditions (half life 8 days) than anaerobic conditions (half life 29 to 46 days). Thus, aerobic conditions that may develop around a recharge bore (as a result of recharging aerobic recycled water) could provide more suitable geochemical conditions for NDMA degradation. Results from a managed aquifer recharge field trial, recharging an anaerobic aquifer with aerobic recycled water, showed that NDMA concentrations reduced from 2.5 ± 1.0 ng L-1 to 1.3 ± 0.4 ng L-1 between the recharge bore and a monitoring location 20 m downgradient (an estimated aquifer residence time of 10 days). These data are consistent with data from the aerobic microcosm experiment, considering an aerobic environment may be developing in this near recharge zone. Further downgradient, NDMA degradation could not be assessed as NDMA concentrations were too close to their analytical detection limit (< 1 ng L-1).

EFFECTS OF NITROGEN AND REDOX CONDITIONS ON THE REMOVAL OF ORGANIC MICROPOLLUTANTS DURING MANAGED AQUIFER RECHARGE

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Pharmaceutically active compounds (PhACs) are persistant organic micropollutants (OMPs) in the environment that have been acknowledged to constitute a health risk for humans and terrestrial and aquatic ecosystems. They have been detected at a alarming rate in many surface and ground water bodies as a consequence of discharge of wastewater treatment plant effluents into the aquatic environment. Natural wastewater treatment systems (NWTSs) such as aquifer recharge and recovery (ARR) and soil aquifer treatment (SAT) have emerged as a sustainable, cost-effective and efficient process over conventional wastewater treatment technologies for wastewater treatment and polishing aiming at reuse. ARR systems are used to enhance reclaimed water quality and to recharge the groundwater and can be an attractive option for removal of PhACs present in the source water. The performance of ARR systems, including bulk organic matter, nutrients and OMPs removals, depends on many factors such as feed water quality, soil type, redox conditions, available nitrogen species, hydraulic loading rate and residence time. Furthermore, some studies have indicated that ANAMMOX conditions sustain nitrogen removal in soil systems. It was also found that ANAMMOX conditions enhanced the removal of some OMPs (e.g. ibuprofen and metoprolol). The main goal of this work was to assess the potential removals of nutrients as well as OMPs during managed aquifer recharge. The removals of a selected group of PhACs through ARR from a secondary effluent (SE) under different redox conditions (aerobic and anoxic) in the presence of ammonium or nitrate were studied. To achieve this goal, laboratory-scale soil columns (SCs) and batch reactors were employed to simulate process conditions. Silica sand (0.8-1.2 mm) was used as a filter media and SE was used as feed water. Twelve PhACs including bezafibrate, caffeine, carbamazepine, clofibric acid, diclofenac, fenoprofen, gemifibrozil, ibuprofen, ketoprofen, naproxen, pentoxifylline and phenacetin were selected for this research. Batch reactors and SCs were operated with varying nitrogen concentrations (20 mg/L NO3-_N, 0 mg/L NH4+-N, 5 mg/L NH4+-N and 20 mg/L NH4+-N). Both aerobic and anoxic conditions were applied to evaluate the attenuation of the target PhACs. All of the selected PhACs exhibited similar removals during aerobic and anoxic conditions except for caffeine and naproxen, which exhibited higher removal under anoxic conditions (95% and 60 % , respectively). Phenacetin and caffeine were removed >90% under different redox and nitrogen conditions. Carbamazepine, clofibric acid, gemifibrozil and ketoprofen were found to be highly persistence (<30% removed) under different redox and nitrogen process conditions. It was also found that redox conditions have more impact on PhACs removal than nitrogen conditions. Bezafibrate, fenoprofen, ibuprofen and naproxen achieved better removal in the presence of 20 mg/L NH4+-N under aerobic or oxic conditions: 78%, 75%, 95% and 92%, respectively, while nitrate conditions did not enhance.

NATURAL ATTENUATION OF CHLOROBENZENE AT DIFFERENT TEMPERATURES DURING GROUNDWATER ARTIFICIAL RECHARGE

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Artificial recharge of aquifers is an important water management strategy. The main purpose of this process is to prevent and control land subsidence, to increase the amount of groundwater resources and to prevent seawater intrusion into aquifers. The quality of recharging water was monitored for organic components such as chlorobenzene (CB). Chlorobenzene is a toxic synthetic chemical that targets multiple organs by all routes of exposure and has been classified as a pollutant of major concern.Therefore, to protect the safety of the underground environment during artificial recharge. This paper discusses the mechanisms and effects of CB elimination at different temperatures during artificial recharging in the fourth confined aquifer in Shanghai, China. Pilot scale experiments were conducted in the laboratory, including adsorption and biodegradation experiments at different temperatures (0, 10 and 20 °C). The equilibrium times of adsorption experiments were 8 h (20 °C), 10 h (10 °C) and 12 h (0 °C), respectively, Results indicated that the adsorption rate increased within the temperature range 0 °C to 20 °C. Adsorption kinetics experiments were fitted to the pseudo-first- and second-order kinetic equations and Adsorption thermodynamics experiments were fitted to Freundlich and Langmuir models. Maximal amounts of adsorption were 20.747, 21.505, 23.364 μg/g at 0 °C, 10 °C, 20 °C, respectively. The adsorption of CB was an endothermic process calculated by Van't Hoff equation, higher temperature promotes the adsorption reaction. Results from biodegradation experiments indicated that the processes were well fitted by the Monod and first-order decay kinetics equations at different temperatures. We showed that qmax of Monod changed from 0.0314 to 0.0387 h-1, and the half-life (t1/2) decreased from 3.02 to 1.46 d, the highest amount of biodegradation obtained was 28.32 μg/g with an increase in temperature from 0 °C to 20 °C. The influence of temperature on biodegradation rate was expressed by Arrhenius equation. The best season for artificial recharge is summer, as higher rates of adsorption and biodegradation of CB are obtained at higher temperatures, which will reduce leaching potential of this toxic chemical. This study provides information on the mechanisms of natural attenuation of CB in the underground environment, whilst also providing the necessary technical information for security of artificial recharge implementation.

INFLUENCES OF LONG-RESISTANT PHARMACEUTICAL COMPOUND IN ANAEROBIC DIGESTION PROCESS

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Pharmaceutical compounds with increased demand for consumption have been recently issued and considered as potential toxicity in the biosphere which could affect the biological treatment processes. The aim of this study was to investigate the effects of the long resistance pharmaceutical compound, carbamazepine, on the activity of anaerobic digestion process and to observe the change of the residual concentration of carbamazepine based on the BMP (Biochemical Methane Potential) test. Carbamazepine concentration was quickly decrease by 30% when supplied with 0.1 g/L of glucose as substrate. And part of it was accounted by adsorption onto suspended particles and EPS. Inhibition on methane production by carbamazepine was occurred temporarily in the middle of experimnets, and exerts no significant difference in the final methane productions. Also it seems that residual carbamazepine concentration lower than the present experimental conditions if detected, might not significantly affect the microbial metabolism.

Keywords: pharmarceutical compound, carbamazepine, BMP test, anaerobic digestion, HPLC

TRANSPORT AND FATE OF AMMONIUM AT A RIVERBANK FILTRATION SITE IN DELHI, INDIA

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In India's capital Delhi, drinking water resources are stressed, and the public water supply is not sufficient to cover the actual water demand. To help close this gap, an intensified use of the flood plain aquifer along the Yamuna River is proposed (Sinha 2009). Several existing wells already tap this aquifer in central Delhi. Due to losing stream conditions of the Yamuna (Lorenzen et al. 2010a), they draw a share of bank filtrate. However, because of substantial shares of untreated sewage in the river, ammonium concentrations in the aquifer close to the river are elevated and vary between 0.2 and 26 mg/L depending on season and distance to the river. To improve the understanding of the central Delhi field site and to identify the dominating processes concerning ammonium contamination, different methods were applied. Aquifer material was analyzed to obtain information on clay content in the sediment; the cation exchange capacity (CEC) and the adsorbed ions were measured. Column experiments with aquifer material give first information about the retention and mobilization as well as degradation of ammonium in the aquifer material.

The results will help to set up an ammonium balance and will give implications about the processes controlling the development of the ammonium plume in the central Delhi flood plain aquifer. This will contribute to estimating future ammonium concentrations, which is necessary to evaluate the suitability for drinking water production and to plan appropriate treatment options.

Key words: Delhi flood plain, Yamuna River, ammonium contamination, column experiments

RAPID DETERMINATION OF SEVEN SELECTED ENDOCRINE DISRUPTING CHEMICALS IN WASTEWATER BY SOLID-PHASE EXTRACTION AND ULTRA-PERFORMANCE LIQUID CHROMATOGRAPHY TANDEM MASS SPECTROMETRY

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As emerging pollutants, endocrine disrupting chemicals (EDCs) are harmful to aquatic organisms even at a very low concentration (ng/L) and have received much attention. The effluents of wastewater treatment plants (WWTPs), also as original sources for managed aquifer recharge (MAR), are considered to be one of the major sources of EDCs released in the environment. This research developed an analytical method based on solid-phase extraction (SPE) and ultra-performance liquid chromatography (UPLC) tandem mass spectrometry (MS/MS) to separate and determine seven selected endocrine disrupting chemicals (EDCs) in wastewater: estrone (E1), 17β-estradiol (E2), 17a-ethinyl estradiol (EE2), estriol (E3), bisphenol A (BPA), 4-octylphenol (4-OP) and 4-n-nonylphenol (4-n-NP). The recoveries of seven EDCs ranged from 79.1 to 89.2% and the limit of detections was 0.1ng/L for the secondary effluent from WWTPs. The method was applied to determine EDCs in two WWTPs in Beijing, China, and the concentrations of seven EDCs in secondary effluent ranged from 0.5 to 148.7ng/L. The concentrations of E1, EE2, BPA and OP were higher than their predictive non-effect concentrations, which would pose a potential risk to aquatic organisms in receiving water bodies.

Keywords: Endocrine Disrupting Chemicals, Solid-phase extraction, Ultra-performance Liquid Chromatography Tandem Mass Spectrometry, Wastewater, Steroid Estrogen, Alkylphenol

Track 4.3: Geochemistry and hydrogeology in MAR

DISSOLVED SILICA AS AN INDICATOR OF ASR EFFICIENCY IN A CHEMICALLY HETEROGENEOUS AQUIFER WITH SIMILAR SOURCE WATER AND GROUNDWATER

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Geochemical tracers are commonly used in artificial storage and recovery (ASR) projects to evaluate the efficiency of recharge, storage, and recovery during cycle tests. The tracers are usually chemically conservative species such as chloride, whose concentrations differ significantly in the source water and groundwater. The selection of a chemical tracer can be difficult when injection and groundwater chemistries are similar, chemically heterogeneous conditions exist in the aquifer, or when pretreatment alters the chemistry of the source water. We examined the use of dissolved silica as a conservative indicator of ASR efficiency at a site in north-central Thailand, where all three conditions exist. The ASR project was initiated by the Thailand Department of Groundwater Resources as a means of alleviating the drought crisis in the Upper Chao Phraya Basin. The injection site is located approximately 100 meters from the Yom River, which provides the recharge source when the river stage is high. Background geochemical conditions in the aquifer were determined prior to initiation of cycle tests in 18 monitoring wells from shallow and deep aquifer zones. Although chloride concentrations in the river water are lower than in groundwater, high levels of turbidity require the addition of polyaluminum chloride in the treatment process, causing elevated chloride levels and prohibiting the use of chloride as a tracer. Similar average total dissolved solids levels exist in the ground water (166 mg/L) and river water (159 mg/L), and the concentration ranges of most major ions in river and groundwater overlap. The groundwater is near equilibrium with siderite and other reactive carbonate minerals observed in the aquifer. Iron oxides are abundant in the predominantly feldspar and quartz sand aquifer matrix, along with some detrital clays. Low average dissolved silica concentrations (15 mg/L) in river water, and higher average values in the aquifer (39 mg/L), suggest that dissolved silica may be used to index relative proportions of groundwater and source water during the pilot tests. Silicate and clay minerals should remain stable at post-injection groundwater pH levels, so the release of significant amounts of silica by mineral weathering and the precipitation of amorphous silica, are unlikely on the time short (30-day) time frame of the cycle tests. Two pilot tests are currently underway and will be discussed. The use of silica as a conservative tracer may provide an alternative to isotopic or other expensive or time-consuming methods for evaluating aquifer-source water mixing, and could aid in evaluations of other surface water-groundwater ASR projects.

TRACE ELEMENT PATTERNS AND BEHAVIOR IN A LONG TRANSECT, FROM RECHARGE TOWARDS RECOVERY CANAL IN DUTCH COASTAL DUNES, DEPICTING 50 YEARS OF RHINE RIVER INFILTRATION

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Trace elements (TEs) are important in water quality monitoring of managed aquifer recharge (MAR) systems, because there are maximum permissible concentrations (MPCs), and some form a tracer of either infiltration water or geochemical processes. The behavior of 55 dissolved trace elements and 20 main constituents is shown for an 800 m long, 40 m deep transect between a recharge and recovery canal, in coastal dunes of the Netherlands. Infiltrated Rhine River water was monitored there via 8 multilevel wells (each with ~22 miniscreens), in 1981 and 2007. In this transect, infiltration water from the whole artificial recharge period (starting in 1957) was sampled, displaying historical input changes and spatial patterns due to hydrogeochemical processes. The data justify the following conclusions: (1) Flushing of the aquifer with cleaner infiltration water since the late 1970s has led to a significant decline of TE concentrations in the transect. This is due to desorption and an increased oxidation state of the aquifer. The latter also resulted from progressive leaching of pyrite and organic material from the aquifer. Concentrations of heavy metals like Cr, Cu, Hg, Ni, Pb and Zn, once showing worrying concentration levels in the water recovered, today are very low. (2) Mo is an emerging TE, showing high concentrations and little retardation, except for deeply anoxic and finer-grained zones. (3) As and U show distinct mobilization and immobilization zones near redox boundaries. As peaking up to 50 µg/L was limited to anoxic aquifer zones in between (sub)oxic and deeply anoxic layers. (4) The Cl/Br ratio is an excellent tracer of infiltrated surface water, whereas B, F and Li, although relatively mobile, are bad tracers due to sorption in more silty/clayey compartments of the aquifer. (5) 23 TEs were always below their minimum detection limit (MDL) and should therefore be given low priority in monitoring: <0.01 ug/L for Cs, Hf, Ho, In, Lu, Pt, Re, Rh, Ta, Tb, Tm; <0.05 for Ag, Au, Bi, Ga, Ge, Ir, Os, Ru, Te; <0.1 ug/L for Hg and Pd. In case of filtration bias (see below) concentrations were above MDL. Higher monitoring priority should be given to Mo (see above), As (especially if MPC is lowered from 10 to 1-5 µg/L), and CrO42- ((sub)oxic systems only). (6) Al was a good indicator of filtration bias, also allowing to correct high pH samples (>5.5) for dissolution of suspended fines that passed the 0.45 µm filtration unit and subsequently dissolved in the sample when acidified for storage. This study demonstrates how TEs behaved in pH7-8 MAR systems in coastal sediments during the past 50 years, which TEs can be used as tracers, which are emerging and important enough to monitor, and how sampling errors arise which can be corrected.

INORGANIC SOLUTES' FATE AND TRANSPORTATION DURING GROUNDWATER ARTIFICIAL RECHARGE

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In recent years, environmental geological problems such as land subsidence, land collapse, land cracking and salt-water intrusion have become important factors limiting economic development in some cities due to severe overexploitation of groundwater. So, a number of cities have carried out artificial recharge projects, which have played a significant role in controlling these problems. However, in the result of the complexity of the water-rock interaction mechanism, it remains unclear whether the implementation of artificial recharge negatively impacts the environmental quality of groundwater. Then, this research selected an artificial recharge test site in Shanghai as an example. Based on the complete control of geological, hydrogeological and hydrogeochemical conditions of the test site, a series of laboratory simulation experiments (combined the hydrogeological conditions of the target aquifer and reduced the field aquifer to the model aquifer based on the geometric similarity theory. The scale was 1:250) and numerical models (used TOUGHREACT, 1-Dimension) have been carried out to investigate the fate and transportation processes of the inorganic solutes in groundwater during artificial recharge. The results showed that during the recharge process: (1) the composition of the inorganic ions in groundwater was mainly affected by the mixing, cation exchanging and dissolution of aquifer minerals (calcite, dolomite, K-feldspar); (2) the elemental dissolution of As, Cr and Fe occurred in the aquifer due to the transformation of the underground environment from anaerobic to aerobic systems; (3) as indicated by the predicted results, the impact radius of water quality in the field aquifer was approximately 50 m, 300 m and 500 m after 5d, 50d and 100 d of groundwater recharge, respectively; and (4) the hydrochemical type of groundwater gradually changed from the initial Cl-HCO3-Na type to the Cl-HCO3-Na-Ca type. The results presented herein could provide a theoretical basis and technical support for the safety and stability of groundwater associated with artificial recharge.

Keywords: Artificial Recharge; Groundwater; Laboratory Experiment; Water-rock Interaction

AQUIFER CONDITIONING TO MINIMIZE IRON AND MANGANESE IN RECOVERED WATER FROM ASR PROJECTS

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Many ASR projects involve storage in aquifers that contain groundwater with elevated concentrations of iron (Fe) and manganese (Mn). Other ASR aquifers may contain groundwater with acceptably low concentrations of Fe and Mn, but contain iron sulfide (pyrite) and iron carbonate (siderite) that can contain high concentrations of arsenic and other metals. Pyrite and siderite can relatively rapidly react with oxygenated water during the ASR project. Pyrite oxidation releases iron, manganese, other contained constituents and forms sulfuric acid. This acid can significantly lower the pH in aquifers that have low alkalinity and are poorly buffered. Other minerals dissolve during neutralization of the acid, ultimately increasing TDS and released metals concentration in the water recovered from the ASR well. If the recovered water is utilized for drinking water supply, the elevated metal concentrations in the recovered water may not meet drinking water standards. One option is to increase the alkalinity of the water in the aquifer around the ASR well where this addition is compatible with the native groundwater. The pH change resulting from ASR recharge is limited by this alkalinity increase as iron oxyhydroxide coats the pyrite surfaces, minimizing the dissolution of pyrite and forming an adsorption media for arsenic and other metals. This adsorption media also forms when siderite dissolves. The higher pH also promotes manganese dioxide precipitation, thereby limiting the dissolved manganese concentration. This was the situation for Orangeburg, South Carolina. Two adjacent ASR wells were constructed in two different coastal plain, alluvial aquifers, one semi-confined and one fully-confined. Ambient concentrations of Fe and Mn in each aquifer prior to ASR recharge were close to drinking water standards such that, in the absence of pyrite oxidation, recharge with drinking water could yield an acceptable recovered water quality. ASR recharge with oxygenated, treated surface water caused Fe and Mn concentrations in the recovered water to exceed drinking water standards. Adding soda ash (sodium carbonate, Na2CO3) to the recharge water increases the alkalinity in the aquifer surrounding each of the ASR wells, thereby promoting iron oxyhydroxide coating and precipitation. This coating stabilizes pyrite oxidation and siderite dissolution, rendering them essentially non-reactive. Recovered water from ASR storage during initial cycles confirmed the effectiveness of this low-cost pretreatment process. Based upon initial test results, a sufficient volume of aquifer will be conditioned around each well so that each well will yield acceptable recovered water quality. Aquifer conditioning should be needed for a limited period of time after which it could be discontinued. Water quality monitoring under operational conditions continues as the volume of soda ash is adjusted to effectively condition a sufficient radius around each ASR well so that subsequent ASR operations will yield an acceptable recovered water quality.

Keywords: aquifer storage recovery; soda ash; iron and manganese removal; passivation.

QUANTIFYING NUTRIENT REMOVAL DURING AQUIFER STORAGE AND RECOVERY (ASR)

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Water quality improvement, or treatment, has been reported during aquifer storage for various contaminants, including pathogens, bulk organic matter, nutrients and trace organic chemicals. However, the aquifer is not always acknowledged as a treatment step or barrier that can be relied upon within a multiple barrier approach to water reuse. This paper applies a statistical method to quantify organic carbon, nitrogen and phosphorus removal during four cycles of aquifer storage and recovery (ASR) with recycled water in an anoxic carbonate aquifer. The modelling approach applied incorporates the use of probability density functions (PDFs) and is consistent with methodology used recently to assess the performance of advanced water treatment and wetland treatment barriers within multiple treatment barrier systems for water recycling. While the extent of aquifer treatment will vary between managed aquifer recharge (MAR) operations, the probabilistic approach is proposed as a consistent methodology, which can potentially be used for each treatment barrier (engineered or natural). This method was found to be suitable for the calculation of removal efficiencies for total organic carbon (TOC) and total nitrogen (TN) over four ASR cycles with variable concentrations of nutrients in the tertiary treated wastewater injectant. TOC and TN removal was dominated by redox processes, aerobic respiration and denitrification. Median removal of TOC ranged from 25 to 40% and TN from 46 to 87% over the four cycles. However, total phosphorous (TP) was subject to reversible removal via adsorption and desorption processes. As TP removal was not consistent within this ASR system, removal efficiency could not be calculated. It is suggested that the statistical technique described in this paper could be more widely and routinely applied to MAR to build the knowledge base on the capacity of aquifers across a variety of aquifer types and operational conditions to provide sustainable natural treatment and therefore allow the performance of the aquifer treatment step to be assessed in a similar manner to engineered treatment steps.

Track 4.4: Groundwater hydraulics and storage recovery

TRAPPED GAS BUBBLES AROUND INFILTRATION WELLS - INDICATIONS FOR POTENTIAL IMPACTS ON WELL PERFORMANCE

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The use of infiltration wells has been increasing throughout the world. They have been widely applied in the field of managed aquifer recharge, but are also used in other fields of groundwater utilization and remediation. Although there is a broad spectrum of infiltration well designs, dimensions and operational modes, the creation and preservation of optimal hydraulic conditions is a common goal in construction and operation, not only for infiltration but also for abstraction and combined applications. While the relation between hydraulic conductivity and saturation of a porous medium is generally known and well investigated, the circumstances that favour the occurrence of unsaturated conditions around wells and the degree of accumulation of gas bubbles are poorly understood and difficult to predict. This is partly due to the complex combination of chemical and physical processes occurring under site-specific hydrochemical, hydraulic, physical well design and operational boundary conditions, but is due also to a lack of basic research into the issue. Thus, the contribution of trapped gas bubbles to the decline of infiltration well performance remains unknown. In the division of water sciences at the University of Applied Sciences Dresden several different field and laboratory experiments have been designed and conducted aimed at studying physical clogging of well filter material and the adjacent aquifer by trapped gas bubbles. The different aspects investigated were (1) possible paths of gas bubble entry through infiltration wells, (2) mobility of gas bubbles in porous media under different hydraulic conditions and (3) possible measures for elimination/reduction of bubble entry and/or removal of bubbles trapped in the subsurface. As the experiments proceeded several modifications were made in order to improve the transferability and quantifiability of results. However, generalizable results have proven difficult to obtain. This presentation has three aims. First, visual results from experiments with different setups involving sand boxes, vertical water columns and field tests at existing observation wells will be presented to prove the possibility of gas bubble entry into the subsurface via infiltration wells. Secondly, the problem of remobilization of trapped gas bubbles and their detrimental effect on well capacity will be highlighted. Thirdly, a summary description of the complexity and potential impacts of gas bubbles is intended to raise awareness about the problem and prompt further discussions about experimental approaches to investigate the behaviour of gas bubbles in infiltration wells and porous media in general.

Keywords: clogging, bubble, infiltration, well performance

HYDRAULIC CHARACTERIZATION AND RECHARGE POTENTIAL OF WEATHERED BASEMENT AQUIFER SYSTEM OF IBARAPA AREA, SOUTHWESTERN NIGERIA

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Reliable estimates of aquifer parameters are fundamental to a better understanding of groundwater recharge process and management. This is more important in the basement aquifer setting where the development of the groundwater bearing zones is complex and erratic. Therefore, this study focus on the use of resistivity survey and pumping test techniques, to characterize the recharge potential and the hydraulic properties of the dual weathered–fractured aquifer system of the crystalline rocks of Ibarapa areas of southwestern Nigeria. For the field aspect, a total number of 82 geo-electric soundings comprising of 25 vertical electrical soundings on amphibolites, 19 on gneisses, 18 on migmatites and 20 on granites were carried out. In addition, pumping tests were carried out on a total number of 21 boreholes distributed across the different bedrock types in the study area. The geo-electric survey revealed predominantly 3-layers H type curve, indicative of more conductive middle layer terminating on resistive infinite basal layer. The estimated total regolith thickness revealed higher thickness range of 4.4 - 47.5m (av. 18.0m) for both amphibolites and gneisses bedrock settings compare to the shallower thickness of 2.4-23.6m (12.2m) for areas underlain by migmatite and granite, implying relatively low degree of weathering. However, the estimated Dar Zarrouk functions of the longitudinal unit conductance of 0.23mhos and 0.15 mhos for the regolith units developed over migmatites and granites respectively compared to 0.47 mhos and 0.27mhos for the regolith units overlying the amphibolites and gneisses respectively is an indication of relatively high recharge potential for migmatites and porphyritic granites. This is consistent with the average weathered layer resistivity of 95 and 93 Ohm-m respectively suggesting sandy weathered overburden materials. The results of the hydraulic characterisation revealed that the weathered-fractured aquifer in areas underlain by amphibolites have higher transmissivity of 1.11 – 7.75m2/day (av. 4.11m2/day) and hydraulic conductivity values of 0.39-4.51 x 10-6m/s (1.56 x 10-6m/s) compared to areas underlain by migmatites with lower transmissivity of 0.56-0.73 m2/day, (av. 0.69 m2/day) and hydraulic conductivity of 0.28-0.38 x 10-6m/s (av. 0.34 x 10-6m/s). However, areas with gneisses and porphyritic granite have moderate transmissivity with average of 1.61 m2/day and 1.43 m2/day and average hydraulic conductivity of 0.66 x 10-6m/s and 0.85 x 10-6m/s respectively. These is a reflection of the higher discharge of 43.56-98.12 (av.72.05) m3/day for amphibolites compared to migmatites with 41.91-99.79 (67.97) m3/day, granite with 45.62-91.01(62.79) m3/day and gneisses with the lowest yield of 32.78-78.92 (av.53.45) m3/day. Based on the overall results, areas underlain by amphibolites and gneisses are characterised to have lower recharge attributes due to development of more clayey regolith soils while the regolith unit associated with porphyritic granite have good recharge potential due to the development of more sandy soils. This clearly highlights varied hydraulic and recharge characteristics in a typical basement terrain.

Track 4.5: Innovation in harvesting and storing flood waters

DEVELOPMENT OF A FLOOD DETENTION/STORMWATER CAPTURE/AQUIFER RECHARGE FACILITY IN A SEMI-ARID ENVIRONMENT

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Stormwater capture and aquifer recharge is being evaluated as a method to augment surface water base-flow and protect riparian habitat in one of the few remaining free-flowing rivers in the desert American Southwest. Groundwater mining in this area is resulting in declining river base flows and the use of flood control basins used to mitigate stormwater flows from urbanized areas are being investigated for stormwater capture and aquifer recharge at locations near the river in order to augment groundwater storage which contributes to river base flow during dry periods. This presentation reviews the results of several studies performed over the last twelve years and a current pilot project to evaluate the feasibility of stormwater runoff capture and aquifer recharge in this semi-arid climatic regime. The study area receives approximately 350 mm of precipitation on an annual average. The precipitation regime is characterized by low intensity winter storms and high-intensity, localized, monsoonal type summer rains. In order to predict the amount of stormwater that could be captured by flood control basins and the potential aquifer recharge benefits, a three-part modeling approach was used. Multi-year data from a nearby high-density precipitation gauge network were used to create synthetic annual records for average, wet and dry years. These daily precipitation data were then used with the Automated Geospatial Watershed Assessment tool (AGWA/KINEROS2) to predict stormwater runoff, channel infiltration and basin infiltration for a 4990 hectare, variably urbanized subwatershed within the study area. AGWA/KINEROS2 was chosen due to the explicit capability to predict infiltration in channels and basins. The rainfall/runoff/infiltration predictions generated by AGWA were then analyzed for regression relationships (precipitation-runoff; runoff-channel infiltration, and runoff-basin infiltration) and scaled up to permit their application to other watersheds in the 36,940 hectare study area. Each sub-watershed can now be modeled using data on surface and channel areas, soil types, land cover and percent impervious surface with a 56-year daily precipitation record as input to the regression models. Finally, monitoring data on groundwater recharge in channels and basins were collected over a five year period and then used to predict the percent of modeled daily infiltration that would recharge groundwater. To test the accuracy of the stormwater and infiltration modeling and to test optimum stormwater capture and recharge facility designs, a pilot project is being implemented in a 2000 hectare sub-watershed. Design efforts began with identification of the optimum area for placement of a flood control detention basin followed by a groundwater recharge feasibility assessment of the proposed detention basin site and other nearby sites. An initial data screening identified optimum hydrogeologic areas for recharge and subsequent near-surface and deeper sub-surface field investigations assessed subsurface lithologic and hydraulic properties. The spatial and stratigraphic distribution of estimated hydraulic properties was then used to design a joint flood control detention basin and downstream recharge basins in higher hydraulic conductivity channel sediments. Proposed monitoring will quantify the amount of stormwater capture and estimated groundwater recharge over the next several precipitation years.

Track 4.5: Management of clogging

MAXIMIZING INFILTRATION RATES BY REMOVING SUSPENDED SOLIDS: RESULTS OF DEMONSTRATION TESTING OF CLOTH FILTRATION

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Over the past 80 years, the Orange County Water District (OCWD) has developed a large managed aquifer recharge (MAR) system that includes 600 ha of surface water spreading facilities and over 100 injection wells to prevent seawater intrusion. The surface water recharge system provides over two thirds of total recharge to the groundwater basin, recharging an average of 274 million m3/yr over the last decade. Maximizing the capacity of the surface water recharge system is critical but constrained by clogging caused by suspended sediments in the recharge water. OCWD tested multiple treatment methods to remove suspended sediments from the recharge water. While treatment methods that used chemical additives were successful in reducing suspended sediment concentrations, they were unsuccessful in reducing clogging. The two methods that reduced clogging were Cloth Filtration and Riverbed Filtration, both of which are mechanical filtration methods that require no chemical additives. Multi-year demonstration projects using Cloth Filtration and Riverbed Filtration are underway. A 12,000 m3/day AquaDisk cloth media filter system manufactured by Aqua-Aerobics Systems, Inc. (http://www.aqua-aerobic.com) started operations in September 2012 and is sending treating water to a small dedicated recharge basin. A wide array of data are being collected to assess any improvements in recharge capacity provided by the filter system, water quality improvements and the potential penetration of fines into recharge basin sediments. Given that the cloth filter, which as a nominal pore size of 5 microns, is able to remove up to 90 percent of the suspended sediment, there is concern that the smaller particles that pass through the filter will penetrate more deeply into recharge basin sediments and eventually clog the facility in such a way that it may be irreversible. The Riverbed Filtration project is a variation of riverbank filtration where the surface water is collected several feet below the riverbed and conveyed to a dedicated recharge basin. Pilot study results showed that this method was extremely effective in removing suspended solids and resulted in some water quality improvements, such as organic carbon removal. The Demonstration Project will be sized to collect up to 50,000 m3/day with two collector system designs, including slotted PVC pipe and a linear array of underground modular water tanks manufactured by Atlantis Corporation (http://www.atlantiscorp.com.au/). This is a unique application of the water tanks, which are being used because they have over 90 percent void space and a tremendous amount of open area compared to slotted PVC pipe (2%). The Riverbed Filtration system has great promise because of the excellent quality of water it produces, the potential for high volumes that could be collected in the Santa Ana River channel, and the fact that filtered suspended sediments remain in the river channel and do not require costly handling or disposal. Results of the Demonstration Projects will be used to assess whether or not it is economically feasible to apply the techniques at a larger scale in other locations. The results of this study will be applicable to surface recharge facilities in other parts of the world that are wrestling with clogging caused by suspended sediments in the source water.

IDENTIFICATION AND MANAGEMENT OF CLOGGING IN A FRACTURED ROCK AQUIFER DURING ASR OPERATIONS

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Control of clogging is a key consideration for the long-term sustainable operation of managed aquifer recharge (MAR) schemes. Control of the source water quality is the first and most obvious measure to minimise the potential for clogging. However, over time, loss of injection or infiltration performance due to clogging which can manifest from; the accumulation of suspended solids; biological growth; microbiological activity; geochemical reactions; dissolved or entrained air from turbulence; mobilization of interstitial clays or a temperature differential between the injected water and ambient groundwater, is not uncommon. Often multiple cause of clogging may be occurring simultaneously, for example, gas entrainment may induce precipitation of iron which can stimulate an increase in iron bacteria. What started out as a simple air entrainment problem has the potential to develop into a significant clogging problem driven by three different processes. Each potential clogging cause may now require individual treatment. This paper discusses some of the clogging mechanisms encountered when the injection to, and recovery from, the aquifer utilises bores, more commonly referred to as aquifer storage and recovery (ASR). Results of a case study and the approach to identification of clogging using the aquifer hydraulic response are presented and the corrective measure adopted are discussed.

The City of Tea Tree Gully has an integrated MAR system comprising four individual aquifer storage and recovery (ASR) sites linked by a common pipeline. Collectively the schemes harvest, treat and recharge, to the underlying fractured rock aquifer, approximately 300 megalitres per year (ML/yr) of urban stormwater runoff. A further two schemes, outside of the linear pipeline, harvest up to 80 ML/yr each. Integration of the schemes through the single pipeline has enabled greater operating flexibility and the servicing of many smaller open spaces that may otherwise have had to continue to be irrigated with potable mains water. During pre-commissioning one of the schemes, Tilley Reserve, experienced significant head build up beyond the pre-selected trigger limits set for safe operation of the scheme. Investigations into the origin of the greater than expected head buildup identified gas entrainment at the onset of injection followed shortly thereafter by colonisation of the drillhole by iron bacteria as the causes of the clogging. Gas entrainment resulted from an oversight in the overall engineering design when the scheme was linked into the common pipeline. The air entrainment encouraged the growth of iron bacteria which have a propensity to colonise areas of highest velocity, that is, pump intakes, or in this case, the fracture zones within the bore.

Keywords: Fractured rock, Managed aquifer recharge, chemical clogging, Physical clogging, Biological clogging

RIVERBED CLOGGING EXPERIMENTS AT POTENTIAL RIVER BANK FILTRATION SITES ALONG THE PING RIVER, CHIANG MAI, THAILAND

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Many riverside communities in Thailand rely fully on surface water abstraction for their water supply. Only basic treatment steps such as flocculation and sedimentation are used. High turbidity and poor river water quality are a constant health risk for consumers. Thus, river bank filtration (RBF) is being studied as a potential alternative water source by the Department of Groundwater Resources (DGR), Thailand. High turbidity in river water can limit the applicability of RBF by severe riverbed clogging (colmation), resulting in decreasing riverbed permeability and abstraction rates. Therefore, clogging experiments were conducted at two sites in Mea Rim and San Pa Tong along the Ping River, Chiang Mai Province, Thailand. A mobile experimental apparatus was constructed and equipped with three columns filled with riverbed sediments. The channel was continuously fed by river water. Piezometers were installed to measure the hydraulic heads in the channel and at different depths in the columns. Infiltration rates at Mea Rim with a river water turbidity of 70 - 950 NTU gradually decreased from 1.3×10-4 to 3.2×10-5 m/s within 22 days. Infiltration rates at San Pa Tong with river water turbidity of 33 - 145 NTU gradually decreased from 8.5×10-4 to 4.0×10-5 m/s within 21 days. An increase in channel flow velocity caused partial removal of the upper clogging layer and slower clogging in the columns. For planning new RBF sites, riverbed samples have to be analyzed, based for example on grain size and geochemical parameters. But K values used to estimate RBF well yield cannot be calculated based on sieve analyses alone, as the high turbidity can cause riverbed clogging and decrease the infiltration rate and the K value of the upper 10 cm by factors of more than 25 and 200, respectively. This documented effect must therefore be carefully taken into account during the planning and execution of RBF schemes along high-turbidity river water, otherwise there is a risk of premature system failure or severely overestimated abstraction rates.

Key words: River bank filtration, riverbed clogging, clogging experiment, Ping River, Chiang Mai

CASE STUDY: RECHARGE OF POTABLE AND TERTIARY-TREATED WASTEWATER INTO A DEEP, CONFINED SANDSTONE AQUIFER IN PERTH, WESTERN AUSTRALIA

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The Water Corporation of Western Australia started investigating the feasibility of recharging potable water into the deep, confined aquifers beneath the Perth Metropolitan area, Western Australia, in 2000. Managed aquifer recharge (MAR) was identified as a potentially significant operating strategy for the Integrated Water Supply Scheme (IWSS) with possible benefits to the environment and contingency issues such as drought security, improved groundwater quality, groundwater banking and maintenance of groundwater levels.

Perth is largely dependent on groundwater for its municipal water supply, with up to 50% of the total supply sourced from the vast groundwater system that underlies the region. The Perth groundwater system is part of the sedimentary Perth Basin; it is bounded on the east by crystalline rocks of the Darling Scarp and extends many kilometres off shore. The onshore portion of the aquifer stretches 250 km along the coast in a narrow strip of clastic sediments that are more than 2,000 m deep. The sediments have been laid down under varying depositional environments over millions of years. The groundwater system can be broadly divided into three main aquifers: the shallow, unconfined superficial aquifer, and the deep, confined Leederville and Yarragadee aquifers. The Leederville aquifer has been the target aquifer for MAR to date, and there are plans to incorporate the deeper Yarragadee aquifer into future groundwater replenishment operations.

The Leederville aquifer is a major confined aquifer that is typically between 150 and 400 m thick. It is subdivided into three members:

- The Pinjar Member comprises mainly thin sandstone beds interlayered with siltstone and shale. It generally acts as an aquitard and conformably overlies the Wanneroo Member;
- Individual sandstone beds of the Wanneroo Member, are about 10 to 20 m thick, with interlayered siltstone and shale beds of varying thickness. The sandstone beds are weakly consolidated and composed predominantly of coarse-grained, poorly-sorted quartz. The aquifer transmissivity is in the order of 500 to 2,000 m3/d/m, and groundwater salinity is generally between 250 and 1,000 mg/L TDS. The Wanneroo Member is the target zone for aquifer recharge and conformably overlies the Mariginiup Member;
- The Mariginiup Member consists of thinly interbedded siltstone and shale with few very thin sandstone beds. It acts as a confining layer.

Investigations commenced with the establishment of a small aquifer storage and recovery (ASR) trial at Jandakot, recharging potable surface water into an existing production bore. The preliminary trial was successful, with clogging managed by backwash-pumping techniques. This facility was upgraded to a pilot scale operation with a new recharge bore and associated infrastructure. Having demonstrated the technical feasibility of ASR in the Leederville aquifer, a large scale ASR site was established at Mirrabooka, where potable treated groundwater water was recharged to the aquifer at rates up to 7 ML/d. Clogging was similarly managed using down-hole backwashing techniques. These ASR trials have ultimately led to the establishment of a state of the art Groundwater Replenishment Trial at Beenyup, where ultra-purified wastewater is currently being recharged to the Leederville aquifer for future re-use in the IWSS. This case study presents results from these investigations with particular regard to the degree and type of clogging encountered using different water types at each site and the operational management of that clogging.

PRACTICAL CRITERIA IN THE DESIGN AND MAINTENANCE OF MANAGED AQUIFER RECHARGE WELLS AND BORES IN ORDER TO MINIMIZE CLOGGING IMPACTS, OBTAINED FROM THREE DIFFERENT OPERATIVE SITES IN SPAIN

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According to the experiments carried out in the framework of R&D DINA-MAR Project, related to management of aquifer recharge in the context of sustainable development, since 2006 are being accomplished studies aimed at the study of clogging in managed aquifer recharge facilities, specifically the detection and distribution of physical (including air), chemical and biological clogging processes.

Synergistic combinations have been studied by means of core sampling, analysis, radiometric images and field photographs at different scales, from aerial to binocular microscope serial radiometric images.

These studies have been focused, specifically, to well known experimental sites where other methods are being accomplished, as chemical analysis, interaction models, sequential gauging tests, infiltration tests, etc.

Conclusions collected from three distributed pilot sites have driven to design and implement a practical specific methodology for cleaning and maintenance of infiltration ponds, canal and wells, as well as design recommendations prior building work willing to be extrapolated to other analogous scenarios.

The article summarizes most of the practical rules reached along the project´s development.

CHARACTERIZATION OF CLOGGING OF MODERATE CLAY CONTENT SANDSTONE DURING WATER INJECTION: EFFECTS OF CHEMICAL AND HYDRODYNAMIC PERTURBATIONS

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The single most important cause for operational failures of Managed Aquifer Recharge (MAR) systems is the decrease of permeability that results from clogging of pores in porous media. The release of colloidal particles present in sandstone aquifer and subsequent entrapment in the down-gradient pores can cause a drastic reduction in permeability resulting in severe decline in injection rate (injectivity) or the need to continually increase the pressure head to maintain a constant injection rate. The clogging potential of injection wells manifests itself when relatively fresh water contacts the formation sandstone. The presence, cause, and magnitude of pore plugging were studied by a combination of the following methods: (a) X-ray diffraction analysis were undertaken to determine clay mineralogy of the core samples, (b) microscopic examinations of rock think sections to determine the distribution of clay minerals relative to the pore system, (c) and by subjecting the aquifer core samples to flow at near in situ conditions in the laboratory. The core flooding tests were carried out over a range of variables which provided valuable data and insight into the reaction of the core samples to fluid conditions and its effect on the alteration of the core permeability. These data were used for model-assisted analysis of the processes leading to clogging. The findings provide important information about the relative contributions of the various parameters such as solution ionic strength, ion composition, flow velocity on clogging and help determine the values of the relevant process parameters.

THE DISCRIMINATION METHOD OF SUSPENDED SOLIDS CLOGGING TYPE IN MANAGED AQUIFER RECHARGE (MAR)

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The implementation and development of managed aquifer recharge (MAR) have been limited by the clogging attributed to physical, chemical, and biological reactions. Laboratory column experiments were often used to describe the clogging process. During laboratory column experiments, the hydraulic conductivity (K) of infiltration medium initially declines significantly owing to the physical clogging of suspended solids, subsequently, along with chemical clogging and biological clogging. In engineering applications of MAR, physical clogging is dominant. Although numerous studies on the physical clogging mechanism during MAR are available, studies on the determination and prediction of suspended solid clogging types remain few. In this study, coarse sand (sieve number 20 to 40), medium sand (sieve number 40 to 70), fine sand (sieve number 70 to 150), and mixed sand (containing equal amounts of fine, medium, and coarse sands) were adopted as the infiltration medium. Ultra-purified water (TDS = 0 mg/L, TDS = 0–2 mg/L) and water with different diameters of suspended solids were used as the recharge water source. Laboratory columns were used to describe the clogging process. Specific interval observations of the water equipotential head, outflow rate, total suspended solids, and total dissolved solids of input and output water were undertaken. The results indicated that three types of suspended solid clogging exist: surface cake clogging, internal-surface clogging, and internal clogging. Moreover, according to the relationship among the types of suspended solids, pore diameter of infiltration medium, and size of suspended solids, the differentiation method and criterion of clogging type have been proposed.

Key words: managed aquifer recharge; suspended solids; physical clogging

MANAGEMENT OF CLOGGING IN SMALL-SCALE AQUIFER STORAGE AND RECOVERY SITES IN THE COASTAL PLAIN OF SOUTHWEST BANGLADESH

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Management of clogging is very crucial in any aquifer storage and recovery (ASR) scheme as the success rate of the scheme mainly depend on well clogging. The reduction in hydraulic conductivity beneath infiltration facilities and around recharge wells is still a frequent reason for abandonment of ASR scheme. Small scale ASR have been implemented by infiltrating pond and rooftop rainwater into shallow, locally confined brackish aquifers on the southern deltaic plains of Bangladesh in order to provide safe drinking water to local community. This paper deals with physical clogging specifically focuses on control of clogging by filtration and the issues of clogging related to aquifer material, design, drilling and construction methods at 20 sites. The target aquifer in the research area is composed of fine to medium grained sand, hydraulic conductivity in the range of 10 to 100 m/d, overlain by clay aquitard of varying thickness.

Two types of infiltration system have been designed; one with underground recharge vault and another with over ground filtration tank. For the underground recharge vault, the infiltration wells are placed below the recharge vault which is 3m under the ground level. A 30cm layer of fine sand has been placed at the floor of the vault covering the wells. For the over ground filtration systems, a double chambered tank has been constructed, placed on the ground or elevated up to 3m above the ground, with a graded sand filter in one chamber composed different sized sand-coarser at the bottom and finer at the top. Pond water is pumped into the filtration tank to pass through sand filter in both the system.

Efficiency of turbidity removal is assessed by analysis of turbidity at the source pond, after passing though the sand filter and at the abstraction well. Clogging is assessed by performing falling head tests at each infiltration well at number of times during the operation of the test sites. The turbidity of source (pond) water ranges from 50 to 150 NTU with a higher value at the advent of monsoon and lower in peak monsoon. Turbidity decreases to 5 NTU after passing through the sand filter in most of the sites. The finer materials that deposit on the sand filter is scratched periodically to enhance the rate of filtration to maintain optimum infiltration rate. Filtered water is then regulated to the large diameter injection wells through a pipe network fitted with stop valve and flow meter to pass through the injection well to reach the aquifer under gravity. The injection wells are filled with sorted gravel of nearly 2 mm with thin layer of fine sand at the top which acts as the second stage filter. Accumulated finer materials are scratched time to time to maintain good infiltration rate. A maximum infiltration rate of 6m3/day has been achieved at a number of sites where the average is about 3 m3/day. After three years of operation no deterioration in infiltration rate has been observed in the oldest sites.

Track 4.6: Monitoring and modeling for MAR

10^{B}-ENRICHED BORIC ACID, BROMIDE, AND HEAT AS TRACERS OF RECYCLED GROUNDWATER FLOW NEAR MANAGED AQUIFER RECHARGE OPERATIONS

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Recycling wastewater for subsequent potable and nonpotable use by artificially recharging underground aquifers is a decades-old but increasingly popular practice. Natural attenuation processes in the subsurface, known as soil aquifer treatment (SAT), purify recycled water during recharge. Travel time criteria are often used to regulate managed aquifer recharge (MAR) operations as a result. California state draft regulations currently requires the application of groundwater tracers to quantify underground residence time, with a target retention time of >6 months from infiltration to drinking water extraction for surface spreading projects using tertiary wastewater (less time is required if full advanced treated water is utilized). In the past sulfur hexafluoride (SF6), a very strong green house gas, has been the principle deliberate tracer for this work. However, its emission has recently become regulated in California and new tracers are needed. Here, two prospective tracers are evaluated: the stable isotope boron-10 (10B), and heat (with recharging water naturally warmed at surface-spreading basins). An additional deliberate tracer (bromide, Br-), which is a well-studied conservative tracer, was released as a control. Tracer injection occurred at the San Gabriel Spreading Grounds research test basin in Los Angeles County, CA, USA. The basin was constructed and characterized by the US Geological Survey in the mid-1990s. Recycled wastewater was piped directly to this basin at a known rate (about 1.5 m3/day). Down gradient from the test basin are nine high quality monitoring wells in a line, all equipped with temperature loggers. The pre-experiment expected arrival times ranged from less than one day to six months. Arrival of Br- was always coincident or preceded the 10B arrival, reflecting the relative retardation of 10B through exchange with clay surfaces. 10B/Br- travel time ratios determined from the center of mass range from 1 to 1.4. Temperature time series were developed from data loggers, which recorded measurements hourly with an accuracy of one thousandth of a degree. Basic analysis of temperature profiles yields a reliable but not precise estimate of the underground residence time; heat flow travel times are in good general agreement with those derived from the geochemical tracers.

Keywords: Multi-tracer Experiment, Travel Time, 10B-Enriched Boric Acid, Heat (Temperature), Water Replenishment District, CA, USA

EFFECTS OF RECLAIMED WATER USE FOR SCENIC WATER ON GROUNDWATER ENVIRONMENT IN A MULTI-LAYERED AQUIFER SYSTEM BENEATH THE CHAOBAI RIVER, BEIJING, CHINA

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Reclaimed water has been widely utilized because of drought and water shortages in Beijing, China. About 18 million m3/a reclaimed water were used for scenic water in the dry Chaobai River, and over 12 million m3/a of this water percolated beneath the river bed and recharged the underlying aquifers. These aquifers supply drinking water to the city of Beijing and irrigation water to the areas adjacent to the river. Therefore, the effects of this recharge on groundwater environment must be assessed. Twenty-seven monitoring wells were drilled to 30m-, 50m- and 80m-depths to quantify changes in groundwater level and quality in the multi-aquifer system beneath the river and adjoining areas. The data collected was utilized to develop a groundwater flow model and a numerical solute transport model to quantify observed groundwater level and quality changes, and project future changes in the multi-aquifer system. It is deduced from the measured data that the hydrodynamic field in the 30m-depth aquifer was obviously affected by reclaimed water recharge; whereas the 50m-depth and 80m-depth aquifers were negligibly affected. Model projections indicate that continuation of existing recharge and extraction conditions over the next 20-years will decrease groundwater levels and storage in all three aquifers. Chloride ion was utilized to track the movement of reclaimed water recharge and dissolved constituents in groundwater. The measured data showed that groundwater quality in the 30m- and 50m- depth aquifers was substantially influenced by the reclaimed water. The model results showed that the Chloride concentration in the 80m-depth aquifers will also be influenced by reclaimed water recharge over the next 20 years.

Keywords: Reclaimed water; Multi-aquifer system; River bed recharge; Groundwater model; Chloride tracer

QUESTIONING THE IMPACT AND SUSTAINABILITY OF MANAGED AQUIFER RECHARGE BY PERCOLATION TANKS IN SEMI-ARID HARD ROCK AREA (SOUTHERN INDIA)

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Since the beginning of the green revolution in the 1970's, large areas of India are dependent on groundwater for irrigation which has led to aquifer overexploitation in various parts of the country. To tackle this problem, India relies on management of aquifer recharge (MAR) and the Indian government launched various programs to increase the number of recharge structures over the country. Despite the common view that MAR is a possible solution to face the actual water scarcity problems, various authors point out the lack of data available for quantitative assessment and the limited evidence on the positive impact of those structures at both local and watershed scale. Perennial water resources in semi-arid regions of South India consist mostly of hard rock aquifers that are prone to water scarcity and MAR is promoted (through percolation tanks among other structures), despite the limited storage capacities and high potential evaporation. To assess the efficiency of MAR we conduct a long-term monitoring program on a percolation tank in the Maheshwaram watershed near Hyderabad, India focusing on qualitative and quantitative impacts at the local scale. The tank has a maximum potential surface area of 113500 m2. In 2012 due to moderate monsoon rains, the flooded area was only of 21300 m2, limited to the lowest clayey zone of the tank with low infiltration capacity. By measuring water level, tank surface, and the rainfall intensity we show that only few events contribute to the tank replenishment and that enhanced infiltration is of the same order of magnitude than evaporation (6570 m3). Those results are in agreement with the few existing studies (Perrin et al., 2009) Hydrogeological characterization shows a limited impact of the structure. Potential benefits of the tank system depend on the observation scale. Local impact may be positive but in years of insufficient rainfall where no runoff leaves the watershed, the tank only redistributes the water compared to a "non-managed" situation. "Basin closure" (outflow tending to zero) is an increasing problem in India. Under such conditions, tanks provide no net recharge gain at the watershed scale. However, for years with precipitation surplus there may be a net benefit in terms of underground storage. When evaluating benefits of infiltration tanks we need to take into account (1) net "non-managed" water balance (runoff, infiltration, evaporation) at watershed scale and (2) inter-annual variations of precipitations inducing varying runoff exportation down to nil, (3) the fact that those tanks are the only form of surface water on the watershed which may be crucial in terms of local water supply. Further investigations are also needed to assess the social and economic impact of such redistribution as well as its impact on water quality.

Other issues related to MAR

MAR as a strategy for adaptation to climate change

INTEGRATING LARGE SCALE SEASONAL STORAGE IN THE AMSTERDAM DUNE AREA

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Integrating large scale seasonal storage in the Amsterdam Dune Area After having overexploited since 1853 the coastal dunes phreatic aquifer, Amsterdam (capital of the Netherlands) started extracting in 1903 from underlying semi-confined aquifers, in which fresh water floats on saline water. Heavy intrusion and upconing resulted, until, in 1957, artificial recharge of treated river Rhine water was introduced to resolve the replenishment deficit. The success was great, so that the underlying aquifer could be reserved to function as emergency storage with a capacity to help bridging demand for up to two months. Irregular intake stops irregularly occurred over the last almost 60 years that river Rhine water has been artificially recharged, but really long-term ones never did. This allowed to naturally restore the freshwater lens below the dune area. With climate changing, the Rhine's flow regime is bound to change toward a more rain-type from a melt-water type, causing lower summer discharges, which concentrate pollution. Consequently longer intake stops and lower river-water quality is expected during summers. Hence, forced large-scale seasonal subsurface storage is now envisioned as a potential solution, in which good quality river water is would be treated and stored during times of large river flow to be recovered during times of low river discharge, when quality is also low. Hence, the hydrologic regime of the underlying aquifers with the floating freshwater lens will no longer be left at rest, but rather intensively used on a year-by-year basis. The presentation will provide insight in the consequences, possibilities and limitations for the distribution of fresh and salt water in the aquifer, for the development and management of the inevitable brackish water, and into effects on surrounding areas with their interests and specific stakeholders.

THE ECONOMICS OF GROUNDWATER REPLENISHMENT FOR RELIABLE URBAN WATER SUPPLY

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Abstract: This paper explores the potential economic benefits of water banking in aquifers to meet drought and emergency supplies for cities where population is growing and changing climate has reduced the availability of water. A simplified case study based on the city of Perth, Australia was used to estimate the savings that could be achieved by water banking. This is a practice that the Water Corporation has already begun in Perth by making use of highly treated recycled water to replenish groundwater. In this simplified analysis, a Markov Chain model was constructed to approximate the variability and temporal persistence of observed surface water availability. Scenarios for investment in seawater desalination plants and groundwater replenishment were considered over a 20 year period of growing demand, using a Monte Carlo analysis that embedded the Markov model. An optimisation algorithm identified the minimum cost solutions that met specified criteria for supply reliability. The impact of depreciation of recharge credits was also explored. The results revealed savings of more than A$1B (~US$1B) or 37% to 33% in supply augmentation costs by including water banking in aquifers for 95% and 99.5% reliability of supply respectively. When the hypothetically assumed recharge credit depreciation rate was increased from 1% p.a. to 10% p.a. savings were still 33% to 31% for the same reliabilities. These preliminary results show that water banking in aquifers has potential to offer a highly attractive solution for efficiently increasing the security of urban water supplies where aquifers are suitable.

Keywords: water allocation, groundwater, drought, risk assessment, economics, Markov switching model

THE CRUCIAL ROLE OF MANAGED AQUIFER RECHRAGE AS AN ADAPTATION STRATEGY FOR GROUND WATER SUSTAUNABILITY IN THE FACE OF CLIMATE CHANGE IN INDIA.

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As per key findings of climate change projections for India, the increase in the frequency of extreme precipitation, will also mean that much of the monsoon rain would be lost as direct run-off resulting in reduced groundwater recharge and increased ground water withdrawal, which might further exasperate the present scenario of imbalanced development. adaptation strategies to enhance aquifer recharge, demand management through intelligent power rationing and conjunctive management have been examined . Mechanism to promote synergy amongst stakeholders for implementation has been spelt out.

The adaptation strategies proposed for mitigating the increasing stress on ground water resources due to climate change for enhancing recharge of groundwater aquifers, mandating water harvesting and artificial recharge in urban areas, ground water governance, incentivising to promote recharging of ground water, intelligent power rationing for irrigation ,optimizing water use efficiency, conjunctive management etc have been examined at great length in terms of the technical feasibility as well as social relevance of implementation in the light of extensive experience gained in the country..

Sustainable development of ground water resources and various mitigation programmes required in the event of possible climate change in the country can be accomplished only with the help and active cooperation of all stakeholders such as the Ministries of Government of India for Water Resources, Environment & Forests, Power, Rural Development, Agriculture, Science & Technology and the institutions working under them; State Governments & their organizations; Associations of Industry, Non-Government Organizations, District Administrations and Panchayati Raj Institutions and the individuals users. To be successful in this mission we also have to create conditions for complete synergy in the activities of all the stakeholders.

As of now, managing the energy-irrigation nexus with sensitivity and intelligence is the principal tool for groundwater demand management as evident from the experiences with some states like Gujarat, Punjab and Andhra Pradesh having very high stage of ground water development. It is surmised that power rationing can be a simple and effective instrument for groundwater demand management.

The most critical response to climate change in India's water sector demands exploring synergies from a variety of players for a nation-wide groundwater recharge program. India's water policy has so far tended to focus on what governments and government agencies can do. Now, it needs to target networks of players, each with distinct capabilities and limitations by sensitizing them to the social relevance of technical decision on mitigation. The role and space for various stakeholders namely Farmers, NGOs, local communities, Canal system managers and Groundwater Recharge SPV, in groundwater recharge strategy as a major response to climate change is outlined.

Keywords: managed aquifer recharge, energy-irrigation nexus, intelligent power rationing, synergy, conjunctive management.

MAR in karst aquifers

STUDY ON MAJOR STRESS FACTORS AND VULNERABILITY ASSESSMENT OF KARST AQUIFER

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The vulnerability of karst aquifer is stressed by karst development intensity, karst networks system, groundwater recharge types, surface vegetation, topographic gradient, soil cover thickness, soil types, land use types, and the exploitation degree of groundwater, etc. Karst aquifer under subtropical humid monsoon climate in southern China has a unique property. There is no suitable effective vulnerability assessment method for Karst aquifer in this area until now. This article selected seven factors as karst aquifer vulnerability assessment indicators in accordance with the principle of quantifiable, systematic, and available, and then the karst aquifer vulnerability assessment indicators system was established. On the basis of reviewing the current groundwater vulnerability assessment methods, aquifer vulnerability of a typical karst area in south of China was evaluated, through using improved Slovenia model combining with GIS spatial analysis functions. The aquifer vulnerability maps drawn by this model were verified through the existing pollution data. The results show that the vulnerability partitioning maps matches the real situation well. This provides a bettering method for karst aquifer vulnerability assessment.

REMOVAL OF LONG-RESISTANT PHARMACEUTICALS BY THE ELECTRIC FIELD ALONG WITH UNIQUE BIODEGRADATION SET-UP IN SIMULATED SOIL AQUIFER

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This study was conducted to assess the fate of the carbamazepine and diatrizoate in an artificial aquifer when they were injected after being treated by electric field charge and microbial decomposition throughout the simulated soil column. The pharmaceutical compounds are discharged into water system through various routes such as clinical waste, hospital wastewater, households, manufacturing facilities and so on. Some pharmaceutical compounds may not be removed during sewage treatment process entering the river or drinking water supplies. Especially the target compounds have low and medium hydrophobicity, respectively, and relatively substantial stability to natural way of degradation, once disposed of, which thus cause residual persistence at the environment leading to emerging potential toxicity problems. As the electric field system is proper in pretreatment against target compounds, it could thereafter be expected to be the positively decomposed by means of physiobiochemical pathways while migrating through the artificial aquifer. In addition, residual concentration in the aquifer could be consequently disappeared. A series of laboratory-scale soil column set-ups were used in this study. Columns are initially seeded with a unique microbial community to adaptively treating target compounds since the artificial wastewater amended with target compounds has been treated with electric field charge. For the test of period, the behavior of the compounds will be monitored under different concentrations and aerobic or anoxic condition. Depending on the conditions, either microbial adaption or biotransformation of compounds along with electric field charge could be addressed. As an analytical method, solid phase extraction (Oasis HLB cartridge) for sample preparation was essentially carried out according to Miao and Metcalfe (2003) with some modification where HPLC system (Agilent 1200series HPLC) was used to simultaneously quantify their concentrations (4-80ug/L). A binary gradient consisting of 0.1% formic acid (v/v) in water (A) and 100% methanol (B) at a flow rate of 1ml/min and UV-adsorption at 258nm were utilized. The gradient was as follows: 5% B held for 3.5 min, increased linearly to 50% by 5min and held for 3 min, stepped to 100% for 8min. Previously, calibration curve was prepared for analysis of carbamazepine and diatrizoate considering the efficiency of recovery in terms of the change of pH. As demonstrated in this study, electric field charge along with unique set-up of bio-decomposition would be effective to remove carbamazepine and diatrizoate present in artificial aquifer systems.

REGIONAL DISTRIBUTION PATTERNS OF TDS AND HEAVY METALS IN GROUNDWATER AT DAMASCUS CITY ANDS ITS SURROUNDINGS, SYRIA

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Contamination of groundwater by heavy metals due to agricultural and industrial activity is growing recently. The objective of this study is to evaluate and map regional patterns of heavy pollutants (NO3, Al+3,, Cd, Fe, Mn, Ni, Pb, Cr, As, Sb, Se, Sn, and V) and TDS concentration in groundwater. Presently, the groundwater is the only water resource for drinking and irrigation purposes in Damascus basin. Forty-one groundwater samples were collected from the Quaternary and Quaternary-Neogene aquifers and analyzed with respect to major and trace elements by ICP-MS and conventional techniques. The TDS concentration decreases due the northwestern part (400 ppm) and increases in the southeastern part (1500 ppm). Most of the groundwater are unsuitable for potable uses with respect to Al and Cd concentrations. Also, they are frequently unsuitable for drinking purpose with respect to Fe, Mn, and Ni. They are suitable for irrigation with respect to Pb content, but unsuitable regarding Cr content. The As, Sb, Se, Sn and V concentrations are below the detection limit and far below the maximum permissible limits estimated by WHO (2006). The principle component analysis was classified into six factors depending on major and trace elements. Some of the contaminants have high level in the groundwater due to the absence of sewer system, the municipal, industrial, agricultural, and hospital wastewaters dump in the Barada River. Septic tanks are widely distributed in the study area and, in addition, there is extensive use of recycled wastewaters from Adra station, and cattle breeding activity

9th International Symposium on Managed Aquifer Recharge

SOLUTIONS TO SUSTEINABLE WATER MANAGEMENT SUBJECT TO SCARCITY AND CLIMATE CHANGE

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