Abstract Book

ISMAR 5

5th International Symposium on Management of Aquifer Recharge

11 – 16 June 2005

in Berlin

Germany

Sponsors:

KompetenzZentrum Wasser Berlin gGmbH

Table of Contents

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Invitation

Managing water is a global challenge that impacts the environmental, social, economic and political cornerstones of our existence on Earth. Artificial recharge provides a sustainable opportunity to conserve drinking water resources and to improve water quality. Recharge concepts are simple but practitioners know that we have much to learn about issues that will be discussed at the symposium.

The theme of ISMAR 2005 is Recharge Systems for the Protection and Improvement of the Groundwater Resources. With the support of the Scientific Committee we developed an ambitious programme with the following topics:

- River Bank Filtration
- MAR strategies to enhance groundwater resource management
- Water Re-Use
- Effects of Managed Aquifer Recharge
- Evaluation of MAR and its sustainability
- Health Aspects: Organic substances, pathogens and micro pollutants, PAC and EDC
- Alternative recharge systems and case studies
- Clogging
- Geochemistry
- Aquifer Storage and Recovery

Join leading researchers, engineers, planners and other water professionals from around the world at this comprehensive programme. The Organizing Committee invites you to attend the ISMAR 5 with the opportunity to share all your experiences, ideas and results.

We would like to welcome you in Berlin.

Sincerely yours,

Dr. Francis Luck

Co-Organisers

NWRI National Water Research Institute

iah aih

ASCE American Society of Civil Engineers

Scientific Programme

Sunday, June 12, 2005

09:00 **Welcome & Introduction**
Francis Luck, KompetenzZentrum Wasser Berlin gGmbH; Peter Dillon, IAH- MAR; Alice Aureli, UNESCO; Christophe Hug, Veolia Water, Ludwig Pawlowski, Berliner Wasserbetriebe

10:40 Morning Tea

River Bank Filtration **Chair: A. Pekdeger**

11:20 **Dynamic processes during bank filtration and their impact on raw water quality**
Eckert P., Rohns H. P., Irmscher R. (Düsseldorf)

11:40 **Removal capacity of riverbank filtration and conclusions for the operation of water abstraction plants**
Lenk S., Remmler F., Skark C., Zullei-Seibert N. (Schwerte)

12:00 **Management of river bank filtration in the Elbe River Basin near Torgau, Germany**
Krüger M., Ende K., Grischek T. (Torgau, Dresden)

12:20 **Sustainability of river bank filtration in Dresden, Germany**
Fischer T., Hoche D., Day K., Grischek T. (Dresden)

12:40 Lunch

MAR strategies to enhance groundwater resource management **Chair: M. Jekel**

14:00 **A strategy for optimizing groundwater recharging by flood water in the Northwestern Coastal Zone of the Gulf of Suez Area, Egypt**
Elewa H. (Cairo/ET)

14:20 **Mapping groundwater bodies with artificial or induced recharge, by determination of their origin and chemical facies**
Stuyfzand P. J (Nieuwegein/NL)

14:40 **Application of GIS mapping to aquifer retention time and river depletion calculations to determine optimum locations for artificial recharge**
Anderson M., Jones M. A., Baxter K. M., Gamble D. (High Wycombe/UK, Reading/UK)

15:00 **Inexpensive soil amendments to reduce salt water intrusion into the aquifer**
Singh R. P., Suman R., Parthvi R., Parthvi P. (Agra/IND)

15:20 Coffee Break

MAR strategies to enhance groundwater resource management (continued)
Chair: B. Heinzmann

16:00 **The Streatham groundwater source: An analogue of the development of recharge enhanced groundwater resource management in the London Basin**
Jones M. A., Harris S. J., Baxter K. M., Anderson M. (Reading/UK, High Wycombe/UK)

16:20 **Proposal of a system of environment core indicators for the monitoring and control of the operations of recharge of aquifers based on empirical experiences**
Escalante E. F., García Rodríguez M., Villarroya Gil F. (Madrid/E)

16:40 **Developing regulatory controls for stormwater discharge to a potable aquifer in regional South Australia**
Gorey P. G., King H. J. (Mount Gambier/AUS)

17:00 **Hydrogeology and water treatment performance of the Dösebacka artificial recharge plant – the basis for an efficient system for early warning.**
Lundh M., Jonasson S. A., Jørgensen N. O., Johnson M. D. (Angered/S, Alingsås/S, Copenhagen/DK, Gothenburg/S)

17:20 Information

20:00 Icebreaker Party (sponsored by Berliner Wasserbetriebe)

Monday, June 13, 2005

Modelling — Chair: P. Engesggard

09:00 **Evaluation of Innovative Collector Well Design Using an Analytic Element Groundwater Flow Model**
Kelson V., Jasperse J. (Bloomington/USA, Santa Rosa/USA)

09:20 **High resolution digital geological 3D models as a base of hydrodynamic calculation in heterogeneous aquifers**
Wycisk P., Gossel W., Wollmann A., Fabritius H. (Halle/Saale)

09:40 **Gas Transport Below Artificial Recharge Ponds: Insights from Dissolved Noble Gases and a Dual Gas Tracer Experiment**
Clark J. F., Hudson G. B. (Santa Barbara/USA, Livermore/USA)

10:00 **Visual CXTFIT – a user-friendly simulation tool for modelling one-dimensional transport, sorption and degradation processes during bank filtration**
Nützmann G., Holzbecher E., Wiese B., Licht E., Knappe A. (Berlin)

10:20 **Simulation of Bacteriophage Populations during Sub-Surface Passage**
Holzbecher E., Dizer H., Lopez-Pilar J. (Berlin)

10:40 Morning Tea

Modelling (continued) — Chair: G. Nützmann

11:20 **Colloid Transport in Variably Saturated Porous Media**
Fischer C., Weisbrod N., Yakirevich A., Kuznetsov M. (Midreshet Ben-Gurion/IL)

11:40 **A Coupled Model for Transport, Geochemical Reactions and Redox Processes**
Horner C., Holzbecher E., Nützmann G. (Berlin)

12:00 **On the use of Reactive Multicomponent Transport Modelling for assessing Water Quality Changes during Managed Aquifer Recharge**
Prommer H., Stuyfzand P. J (Wembley /AUS, Nieuwegein/NL)

12:20 **Quantifying Biogeochemical Changes during ASR of Reclaimed Water at Bolivar, South Australia**
Greskowiak J., Prommer H., Vanderzalm J. L., Pavelic P., Dillon P. J. (Berlin, Wembley /AUS, Urrbrae/AUS, Adelaide/AUS, Glen Osmond/AUS)

12:40 Lunch

Modelling (continued) — Chair: I.Gale

14:00 **Development of a microbial pathogen attenuation model to aid management of managed aquifer recharge systems**
Bekele E. B., Toze S. (Wembley/AUS)

14:20 **Transient flow modelling of an overexploited aquifer and simulation of artificial recharge measures**
Valley S., Landini F., Pranzini G., Puppini U., Scardazzi M. E., Streetly M. (Milano/I, Firenze/I)

Water Re-Use

14:40 **Wastewater reuse and potencialities for agriculture in Nigeria**
Akpan A. J. (Lagos/WAN)

15:00 **Protecting an island aquifer by using recycled water as a hydraulic barrier**
Pipe-Martin C. (Caboolture/AUS)

15:20 Coffee Break

Case studies/Effects of Managed Aquifer Recharge Chair: F. Remmler

16:00 **Hydraulic and geochemical characterization of Ajali sandstone aquifer, SE – Nigeria: Implication for groundwater recharge process**
Tijani M. N. (Higashi-Hiroshima/J)

16:20 **Development and investigation of an underground infiltration system with pollutant control device**
Göbel, Patricia (Münster)

16:40 **Investigation of Water spreading effects on Water table of aquifer in arid and semi - arid regions**
Salajegheh A., Keshtkar A. R. (Karaj/IR)

17:00 **Pumping influence on transport properties of a chalk karst aquifer exploited for drinking water supply**
Fournier M., Massei N., Dussart-Baptista L., Bakalowicz M., Rodet J., Dupont J.-P. (Mont Saint Aignan/F, Montpellier/F)

18:00 MAR Meeting

Tuesday, June 14, 2005

Aquifer Storage and Recovery — Chair: G. Amy

09:00 **Recent advances in ASR Technology in the United States**
Pyne R. D. G. (Gainesville/USA)

09:20 **Windhoek, Namibia: Designing a large-scale borehole injection scheme in a fractured aquifer**
Murray R. (Stellenbosch/ZA)

09:40 **Stormwater ASR and ASTR (Aquifer Storage Transfer and Recovery) in practice and under investigation in South Australia**
Rinck-Pfeiffer S., Pitman C., Dillon P. J. (Adelaide/AUS, Glen Osmond/AUS)

10:00 **Modelling Approaches to Optimise Well Field Design and Operation for an Aquifer Storage Transfer and Recovery (ASTR) Trial**
Pavelic P., Dillon P. J., Robinson N. (Adelaide/AUS)

10:20 **A Model Study of the Proposed Everglades Restoration Hillsboro ASR Pilot Project**
Brown C., Nevulis R. (Jacksonville/USA, West Palm Beach/USA)

10:40 Morning Tea

Aquifer Storage and Recovery (continued) — Chair: D. Pyne

11:20 **Water quality improvements during aquifer storage and recovery**
Dillon P. J., Toze S., Pavelic P., Vanderzalm J. L., Barry K., Ying G.-G., Skjemstad J., Nicholson B., Miller R. (Glen Osmond/AUS)

11:40 **Feasibility of ASR for surface water storage in Haarlemmermeer (The Netherlands)**
Drijver B., Willemsen A. (Arnhem/NL)

12:00 **NLARS: Evolution of an artificial recharge scheme**
Harris S. J., Adams M. J., Jones M. A. (Reading/UK)

Alternative recharge systems/Sustainability

12:20 **Assessment of ground water recharge through continuous contour trenches**
Shinde M., Smout I., Gorantiwar S. (Loughborough/UK)

12:40 Lunch

Alternative recharge systems/Sustainability (continued) — Chair: P. Pavelic

14:00 **Approximating technical effectiveness of low technology aquifer recharge structures using simple solutions**
Macdonald D., Neumann I., Barker J., Gale I. (Wallingford/UK, London/UK)

14:20 **Artificial recharge of treated wastewater effluent enables sustainable groundwater management of a dune aquifer in Flanders, Belgium**
van Houtte E., Verbauwhede J. (Koksijde/B)

14:40 **Study on sustainability of irrigation agriculture by diversion in the lower reach of the Yellow River**
Chen J., Fukushima Y., Taniguchi M. (Guangzhou/CN, Kyoto/J)

Geochemistry

15:00 **Geochemical and microbial processes in the unsaturated zone at the Arrenaes artificial recharge trial plant**
Jensen T. Ø., Berg R. L., Bennedsen L., Brandt G. (Copenhagen/Denmark)

15:30 Postersession (and refreshments)

Wednesday, June 15, 2005

Geochemistry — Chair: P. Dillon

09:00 **Use of geochemical and isotope plots to determine recharge to alluvial aquifers: Lockyer Valley, Queensland, Australia**
Cox M. E., Wilson A. S. (Brisbane/AUS)

09:20 **Exploring surface- and groundwater interactions with the help of environmental tracers and sewage indicators in Berlin**
Knappe A., Massmann G., Richter D., Ohm B., Pekdeger A. (Berlin)

09:40 **A Sulfur Hexafluoride Tracer Experiment as a Tool to Check the Previous Results of 3H/TU Ages and Geohydrology at the Montebello Forebay, California**
Avisar D., Clark J. F., McDermott J., Hudson G. B. (Tel-Aviv/IL, Santa Barbara/USA, Livermore/USA)

10:00 **Arsenic Mobilization and Sequestration During Successive Aquifer Storage Recovery (ASR) Cycle Tests in the Carbonate Upper Floridan Aquifer, South Florida**
Mirecki J. E. (Vicksburg/USA)

10:20 **Biological clogging of porous media: Tracer studies of non-uniform flow patterns**
Seifert D., Engesgaard P. (Copenhagen/DK)

10:40 Morning Tea

Geochemistry (continued) — Chair: P. Stuyfzand

11:20 **Effect of sprinkling infiltration on soil properties on a forested esker in Central Finland**
Derome J., Lindroos A.-J., Helmisaari H.-S. (Rovaniemi/FIN, Vantaa/FIN)

11:40 **Artificial recharge in Finland through basin and sprinkling infiltration: soil processes, retention time and water quality**
Helmisaari H.-S., Illmer K., Derome J., Hatva T., Kitunen V., Lindroos A.-J., Miettinen I., Pääkkönen J., Reijonen R. (Vantaa/FIN, Jyväskylä/FIN, Helsinki/FIN, Kuopio/FIN)

12:00 **Subsurface residence time of hyporheic ground water and mixing with alluvial ground water**
Hoehn E., Hofer M., Zobrist J. (Dübendorf/CH)

Health Aspects: Organic substances, pathogens and micro pollutants, PAC and EDC

12:20 **Fate of Wastewater Effluent Organic Matter (EfOM) through Soil Aquifer Treatment**
Sattler A., Amy G., Drewes J. E. (Boulder/USA)

12:40 Lunch

Health Aspects: Organic substances, pathogens and micro pollutants, PAC and EDC (continued) **Chair: S. Toze**

14:00 **Fate of bulk organics during bank filtration and groundwater recharge of wastewater-impacted surface waters**
Grünheid S., Jekel M. (Berlin)

14:20 **Fate of trace organic pollutants during bank filtration and groundwater recharge**
Grünheid S., Jekel M. (Berlin)

14:40 **Fate of Organic Micropollutants in Artificial Groundwater Recharge Systems**
Rauch T., Munoz J., Drewes J. E., Amy G., Choi H. (Golden/USA, Gwangju/ROK, Boulder/USA)

15:00 **Temperature effects on organics removal during riverbank filtration**
Schoenheinz D., Börnick H., Worch E. (Dresden)

15:20 Coffee Break

Health Aspects: Organic substances, pathogens and micro pollutants, PAC and EDC (continued) **Chair: E. Hoehn**

16:00 **On the behaviour of microcystins in saturated porous medium**
Grützmacher G., Wessel G., Bartel H., Chorus I., Holzbecher E. (Berlin)

16:20 **Influence of groundwater conditions on decay of enteric viruses**
Sidhu J., Hanna J., Toze S. (Perth/AUS)

16:40 **Occurrence, Transport, Attenuation and Removal of Pharmaceutical Residues in the Aquatic Environment and Their Relevance for Drinking Water Supply in Urban Areas**
Heberer T. (Berlin)

17:00 **The influence of variable redox conditions on the behaviour of pharmaceutically active compounds during artificial recharge in Berlin**
Massmann G., Greskowiak J., Dünnbier U., Zuehlke S. (Berlin)

17:20 **Announcement ISMAR 6**
Doug Bartlett

Farewell

20:00 Dinner (sponsored by Veolia)

Expert Tours (Mid-Conference Tours, 16 June 2005)

Included in the registration fee

M1 Water supply system in Berlin-Spandau: surface-water treatment plants, artificial groundwater recharge, extraction by wells, water works

M2 Semi-technical test site for bank-filtration at Berlin-Marienfelde: slow sand filtration and artificial groundwater recharge

M3 Wastewater Treatment Plant Stahnsdorf and New Sanitation Concepts

M4 Historical water works and museum Berlin-Friedrichshagen

M5 Well Rehabilitation: methods and opportunities for the efficient improvement of the water supply

M6 Stormwater management Berlin.Adlershof: greening yards and roofs, soil filters, active infiltration systems etc.

For additional information and registration please contact our colleagues at the registration desk!

General information

Icebreaker Party

Location: Neue Jüdenstr.1, Headquarters of the Berliner Wasserbetriebe (see map on last page). Included in the registration fee.

Conference Dinner

The dinner will cost 50 € (menu and beverages incl.). Please register until Monday, June 13.

Location: „Tipi das Zelt am Kanzleramt“, Große Querallee, 10557 Berlin.

How to get there

Bus 100, rapid transit railway station “Unter den Linden”, located in between the Office of the Federal Chancellor and the „House of World Cultures”

info@tipi-das-zelt.de

More information on the ISMAR5

http://www.ismar2005.org/

Venue

Radisson SAS Hotel

Karl-Liebknecht-Str. 1, D-10178 Berlin

Location and Access

The Radisson SAS Hotel is located in the Berlin city centre, opposite the Berliner Dom and right on the bank of the River Spree. The hotel is within walking distance from the rapid transit railway **“**Hackescher Markt**”** (see map on last page).

Scientific programme at one glance

Sunday, June 12, 2005

9:00 Welcome and Introduction
10:40 Morning Tea
11:20 River Bank Filtration
12:40 Lunch
14:00 MAR Strategies
15:20 Coffee Break
16:00 MAR Strategies
17:20 Information
20:00 Icebreaker Party

Monday, June 13, 2005

9:00 Modelling
10:40 Morning Tea
11:20 Modelling
12:40 Lunch
14:00 Modelling/ Water Re-Use
15:20 Coffee Break
16:00 Case studies/Effects of MAR
17:20 Information
18:00 MAR Meeting

Tuesday, June 14, 2005

9:00 Aquifer Storage and Recovery
10:40 Morning Tea
11:20 Aquifer Storage and Recovery/ Alternative Recharge Systems
12:40 Lunch
14:00 Alternative Recharge Systems/Sustainability
15:00 Geochemistry
15:30 Postersession (and refreshments)

Wednesday, June 15, 2005

9:00 Geochemistry
10:40 Morning Tea
11:20 Geochemistry/ Health aspects
12:40 Lunch
14:00 Health aspects: organics, PhAC, Pathogens
15:20 Coffee Break
16:00 Health aspects: organics, PhAC, Pathogens
17:20 Information
20:00 Conference Dinner

Thursday, June 16, 2005

Expert tours

Abstracts

The abstracts of the oral presentations are in chronological order, followed by the poster presentation abstracts in classification order.

River Bank Filtration

Abstracts

Dynamic processes during bank filtration and their impact on raw water quality

Eckert P., Rohns H. P., Irmscher R.

Stadtwerke Düsseldorf AG, Düsseldorf, Deutschland

Objective: Since 1870 Riverbank filtration (RBF) at the river Rhine, Germany has been used successfully by the Düsseldorf waterworks as the first step for treating drinking water. The production wells discharge raw water from a quaternary aquifer with a proportion of 50 to 90% of bank filtrate. In order to achieve a profound knowledge of the purification processes a research program was performed in the year 2003/2004. The investigation period includes the extreme low water event in the summer of 2003 and the following flood event.

Methods: The assessment of the purification processes requires the consideration of the dynamic character of RBF, which is linked to the varying chemical composition of the river water, the discharge of the river and therefore the hydraulic conditions within the aquifer. At the test site two multi-level wells are situated between the river Rhine and the production well. The monitoring program includes the chemical as well as biological parameters relevant for drinking water quality. Because of the complexity of the hydrogeochemical processes during RBF, the 1D-reaction transport model PHREEQC-2 was applied to evaluate the obtained data.

Results: The yearly variations of the river water composition are obvious in the parameters dissolved oxygen, total organic carbon, pH-value and conductivity. Coupled to the extreme low water of the river Rhine was an extended period with high temperatures above 25°C. Due to heat exchange during RBF and the mixing with groundwater the temperature of the raw water in the production well never exceeded 17°C. It was possible to show that the annual changes of the river water temperature trigger a string of subsequent reactions within the aquifer. The temperature increase during spring leads at first to a more efficient biological activity within the aquifer. During the summer the biological degradation of organic carbon is then limited by the decreasing oxygen concentration of the infiltrating river water. Over a period of 12 weeks anaerobic conditions were observed combined with an increased degradation of micro-pollutants. The microbiological activity has, together with the varying composition of the river water, a significant impact on the quality of the raw water. While mostly the raw water already fulfills the European Drinking Water Standard, elevated colony counts were observed in the production wells following the flood event. Based on the depth-orientated sampling the most vulnerable parts of the aquifer were detected in the high permeable gravel layer and in the upper part of the aquifer which was unsaturated prior to the flood event.

Conclusions: Temporal changes of river water quality and hydraulics influence the natural purification processes during bank filtration. They have to be well understood to design adequate treatment steps and to define specific target values on river water quality. Even during extreme low water and during flood events, the multi protective barrier concept including both natural and technical purification has proven to be a reliable method for drinking water production.

Removal capacity of riverbank filtration and conclusions for the operation of water abstraction plants

Lenk S., Remmler F., Skark C., Zullei-Seibert N.

Institut für Wasserforschung GmbH, Schwerte

Objective: In the project "Technical concepts and adjusted operational modes for an optimal adaptation of riverbank filtration to local boundary conditions", as part of a joint research project of the German Ministry of Education and Research (BMBF), fundamental variables for planning, dimensioning and running water production plants were compiled. For this reason it was referred to long term practical experience in operating riverbank filtrate abstraction plants, which especially prevails in Germany.

Methods: Knowledge from literature was supplemented with a representative data inquiry among water supply companies in Germany. By these 33 case studies of riverbank filtration in middle-Europe, comprising 19 different surface water sources were collected. The data were interpreted using multi-variate statistical methods.

Results: By a hierarchic cluster analysis four different characteristic site groups, regarding hydrochemical and hydrogeological parameters of riverbank filtration, could be classified. A further result was that in each site group the local boundary conditions had a specific impact on the elimination potential towards unwanted substances in water.

Degradation capacities of subsurface passages were further characterized using bi- and multi-variate correlation and regression analysis. As the essential determining variables for the measured dissolved organic carbon (DOC)-elimination at the examined locations, the initial DOC concentration in surface waters, residence time of the riverbank filtrate in subsurface passage and transmissivity of the adjacent aquifer could be found. All correlative dependencies and interactions were described by multiple, non-linear regression functions regarding the DOC-elimination capacity. They were summarized in nomograms. In a similar way the decrease of oxygen and nitrate removal in the passage between surface water and abstraction well as well as the development of the redox environment were investigated.

Conclusions: These empirical-statistical prognosis functions can be used for the estimation of the development of hydrochemical parameters at new planned sites, as well as for optimizing operation processes of existing abstraction plants using riverbank filtration. The range of variables used for these calculations has to be respected. The summary of these results can be used by engineers as a practical guideline for planning purposes, and dimensioning drinking water production plants with riverbank filtration as well as to adapt them to the local situation.

Management of river bank filtration in the Elbe River Basin near Torgau, Germany

Krüger M., Ende K., Grischek T.

Fernwasserversorgung Elbaue-Ostharz GmbH, Torgau; [2]University of Applied Sciences Dresden, Div. Water Sciences, Dresden

Objective: The company manages five bank filtration waterworks in the Elbe River Basin near Torgau. To sustain pumped raw water quality, processes in the zone of river water infiltration must be understood and their long-term potential evaluated. By managing the abstraction rates of the wells, water quality changes due to natural attenuation and mixing processes can be optimised.

Methods: Two sampling profiles have been installed between the river and the production boreholes. Intensive studies were carried out to investigate groundwater flow, retention times, the behaviour of dissolved organic carbon, major cations and anions and relevant organic trace compounds. Afterwards a routine monitoring programme was established to control water flow and quality. Data gained from more than 10 years of water sampling are used to show trends in water quality of the bank filtrate and changes in water flow.

Results: Closure of industries and sanitation measures at the end of the 80`s and the beginning of the 90`s resulted in a slow improvement of bank filtrate quality. Nevertheless, there is still a high oxygen consumption in the river bed causing anoxic conditions in the aquifer. But for the case of long flow paths attenuation of most organic compounds under anoxic conditions was observed to be in the same range as under aerobic conditions. The continuous monitoring allows to show slight changes in DOC, nitrate, Fe(II) concentrations and infiltration paths in the aquifer. The 100-year flood of the River Elbe in 2002 did not show a serious effect on raw water quality, the available technology for drinking water treatment was successful in producing high-quality drinking water.

Conclusions: A site specific, scientifically based and long-term monitoring of bank filtrate and groundwater quality is the basis for an effective management of bank filtration sites and the prediction of changes in water flow and quality.

Sustainability of river bank filtration in Dresden, Germany

Fischer T., Hoche D., Day K., Grischek T.
DREWAG Stadtwerke Dresden GmbH, Dresden;

Objective: Since 1874, bank filtration along the River Elbe in the city of Dresden has been an important source for public and industrial water supply. Infiltration has been induced by pumping of wells and installation of drain pipes. Today, some of the old systems are still in operation. Periods of poor river water quality in the 70`s and 80`s are overcome. Water works were modernized and treatment technologies adapted. Nevertheless, there is a periodical demand to prove that bank filtrate is a reliable and economic raw water resource for Dresden.

Methods: Available historical maps and data from water level measurements and water quality analyses are compared with results from recent investigations. Operation of the old systems is reviewed and the time frames of renewals of wells and pipes are identified. Groundwater flow modelling is used to analyse former assumptions on groundwater flow towards the production wells and clogging of the river bed.

Results: Drain pipes at water works Saloppe have been in operation for more than 130 years. Some production wells at water works Tolkewitz had to be replaced only after 60 years. Severe clogging of the river bed occurred in the 80`s mainly due to high loads of sewage from pulp and paper mills upstream. After improvement of river water quality in the 90`s there were no problems with clogging of the river bed and sometimes bad taste and odour of the drinking water any more. Raw water quality and treatment are optimised by managing specific mixing ratios of bank filtrate and land-side groundwater. Pumping rates were reduced to get longer retention times in the aquifer and higher attenuation rates of organic compounds. There is no indication observed for a decrease in attenuation capacity of the aquifer with time.

Conclusions: Long-term experiences and results of the evaluation of historic and recent data and of investigations using modern modelling tools prove that river bank filtration is a sustainable water resource for water supply in Dresden.

MAR strategies to enhance groundwater resource management

Abstracts:

A strategy for optimizing groundwater recharging by flood water in the Northwestern Coastal Zone of the Gulf of Suez Area, Egypt

Elewa H.

National Authority for Remote Sensing and Space Sciences (NARSS), Nozha Gedida, Cairo, Egypt

Objective: In the northwestern coastal zone of the Gulf of Suez region, the groundwater is being excessively pumped thorough a number of domestic and commercial wells. For this sake, recent groundwater recharging by direct rainfall and surface runoff water needs to be maximized and optimized.

Methods: The hydrographic basins of the study area are distinguished into five hydrographic basins. These basins are W. Ghweibba, W.Badaa, W.Hagul, W. Hammtih and W.South Hagul. They are more or less circular or hexagonal in shape, where the runoff flows to their outlets in a considerably short period of time. The construction of retardation dams in some selected locations will enhance the groundwater recharging, or at least minimize the flood damage with the concomitant increase in seepage/runoff ratio. The sites selection of these dams was determined according to several criteria, e.g. soil characteristics, soil infiltration capacity, slope factors, morphometric characteristics and flood mitigation measurements.

Results: The water seepage rate in Wadi South Hagul is 0.08 x 10^6 m^3/h, which gives good chance for a large part of flood water to percolate through the surface soil to the under ground. The trunk channel of W. Hammtih flows easterly to south southeasterly towards the Gulf of Suez. This basin is characterized by high runoff rate, when it is compared with the seepage rate ($0.17x10^6m^3$/h). The main trunk of W. Hagul flows to Gulf of Suez at the southeast. Wadi Hagul also is characterized by low seepage rate. High flooding episode of 3.25 $x10^6m^3$ occurred in 1990 with runoff of rate $2.25x10^6$ m^3/h, where the seepage rate is $0.71x10^6$ m^3/h. This in turn increases the flash floods potentiality with the low groundwater replenishment. The W. Badaa basin drains from the moderately elevated mountains with steep slopes and elevations up to 700 m. The seepage/ runoff seepage relationship indicates that W. Badaa is moderate in the accumulation of floods water. The high seasonal floods occurred in 1988, 1990, 1991, and 1998 had volume of water of about 4.3,7.3, 4.6 and 5.67 millions m^3, respectively. The high flood rate of $5.05x10^6$ m^3/hour happened in 1990 with seepage rate of 2.93 x 10^6 m^3/hour. W. Ghweibba is a large basin of the northwest Gulf of Suez and has area of about 2978 km^2. The high runoff rate is 22.8 x 10^6 m^3/hour in 1990 with seepage rate of 9.70 x 10^6 m^3/h. Wadi Ghweibba includes large part of economic area of north west Gulf of Suez and this floods accumulation is very dangerous, especially during the high depth rainfall storm.

Conclusions: A flood harvesting plan was prepared to maximize the groundwater recharging by surface runoff water depending on the previously discussed techniques and measurements

Mapping groundwater bodies with artificial or induced recharge, by determination of their origin and chemical facies

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The European Water Framework Directive and in particular the European Groundwater Directive have or will have a strong impact on how to map, protect and monitor groundwater bodies. This holds in particular for those with artificial or induced recharge. These groundwater bodies are as a matter of fact very special by virtue of their recharge with surface water either by managed aquifer recharge (MAR) or induced recharge (BAnk Filtration; BAF).

Good water quality maps need to be made anyhow, for a.o. allocating water resources, optimizing monitoring networks, and controling water pollution. In addition, maps form the most effective communication tool for transfer of water quality data in a geographical context, either from expert to expert or from expert to policy-maker.

With mapping is intended here the preparation of maps with the spatial distribution of both groundwater bodies (hydrosomes) and hydrochemical facies within these hydrosomes. A hydrosome is defined as a coherent, 3-dimensional unit of groundwater with a specific origin, like for instance coastal dune groundwater, intruded North Sea water and recharged Rhine River water in the dunes. A hydrochemical facies is defined as a coherent, 3-dimensional unit of groundwater with various chemical characteristics each of which falling within a specific class. For instance, recharged Rhine River water may have the following facies: calcareous (calcite saturated), deep anoxic (with significant SO_4-reduction), salinizing (negative base exchange index) and moderately polluted (pollution index = 2.5-3.5). The mapping of hydrosomes requires the use of environmental tracers to detect the origin of groundwater, in particular of groundwaters with MAR or BAF. The following tracers are demonstrated to be extremely powerful, especially when combined : tritium, oxygen-18, Cl and Cl/Br-ratio.

The mapping of hydrochemical zones requires to determine 4 chemical characteristics of groundwater: the calcite saturation index (2-5 classes), redox index (3-7 classes), base exchange index (3 classes) and pollution index (2-7 classes). The number of classes depends on the desired level of subdivision on the map. How to easily determine these indices is indicated.

Examples of thus prepared maps are shown: (1) the coastal dune aquifer system in the Western Netherlands with 2 different MAR-hydrosomes (Rhine and Meuse River water); (2) a deep Miocene aquifer with deep well injection of canal water; and (3) a BAF-system in the compound Rhine-Meuse delta.

Application of GIS mapping to aquifer retention time and river depletion calculations to determine optimum locations for artificial recharge

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Objective: In aquifers where flows to and from surface water are significant, river depletion by groundwater abstraction and loss of aquifer storage to rivers during artificial recharge are important environmental and engineering considerations. These issues can affect the economic feasibility of artificial recharge operations. In complex aquifer systems, optimum artificial recharge locations are not always located at the greatest distance from surface waters. For instance in south London other factors that significantly affect the optimum recharge and abstraction locations include the dominant fracture orientation and style, local variance in aquifer transmissivity and storage, as well as the vertical hydraulic conductivity of leaky layers separating the target aquifer and surface water features. The complex interplay of these factors can be counter-intuitive and prevent the identification of optimum recharge and abstraction locations by simple inspection methods.

Methods: This problem can be overcome by importing spatial distributions of key parameters such as distance to river (spill point), transmissivity, storage and vertical hydraulic conductivity of intervening layers in to a GIS, and then calculating spatial variations in diagnostic parameters of aquifer retention time, river flow depletion, well injection capacity and abstraction capacity.

Conclusions: Optimum recharge locations can then be easily identified where the diagnostic parameters are optimised. This approach was subsequently proven to provide reliable results by hydraulic testing at two locations in the Chalk aquifer of south London and from operational recharge data from north London.

Inexpensive soil amendments to reduce salt water intrusion into the aquifer

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Apatite, bentonite, zeolite, beringite, zero valent iron (ZVI), iron oxide and alkaline biosolid were evaluated as inexpensive and abundant stabilizing agents in metal-contaminated soils for a better recharge. The influence of the stabilizing agents on the mobility, bioavailability and toxicity of As, Mn, Ni, Cu, Zn, Cd and Pb were evaluated using newly developed availability indices such as the modified distribution coefficient (Kmd), bioavailablity factor (BF), recalcitrant factor (RF) and transfer factor (TF), all of which give us information about the amount of a metal contaminant that remains in the soil vs. the amount that moves into solution or the food chain. The amendments significantly reduced the mobility of metals in soil, metal uptake by plants and metal phytotoxicity. However, the effectiveness of these amendments varied. For example, iron oxide was most effective for soils contaminated with arsenic, whereas apatite was best at reducing the mobility of lead, cadmium, and zinc. The alkaline biosolid played an important role in stabilization of copper and nickel. Zeolite stabilized cadmium, zinc, lead, copper, and nickel in soil, especially when metal levels were low, but its efficacy might be questionable. Such changes among the soil quality indices indicate success of the remediation technique and may have relevance in risk assessment and monitoring.

The Streatham groundwater source: An analogue of the development of recharge enhanced groundwater resource management in the London Basin

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Abstraction began from the confined Chalk aquifer of the London Basin in the late 18th century. Abstraction increased steadily throughout the Industrial Revolution into the 19th century, and it was in the latter part of that century that the Streatham groundwater source began making a 6 Ml/d contribution to that increase. Base load abstraction from the Chalk continued to increase until the 1940s resulting in over-exploitation of the aquifer and declining groundwater levels. The consequence at Streatham was a progressive reduction in base load yield to around 3.5 Ml/d, followed by a change to seasonal abstraction by the time it ceased operation in 1954. Chalk groundwater levels throughout the London Basin continued to decline until around 1965, but have subsequently recovered dramatically in response to reduced abstraction. It was in the period of declining groundwater levels that a large part of London's subsurface infrastructure was developed, including underground railways. The consequence was that the subsequent rise in groundwater levels since the 1960s posed a significant risk of structural damage and flooding. The risk was such that groundwater abstraction has progressively been increased since the late 1990s, with a new 5 Ml/d borehole at Streatham being one of many boreholes constructed. This development was envisaged as providing a control on rising groundwater levels, with the abstraction subsequently to be reduced to prevent a return to over-exploitation. However, abstraction since the late 1990s has identified the possibility of a new, more dynamic role for these boreholes, including Streatham. The concept is one where groundwater storage is managed to ensure that maximum groundwater levels do not impact subsurface infrastructure, while minima define a resource limit and/or a level at which derogation of other abstractors occurs. The process that facilitates this active, enhanced groundwater resource management is artificial recharge. For the 120 years after its commissioning, the Streatham groundwater source followed the wider evolution of the confined Chalk aquifer in the London Basin. In the 21st century artificial recharge testing at Streatham has demonstrated borehole injection rates of 14 Ml/d, and Streatham is now in the forefront of investigations of a South London Artificial Recharge Scheme. The challenge is to define the optimum strategy for storing injected water to ensure that resources available to meet both seasonal peak and drought demands are enhanced and reliable.

Proposal of a system of environment core indicators for the monitoring and control of the operations of recharge of aquifers based on empirical experiences

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Objective: It is tried to design a system of environment core indicators for monitoring the evolution of an aquifer by effect of the workings of artificial recharge recently implanted. This way it is possible to value its effectiveness, and monitoring the evolution and the interaction between the different technical, economical and environmental aspects.

Methods: It has been studied the different factors that experience modifications by effect of the artificial recharge during the first two cycles of activity with the greater possible exhaustive level. In general they have been grouped into hydrochemical, hydrogeological, social-economical and environmental factors. For the study of its evolution and the degree of interaction a system of rank-weights and an evaluation multicriterion polygon has been set out as well.

Results: The application of the proposed methodology permits to monitor the evolution of the different parameters, allowing to correct some environmental adverse impacts and to improve technical some low efficiency operations with rigor and organization. The evolution of the proposed systems, specially the variogram, has demonstrated that it is necessary to change the location of certain AR devices, in order to improve the maintenance program and to apply specific SAT technologies.

Conclusions: The proposed method is based on empirical experiences that allows to reach a "good status" of water, according to the political targets of 200/60/CE Directive. The method, though its numerical base, suffers of certain subjectivity. It is necessary to emphasize that the environment core indicators system and the variogram initially proposed will be improved throughout the time, as soon as new empirical experiences are obtained.

Developing regulatory controls for stormwater discharge to a potable aquifer in regional South Australia

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Objective: This paper describes the development and implementation of regulatory controls to protect the beneficial uses of an aquifer receiving stormwater from a regional city in South Australia. The experience of developing these controls will be useful for consideration by other jurisdictions when considering the regulation of stormwater discharge to aquifers.

Methods: The stormwater that is generated from the small regional city of Mount Gambier (population 22,000) has historically been managed through the direct discharge to over 500 drainage wells. The carbonaceous aquifer that receives this stormwater feeds into the famous Blue Lake, which is also used as the main drinking water supply for the city. Annually, the volume of stormwater discharge represents up to 50% of recharge to the Blue Lake. The highly karstic nature of the aquifer means that preferential pathways may dominate groundwater flow in many locations underlying the city, and therefore the attenuation/adsorption capacity of the aquifer cannot be measured with any degree of accuracy, nor relied upon to protect the potable use of the aquifer. The South Australian Environment Protection Authority (SA EPA), the peak environmental regulator for South Australia, recognises that mandatory treatment of all stormwater within the city to drinking water quality is not achievable at this time, and so has developed an approach that attempts to deliver the greatest level of protection for the aquifer while providing controls that are economically achievable to the region. The approach that has been adopted by the SA EPA has five key components considered necessary to achieve the protection of the receiving groundwater. These being; 1) a hazard analysis and risk assessment to quantify the degree of risk posed by stormwater discharge, 2) the development of stormwater treatment design standards that are relevant and applicable to the city, 3) legislation that allows the enforcement of these design standards, 4) a communications program and 5) commitment and partnerships with other regional government agencies and scientific organisations.

Conclusions: The adoption of this approach has seen significant advancements in strategic stormwater management within the city, and although the full application of the improved standards will take many years to implement, the approach demonstrates that a balanced consideration is required to recognise the difficulties of regulating stormwater discharges.

Hydrogeology and water treatment performance of the Dösebacka artificial recharge plant – the basis for an efficient system for early warning

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Objective: The operation of an AR-plant and the retention of organic matter, pathogenic organisms and other water quality parameters may depend on the quality of the infiltrated water, thus calling for an alert early-warning system. The Dösebacka AR-plant participates in the EC-project ARTDEMO with the main objective of demonstrating a system for monitoring and management of AR-plants with advanced on-line/at-line instruments and surveillance IT-technology. The aim of this paper is to present the initial stage of the project for the test site in Dösebacka in Sweden. The focus is set on understanding the hydrogeology and the water treatment performance of the formation for the definition of an early warning system. The plant operates 9 infiltration basins and 15 abstraction wells and produces 2,2 million m^3 per year.

Methods: Resistivity profiling (using CVES - Continuous Vertical Electrical Sounding) and refraction seismic soundings were performed together with the drilling of boreholes in order to map the geometry of the aquifer system. Flow path and residence time were calculated from tracer experiments, observed groundwater levels and temperature measurements. Water treatment efficiency was evaluated from water quality data measured once a month during a period of one year in 2003/2004, with a special test period of four weeks regarding the microbiological barrier effect of indicators of faecal contamination such as E.coli and Cl.perfringens.

Results: The resistivity profiles clearly show the extension and depth of the clay layer adjacent to the river. The clay layer is deepest (approx.40m) close to the river and becomes thinner up along the slope of the shore and thus the aquifer is confined. The drilling showed the existence of only one aquifer, stratified with sand and coarse gravel. The depth to bedrock was not discovered in the resistivity profiles but the drilling showed that the depth is only 15 meters close to the infiltration basins. Other studies have shown that the depth to bedrock under the river is 100-200 m, which implies a step inclination of the bedrock. However, salt water has been detected in at least three wells (depths of 20-45 m), and the salt water (indicated by the salinity gradient) probably constitutes a lower boundary of the aquifer. The tracer experiment displayed a residence time (first response) of 6 to 12 days for two of the abstraction wells, which together with the temperature curves, Figure 1, implies residence times less than a month for the plant in general. Too high a capacity in pumping produces a higher salinity, which suggests a more even distribution between the abstraction wells. In two wells the turbidity and content of organic matter is relatively high, probably due to a short residence time, demanding post treatment by chemical precipitation and filtration. Salty conditions also seem to generate problems with manganese, nitrite and iron. The removal of faecal microorganisms was found to be 2 to 3 log, also for the wells with short residence time.

Conclusions: A single aquifer is confined under clay adjacent to the river. Bedrock and a salt-water gradient define the lower boundary of the aquifer. Salty water is mixed with fresh water in the abstraction wells and causes problems with manganese, iron and nitrite. Short residence

time causes problems with high turbidity and organic content. However, the microbiological barrier effect seems to be very efficient, even for a short residence time.

Modelling

Abstracts:

Evaluation of Innovative Collector Well Design Using an Analytic Element Groundwater Flow Model

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The Sonoma County Water Agency (SCWA) operates five radial collector wells in a highly-productive alluvial aquifer bounding the Russian River in Sonoma County, Califiornia. SCWA is currently constructing a sixth collector well using an innovative design approach to enhance the reliable production of the collector well. To comply with the requirements of the Endangered Species Act, it was necessary to locate Collector No. 6 several hundred feet from the Russian River to protect fish habitat. Because conventional installation techniques result in laterals extending only 70 to 180 feet into the aquifer, SCWA developed a new approach for installing larger diameter and longer laterals to compensate for the distance of the collector well from the river. An 18-inch diameter 350 foot long pilot lateral was constructed using innovative drilling techniques.

Based on the success of this initial pilot lateral, a new pilot lateral was proposed. Prior to construction, a new groundwater model of flow to a collector well developed by WHPA Inc. of Bloomington, IN was used to study the effects of the modifications. Previous planning evaluations were conducting using MODFLOW, however SCWA was interested in better understanding the flow characteristics associated with friction losses in the longer pilot laterals in addition to aquifer flow characteristics. Based in part on this evaluation, a second 18-inch diameter pilot lateral was installed to a length of 375 feet.

The new model code is based on the analytic element model TimML (Bakker, 2002). TimML makes use of "Bessel" analytic elements that efficiently represent leakage. The collector well module represents the hydraulics of a collector well in three dimensions, including the three-dimensional geometry of the collector laterals, interference between the lateral arms, resistance to vertical flow in the aquifer (including aquifer stratification), entry resistance into the well due to fines near the well screen, head losses within the lateral arms due to friction, and interactions with surface waters or nearby wells.

The modeling effort demonstrates that the new arm will enhance the well's capacity, but that the distribution of water into the existing lateral arms would be strongly affected indicating that the model can be used to help optimize collector well operations. In addition, the model can be used to evaluate flow paths and to develop population curves of residence times for each lateral. It was also found that head losses due to friction will limit the capacity of the new lateral arm, a result that will be applicable to design of new collectors. The authors will describe the new model code, discuss its application at SCWA, and suggest additional experimental work that will improve the utility of the model for collector well design problems.

High resolution digital geological 3D models as a base of hydrodynamic calculation in heterogeneous aquifers

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The flood event of the river Mulde in August 2002 in the Bitterfeld region led to a filling of the former open pit “Goitzsche” and thereby to rising groundwater levels in the surrounding aquifers (several meters) and to changes in the groundwater flow directions. To calculate the effects of contacts between groundwater and layers that were not affected by groundwater before, a high resolution 3D geological model was built. The digital 3D geological model helps to identify these layers and to set up 3D structures and parameters for numerical groundwater modelling. It thus supports a precise forecast of the hydrodynamic conditions which is of crucial importance for the adjacent industrial areas. Up to now, real 3D geolgical modelling is not state of the art except in the field of economic geology. Mostly the required geological information is not available, in case of mining areas the heterogeneity is increased. Due to this, the model area of about 50 km^2 was modelled in detail with 31 geological units (quarternary and tertiary sediments) and a grid resolution of 10x10 m^2. The stuctural model was generated by combining point informations from about 250 boreholes and loggings and lateral information of sediment distribution which were implemented in about 50 cross sections. This model allows – beyond visualization purposes – volumetric calculations of partial or distinct sedimentary units, which are relevant for an assessment of retardation processes in the remaining lignites. The lignites are the most contaminant bearing layers due to their high adsorption capabilities for organic substances. The total volume of the (ground)water in the layers that were affected by rising water levels is calculated. For a better understanding of the anisotropic structures of the open cast mining dumps orthophotos and a high resolution DEM were interpreted to locate internal structures of the anthropogenic layers. The evaluation tools implemented in the modelling software GeoObject 2 and GSI3D are the expanse and thickness in terms of equal area projection, cell-projection and contour lines for distinct sedimentary layers. The GIS software ArcView allows to combine several different thematic layers to get valuable answers to environmental questions. The following numerical groundwater modelling will include aspects of groundwater imbalances, flow and transport on a regional scale.

Gas Transport Below Artificial Recharge Ponds: Insights from Dissolved Noble Gases and a Dual Gas Tracer Experiment

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Objective: A surprising result of the initial single gas tracer experiments performed at artificial recharge facilities in Orange County, CA, USA, was the observation that the gas tracers were transported through the vadose zone to the water table without significant loss or retardation. Clark et al. (2004, Ground Water, 42: 167-174) postulated that the absence of retardation indicates that the gas tracers were infiltrating primarily through saturated pathways contained within the vadose zone. In order to better understand processes affecting the transport of gas tracer through the vadose zone, a dual gas tracer experiment using sulfur hexafluoride (SF_6) and an isotope of helium (^3He) and measurements of dissolved noble gases were preformed at the El Rio Spreading Grounds, Ventura County, CA, USA.

Methods: The dual gas tracer method was initially developed to quantify gas transfer in the ocean and in rivers. More recently, this method has been used to quantify the amount of trapped air in porous media in laboratory (column) experiments. SF_6 and ^3He were chosen as tracers because they are conservative, not retarded in saturated porous media, and have Henry's Law coefficients that differ by about 50%. Laboratory experiments have shown that dissolved gases exchange freely with air trapped in porous media. The expected gas transfer and partitioning between the infiltrating water and soil air will act to retard (slow) the movement of the gas tracers through the vadose zone. Fry et al. (1995. Ground Water, 33: 391-398) showed that the amount of retardation is a function of the Henry's Law coefficient. For 35 days starting on 8-Sept-02, two ponds in the El Rio Spreading Grounds recharged a total of 5x106 m^3 of surface water. The spreading area had received very little water for the three months prior to this release. For a period of 8 days (27-Sept to 4-Oct), a gas mixture containing SF_6 and ^3He was injected into one of the ponds by bubbling through a diffusion stone. At the time of the tracer release, the mean artificial recharge rate was approximately 4 m day-1 and the water table was 12 m below the ground surface. Samples were collected from the pond during the injection period and from eight productions wells that surround the El Rio Spreading Grounds for more than a year.

Results: Breakthrough curves of SF_6 and ^3He at two nearby production wells were very similar. At one well that is located within 10 m of the pond and is screened between 50 and 90 m below the ground surface, both tracers were detected after 5 days and the maximum concentrations arrived after about 20 days. The ratio of the gas tracers in the groundwater was very similar to the initial ratio in the pond and did not vary with time. Noble gas concentrations in the groundwater were much higher than in the pond and the solubility equilibrium value due to the dissolution of trapped air.

Conclusions: The noble gas data clearly show that the infiltrating recharge water exchanged gases with trapped air pressurized above atmospheric at the El Rio Spreading Grounds. As measured by the Ne excess ([Ne]measured/[Ne]equilibrium-1), the amount of excess air formed here is larger by a factor of 2 to 5 than generally observed under conditions of natural recharge. However, significant retardation of the gas tracers caused by trapped air was not detected suggesting that the amount of trapped air was small. The experiment demonstrates that at artificial recharge sites with high infiltration rates and a moderately deep water table, transport times between recharge locations and wells determined with gas tracers are reliable.

Visual CXTFIT – a user-friendly simulation tool for modelling one-dimensional transport, sorption and degradation processes during bank filtration

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Objective: Successful predictions of the fate and transport of solutes during bank filtration and artificial groundwater recharge hinges on the availability of accurate transport parameters. We expand the CXTFIT code (Torijde et al., 1995) in order to improve the handling with the help of pre- and post processing modules coupled with Microsoft Excel. Inverse modelling results of column experiments with tracers, pharmaceutical residuals and algae toxins demonstrate the applicability of the advanced simulation tool.

Methods: Within the interdisciplinary NASRI research project (Natural and Artificial Systems for Recharge and Infiltration) dealing with river bank filtration processes, a set of column experiments were carried out to understand mechanisms of transport, sorption and biodegradation of different compounds. To identify these parameters the CXTFIT code was selected and embedded in a pre- and postprocessing routine programmed with Visual Basic. With the help of a graphical interface and coupling with Excel, experimental data sets can easy be transferred and results – observed and fitted breakthrough curves – are depicted simultaneously. Thus, particularly experimental working groups are enabled to handle this user-friendly simulation tool both for analysing and planning of experiments

Results: Different kind of field, semi-technical and column experiments in the NASRI research project were carried out with tracers (e.g. Bromide, Gadolinium, Uranin), pharmaceutical residuals (e.g. Primidone, Carbamazepine) and blue algae toxins (Microcystin). First of all the model was used to estimate best fits for the transport parameters velocity v/j and dispersion length aL=D/v regarding different types of input functions. Especially for field experiments these parameters are used as first approximations to be improved with the help of numerical modeling. For column experiments, based on these analyses inverse modeling of retardation and decay lead to an better understanding of sorption/desorption and biodegradation effects, sometimes coupled with mobile-immobile transport behavior. Results of Visual CXTFIT modeling often are used further for reactive transport simulation.

Conclusions: Using the Visual CXTFIT add-in measured breakthrough curves for tracers, pharmaceuticals and algae toxins were successfully verified. The simulation results make evident that this easy-to-use program can be a fundamental tool not only for modellers but for experimental working groups also.

Simulation of Bacteriophage Populations during Sub-Surface Passage

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Objective: Phages are present in surface waters in high populations. When the fluid enters the sub-surface, either due to natural conditions or induced by groundwater pumping in the vicinity of the bank, conditions for the species change. Phage concentrations usually decrease drastically in the more unfavourable environment. Moreover the species attach to the porous medium and/or to particulate substances in the fluid. In the different environment or at the surface of the solid material the behaviour of the phages may change also, i.e. they may become inactive. While the possible phenomena are well-known, a quantitative description is difficult. In the paper a mathematical-analytical approach is presented and applied for data from several experiments performed during the interdisciplinary NASRI research project (Natural and Artificial Systems for Recharge and Infiltration) dealing with river bank filtration processes

Methods: First a mathematical-analytical framework (using partial differential equations) is presented, with which it is possible to account for the various different processes, which may play a role concerning the fate of phages in the sub-surface. The final description is very similar to the transport of chemical components, extended to account for decay, sorption and carrier substances. The analysis shows that the complex interaction of the different processes may be lumped into a small set of parameters. The mathematical method is implemented in a numerical model on the computer, using MATLAB. Using the MATLAB model the one-dimensional partial differential equation is solved for different initial and boundary conditions. Parameters can be estimated by an automatic procedure for inverse modelling, which is implemented with help of the MATLAB optimisation toolbox.

Results: Within the NASRI project various experiments with phages have been performed: in small and large columns, in semi-technical slow-sand filters and enclosures at the site. Most of the reported experiments were conducted at the site of the Federal Environmental Agency at Berlin-Marienfelde. For the long column experiment breakthrough curves are available at several locations along the passage. The MATLAB model is used for the simulation of some of these experiments, for two types of phages (138, 241). Modelling of phages turns out to be a challenge for the described model, as population gradients for phages are much steeper than for chemical species. High temporal and spatial fluctuations in the data make it impossible to use an automatic parameter estimation procedure – even after smoothing original data (using splines). The parameters obviously change during the underground passage and thus have to be evaluated from one breakthrough curve to the next anew.

Conclusions: For the simulation of bacteriophages in the sub-surface a mathematical analytical description can be used that is similar to that for chemical species. When this analysis is used in a model the fitting of measured data for phage breakthrough curves may turn out to be difficult, due to relatively high gradients and high fluctuations. It has to be expected that lumped parameters vary along the flowpath.

Colloid Transport in Variably Saturated Porous Media

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Objective: Soil column experiments were conducted to explore the influence of variable water content and colloid size on the transport and fate of fluorescent colloid particles in homogenous and heterogeneous porous media.

Methods: Negatively charged fluorescent microspheres of three sizes (0.02, 0.1 and 1mm) together with a tracer solution (LiBr) were applied by a rotating, drop forming rain simulator to the surface of a vertical column (250 cm length and 23.7 cm inner diameter). Temperature and water content were monitored during the experiments by thermocouples and TDR-probes, respectively. Effluent samples were taken at the column outlet during the experiments under saturated condition. Soil samples were collected at different depths at the end of the experiments under saturated and unsaturated conditions.

Results: Breakthrough colloid concentration curves and the final spatial distribution of colloids retained by the porous media were found to be dependent on the colloid size, water content and homogeneity of the soil. At saturated conditions, increasing colloid size and decreasing soil homogeneity led to a decrease of soil effluent colloid concentration and an increase of mass removal by the soil. This observation was attributed to the phenomenon of straining, when larger colloids block pores and thus creating dead ends. At unsaturated conditions colloid concentration in the soil solution was found to be strongly dependent on the level of soil homogeneity. The interplay between homogeneity and water content significantly influenced concentration recovery. At low water saturation the colloid concentration in the soil solution decreased as homogeneity decreased. Oppositely, at high water content colloid concentration in the soil solution increased with decreasing homogeneity. This is possibly due to preferential flow pathways, which become more meaningful as water content increases. The mathematical model, which accounts for preferential flow under unsaturated/saturated conditions (based on the MACRO model equations) and for transport of colloids, was applied to simulate the conducted experiments

Conclusions: Good agreement was obtained between simulations and experimental results.

A Coupled Model for Transport, Geochemical Reactions and Redox Processes

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Objective: Within the scope of the interdisciplinary NASRI research project (Natural and Artificial Systems for Recharge and Infiltration) dealing with river bank filtration processes at Berlin water works, a semi-technical column experiment to simulate river bank filtration processes is ongoing since January 2003. The objective of reactive transport modelling was to identify the main physicochemical processes within the soil column during the flushing experiment as a model for river bank filtration.

Methods: Here a 30 m long soil column is operated by surface water sampled from lake Tegel (Berlin, Germany) under saturated conditions. Changes in pore water hydrochemistry sampled on 21 sample points distributed over the column are verified by reactive transport modelling. The conceptual model was realised by coupling hydrodynamic transport and chemical speciation via operator splitting within the software environment MATLAB. The hydrodynamic transport module including sorption for organic carbon and the double porosity approach for oxygen was performed by MATLAB procedures, and the geochemical speciation and kinetics calculations were supplied to the external module PHREEQC (batch version) called from the MATLAB environment.

Results: A first evaluation of sampled data showed that the main mechanisms to expect are (1) the biogeochemical degradation processes due to interaction of natural surface water with the soil matrix and (2) the continuous dissolution of refractory air bubbles from the soil column matrix due to possible falling dry in the past. Both are addressed by the model. For simplicity and because of the lack of detailed information about the matrix composition, the biochemical degradation was formulated using a first order kinetic approach. Furthermore, the observed breakthrough of dissolved oxygen showing simultaneously biodegradation and air bubble dissolution could be successfully verified by implementing organic matter fractions of different reactivity and sorptivity. A double porosity approach was found to be appropriate to model the continuous dissolution of refractory air bubble bound oxygen. The assumption of Calcite equilibrium was proven to be appropriate to model the inorganic hydrochemical composition of pore water.

Conclusions: Using this model the measured breakthrough curves for dissolved oxygen, for dissolved organic carbon were successfully verified. The simulation results make evident that during the first seven month of the semi-technical column experiment biogeochemical degradation and removal of interstitial residual air compete as governing physicochemical processes.

On the use of Reactive Multicomponent Transport Modelling for assessing Water Quality Changes during Managed Aquifer Recharge

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Objective: Managed artificial recharge is an increasingly used technique to supplement drinking water supplies. Following recharge the water quality of the injectant is modified by physical and gechemical processes during subsurface passage and storage. Relevant geochemical processes that affect the major ion chemistry include microbially mediated redox reactions, mineral dissolution/precipitation, ion-exchange and surface complexation. Reactive multicomponent transport modelling provides an ideal platform for the quantification of these processes and to develop an understanding of how they interact. The present paper demonstrates this for the analysis of a comprehensive data set that was collected during a deep-well injection experiment.

Methods: To assess the potential water quality changes that occur during subsurface passage a field-scale injection experiment was carried within a deep aquifer near Dizon/The Netherlands. Pre-treated, aerobic surface water was injected at 300m depth into an anaerobic, pyritic aquifer. A three-dimensional geochemical transport model was build on the base of (i) the hydrogeological and geochemical characterisation of the target aquifer and (ii) the water quality data collected during the experiment.

Results: The simulations allowed to delineate the influence of physical and chemical processes on water quality changes and to identify pyrite oxidation as being the key driver for reactive changes. Integrating the simultaneous simulation of heat transport into the reactive transport model it can be shown that the variable temperature of the injectant has a significant impact on reaction rates and causes a vastly changing redox zonation in response to seasonal temperature variations. Comparison of the simulations with the measured data show that the calibrated model provides an excellent qualitative and quantitative description of the spatially and temporally varying hydrochemistry, including pH and redox-zonation.

Conclusions: The model application demonstrates the suitability of the approach for a detailed, process-based quantification of the water quality changes of macro-components and its scope for a future, process-based simulation of other aspects such as trace metal/pathogen mobility and the attenuation of organic micropollutants, e.g., pesticides.

Quantifying Biogeochemical Changes during ASR of Reclaimed Water at Bolivar, South Australia

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Objective: Managed aquifer recharge, including single-well aquifer storage and recovery (ASR), is an increasingly popular technique to secure and enhance water supplies. During injection, storage and recovery of reclaimed water both, physical and biogeochemical process modify the water quality within the target aquifer. To design and operate efficient, sustainable and safe ASR schemes not only a qualitative understanding of those processes is important, but also the capability of quantifying them. In the present study the development and application of a numerical model were driven by the aim of providing a consistent, process-based interpretation of the hydrogeochemical changes that occurred during a large-scale field experiment where pre-treated, nutrient-rich reclaimed water was injected into a limestone aquifer at Bolivar, South Australia.

Methods: A conceptual biogeochemical model for wastewater ASR was developed and incorporated into an existing reactive multi-component transport model. The modelling framework created during this study incorporates advective-dispersive transport, ion-exchange, mineral dissolution/precipitation and microbially mediated redox-reactions. Particular emphasis was put on tracking the fate of organic and inorganic carbon in its various forms. The model was applied to a comprehensive set of data which was collected at the Bolivar field site during a trial injection and recovery between October 1999 and November 2001.

Results: The simulation results demonstrate that the modelling framework is capable of providing a good quantitative description of the physical and biogeochemical processes at the Bolivar site. They suggest that during the storage phase dynamic changes in bacterial mass have a significant impact on the geochemistry in the vicinity of the injection/extraction well. For example, the significant increase in ammonia concentrations and alkalinity can be attributed to bacterial decay. Further away from the injection/extraction well, breakthrough of cations is shown to be strongly impacted by exchange reactions, and, in the case of calcium, by calcite dissolution.

Conclusions: The study demonstrates the suitability of mechanistic multi-component reactive transport modelling as an integrative tool for constraining existing or new hypothesis of how physical, chemical and biological processes interact in systems such as wastewater ASR schemes.

Development of a microbial pathogen attenuation model to aid management of managed aquifer recharge systems

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One of the principal improvements in water quality that occur during subsurface storage in aquifers is pathogen inactivation; however, the development of a predictive model capable of estimating required retention times for the attenuation of microbial pathogens poses a significant challenge. This abstract describes research that is currently underway to investigate pathogen attenuation under a range of environmental conditions and outlines the formulation of a predictive tool to aid management decisions regarding recovery times for MAR systems. There are several intended applications of the model for MAR projects that involve initiatives in Western Australia to use highly treated wastewater for non-potable reuse.

Recent studies reveal that pathogens do decay during aquifer storage and their rate of decay is predominantly influenced by the activity of the indigenous groundwater microorganisms. In addition, several environmental parameters, including temperature, redox state and nutrient levels also impact pathogen decay, but their influence is secondary and mainly relevant when active indigenous groundwater microorganisms are present.

The main hypothesis we are testing is that the die-off rates of selected pathogens (particularly enteric viruses) and an indicator microorganism can be estimated reliably using empirical equations derived from experimental lab data. The experimental data are obtained under carefully controlled lab conditions with the anticipation of comparing with subsurface field conditions at a later stage. The initial focus tests environmental controls on the activity of indigenous groundwater microorganisms and determines inactivation rates for a suite of pathogens (i.e. coxsackievirus, adenovirus, rotavirus, Cryptosporidium, hepatitis A virus, norovirus) and the indicator microorganism MS2. A simple measure of cellular activity for the indigenous microorganisms will allow us to quantify different levels of microbial metabolic activity and the corresponding temporal changes in pathogen inactivity. Pathogen die-off rates are being determined at several temperatures between 5 and 20 deg C, and at redox levels that vary from aerobic to methane production. The characterisation of nutrients for microbial growth is a major research challenge given the variability in available nutrients in the source water and the potential for complex feedbacks between nutrient assimilation, temperature and competition between different indigenous microbe communities. The modelling approach assumes constant environmental conditions, akin to a well mixed aquifer system with no micro-environments and no subsurface transport.

A crucial factor in the development of the model will be to validate the predicted attenuation of selected pathogens against field trials. While the systematic analysis of a wide range of environmental conditions would be ideal for reducing uncertainty in the model results, the approach will be to focus on temperature, redox and nutrient levels with the aim of identifying knowledge gaps and intermediate levels for further investigation, particularly where major deviations between predicted and observed pathogen attenuation rates occur. Another area for further refinement will be to extend the predictive capability to include temporal changes in pathogen population sizes due to subsurface transport and interactions with micro-environments.

Transient flow modelling of an overexploited aquifer and simulation of artificial recharge measures

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The Prato aquifer, mostlyessentially formed by alluvial fan deposits of the river Bisenzio, is the major source of water supply of the whole urban area of the Medio Valdarno, both for drinkable and industrial purposes. A significant depletion of groundwater resources due to strong overexploitation has been recorded over the past 40 years. A numerical groundwater flow model using the MODLOW code was built to increase the understanding of the groundwater flow system and to provide decision support for water resources management.

Continuously monitored groundwater levels and surface water levels of the Bisenzio River for a number of stations in the area of the alluvial fan as well as estimated and measured data for abstractions from municipal and industrial wells were available since the late 1950s.

The modelling process was designed as a two-step process. In the first step the situation in 1986, a year with a high number of data available, was simulated in steady state. This model provided important understanding of the relevance and interrelations of the single compounds of the water balance. It showed the dominant influence of the groundwater abstraction on the groundwater flow system.

In the second step the model was developed into a transient model covering the period from 1960 to 2001. The transient model was calibrated using data on groundwater elevations in different years within the modellingmodelling period and was able to simulate the strong groundwater depletion in the 1970s and the partial recovery in recent years. To evaluate the effects of artificial recharge measures on the depleted groundwater levels, different preliminary predictivery models were built investigating two different scenarios such as the results of an increased hydraulic gradient between river and groundwater and of some recharge wells placed in different locations of the Prato aquifer. The results of these simulations demonstrated a strong dependence of artificial recharge efficiency and on the locations of the wells.

Water Re-Use

Abstracts:

Wastewater reuse and potencialities for agriculture in Nigeria

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Objective: Although the awareness of the impact of human activities on the environment, especially on water resources, and the resulting threat for both nature and man is growing, relatively few effective bridges to properly address water problems are being built in developing countries. An effective and important bridge to be built concerns water reuse for food production. The paper draws attention to the growing importance of wastewater reuse as an essential part of the planning of the integrated and sustainable water resources management can be evidenced.

Methods: Wastewater has been used by mankind in agriculture since the beginning of modern civilization. Treated wastewater has a fundamental role in some sustainable management and planning of water resources as a substitute to the water that would be used in irrigation for agricultural purposes. Thus, if implemented, wastewater reuse in irrigation could increase food production with the purpose of improving living conditions of the inhabitants of several parts of Nigeria and consequently lead to mitigate poverty. At the same time, wastewater reuse plays an important role in environmental and water resources conservation. This practice release good quality water reuse adds an economic dimension to water resources planning. In this perspective, the need for sanitation, wastewater treatment and it's reuse in agriculture for food production are presented in the paper as decisions to be made in Nigeria to build bridges with the objective to promote sustainable development, with reflexes on the country's economic, political and environmental scenes.

Results: Water reuse reduces the water demand on water bodies ue to the substitution of potable water for water with inferior quality. This practice has been put in evidence and discussed intensively in many countries as well as it is used in several part of the world. It is based in the conception of source substitution. Such substitution is possible in function of the required quality for a specific use. Therefore, Large volumes of potable water could be saved Due to reuse when water with inferior quality is used (generally post-treated effluents) to supply the needs that can renounce water within the potability standards framework. The growing demand for water has made planned wastewater reuse an update issue of growing importance. Thus, wastewater reuse must be considered as part of a wider activity that is the rational or efficiecnt water use. This also concerns the control of water loss ans wastefulness, the reduction of waste production and water consumption. Brazil happens to be a county where nature was very generous as far as water availability is concerned. There is about 8% of all the workd fresh water in this county. Although this figure seems very impressive, the relatively abundant Brazilin water resource are facing dangerous threat: population growth, environmental problems, lack of rigid environmental legislation or most times, difficulties even to apply the existing legislaton. The National Congress has been approving modern legislation concerning water resource management policies since 1997 and fortunately many reforms in the water resoures sector are starting to take place. In a country with the Nigerian conditions, so vast and diverse, such reforms may take a long time to be fully implemented.

Conclusions: The paper demonstrates that attention must be driven to the fact that the use of treated wastewater for food production would promote countless environmental benefits and build bridges to sustainability in Nigeria and other developing countries. It would promote the treatment of wastewater in Nigeria – which now barely accounts for 10% of the total effluent

from domestic and industrial discharges. It would save potable freshwater for nobler uses, especially in those regions where water is scarce, as it is the case of the semi-arid region of the Nigerian Northeast. Moreover, it would abate the environmental impacts caused by the discharges of untreated wastewater into water bodies in Nigeria.

Protecting an island aquifer by using recycled water as a hydraulic barrier

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Objective: Bribie Island is a low sand island which uses its shallow unconfined aquifer as a water source. Lowering of the water table has the potential to allow sea water intrusion into the freshwater aquifer. Recycled water is used in a series of infiltration basins to create a hydraulic barrier to seawater intrusion. Modelling and bore monitoring are used to assess the effect on the aquifer water quality and height. This system has been effective in protecting the aquifer during recent droughts.

Methods: Modelling of the aquifer has been used to establish groundwater movement and predict the location of the recycled water plume. Bore monitoring for physiochemical and bacterial parameters is used to confirm effects on the aquifer water quality.

Results: The aquifer has been protected against seawater intrusion during recent droughts when the aquifer level was below sea level in localised areas. The water treatment plant was able to continue to supply water meeting Australian Drinking Water Guidelines. No adverse effects of recycled water use have been detected.

Case studies/Effects of Managed Aquifer Recharge

Abstracts

Hydraulic and geochemical characterization of Ajali Sandstone aquifer, SE–Nigeria: Implication for groundwater recharge process

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Objective: To better understand the infiltration and recharge processes into granular sandy aquifers as well as the possible flow-associated geochemical process, better and reliable information about the hydraulic conductivity (K) in addition to the possible textural and geochemical/mineralogical characters of the aquifer matrix on the distribution of hydraulic conductivity are needed. Hence, the purpose of this study was to determine the distribution of hydraulic conductivity, K in the regional aquiferous Ajali Sandstone Formation in SE-Nigeria on one hand and to assess the influence of textural and geochemical characters of the aquifer materials on magnitude and distribution of the hydraulic conductivity on the other hand. The overall evaluation was to assess the implications for groundwater quality changes during recharge/infiltration process.

Methods: The investigation approach involved field sampling and collection of samples from twelve (12) different outcrop locations followed by complete laboratory grain-size analyses of the samples in order to determine some textural indices and to empirically estimate the hydraulic conductivity values from the results of the grain-size analyses. For comparative purpose, laboratory constant head permeameter tests were also performed on all the samples while geochemical analyses of the major and trace elements composition of the Ajali sandstone samples were determine using XRF and XRD methods.

Results: The results of the textural grain-size analyses generally indicate fine to medium sands (75% sand fraction) with mean grain sizes of 0.23 to 0.53 mm and coefficient of uniformity (C_u) values of 1.58 to 5.25 (av. 2.75) while standard deviation (sorting) values of 0.56Ø to 1.24Ø also implies moderately well sorted materials. The order of empirically estimated K values are $K_{Lab} > K_{Beyer} > K_{Hazen} > K_{Kozeny\text{-}Carmen} > K_{Fair\text{-}Hatch}$ with average values of 9.2×10^{-3}, 4.4×10^{-4}, 3.8×10^{-4}, 2.2×10^{-4} and 8.1×10^{-5} respectively. These values indicate falls within the range of 10^{-5} and 10^{-3} for fine to medium sands and also conforms to the specification for infiltration/recharge systems. However, multivariate factor analysis of the data revealed positive dependence of the empirically determined K values on mean grain size and percentage sand content unlike the laboratory determined K values, which show much dependence on sorting and uniformity coefficient. Furthermore, the measured SiO_2 content of 76.1 to 98.2% (av. 89.7%) confirms the aquiferous potentials of the Ajali sandstone, while the average composition of 4.3% and 1.1% for Al_2O_3 and Fe_2O_3 respectively and elevated trace metal concentrations (2.5mg/l Cu, 7.5mg/l Pb, 6.5mg/l Zn, 3.9mg/l Ni and 19.6mg/l Cr) call for concerns.

Conclusions: Finally, the overall assessment had shown that while textural characteristics of Ajali sandstone units exerts positive impacts groundwater recharge and its applicability in infiltration/recharge system, the possible negative impacts of flow-induced geochemical processes in forms of weathering-hydrolysis and oxidation-ferruginization might promote precipitation and clogging of the infiltration systems. The possibility of formation of Al-Fe oxyhydroxides through weathering under the tropical humid environment will impair

permeability and serve as sinks for adsorbed trace metals due to high surface areas with attendant negative impacts on the groundwater quality.

Development and investigation of an underground infiltration system with pollutant control device

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Objective: The main purpose of the study presented is to develop and to investigate a new pollution control pit as pre-treatment device with a filter of a special porous concrete followed by a partly sealed concrete infiltration pipe. The facility is optimized to a high pollution retention capacity at a sufficient flow-rate. Solid and dissolved pollutants are removed from runoff by sedimentation, filtration, ion-exchange and chemical precipitation. The mobility of heavy metals, hydrocarbons and nutrients and the impact to soil and groundwater is investigated. Sediments and pollutants are removed by the system.

Methods: The project consists of three stages. In the first stage the pollution control pit is developed and investigated on a laboratory model. Secondly, filters of porous concrete are assessed in laboratory rigs. The model and the filters are charged with an artificial water-sediment-mixture which is spiked with pollutants. Therefore de-ionized water is charged with sulfuric acid to a pH of 5, which corresponds to the pH of the rainwater in Germany. Quartz-particles with diameters from 10 to 1800 mm, dissolved heavy metals and mineral oils are added and the water is mixed by a stirrer. Concentrations in the influent and the effluent are measured and the construction details of the pollution control pit with its concrete filters are optimized. In the third step an 1:1 scaled model of the device is built in a test-facility so that the behavior of the system can be assessed under high pollution concentrations and loads and heavy storm events.

Results: The project will end in December 2004, so at the time of the conference at least final results of the study exist. The system is designed to remove more than 95 % of the total annual loads of heavy metals and hydrocarbons even from metals roofs (copper and zinc) and traffic areas. The concrete filters should be exchanged in periods between 5 and 20 years and will be cost effective in comparison to other adsorbing materials like zeolithes or active coal. The system is maintainable and each part can be cleaned if necessary. Because of the filter even smallest particles cannot reach the infiltration pipe and so clogging is prevented, which extends the life cycle of the underground infiltration system. Soils and groundwater are effectively protected from contamination.

Investigation of Water spreading effects on Water table of aquifer in arid and semi - arid regions

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Regarding the climate conditions and average precipitation of 250 mm, central basin of Iran plateau is considered as an arid and semi – arid region of the world, which is mostly encountered, with lake of water consequently leading to water, explore operations.

Most of the watersheds in central plateau rivers are seasonal and their floods maybe come unavailable during a short time of rainfall seasons, and because of some special geological problems of this region, most of the permanent rivers contain saline water, and are useless.

These factors result in the shortage of water in the different districts, therefore people in this region takes advantage of ground water from which utilization is continuously increasing. According to mentioned above, water spreading in watershed of central plateau has been regarded that one of its important aims is aquifer recharge, and stabilization.

This paper analysis water spreading effects on aquifer of four regions in Central basin of Iran Plateau. Investigation showed that in four regions wells discharge and water table of aquifer have been increased in case of water spreading.

Pumping influence on transport properties of a chalk karst aquifer exploited for drinking water supply

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Objective: This study aims is to know the drainage conditions of a chalk karst aquifer exploited for the drinking water supply and to determine if pumpings modified the transport properties.

Methods: The study site located in the Seine river edge corresponds to a chalk karst aquifer of the western Paris Basin. It consists of i) a sinkhole, where the surface water is introduced, ii) an overflow spring which drains naturally chalk aquifer, iii) a well for drinking water supply. Artificial tracer test were carried out to know hydraulics connections of the sinkhole-spring and sinkhole-well systems. Knowing the transit times, each sample introduced at the sinkhole may be compared with those released at spring and well. Thus, the transport properties of both systems may be studied by comparing the grain size distribution of suspended matter released at the spring and the well with those introduced at the sinkhole. We associate these grain size distribution with the groundwater piezometric level and the Seine river tidal range. To identify the drainage conditions and the pumping impact, we added qualitative variables concerning the Seine river dynamics, and the pumping period. Then we treated the whole by a statistical method of factorial analysis allowing the combined use of the qualitative and quantitative variables.

Results: The artificial tracers are released at the well only at the pumping periods.This shows that hydraulic connection between the sinkhole-spring and sinkhole-well systems is carried out artificially by well.The piezometry and the Seine river tidal range define the hydraulic gradient of the chalk karst aquifer. Their variations determine the drainage conditions and thus the transport properties of suspended matter. The strongest drainage conditions arise when the piezometric level is more important and the tidal range is less important. Under these conditions the restitutions of suspended matter at the well are the most important and coarsest. The same amplified phenomena are observed at the pumping period. Those generate the drainage of the aquifer part located under the alluvium and allow to establish a connection with the sinkhole-spring system.

Conclusions: This chalk karst aquifer is naturally and mainly drained by the overflow spring and by the Seine river for the aquifer part located under the alluvium. Well carries out an artificial drainage of this aquifer part. This allow to establish a hydraulic connection with the sinkhole-spring system, to increase the grain size distribution and the concentration of suspended matter released at the well. This phenomenon is to be connected to the degradation of the water quality at the well (increase in frequency and amplitude of the turbide and bacteriological peaks).

Aquifer Storage and Recovery

Abstracts

Recent advances in ASR Technology in the United States

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Objective: After 25 years of successful aquifer storage recovery (ASR) development and implementation at more than 70 sites in the United States, extensive research is underway to better understand the microbial, geochemical and physical processes that occur during aquifer storage, providing a stronger scientific foundation for future application of this technology to meet increasing water management needs, constraints and opportunities. The author has pioneered ASR technology development since 1978, has directed development or contributed substantially to about half of these operating ASR sites, and is directing or contributing to each of the following research programs.

Methods: 1. The WateReuse Foundation is conducting research to investigate the fate of microcontaminants of wastewater origin during storage in ASR wells. A literature review of reclaimed water ASR sites has been completed; a list of conservative microcontaminants has been prepared and peer-reviewed; and sampling is underway at five representative sites. Sampling at some of these sites will have been completed by June 2005. 2. The AWWA Research Foundation is conducting a research project entitled "Design, Operation and Maintenance Considerations for Sustainable Underground Storage Facilities." Work involves development of an updated site inventory of surface recharge, ASR and other well recharge projects; selection of case studies for detailed analysis of design and operation experiences; and development of design criteria, long term operation procedures and maintenance requirements. 3. Design is underway on what will probably be the world's first horizontal directionally-drilled ASR well, storing drinking water in a brackish, relatively thin, confined sand aquifer to meet peak and emergency water demands. 4. Research has recently been completed regarding an extensive laboratory and field investigation, combined with a literature search, regarding the fate of bacteria, viruses and protozoa during ASR storage in aquifers with different temperatures and salinities. 5. An analysis has recently been completed regarding the occurrence and attenuation of arsenic during ASR storage at 13 operating ASR wellfields in the southeastern United States.

Results: Interim project results will be presented for 1. through 3. Final results will be presented for 4. and 5. Item 4. is already posted on the www.asrforum.com website.

Conclusions: ASR experience and scientific development in the United States has developed substantially during the past 25 years. Dissemination of this experience and associated research can be of value to others considering ASR as a water management tool.

Windhoek, Namibia: Designing a large-scale borehole injection scheme in a fractured aquifer

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The city of Windhoek is currently upgrading their borehole injection scheme in order to accommodate a planned maximum injection capacity of ~7Mm^3/a. The quartzitic aquifer is a highly complex fractured system consisting of preferential flow paths and poorly linked "compartments". This heterogeneous system is the result of impermeable amphibolite and schist layers and various episodes of faulting and thrusting. The design of the injection scheme required a sound conceptual flow model and a thorough geological analysis. The geological study took the tectonic history of the area into account as well as the local deformation history. This paper describes the process of designing the scheme – the location of injection and abstraction boreholes, and the principles on which the design is based.

Stormwater ASR and ASTR (Aquifer Storage Transfer and Recovery) in practice and under investigation in South Australia

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Objective: This paper presents a unique project of its type in the world aimed at injecting stormwater into an aquifer with the intention of recovering water fit for continuous sustainable supply at potable quality. This process will be referred herewith as "ASTR" "Aquifer Storage Transfer and Recovery" whereby separate injection and recovery wells are used to extend the residence time of the injectant in the aquifer and to allow for natural treatment through the aquifer. The distinction in the definition of ASTR versus ASR being that a separate recovery well is used as opposed to the same well for injection & recovery. The project builds on aquifer storage and recovery (ASR) research projects conducted over 10 years with stormwater, reclaimed water and potable water in South Australia.

Methods: To date the intended use of stormwater ASR in South Australia has been for irrigation/industrial/aesthetic use and, for that purpose, the use of wetlands as a pre-treatment for stormwater runoff has been convincingly demonstrated at numerous operational sites in the Adelaide metropolitan area. The Parafield Stormwater Harvesting Facility is a unique project of this kind and is a showcase development initiated by the City of Salisbury Council in converting stormwater from an urban nuisance and pollutant threat into a valuable resource for industry and the community. Stormwater from the local catchment is diverted into a series of uniquely designed capture, holding and cleansing basins. Cleansed stormwater excess to the immediate needs of local industry is stored in natural underground aquifers for recovery at times of low rainfall.

Results: This paper will present the first results of a multi stage stormwater ASTR trial for potable water supply in South Australia and outline the results of the existing operational stormwater ASR scheme in place at the site. The aim of this project is to ultimately allow the demonstration of the actual performance of stormwater ASTR projects to meet water quality criteria for drinking water supplies, and provide a rigorous assessment of the design and operating criteria that would ensure adequate water quality is sustained. If successful this would provide the evidence required for licensing these operations for water supply and provide guidelines for adaptation in developing countries to facilitate achievement of UN Millennium goals with reliance on natural treatment processes.

Conclusions: Outcomes of the attendant research will give an understanding of water quality changes, catchment water quality management, and development and implementation of the HACCP plans to provide water quality assurance, it is expected that a robust package of methods will allow ASTR to be successfully adapted to other sites in the same city and elsewhere in developed and developing countries. For country towns with expensive or low yielding supplies this approach could reduce costs for water utilities to between 10% and 50% of costs of current water systems.

Other benefits are improved management of contaminants in stormwater, improved receiving water quality, an economic driver for improving stormwater quality in catchments, and of course increased security of supply for cities and towns particularly in semi-arid areas.

Modelling Approaches to Optimise Well Field Design and Operation for an Aquifer Storage Transfer and Recovery (ASTR) Trial

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"Aquifer Storage Transfer and Recovery" (ASTR) is a description of a new concept that is about to be trialled in Adelaide to establish if subsurface treatment of injected wetland-treated urban stormwater into an aquifer and its recovery from distant wells can create safe and reliable drinking water supplies. A broader description of the project is given in a related submission to ISMAR5 by Rinck-Pfeiffer et al.

Defining the optimal number and arrangement of injection and recovery wells for a full-scale (400-600 ML/yr) trial must take into account two fundamental constraints; 1) the percentage of mixing with the brackish ambient groundwater must be less than 10% so that the salinity does not limit the productive use of the recovered water, and 2) the mean residence time in the aquifer must be at least 12 months to ensure adequate time for chemical and microbial attenuation.

Numerical (FEFLOW) groundwater modelling simulations were performed to test a number of possible ASTR scenarios that compare the shape and dynamics of the injected water plume, the volume of water needed to initially flush the 'transfer zone' (and how the volume available for injection is dependent on climatic variability), the quality of recovered water and travel time to recovery wells for a range of multi-well configurations. The analysis reveals that both constraints can be met only over the long-term at full-scale with a 6-well arrangement within a quadrilateral domain with an inter-well separation distance of approximately 75 m.

An alternative semi-analytical method is based on the Theiss solution for well drawdown and tracking of moving fronts of injected and recovered water. Comparisons between the numerical and semi-analytical methods reveal a good agreement suggesting that the semi-analytical approach offers a useful and robust tool for future design of ASTR well-fields.

A Model Study of the Proposed Everglades Restoration Hillsboro ASR Pilot Project

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Objective: The Hillsboro Aquifer Storage and Recovery (ASR) Pilot Project is one of four ASR pilot projects planned in support of Everglades Restoration in South Florida, USA. Recently, a preliminary model study was completed with two main objectives. First, the model study was completed to evaluate potential impacts from the project to existing users of the Floridan Aquifer System. Second, the model was utilized to provide a preliminary estimate of site performance in meeting the goals of Everglades Restoration and enhancing the existing groundwater resource.

Methods: The Hillsboro ASR Pilot Project model consists of a flow model developed from MODFLOW and a water quality model developed from MT3DMS. Due to the large pumping rate anticipated for the pilot tests, the model boundary included a large part of Palm Beach County, Florida. The model grid is 40 miles X 40 miles and consists of an irregularly-spaced grid with 100 feet grid resolution at the ASR well location and 4,122 feet at the model boundary. The model includes 7 layers and includes the Surficial Aquifer System, the Hawthorn Group, the upper Floridan Aquifer, the middle confining unit, the Avon Park Formation, and the lower Floridan Aquifer. The model was run for a period of two years to match the expected duration of the ASR pilot project. The predicted model head and concentration of specific conductance upon ASR recharge was evaluated using the calibrated model.

Results: The model provided reasonable estimates of ASR well drawdowns and mounding effects, as well as a range of predicted ASR recovery efficiencies. Impacts to existing FAS well users was deemed insignificant with only one ASR well pumping, however, simulations using the proposed full-scale 30 well system revealed some long-term design challenges. The simulations also revealed that the ASR recovery efficiency at the site would improve over subsequent recharge and recovery cycles but at a relatively slow rate due to the brackish nature of the storage zone.

Conclusions: The ASR pilot project at the Hillsboro site should be continued and will provide additional site-specific field data that could be utilized to improve the numerical model. Due to the large pumping rate involved, the model resolution and boundary size are important considerations in model development. For ASR sites involving recharge of natural systems, the recovered water quality is a key determining factor in project performance. In fact, due to water quality limitations in the receiving surface water body, the actual ASR recovery efficiency may be less than if the site was utilized for potable supply.

Water quality improvements during aquifer storage and recovery

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Literature reviews and field evaluations at up to ten aquifer storage and recovery (ASR) sites in USA, The Netherlands and Australia were undertaken to determine the fate of natural organics, disinfection by-products, selected endocrine disruptors and pathogens during subsurface storage. This paper summarises American Water Works Association Research Foundation (AWWARF) project 2618 which evaluated attenuation of these species and incorporated this knowledge in three different models.

The paper briefly characterises the field sites and explains the formation and role of geochemical conditions in the aquifer that influence attenuation rates of these species. Organic matter degradation occurred most rapidly for larger molecular weight materials, including polysaccharides, and organics containing functional groups susceptible to microbial degradation. Low molecular weight acidic material was found to persist and had a signature indistinguishable from native groundwater. Trihalomethanes were degraded under anaerobic conditions with degradation of chloroform requiring reducing conditions and occurring fastest under sulphate reducing and methanogenic conditions. Haloacetic acids were degraded under aerobic and anaerobic conditions. Of five endocrine disrupting chemicals tested, two were degraded under aerobic conditions and none under anaerobic conditions in the absence of a co-metabolite. A selection of pathogenic viruses, bacteria and protozoa were found to inactivate during residence within the aquifer with fastest inactivation under aerobic conditions. It is evident that passage of water through aerobic and anaerobic conditions maximises the opportunity for contaminant attenuation.

At two sites three models were used to describe changes in water quality on a range of time scales. While two of the models are not validated they do reflect the observations for a large number of water quality parameters, suggesting that the process descriptions incorporated may be reasonable, and that an understanding of the biogeochemical interactions during ASR is emerging.

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Feasibility of ASR for surface water storage in Haarlemmermeer (The Netherlands)

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Objective: In Haarlemmermeer (the polder that includes Schiphol Airport) shortages of surface water are experienced in summer, and an excess of storm water is sometimes experienced in winter. In summer surface water supply is required to maintain water quality and to maintain water level in the ditches and canals. In winter storm water has to be pumped to sea to prevent flooding. The problem of shortage in summer and excess in winter is expected to increase in the future due to climate change. Measures in the surface water system itself can not completely cope with these problems and therefore storage of surface water in basins is anticipated in the plans of the water boards. The water board of Rijnland expects to need extra seasonal storage of 2000 ML/year for an average summer and 1000 ML of storm water storage for a peak that lasts18 hours once every 10 year.

Methods: As an alternative to surface water storage in basins, storage in aquifers has been studied to assess the technical, economical and environmental feasibility. For the feasibility study existing data on the local hydrogeology have been gathered and hydrological model calculation have been performed. The surface water is assumed to have a high MFI of 1000 s/l^2. For the harvesting of water for seasonal storage to prevent water shortages a horizontal well under the main body of surface water is foreseen, in order to lower the MFI to a value of 50 s/l^2. For storm water storage surface water is directly injected into the aquifer.

Results: The aquifer storage is projected in an aquifer at a depth of approx. 100 to 150 m deep that contains salt water. For seasonal storage for water shortages 20 wells with an infiltration capacity of 28 L/s each are assumed, for storm water storage 140 wells with an infiltration capacity of 111 L/s each.

Conclusions: The calculations show that the aquifer storage system is technically and economically feasible: injection pressures, clogging rate and change of groundwater level appear to be within acceptable limits. Seasonal aquifer storage for water shortages is expected to require lower investment than storage in basins. Investment costs for storm water storage are in the same range as the expected investments for basins. Further research is recommended into aspects of water quality: recovery efficiency of fresh water, oxygen consumption in the aquifer and the fate of pollutants that are dissolved in the surface water that is injected.

NLARS: Evolution of an artificial recharge scheme

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The North London Artificial Recharge Scheme (NLARS) was originally developed as a drought management tool, aimed at meeting the resources shortfall in times of drought. Emphasis of the Scheme's use has now changed, with more dynamic management of groundwater resources to allow greater operational flexibility. NLARS takes advantage of the large dewatered volume in the confined Chalk and Basal Sands aquifers that had resulted from historical pumping. Additionally, the Lea Valley reservoir chain and the New River aqueduct provided inexpensive methods of transferring the raw water to the main treatment works. Recharge trials were carried out in the 1950s and 1960s, leading to an operational artificial recharge scheme in the late 1970s. During the early 1990s further developments resulted in what is known now as NLARS. It consisted of 35 boreholes, and was capable of 150 Ml/d output with a recharge capability of 45 Ml/d. The Scheme was further extended in 2002 to 40 boreholes and a maximum output of 200 Ml/d. Recharge capability was increased to 75 Ml/d. In the next 5 years abstraction capability will be increased by an additional 30 Ml/d. Historically, since licensing in 1995, NLARS has been in full abstraction mode only three times; 1996, 1997 and 2003. In 1997 it abstracted for four months, totalling 10700 Ml. The scheme was substantially recharged immediately following abstraction, achieving a peak of 45 Ml/d and a total of 3500 Ml. The recharge rate was up to 3 Ml/d per borehole. A similar recharge strategy was attempted following the 2003 event in which 9000 Ml was abstracted. Only a peak rate of 28 Ml/d and a total of 2200 Ml was achieved due to operational and network restrictions, despite the recharge capability of the Scheme having been increased. Typical individual rates of recharge were 3 Ml/d although 7.5 Ml/d was achieved at one borehole. NLARS is now evolving to allow the management of shorter-term operational requirements, such as dealing with water quality issues and local outages. Four NLARS boreholes have recently been equipped to allow direct supply of treated water into the network during peak demand periods. The use of the boreholes in this way requires significant recharge during low demand periods to replenish aquifer storage, ready for the following phase of abstraction. Should this mode of operation prove successful then it may be adopted elsewhere in the Scheme.

Alternative recharge systems/Sustainability

Abstracts

Assessment of ground water recharge through continuous contour trenches

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Objective: To present the developed simulation model for ground water recharge through continuous contour trenches To study the effect of spacing and size of the continuous contour trenches on the ground water recharge with the help of developed simulation model

Methods: Continuous contour trenches (CCTs) are constructed on the non arable lands in the agricultural watersheds in India. These CCTs harvest the rainfall and runoff and recharge the groundwater aquifers. The quantitative information on groundwater recharge is necessary for watershed planning and management. In this study a simulation model is developed to estimate the groundwater recharge through these CCTs. Runoff and infiltration through trenches are modelled with SCS-CN method and Green Ampt equation respectively. The input parameters of the model are climatic data (rainfall and evaporation), trench dimensions (trench size and spacing), CN-parameters (land use, treatment, hydrologic condition and hydrologic soil group) and soils (Saturated hydraulic conductivity, capillary potential and porosity). Output parameters are runoff, infiltration and evaporation from the trench system. Model uses a daily time step for runoff computations and a smaller user defined time step for infiltration computations. In this study groundwater recharge is determined for different combinations of four trench sizes, three trench spacings, three curve numbers and three soils.

Results: Model is run for 25 years climatic data and analysis of results showed that for different years ground water recharge varied from as low as 34% to as high as 99.06% of total inflow to the trench system. The groundwater recharge varied with the amount of rainfall and its distribution. Low rainfall years with more number of rainy days favoured groundwater recharge through trenches. For given trench system configurations, ground water recharge increased with increase in size and decrease in spacing of the trenches. Increase in curve number (or runoff) decreased ground water recharge. There is about 25% increase in groundwater recharge if the size of the trench is doubled.

Conclusions: Continuous contour trenching (CCT) is an important practice for groundwater recharge in agricultural watersheds in India. This model provides an analytical tool for estimating the groundwater recharge through these CCTs. Model can be used to estimate the groundwater recharge from the existing trench system or it can be used to decide the trench size and spacing for achieving a specific groundwater recharge. Different water harvesting and groundwater recharge structures in the watershed can be planned if quantitative information on groundwater recharge is made available. The model helps in providing this information

Approximating technical effectiveness of low technology aquifer recharge structures using simple solutions

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Objective: Much work has been carried out on mathematical modelling of aquifer recharge schemes to establish their effect on site specific aquifers. Setting up of data intensive detailed numerical models is not always possible, especially for low-technology schemes, e.g. small check dams and spreading basins, in developing countries. Based on work carried out during a DFID funded project focusing mainly on low-technology schemes in India, it was found, that simpler solutions to evaluate the technical effectiveness of aquifer recharge schemes, i.e the ability of the structure to replenish the aquifer used by the local community are needed.

Results: It was found, that technical effectiveness of recharge structures needs to be evaluated on three levels. Firstly, the rate of infiltration in relation to evaporation needs to be established. This determines if the structure is fit for the purpose and can be approximated by measurements of water level declines in reservoirs during periods of no inflow and outflow except for recharge and evaporation loss. In a second step, the area of benefit, i.e. the zone of impact of the aquifer recharge structure needs to be approximated, which is dependant on time scale and hydrogeolgical conditions at the site. This will establish the likely beneficiaries of the scheme. Thirdly, the hydraulic capacity, which is the accumulated infiltration over a long period that includes dry periods, needs to be put into context with the overall water demand in the area. This determines the overall significance of the scheme for the local rural community in relation to natural distributed recharge.

Conclusions: In this paper simple solutions to evaluate technical effectiveness are described and preliminary results of effectiveness of low technology aquifer recharge structures for various hydrogeolgical and hydrological settings are presented.

Artificial recharge of treated wastewater effluent enables sustainable groundwater management of a dune aquifer in Flanders, Belgium

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In July 2002 the Intermunicipal Water Company of the Veurne Region (I.W.V.A.) started with the production of infiltration water by the reuse of wastewater effluent. This new treatment plant, called 'Torreele', contains the following treatment steps: prescreening, microfiltration (MF), cartridge filtration, reverse osmosis (RO) and ultraviolet irradiation (UV). The 'Torreele' plant is designed to produce 2,500,000 m^3/year of infiltration water; this is 40% of the current drinking-water demand. The flow chart is shown below.

The whole project was developed to create a sustainable groundwater management of the existing dune water catchment. Because of the presence of salt water north and south of these dunes, the drinking-water production capacity was limited[1] and by the end of the 1980' s the I.W.V.A. was unable to further satisfy the increasing demand of drinking-water. Artificial recharge of the sandy unconfined dune aquifer was chosen as the best alternative: the production capacity could be increased and still the natural groundwater extraction could substantially be lowered. Pilot tests using membrane filtration techniques showed that, although stringent quality standards were set, wastewater effluent could be used as the source for the production of infiltration water.

This presentation will describe the results of infiltration in the dunes, a period that will cover 3 years at the time of presentation. The infiltration water recharges the sandy unconfined dune aquifer; the residence time of the recharged water in the aquifer is minimum 40 days.

[1]Increased production could cause saline water intrusion into the dune aquifer

BIBLIGRAPHY

Van Houtte, E., J. Verbauwhede, F. Vanlerberghe, F. de Bruijn and M. Beumer, 1998.

Completing the Water Cycle : Reuse of WWTP Effluent for Drinking Water Purpose, Koksijde, Belgium. AWWA Water Reuse Conference Proceedings, Orlando, USA, p 321-335.

Van Houtte, E., J. Verbauwhede, F. Vanlerberghe and J. Cabooter, 2000.

Comparison between different out-to-in filtration MF/UF membranes, International Conference on 'Membrane Technology in Water and Wastewater treatment', Lancaster 2000, p 190 –197.

Van Houtte, E. and J. Verbauwhede, 2003.

Reuse of wastewater effluent for indirect production of drinking water in Flanders, Belgium. AWWA Membrane Technology Conference, Atlanta, 2003.

Study on sustainability of irrigation agriculture by diversion in the lower reach of the Yellow River

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The lower reach of the Yellow River is referred to the range starting from Huayuankou of Henan Province to Lijin of Shandong Province. Since groundwater table was shallow and high in salinity, most part of this area was not developed until the 1970s when the Yellow River was diverted to leach out saline groundwater and irrigate crops. With the decrease of flow in the Yellow River, the sustainability of irrigation agriculture is becoming a issue to be dealt with since 1997 when no water flowed in a reach up to about 780 km within a total of 226 days. The purpose of this study is to analyze the sustainability of agriculture after about 30 years of irrigation practice under a new situation of water shortage.

The analyses are composed of the following aspects: (1) identifying groundwater flow system and groundwater table change of 10 years in the lower reach; (2) estimating the amount of diverted water from the Yellow River based on monthly observed discharge data of 50 years at Huayuankou and Lijin; (3) estimating water deficit in the field scale based on the observed actual evapotranspiration (lysimeter) and rainfall data of about 10 years; (4) vertical profile of water quality from 0.3 m to 10 m depth at Yucheng Experimental Station of Chinese Academy of Sciences; (5) estimating mixing rate of groundwater from the Yellow River based on stable isotopic feature.

It is concluded that agriculture in the lower reach depends greatly on the Yellow River, which is low in flow rate in last twenty years, and the diverted water may account for about 60% of local water resources; saline groundwater does no harm to crops as before and agriculture is sustainable as long as the Yellow River could supply water for irrigation.

Geochemistry

Abstracts

Geochemical and microbial processes in the unsaturated zone at the Arrenaes artificial recharge trial plant

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The microbiological and geochemical changes that occur as artificially recharged (AR) water from Lake Arresoe passes through the unsaturated zone have been investigated at the Arrenaes AR trial plant, Zealand, Denmark. Focus has been on removal of pathogenic bacteria and dissolution/precipitation of iron and calcite. This is of concern, as water from a large-scale production plant (4 mill. m3/year) proposed at the locality, will be introduced to the existing groundwater distribution network and used in drinking water production. The investigations include: monitoring of the water quality (1994 □ 2004); analysis of sediment cores; and chemical modelling (PHREEQC). Measurements show that pathogenic bacteria occurring in the input water generally are removed during infiltration, as no pathogenic bacteria analysed for have been detected in concentrations above the guideline levels in the abstracted AR water. Results from collected sediment cores have revealed that the primary removal occurs in the upper 35 cm of the unsaturated zone (25 m thick), where approximately 95% of coliform bacteria, thermotolerant coliform bacteria, and colony-forming units are removed. Enterococci and Clostridium perfringens have not been detected in the sediment samples. Monitoring show that iron dissolves from the unsaturated zone. When the infiltrating water is mixed with the more oxidised groundwater, iron precipitation occurs. This causes problems with clogging in the abstraction wells. Analyses show that calcite is leaching from the unsaturated zone. PHREEQC modelling indicates that long-term operation may result in a depletion of the buffer capacity in unsaturated zone. In the future, aggressive carbon dioxide may therefore constitute a problem with corrosion of the pipelines in the distribution network. To ensure an optimum water quality and operation, consideration of the regeneration methodologies, maintaining removal capacity of pathogenic bacteria, and continuous monitoring of aggressive carbon dioxide are therefore very important.

Use of geochemical and isotope plots to determine recharge to alluvial aquifers: Lockyer Valley, Queensland, Australia

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The Lockyer Valley of southeast Queensland is an important area of crop production based on intensive groundwater irrigation. The valley covers around 2500 km^2 and is formed of a sequence of sedimentary rocks which are dominantly sandstone. Groundwater is extracted from extensive areas of alluvium along the central floor of the valley and the main tributaries. The valley is bordered on the south and west by the Great Dividing Range which is typically 250-300 m higher than the valley floor. This range is flat-topped and covered by Tertiary age basalt flows which weather to form dark fertile soils. Rainfall central to the valley has an annual average of 720 mm, while the annual rainfall on the adjacent ranges is around 1200 mm. Stream flow for much of the drainage system is ephemeral and related to summer storms that characterise the sub-tropical climate. Alluvial groundwater levels respond rapidly to storm stream flow, and are strongly influenced by prolonged dry periods and the associated increase in irrigation extraction; water tables are now commonly below stream bed levels.

Source and character of groundwater recharge to the alluvial aquifers have been difficult to confirm, especially as water chemistry of bores within both the alluvium and the sandstone is highly variable throughout the valley. Many alluvial bores also have a component of bedrock input, which may increase during dry period irrigation. Also of significance is natural evaporation in ephemeral streams and of irrigation runoff, plus the discharge of deep artesian basin CO_2-bearing waters. Groundwater in the basalt aquifers of the surrounding ranges is also chemically different. Hydrological processes are therefore complex, notably mixing of various waters. Typically, alluvial groundwaters have: TDS (mg/L) of 800 to 3,000 (Mg, Na, Ca-Cl type); bedrock groundwaters: 1,500 to over 5,000 (Na, Mg-Cl, HCO_3 type); and basalts: 200-800 (Mg-HCO_3 type). The hydrochemical approach taken involved sampling of over 100 bores and analysing the waters for major ions and stable isotopic ratios δ^2H and $\delta^{18}O$. Some success was achieved in defining hydrological processes by use of ionic ratios (e.g. Cl/HCO_3) and isotope plots, however, these methods did not differentiate source of water and degrees of mixing.

To overcome these difficulties we have developed an approach using a plot of log TDS (mg/L) versus δ^2H ‰. Within the plot four "end members" can be established, with typical values: A. sandstone bedrock (upper-middle formations) (15,000 / -25.0); B. stream storm flow (160 / -24.0); C. deep artesian basin (1,500 / -44.0); and D. strongly evaporated alluvial groundwater (1,500 / -10.0). Basalt groundwater falls near apex B. The end members provide two ternary diagrams, and a total of four quadrants within them; position within the diagram enables determination of groundwater source, but also subsequent processes such as mixing and evaporation. Within the A-B-C triangle relative percentages of each member can be determined; within the A-B-D triangle relative percentages of storm recharge and sandstone water can be established, and the degree of evaporation is assessed as minor, moderate or high. The plot confirms the primary process of storm recharge to basalts, and to alluvium via the drainage system; the contribution to alluvium of bedrock sandstone water is also shown. Use of the approach to date is supported by comparisons with other water chemistry and stable isotope parameters, and with borehole data and drill-logs.

Exploring surface- and groundwater interactions with the help of environmental tracers and sewage indicators in Berlin

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Objective: The aim of the study is to calculate mixing proportions of treated sewage in the surface water and production wells as well as the travel times to observation and abstraction wells. For this purpose, a variety of tracer such as delta-^{18}O, delta-D and several sewage indicators (Cl-, EDTA, B, Gd-DTPA) are used and compared to each other. In addition, the applicability of Gd-DTPA as a conservative sewage tracer is tested in batch and column experiments as well as in field observations.

Methods: The surface water was samples at 59 locations for Cl-, B, Gd-DTPA and delta-^{18}O and delta-D over a period of 1 ½ years. Monthly sampling at the field-transects was conducted over 2 years by the Berlin Water Company (BWB) and samples were analysed for physico-chemical properties, major anions and cations as well as a number of sewage indicators (e.g. B, EDTA) at BWB. The stable isotope measurements of deuterium and ^{18}-O were done at the Alfred Wegener Institute, Research Unit Potsdam with a Finnigan MAT Delta-S mass spectrometer. Samples for analysis of the rare earth element gadolinium (as Gd-DTPA complex) had to undergo an enrichment procedure and were subsequently analysed by mass spectrometry (ELAN 5000 ICP-MS) at the GeoForschungsZentrum (GFZ) Potsdam. In addition, Gd-DTPA was applied to several batch and column experiments.

Results: The percentage of treated sewage in the surface water varies strongly depending on the location and the time of year. The surface water leaving Berlin in the south was found to contain up to 42% of treated sewage in summer and 13% as the annual average. The travel times were obtained by the analysis of the peak shift in time-series of the tracer. Most tracer were found to be applicable but best results were obtained with the stable isotopes. The travel times on the shortest pathway between lake, i.e. pond, vary from site to site with ~1 ½ months at the artificial recharge site Tegel, ~3-4 months at Wannsee and ~5 months in Tegel. The percentage of bank filtrate in the abstraction wells is roughly 60-80%, but the percentage of young bank-filtrate infiltrating at the nearest shore can be considerably smaller, since a portion of water is believed to originate from the other lake shore. Gd-DTPA was found to be a useful sewage indicator, even though it is biodegradable at favourable conditions at very slow rates.

Conclusions: The tracer delta-^{18}O, delta-D, EDTA, Gd-DTPA, B, Cl-and K were found to be applicable for the calculation of travel times and mixing proportions. The percentage of treated sewage in ground- and surface water varies strongly in both space and time. Likewise, the travel times to individual abstraction wells is different from site to site, depending on factors such as distance to shore, thickness and characteristics of the clogging layer and hydraulic regime. While all abstraction wells were found to contain high proportions of bank-filtrate, the proportion of young bank-filtrate can be much lower, because some of the bank-filtrate has an age of decades rather than months.

A Sulfur Hexafluoride Tracer Experiment as a Tool to Check the Previous Results of ^{3}H/TU Ages and Geohydrology at the Montebello Forebay, California

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Sulfur hexafluoride (SF_6) gas tracer was injected into the Rio Hondo and San Gabriel recharge basins in the Montebello Forebay during February and March 2003. At the start of the injection period, all of the basins and the San Gabriel River above inflatable dam #5 were full. Concentrations within the recharge basins were variable and ranged between about 10 and 80 pmol/l. The average concentration was about 30 pmol/l. The observed temporal and spatial concentration variability was due to a number of factors including wetted area, percolation rate, mean depth, and SF_6 injection rate. Details were discussed in the first progress report.

Well samples were collected 6 months and 2 months prior to the start of tracer experiment. SF_6 was not detected in any of these background samples. Following the injection, well samples were collected every two to ten weeks from ten monitoring and eighteen production wells. Between two and four samples were collected in Vacutainers and analyzed from each well. All samples were analyzed on a gas chromatograph (GC) equipped with an electron capture detector.

SF_6 has been detected in about 30% of the well samples collected after the injection of tracer into the recharge water. Approximately one third of the samples with detectable SF_6 have relatively large peaks on the GC indicating the presence of SF_6 in the groundwater. However, the other two thirds of the samples with detectable SF_6 had relatively small peaks on the GC. The source of these small peaks is ambiguous. First, SF_6 may be present in the groundwater at very low concentrations. Second, there could have been a very small leak through the septa of the Vacutainer allowing air to partially fill the containers. Third, the sampling tube and needle could have been incompletely flushed prior to sampling and small air bubbles may have been flushed into the Vacutainer while filling with well water. Therefore, to ensure no false positives, a very strict set of criteria has been developed to establish SF_6 detection in the groundwater. SF_6 must have been detected during two or more sequential sampling events and have concentration greater than or equal to 0.1 pmol/l during at least one sampling event to be considered a detection at the well. Samples that do not meet this set of criteria but had detectable SF_6 are listed as “suspect” in Table 1.

During the first year of this tracer experiment, SF_6 has been detected at seven monitoring wells. All of these wells have screens within 140 ft of the ground surface. The only shallow monitoring well that did not have detectable SF_6 is #100832. The maximum groundwater SF_6 concentration was observed at well #100834. It was 4.8 pmol/l, approximately 15% of the mean concentration in the surface water and approximately 20% of the concentration of the closest basin (RH1). The monitoring well results indicate that SF_6 was successfully transferred from the surface water to the groundwater during percolation at the spreading basins.

SF_6 tracer has been detected at thirteen of the eighteen production wells sampled during this study. At six of these wells, detections have been isolated and most likely due to sampling or storage error. Sequential detections with the concentration in at least one sample exceeding

0.1 pmol/l have occurred at six wells (#200012, #200055, #200058, #200061, #200065, and #200099), indicating that the travel time of recharge water to these wells is less than one year. One well, #200059, had sequential detection but the concentration never exceed 0.1 pmol/l. The travel time to the other production wells is greater than one year based on the SF_6 data. At four of the six wells with confirmed detections, the hydrogeologic travel time determined by Bookman-Edmonston Engineering (using ^3H/TU Ages and Geohydrology), were less than 10 weeks and are in basic agreement with the SF_6 travel time. However, at the other two wells, the hydrogeologic travel times were estimated at greater than 200 weeks, significantly longer than the indicated by the tracer data.

Arsenic Mobilization and Sequestration During Successive Aquifer Storage Recovery (ASR) Cycle Tests in the Carbonate Upper Floridan Aquifer, South Florida

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Objective: Arsenic concentrations that exceed Federal and state drinking- and surface-water criteria have been measured in water recovered during cycle testing at some ASR systems in South Florida. Treated drinking water stored in permeable zones of the Lower Hawthorn Group and upper Suwannee Limestone oxidizes microcrystalline pyrite and amorphous iron sulfides to release arsenic (Arthur et al., 2001). Affected systems can show decreasing maximum arsenic concentrations during successive cycle tests; however the mechanism that controls this apparent sequestration has not been identified. The objective of this work is to interpret cycle test data using geochemical modeling methods to define controls on arsenic mobility under changing aquifer redox environment during ASR cycle tests.

Methods: Cycle test data sets were compiled from south Florida ASR systems where arsenic mobilization was known to occur. These ASR systems are located in Lee and Collier Counties along the southern Gulf Coast of Florida. Data sets include cycle test characteristics (volume recharged; recharge, storage, and recovery duration) and water-quality analyses that consist primarily of major dissolved constituents. Systems that measured redox-sensitive species (dissolved oxygen, dissolved hydrogen sulfide, and iron) that control arsenic mobility. Arsenic speciation was determined in recovered water at selected sites. Data were then interpreted using geochemical modeling codes.

Biological clogging of porous media: Tracer studies of non-uniform flow patterns

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Objective: Chemical and dye tracer studies performed during bioclogging experiments are presented with the objectives of (i) visualizing the development of non-uniform flow patterns, (ii) quantifying the temporal changes in relative mobile porosity, dispersion and mass transfer, (iii) quantifying the effects of an initial heterogeneous distribution of biomass on bioclogging patterns, and (iv) testing models for linking changes in porosity (due to bioclogging) to changes in hydraulic conductivity.

Methods: Two sets of laboratory experiments are discussed; (a) Column experiments and (b) Sand box experiments with either a line or point source. The line source experiments in the (2D) sand box are essentially the same as a (1D) column experiment, but allows visualisation using a dye tracer.

The column and sand box are packed with inoculated sands. Nutrients, such as substrate (acetate) and electron acceptors (oxygen or nitrate), were added to the inlet solution in known concentrations. Changes in the hydraulic gradients were measured continuously. Dye tracer experiments were performed every approximately 4 days in the sand box to visualize the changes in flow pattern due to bioclogging. Chemical (Chloride) tracer experiments were performed every approximately 2-4 days in the column to trace changes in the physical transport mechanisms as bioclogging proceeded.

The experimental results were analysed using numerical and analytical models.

Results: The sand box experiments show a clear development from near-uniform flow at the start of an experiment to what can best be characterized as non-uniform flow, i.e., fingering and flow by-passing zones of bioclogging. The mode of observation (point versus integrated measurements) becomes very important. It is the hypothesis that the initial distribution of biomass is heterogeneous, which may partly explain the observed erratic fingering. The column experiments show that transport in the early stages are affected by changes in effective dispersion, likely due to the growth in number of bacterial micro-colonies. Subsequently, during the stage with severe bioclogging, mass transfer between the mobile porosity and the stagnant biophase becomes important. Modeling shows that very little biomass is needed to reduce the hydraulic conductivity a factor of 100-1000.

Conclusions: Bioclogging is observed to lead to non-uniform flow. The mode of observation thus becomes very important. Point measurements may reflect very specific pathways, while flux-averaged measurements integrate the diversity in the flow regimes and result in significant increases in spreading and tailing due to mass transfer. Tracer studies and modelling offer the possibility of selecting appropriate relationships that link observed reduction in biomass porosity to reduction in hydraulic conductivity.

Effect of sprinkling infiltration on soil properties on a forested esker in Central Finland

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Objective: The aim of the study was to determine the nutrient status of the organic layer of a forest soil two years after the cessation of sprinkling infiltration.

Methods: Representative organic layer samples were taken from a control plot and a plot subjected to sprinkling infiltration for a period of 4 years. Sampling took place two years after cessation of the treatment The pH of the air-dried, milled samples was measured, exchangeable Ca, Mg and K and extractable P concentrations were determined following extraction with 1.0M $BaCl_2$, and extractable NH_4 and NO_3 concentrations following extraction with 1 M K_2SO_4.

Results: As a result of sprinkling infiltration, the base saturation of the organic layer was close to 100%, and the pH above 6. The organic layer had retained large amounts of Ca and Mg from the lake water used in irrigation, but there was no corresponding increase in exchangeable K concentrations. The concentrations of extractable NH_4 and NO_3, which were elevated during sprinkling infiltration, had returned to normal levels within 2 years after cessation of the treatment. This indicated that, despite the relatively high pH values, nitrification has not continued at detrimental levels. There were signs of a strong decrease in extractable P, presumably due to reduced availability caused by the elevated pH values.

Conclusions: Sprinkling irrigation appears to have had a relatively long-lasting, positive effect on the nutrient status of the organic layer of the forested esker. However, there were signs that P availability has decreased considerably.

Artificial recharge in Finland through basin and sprinkling infiltration: soil processes, retention time and water quality

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Objective: The aim of the "TEMU" research project (1998-2003) was to optimise the infiltration techniques of artificial recharge (AR) of groundwater in relation to water quantity, water quality and environmental impacts. Special attention was paid to determining the causal relationships between soil processes, hydraulic characteristics and retention times in the aquifer, and water quality in different phases of infiltration.

Methods: Hydrogeochemical variables and hydraulic processes of the surface soil zone, percolation water zone and groundwater zone were studied at five AR groundwater supply plants in Finland. These studies included analysis of soil, infiltration water, percolation water and groundwater samples, and measurements of groundwater flow characteristics and retention time. The causal relationships between the data were investigated. Groundwater flow was modelled using the data.

Results: The reduction of TOC concentration was mainly restricted to the groundwater zone. Moreover, the highest molecular size fractions of dissolved organic carbon were removed from the AR groundwater more efficiently than the lower size fractions. The infiltration method – basin or sprinkling – did not noticeably influence either this removal or the reduction of TOC concentration. However, the retention time and the groundwater flow characteristics significantly influenced the TOC concentration of the AR groundwater. The target TOC concentration -less than 2 mg/l – was attained with varying retention times (7-80 days) and with varying groundwater path lengths (160-1300 m).

Conclusions: The planning and dimensioning of an AR groundwater supply plant is controlled by the quality of infiltration water, groundwater flow characteristics such as aquifer particle size distribution and hydraulic conductivity as well as the retention time. Therefore, different AR groundwater supply plants may need infiltration areas of different size to produce the same water quantity and water quality. Thus, each planned AR plant requires thorough field studies beforehand.

Subsurface residence time of hyporheic ground water and mixing with alluvial ground water

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Objective: Groundwater wells for drinking water near downwelling rivers conflict with river rehabilitation and flood protection operations. Mixed water ages of the pumped water yield the scientific basis for decision making.

Methods: Natural isotope and environmental groundwater tracers are combined with water chemical analyses. Both methods are the basis for numerical modeling of groundwater flow and transport.

Results: Experimental results from two perialpine valleys (Töss and Thur) in northern Switzerland show that downwelled river water to a well flows on top of the layered alluvial aquifer and does not mix well with older bank-filtrated water and alluvial ground water. Time-series measurements showed that the specific infiltration rates are not constant, due to clogging processes.

Conclusions: Changing a river's shape for restoration or flood-control purposes has an impact to the flow and the composition of the underlying ground water. Drinking-water wells near downwelling river sections are endangered by such plans.

Health Aspects: Organic substances, pathogens and micro pollutants, PAC and EDC

Abstracts

Fate of Wastewater Effluent Organic Matter (EfOM) through Soil Aquifer Treatment

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Wastewater effluent organic matter (EfOM) consists of natural organic matter (NOM) derived from the drinking water sources that are dominated by humic substances, plus soluble microbial products (SMPs) derived from biological (secondary) wastewater treatment and that reflect a microbial origin. Soil aquifer treatment (SAT) represents a wastewater reclamation/reuse technology that can renovate wastewater effluent to drinking water levels, and hence can be an important component in an indirect potable reuse system. SAT has proven very effective in removing total nitrogen and viruses but is now receiving scrutiny in assessing its ability to remove organics, both bulk organic matter and trace organic compounds. The SAT technology involves infiltration of secondary effluent through a recharge basin with subsequent extraction through recovery wells, and embodies both treatment, dominant in the vadose (unsaturated) zone, and storage within the saturated zone (aquifer). The emphasis of this paper is on transformations and removal of EfOM components during SAT. From a drinking water perspective, various EfOM components are problematical in imparting color and serving as a precursor to disinfection by-products (DBPs). Beyond the traditional measurement of dissolved organic carbon (DOC) as a measure of the amount of EfOM, we address areas of new interest in the composition of DOC and the corresponding measurement of dissolved organic nitrogen (DON), of importance given the nitrogenous content of SMPs.

To characterize the amounts and compositions of DOC and DON through SAT, samples were collected from three operating SAT facilities: (i) the Rio Hondo Spreading Grounds (RHSG) in Los Angeles, California; (ii) the Northwest Water Reclamation Plant (Mesa WRP) in Mesa, Arizona; and (iii) the Sweetwater Underground Storage and Recovery Facility (Tucson WRP) in Tucson, Arizona. The RHSG site is unique compared to the other two sites because the entire vadose zone, with a thickness of ~3 to 10 meters, is aerobic. In contrast with RHSG, the Mesa WRP site has a dissolved oxygen concentration that remains below 1 mg/L throughout the infiltration zone below the first 1.5 meters, making almost the entire vadose zone of 15 meters thickness anoxic, with the first 1.5 meters aerobic; the plume of reclaimed water extends greater than 2000 meters down gradient from the recharge site and is about 30 meters thick. Relative to the other two SAT sites, a key feature of the Tucson WRP is its deep vadose zone of 30 meters where high concentrations of DOC and ammonia in the feed water (recharge basin) create a high oxygen demand; as the dissolved oxygen decreases with depth, and the ammonia is nitrified and denitrified, nitrate because the electron donor at a typical depth of about 1.5 meters.

In the work reported herein, the composition of the EfOM in various SAT samples was characterized by: (i) size exclusion chromatography with on-line DOC detection, describing the molecular weight (MW) distribution and classification of organic matter according to polysaccharides (PS), humic substances (HS), and low MW acids (LMA); (ii) fluorescence excitation-emission matrix (EEM), distinguishing protein-like organic matter from humic-like organic matter; and (iii) nitrogen species including total nitrogen (TN), ammonia-nitrogen, nitrate-nitrogen, and dissolved organic nitrogen (DON). SEC-DOC chromatograms have successfully revealed transformation/removal patterns of PS, HS, and LWA components, with

PS components readily removed in the upper vadose zone and HS components more slowly removed during through the vadose zone and aquifer; the persistence of some LMA components likely reflects a by-product of HS components biodegradation. EEM spectra, representing a 3-D plot of fluorescence intensity versus excitation and emission wavelengths, have revealed effective removals of protein-like organic matter (corresponding to an EEM peak at lower excitation/emission wavelengths) and partial removals of humic-like organic matter (corresponding to an EEM peak at higher excitation/emission wavelengths). Tracking nitrogen species through SAT has served two purposes: (i) an indication of redox zone transitions (e.g., aerobic to anoxic) that affect biodegradation pathways and (ii) a quantification of DON as a precursor for N-DBPs that exhibit a high cancer potency.

A representative SEC-DOC chromatogram for the Mesa WRP is presented in Figure 1 where the NW- series wells correspond to samples immediately downgradient from the recharge basin and the -u series wells correspond to samples further downgradient with greater travel distances and longer travel times. In Figure 1, one can see the almost complete elimination of the PS peak and partial removal of the HS peak, both attributable to (sustainable) biodegradation. A representative set of EEM spectra appears in Figure 2 where the samples RB1, MW5, and WR199 samples correspond to the recharge basin, a shallow monitoring well, and a deep recovery well. Here, one can see a significant diminishment of the lower excitation/emission wavelength peak, corresponding to protein-like organic matter removed by (sustainable) biodegradation. A representative series of data describing nitrogen species appears in Table 1, with two of the same sampling points as designated in Figure 2. In comparing sample RB1 (recharge basin) with MW5 (shallow monitoring well with 100 % reclaimed wastewater), one can see a significant removal of TN, DON, and ammonia-nitrogen, with an increase in nitrate-nitrogen reflecting nitrification and partial denitrification.

Overall, significant removals of DOC were observed at all sites, ranging from greater than 50 % to almost 75 % after accounting for dilution with native groundwater. These DOC removals were accompanied by almost complete elimination of DON. Effective removal dominated by biodegradation was observed for polysaccharides and proteins with lesser but significant removals of humic substances under longer-term anoxic conditions. Other related work has also shown effective removal of pharmaceuticals and endocrine disruptors by aerobic and/or anoxic biodegradation. Thus, SAT represents a sustainable advanced wastewater treatment process that can play an important role in a multi-barrier, indirect potable reuse system.

Fate of bulk organics during bank filtration and groundwater recharge of wastewater-impacted surface waters

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Objective: This research study is part of the NASRI project of the Center of Competence for Water Berlin. As part of this project the TU-workgroup studies the removal of bulk organics (dissolved organic carbon (DOC), effluent organic matter (EfOM)) at three field sites with different characteristics and in two soil column systems. Since the processes during infiltration are very complex, it is difficult to predict bulk organic composition in the bank filtrate or to estimate important factors of influence for the degradation. There are indications that bank filtration under anoxic/anaerobic conditions provides different removal of organics compared to aerobic bank filtration. In addition to the redox state, factors such as retention time, temperature, initial degradable carbon concentration, soil properties, and hydrogeological conditions may affect the final concentration. The factors of influence and the fate of these bulk organics are studied in the field and in long-term experiments.

Methods: For the field monitoring three field sites in Berlin were chosen, one artificial recharge site and two bank filtration sites. A significant influence of treated wastewater on the surface water is given at all field sites. Soil column studies were conducted on a 30 m long column system, which was operated with original surface water. This column system was used for long term experiments (retention time = 30 d) on a simulated one-dimensional aquifer. Furthermore, 9 columns (length 1 m, retention time 6 d) were operated to study the importance of different redox conditions on the degradation of bulk organics. The monthly analytical program of the field and column samples is comprised of DOC, UVA, and LC-OCD.

Results: The long-term monitoring of the surface water confirmed stable concentrations of DOC in the lake and some seasonal changes. The residual of the dissolved organic carbon after infiltration is comparable under aerobic (groundwater recharge) and anoxic (bank filtration) conditions. Statistical analysis of the kinetics reveals that aerobic degradation seems to be faster than anoxic or anaerobic degradation. Aerobic field wells and column tests show a fast DOC-degradation within a month, while anoxic conditions appear to require up to 6 months. The results of the LC-OCD analysis show clearly that the fraction of polysaccharides is completely removed very fast at all field sites (only minor filtration effects in abiotic column) whereas other fractions (humics, humic hydrolysates) exhibit only partial removal. The results of the soil column experiments support these findings and reveal more details about the redox sensitivity of bulk organic removal.

Conclusions: Aerobic and anoxic underground conditions during infiltration can lead to about the same residual DOC but the study indicates significant differences in the kinetics of DOC-removal depending on the redox conditions. The LC-OCD analysis reveals that the change in character is comparable under different redox conditions and that the fraction of polysaccharides is removed very fast.

Fate of trace organic pollutants during bank filtration and groundwater recharge

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Objective: This research study is part of the NASRI project of the Center of Competence for Water Berlin. Within this project the workgroup of the Department of Water Quality Control studies distinct trace organic pollutants and absorbable organic halogens (AOI/Br) at three field sites with different characteristics and in two soil column systems. In order to be able to prevent the intrusion of persistent pollutants into the drinking water, the factors of influence for the degradation are studied for the differentiated AOX (AOI, AOBr) and a few model compounds that represent groups of trace pollutants. Model compounds were chosen from the group of X-ray contrast media (Iopromide), bacteriostatica (Sulfamethoxazole) and persistent polar industry chemicals (Naphthalenesulfonic acids). A monthly field monitoring was established to investigate the actual situation at the field sites. The soil column experiments were used to isolate the important factors of influence for the removal of these compounds (retention time, temperature, DOC-concentration, soil properties and hydrogeological conditions).

Methods: The field monitoring was conducted at three field sites in Berlin, one artificial recharge site and two bank filtration sites. The selected trace organic compounds were present in the surface water in detectable concentrations. Besides the bulk parameters the monthly analytical program contained differentiated AOX (AOI, AOBr)-analysis and solid phase extraction (SPE) and HPLC analysis of the trace compounds. Fluorescence (FLD) and quadrupole mass spectroscopy (MS-MS) were used as detectors. Soil column studies as a simulation of a one dimensional aquifer were conducted on a 30m column system, which was operated with spiked surface water (retention time = 30d). The columns were sampled at different depths to investigate the kinetics of the degradations. Additionally, 9 columns (length 1m, retention time 6d) were operated to study the fate of the trace pollutants under different redox conditions.

Results: After more than one year of monitoring the results of the trace pollutant analysis will be presented. It was found that the removal of Iopromide is very efficient under anoxic and aerobic conditions. But column studies proved that under aerobic conditions Iopromide is only partially degraded and not effectively dehalogenated. Sulfamethoxazole showed a more efficient removal at the anoxic bank filtration site (removal rates≥~80%). Under oxic conditions at the groundwater recharge facility Sulfamethoxazole appeared to be more persistent with removal rates of around 50% after 50 days of underground passage. The 1,7- and 2,7- Isomers of the Naphthalenedisulfonates (NSA) were better degraded under oxic conditions. Despite of a lower retention time, the water at the recharge facility showed lower concentrations than at the bank filtration site. The 1,5-NSA is known to be very persistent. Consistently with these findings, the 1,5-NSA was not significantly degraded at all field sites.

The measured variation of AOI in the surface water is probably due to variation in the dilution of the sewage treatment plant effluents over the year and can be observed in the monitoring wells of the bank filtration sites and at the groundwater recharge site. It was found that the anoxic/anaerobic soil passage is more effective in removing AOI from surface water. The field results will be supplemented by the results of the soil column experiments. The long

retention columns will give more insight into the kinetics of the trace organic degradation and the short columns will focus on the redox sensitivity.

Conclusions: The monitoring of field data revealed a different behaviour of the examined trace compounds during infiltration. Statistic analysis will be used to find the key parameters of influence for the degradation behaviour of the trace compounds.

Fate of Organic Micropollutants in Artificial Groundwater Recharge Systems

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Objective: One of the major concerns regarding the use of water sources of impaired quality for drinking water supply is the survival and accumulation of organic micropollutants, such as endocrine disruptors (EDCs), pharmaceutically active compounds (PhACs), or carcinogenic disinfection by-products (DBPs). In particular polar (hydrophilic), small molecular size organic contaminants are likely to survive even advanced water and wastewater treatment processes such as activated carbon filtration or membrane treatment. Soil-aquifer treatment (SAT) and direct aquifer injection (DI) are common methods for replenishing groundwater resources. However, many hydrophilic micropollutants are not efficiently attenuated during soil passage by physical adsorption and have been contaminating production wells at groundwater recharge facilities. The purpose of this study was to investigate the role that biological metabolism and adsorption play in the removal of selected hydrophilic trace organic contaminants in artificial groundwater recharge systems. Specifically, we investigated how different source water qualities and recharge operations promote the microbial breakdown of trace organic contaminants. The working hypothesis for this study was that the composition and concentration of organic carbon in recharged water introduced into an aquifer has a major impact on establishing soil biomass activity and a soil microbial community to enable the metabolic breakdown of the certain trace organic contaminants. Principal funding for this project was provided by AwwaRF, the U. S. EPA, and the Gwangju Institute of Science and Technology, Korea.

Methods: Several emerging micropollutants were selected for this study that differ in terms of physico-chemical properties such as molecular size and hydrophobicity (indicated by K_{OW}), and their reported biodegradability. The target compounds were: carbamazepine (antiepileptic), primidone (antiepileptic), tris(2-chloroethyl)-phosphate and tris(1,3-dichloroisopropyl)phosphate (flame retardants), ibuprofen (analgesic), gemfibrozil (blood lipid regulator), naproxen (analgesic), fenofibrate (blood lipid regulator), ketoprofen (analgesic), diclofenac (analgesic), caffeine (stimulant), and NDMA (disinfection by-product). Removal of these compounds was studied in different soil column systems representing two different groundwater recharge strategies: SAT versus DI. Column system 1 (L=60 cm, i.d.=15 cm, filled with silica sand, d_{50}=0.65 mm, f_{oc}=0.004%) was acclimated with a reverse osmosis (RO) treated effluent generated with a laboratory-scale RO unit for a duration of 1.5 years and simulated the direct injection of an advanced treated effluent low in organic carbon sources into an aquifer. The column was operated under aerobic, saturated flow conditions. Column system 2 consisted of four 1-m columns (i.d. 15 cm, filled with sandy aquifer material) operated in series under anoxic saturated flow conditions and were acclimated for over 6 years by infiltrating secondary and tertiary treated effluent. This column system simulated recharge of treated effluent via SAT. In parallel to the anoxic columns one additional 1-m aerobic column was operated under otherwise similar conditions to study differences in micropollutant removal under aerobic versus anoxic conditions. All column system influents were spiked with the selected micropollutants at environmental concentrations and column performances were monitored twice a week in terms of soil biomass activity (measured as phospholipids extraction and dehydrogenase activity), organic carbon removal, pH, conductivity, and trace compound removal. In parallel, the adsorption

behavior of selected compounds was evaluated in abiotic column and batch tests under addition of sodium azide. Four small columns (i.d. 5 cm, L=30 cm, filled with silica sand, d_{50}=0.65 mm) were used to investigate the effects of different organic carbon matrices (hydrophilic carbon (HPI), hydrophobic acids (HPO-A), colloidal organic carbon) on micropollutant removal during saturated recharge. These organic carbon matrices were isolated from a domestic secondary treated effluent. Trace organic compounds were quantified following the method established by Reddersen and Heberer (2003). NDMA was quantified following EPA method 3510C and 8270D.

Results: Results of the column experiments spiked with organic micropollutants showed that soil biomass activity was considerably higher in column system 2 (secondary effluent) as compared to column 1 (RO permeate). No further organic carbon removal was observed in the column fed with RO membrane treated effluent. Column system 2 showed an organic carbon removal of more than 50% under denitrifying conditions. Results from both column systems allowed determining the effect of different soil microbial systems (as a function of organic carbon system inputs) on the removal of micropollutants. Further insight on the effect of organic carbon composition in the feed water on the removal of certain micropollutants was gained in small column experiments. The different organic carbon fractions were able to support different soil biomass activities and promoted different removal behavior for certain micropollutants. Adsorption played a significant role for some compounds (e.g., ibuprofen) depending upon the pH regime.

Conclusions: With this study we were able to isolate the mechanisms leading to the removal of selected organic micropollutants. Results of this study have a critical implication for the evaluation of technical pre-treatment strategies and the design and operation of artificial groundwater recharge systems.

Temperature effects on organics removal during riverbank filtration

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Objective: The application of river bank filtration as efficient low-cost pre-treatment technology might support the drinking water supply in areas with water scarcity, lack of treatment plants or poor hygienic conditions. The objective of the presented investigations was to show the effects of extreme temperature conditions on the organics removal efficiency and transport behaviour during river bank filtration considering both total concentrations of dissolved organic carbon compounds and selected tracer organic compounds. The knowledge of this relationship would allow to transfer experiences with river bank filtration from Europe to regions with other climatic conditions.

Methods: Bench-scale soil columns were performed at three different temperatures, 5 °C, 15 °C, and 25 °C. The soil columns were operated In circulating and flow-through regime to consider both the kinetics of dissolved organics removal and absolute removal degrees. The degradation of dissolved organics measured as DOC (dissolved organic carbon) and UVA (ultraviolet absorbance) was characterized by rate constants and removal degrees.

Results: The results showed a temperature dependency of both the organics removal efficiency and the degradation rate. For example, the removal efficiencies for a lake water with an initial DOC concentration of 7.5 mg/L within a 0.5 m soil passage were between 16 % at 5 °C and 39 % at 25 °C. However, the influence measured at the degradation rates was less significant than expected. While the degradation rate was doubled between 0.48 d-1 and 0.96 d-1 at 5 °C and 15 °C, respectively, it was increased by factor 1.5 only from 15 °C to 25 °C. The different removal degrees indicate the temperature dependency of the biological availability of some organics.

Conclusions: Higher average temperatures along filtration paths result in higher DOC degradation rates, removal degrees and accelerate the development of anaerobic conditions. This might improve both the aerobic organics removal within the first few infiltration centimeters and the anaerobic elimination of trace organics. However, the degradation rates for a temperature increase between 10 °C and 20 °C cannot be simply doubled. For most investigated waters and materials, the increasing factor was less than 2. Also, at high temperatures sorption processes are impeded and desorption is favored.

On the behaviour of microcystins in saturated porous medium

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Objective: Microcystins are a group of structurally similar toxic substances produced by cyanobacteria or "blue-green-algae". They occur frequently in toxic cyanobacterial blooms which can be observed in surface waters world wide. When using these surface waters for drinking water production via bank filtration or artificial recharge elimination of microcystins by underground passage has to be ensured as the WHO has proposed a guideline value for drinking water of 1 µg/L. Microcystins are subject to different processes in the porous medium, such as degradation, sorption and desorption. The relevance of the different processes depends on various conditions: on the properties of the porous medium (grain size distribution, organic content), as well as on the redox state (aerobic / anoxic / anaerobic), the pH, temperature, etc.. Within the interdisciplinary NASRI research project (Natural and Artificial Systems for Recharge and Infiltration) dealing with river bank filtration processes several experiments have been conducted. The aim of the paper is to present the outcome of the different measurements and to compare the main sorption and degradation parameters.

Methods: Experiments were carried out in laboratory batch- and column systems, as well as in technical scale enclosures and slow sand filters with and without clogging layer. Extra-cellular microcystins were applied in realistic concentrations of about 1 to 10 µg/L. In batch experiments the parameters can be obtained directly from the measured temporal change in the system. In the column and technical scale experiments sorption parameters (distribution factor k_d) and degradation factors were obtained from breakthrough curves of microcystins and tracers. Modelling was carried out with the computer program Visual CXTFIT.

Results: Batch and column experiments showed that adsorption of microcystins is closely linked with the amount of clay and silt in the sediment. In sandy material as it is mostly used for bank filtration and artificial recharge biological degradation is the main elimination process. Enclosure experiments were therefore conducted in order to simulate biological degradation of microcystins during infiltration in a natural setting. These experiments yielded high degradation rates with half lives of less than one day under aerobic conditions. Changes in degradation rates in dependence on biomass could not be observed. Modelling of the breakthrough curves obtained at different depths showed decreasing kd-values with increasing depth.

Conclusions: Under aerobic conditions with sufficient nutrient loading biological degradation during sand passage was shown to be effective in eliminating extra-cellular microcystins. Contact times of only a few days seem to be sufficient to reduce concentrations typical for cyanobacterial blooms in the water body to values below the WHO guideline value. Adsorption is only relevant in material with clay or silt content and can lead to longer contact times which supports elimination by biological degradation. There are however indications of reduced degradation rates under anoxic and anaerobic conditions. These conditions are subject to further investigations that are currently being carried out.

Influence of groundwater conditions on decay of enteric viruses

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Objective: The managed recharge of recycled water (MAR) to aquifers is gaining popularity in Australia and worldwide. Stored water in underground aquifers can be later recovered and used to supplement portable water supplies. A significant advantage of MAR is an improvement in water quality of the recharged water that can be achieved during storage. One of the water quality issues associated with the recharge of aquifers with reclaimed water is the potential presence of pathogens such as enteric viruses in the recharged water. The processes affecting the decay of enteric viruses in groundwater are still not clearly understood.

Methods: The survival of enteric viruses in groundwater under aerobic and anaerobic conditions, different temperature, redox potential and bio-available nutrients was investigated.

Results: We observed a difference in the decay rate of seeded viruses in the presence and absence of oxygen. It is known that aquifers receiving reclaimed water go through a series of redox potentials depending on available nutrients in the injected water. Very little is known about the pathogen decay at various redox levels. Enteric viruses displayed higher decay at 20 ºC under aerobic conditions in the presence of indigenous microorganisms. Whereas, no significant decay of seeded viruses in groundwater occurred at a lower temperature (5 ºC).

Conclusions: Results suggested that the presence of metabolically active indigenous microorganisms was the single most important factor affecting decay of enteric viruses in the groundwater. Temperature appears to influence the metabolic activity of indigenous microorganisms which ultimately affect the decay of viruses. Results also suggest that bio-available nutrients influence the activity of indigenous microorganisms and its effect on decay of viruses also depend upon the type of virus. The results of this study will be important for managing and modelling risk from pathogens in reclaimed water stored in aquifers.

Occurrence, Transport, Attenuation and Removal of Pharmaceutical Residues in the Aquatic Environment and Their Relevance for Drinking Water Supply in Urban Areas

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Objective: In Europe and the U.S., residues of more than 100 different pharmaceuticals have recently been detected in municipal sewage and in several samples of surface, ground, and drinking water. For the most part, such residues are entering the receiving surface waters by discharges from sewage treatment plants but that are also several other potential sources. Under recharge conditions, polar pharmaceutical residues can also be leaching through the subsoil into the groundwater aquifers. The mere occurrence of such residues at trace-level concentrations in ground water or even in drinking water does not necessarily imply that ground water recharge techniques such as bank filtration should in general be avoided. Depending on various parameters such as the composition of the colmation layer or the individual traveling times several pharmaceuticals such as antibiotics, estrogenic steroids and some other compounds can efficiently be removed during bank filtration or other natural recharge processes. Thus, there is an essential need for and a lack in information on the fate and transport of pharmaceutical residues and related compounds in the aquatic environment and during groundwater recharge that enables to understand and to enhance the efficacy of natural attenuation processes and of water management strategies. Moreover, the occurrence of such residues in ground water resources should not only be approached as a potential thread to drinking water supplies. Such residues might also be seen and used as indicators to monitor and improve the efficiency of natural and artificial treatment techniques.

Results: This paper compiles the recent state of knowledge on the occurrence and fate of pharmaceutical residues in the aquatic environment of urban areas. Findings in sewage effluents, surface, ground, and drinking water in Berlin, Germany, are presented as examples to show the impact of pharmaceutical residues on the aquatic environment and on public water supply. Strategies for environmental and human risk assessment and natural and technological processes for the removal of pharmaceutical residues such as estrogenic steroids, analgesics, anti-epileptic drugs, blood lipid regulators, and drug metabolites shall also be discussed.

The influence of variable redox conditions on the behaviour of pharmaceutically active compounds during artificial recharge in Berlin

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Objective: The study perpetuates the investigations of Greskowiak et al. in the unsaturated zone below the pond, who identified the reasons for the alternating redox processes to be of operational and seasonal nature. The aim of this study was to investigate the impact of the processes in the unsaturated zone on the saturated zone. The focus was on the effect of the redox changes on some pharmaceutically active compounds, namely carbamazepine, phenazone and AMDOPH (1-acetyl-1-methyl-2-dimethyl-oxymoyl-2-phenylhydrazide).

Methods: Monthly sampling at the field-transects was conducted over 2 ½ years by the Berlin Water Company (BWB) and samples were analysed for physico-chemical properties, major anions and cations as well as for the analgesic phenazone, the drug metabolite AMDOPH (1-acetyl-1-methyl-2-dimethyl-oxymoyl-2-phenylhydrazide) and the antiepileptic carbamazepine at the laboratory of BWB. The method of the PhAC determination is based on a solid phase extraction of the analytes on RP-C18 materials at an automated extraction system. Liquid chromatographic separation coupled with mass spectrometry was used for the detection of the analytes. To obtain both high sensitivity and selectivity, tandem mass spectrometry, recording multiple reaction monitoring chromatograms, was applied.

Results: The temperature changes of 0 to 24°C are the main factor influencing the redox state of the groundwater below the pond. In winter, aerobic conditions prevail along the entire transect (~100 m, 50 days of travel time) the oxygen reduction resembles a first order reaction with a half-life of oxygen of around 14 days. In summer, the reinforced microbial activity leads to more reducing conditions and manganese appears even directly below the pond. The corresponding half-life of nitrate following an exponential removal is approximately 16 days. Phenazone was found to break through as soon as conditions turn anaerobic, suggesting that its elimination is more efficient at aerobic conditions. The time-series of AMDOPH in the infiltrate indicates that AMDOPH may be degraded under certain favourable conditions. The presence of oxygen and high temperatures seem to have a positive effect on the removal of AMDOPH, but results still need a better verification. Carbamazepine showed a conservative behaviour at the site.

Conclusions: Redox conditions are highly transient during artificial recharge in Berlin. The major factor influencing the redox state of the infiltrate is the seasonal temperature change. Phenazone and AMDOPH were found to respond to the alternating redox conditions, while carbamazepine was not affected.

Postersession

Alternative recharge systems: subsurface dams, rainwater harvesting, percolation tanks etc.

Abstracts

Promotion of Equity by Small Scale Community Based Water Harvesting in the Semi-arid Aravali Hills of Rajasthan, India

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The famous seven lakes of Udaipur lie empty; the city faces a drinking water crisis and the Indian High Court has instructed the local Government to evaluate the effects of upstream water harvesting. In a neighbouring river basin lies Jaisamand Lake, the world's second largest artificial lake. Its waters are piped to Udaipur for drinking and are used to irrigate the land belonging to many villages downstream.

Case studies are presented from different locations in the Jaisamand river basin, which demonstrate that upstream water harvesting is the key to poverty alleviation and regeneration of the heavily degraded Aravali Hills. Only 60 years ago the Aravali Hills were thickly forested. The studies show that water harvesting promotes equity across the basin and lifts out of extreme poverty the tribal people who live in the villages of the upper catchments. Water harvesting provides a way forward towards meeting the UN millennium targets by providing food and water security across the basin.

Conceptual Approach of Recharge Estimation at the West Bank Aquifers-Palestine

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Objective: The primary aim of the research is to improve the current understanding of the flow system of the aquifers of the West Bank, and to assess the sustainability of the aquifers under a variety of economic, demographic and land use scenarios in terms of meeting the consequent water demand from aquifers. This is achieved through a set of management tools based on mathematical simulation of flow in the aquifers.

Methods: The approach that will be followed in this study will be to disaggregate recharge into elements following different pathways through the environment and to the principal aquifers. The main factors will be are divided into: Recharge type, Rainfall characteristics, geological features and topography. The factors of recharge are integrated within a GIS model allowing refinement and development of the model. This allows the recharge to be calculated for different climate scenarios and with different contributions from leakage, waste water and irrigation returns to reflect the changing management of West Bank water resources. The GIS also incorporates the recharge estimates used in previous modeling exercises (where available), and estimates of recharge from the literature to provide users with a clear view of uncertainties and sensitivities within the models.

Results: The only spatial controls on recharge distribution in the initial model have been derived from rainfall distribution and from aquifer outcrop areas. The model needs to explicitly incorporate the following spatial factors: a. Distribution of epi-karst and major karst recharge pathways, b. Distribution of specific land uses with higher than average recharge, i.e. urban areas and irrigated areas, c. Routing of rainfall on steep hill slopes and over aquicludes to down slope recharge points, either at aquifer outcrop or as infiltration from wadi beds.

Conclusions: The distribution of recharge in time and space is easier to calculate than the absolute amount of recharge, so that refinement of quantitative estimates of recharge is required. The water cycle and water balance is still poorly understood in the area, resulting in a high degree of uncertainty. More research has to be focused on the water cycle.

Proposed scheme for anatural soil treatment system in Kuwait

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A pilot scale project using soil aquifer treatment (SAT) was constructed in the Sulaibiah area southwest of Kuwait City to assess the treatment efficiency and the suitability of the site. The study included seven recharge basins with a depth of 2 m and a total infiltration area of 900 m^2. Seventeen monitoring wells were installed in the vicinity of the recharge ponds to monitor the water levels below the recharged basins and to collect water samples for chemical and biological analysis. Several difficulties were encountered during the operation of the pilot study. These were mainly attributed to the impermeable nature of the soil and the high evaporation rates. Based on this, it was recommended to implement a large scale SAT project in northern Kuwait taking into account the maximization of the recharge/recovery efficiency and minimizing the loss of water due to evaporation. The recommended location to implement the first stage of this large-scale SAT should have a suitable subsurface lithology for basin recharge and enough unsaturated thickness for proper soil aquifer treatment in addition to the continuous source of treated wastewater. The proposed scheme should include 12 recharge basins with a side slope 1:1 and a total base area of 4800 m^2. The basins will be classified into four groups' base on the difference in their bed elevations. Each 4 basins will be lowered by 30 cm from the other group allowing the flow of the water under gravity conditions. The system will be operated in short alternative cycles of wetting and drying (three days), and proceed only during the period of October – May.

Groundwater recharge from a percolation tank to a Deccan basalt aquifer: a case study from western Maharashtra, India

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Objective: 1. To validate generic conclusions about artificial recharge using spreading methods in small check dams in the Deccan basalt region of central-west India. 2. To help understand, on a micro-scale, artificial recharge processes within basalt aquifers and their implications on the livelihoods of rural populations.

Methods: Check dam CD3 in Chikhalgaon village forms the main site for monitoring the impacts of a recharge structure on the surrounding shallow basalt aquifer. A network of 9 observation bore holes has been constructed around a check dam in Chikhalgaon microwatershed in Mulshi taluka of Pune district from the state of Maharashtra in western India. These bore holes were drilled in order to map spatial and temporal water level data and changes. There are 8 shallow bore holes (penetrating only the shallow aquifer) and 1 deep borehole wherein the shallow aquifer has been sealed off, to record changes in the deeper (confined) aquifers. In addition, 9 dug wells are also being monitored and pump tested to understand the aquifer better. Weather data from an automatic weather station in Chikhalgaon helps obtain meteorological data. Meteorological, hydrological and hydrogeological information is brought together with the aim of developing a water balance for the check dam and for the aquifer underlying it.

Results: 1. Water level rise in areas adjoining the check dam (CD1) is quite rapid after the first rains. 2. A part of this water level rise can be attributed to infiltration from the check dam and a part from the process of natural recharge to the aquifer from a natural recharge area upstream. 3. A groundwater mound is created in and around the check dam, influencing an otherwise natural down gradient groundwater flow for as long as 6 months after the last rains and 4 months after the check dam dries up. 4. The groundwater mound also contributes flow to a natural discharge area downstream. This can be observed in the form of base flows another check dam (CD2) 500 m downstream, which holds water for two more months after the check dam CD1 has dried up. 5. The groundwater mound in the vicinity of CD1 dissipates by the end of April and groundwater flow in the aquifer is more predictable in its sense of general movement downstream. 6. The water level in the deeper bore hole continued to rise until the month of February after which it has steadied at an elevation below the regional (unconfined) water table. It is quite likely that the response of the deeper aquifer to recharge (natural and artificial) begins much later than that to the shallow aquifer. However, this theory needs to be further supplemented during the next monsoon and dry season.

Conclusions: The basalt aquifer in Chikhalgaon is a low storage, variable transmissivity aquifer. Both natural and artificial infiltration (through the check dam) contributes to the net recharge to the shallow basalt aquifer in Chikhalgaon. The water levels in the aquifer in the vicinity of the check dam are influenced by the mound created from dam infiltration. Groundwater abstraction for irrigation is limited but there are signs of increasing abstraction, after the check dam was constructed. The response of the shallow basalt aquifer to natural and artificial infiltration is quick and takes a few weeks. The response of the deeper aquifer to infiltrating water is slightly delayed and takes a few months.

Artificial recharge using ditches excavated in the bed of an ephimeral river in a small alluvial aquifer located in a mediterranean spanish basin

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The quaternary aquifer of Jávea, located in the north of the spanish province of Alicante, closely related to the Gorgos river, has been historically exploited for urban supply and irrigation. Its small extension, together with the exploitation regime, have originated a problem of overexploitation (cuantified in 2 Mm^3/y) and seawater intrusion that have caused a progressive salination of groundwater due to the hydraulic gradient inversion (up to -3 m during the summer time), which consecuences have beed the abandonement of many water extraction wells and the need to look for alternative water supply sources for the touristic village of Jávea.

To alleviate as much as possible this situation, from the middle of the nineties, and by an initiative of the local farmers, an artificial recharge system was constructed in the Gorgos river bed, with the aim of increasing the aquifer recharge using the high water volumes that go by the river during the “gota fria” (cool drop in english), a climatic phenomena that take place once or twice a year, characterized by very high water precipitation in a very short time and generation of very high runoff, and eventually very dangerous floods, and water circulation by the river during 3 or 4 day each one. The rest of the year, under normal climatic conditions, the river is absolutely dry.

The ditches are excavated in the river bed, with a depth of 4 m and a width of 2 m, and have been filled with great limestone blocks to ease the infiltration. 8 ditches were put into opetarion, and they worked very well during the first years, but lately, a progressive diminishing of the infiltration rate has been detected, probably due to clogging effects, caused by the high suspended solid contents of the flood water. The effects of this recharge were evaluated by a mathematical flow model.

In this paper, the results of the analysis of the effects that artificial recharge using this system have produced in the aquifer are shown, and too a new proposal for replacing the ditches by a new system based on the construction of smaill dykes in the river bed to create small water reservoirs and ease the infiltration of the circulating water into the aquifer. This devices have higher water retention and infiltration capacity than the ditches have.

Impact of meteorological elements on groundwater level in Rostov region

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Objective: Substantial changes are occurred in a variety of environmental variables including meteorological elements such as temperature, precipitation and some other. The magnitudes of these changes are expected to vary temporally and spatially. It is unclear how much of an impact climate change could have on hydrogeology. The goal of the project is to estimate this influence on groundwater level.

Results: Rostov region is situated in the south of Russia where due to climate, geographical location and human activity the water we have is of low quality and its quantity is not big enough. That is why water and especially groundwater is the subject of special interest. Groundwater level study gives an opportunity to estimate change of climate and its influence in Rostov region. Rostov region is situated in a semi-arid zone, which is characterized by limited water resources. More over the region is situated on the borderline of four artesian basins. As a result, the main part of water resources is concentrated to the river valley, where water is contaminated. Climate of Rostov region gives a positive influence on the groundwater recharge but its quantity is not large enough. Climate is under constant change. In Rostov region can be found traces of different climate changes but the most interesting are connected with climate change for last 50 years, as it's the period of intensive human influence on nature. Annual air temperature trend is 0,71°C/100 years for 1882-1992, in winter - 1,61°C/100, while in autumn – 0,25°C/100. Annual precipitation trend during this period of time is 101,9 mm/100 years, max is 72,4 mm/100 in winter, min is 2,3 mm/100 in autumn. Annual precipitation is 5-24% above average. During last 50 years average temperature and precipitation become higher. Influence of meteorological element on groundwater is 20 – 70 %, which is depend on place of the well.

Conclusions: Three ecoregions were studied to estimate correlation of groundwater level and climate change in Rostov region: Veshenskaya, Morozovsk, Gashun. Veshenskaya situated on the low bank of the Don River. Low mineralization level shows influence of precipitation. Mineralization was high in the years with extremely high air and soil temperature – 1967,1972,1979. It was found out that there is a high correlation between climate and water level. However, the influence of climate change on ground water level needs to be better quantified at the regional scale.

A Case in Traditional Ingenuity: 'Khatri' System of Water Management

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This paper seeks to examine the ingenuity, efficacy, utility and current relevance of a traditional knowledge based water harvesting and aquifer recharge system used by the mountain communities in northern hills of India for centuries and demonstrate its potential for transplantation in other similar parts of the globe.

Khatri is a unique time-tested combinatorial system of community based rain water harvesting and recharge based on indigenous knowledge, self regulation and community based management that has sustained rural communities scattered across dry calcareous conglomerates of peripheral Shivalik hills adjoining the Dhauladhar Himalayas in India for centuries. Even today, the system exists as lifeline for people in typically water starved Hamirpur hills of Himachal Pradesh with first recorded implementation of modern piped water supply dating as recent as late seventies. The system is entirely based on traditional ingenuity with strong tradition of property rights and role of women in the management process. System manifests high-caliber traditional knowledge of design & construction assuring adequate water quantity and quality with least-cost ideally suited for mountain communities.

Innovative aspects include rainwater harvesting based on scientific utilization of natural bouldery strata for retention and percolation of rainwater seeping into manmade rock-cut cavities in sandy layers for recharge of aquifers and storage of pure drinking water. Sandy layers are used for filtration using natural properties of calcareous formations for water quality preservation while covered storage ensures prevention of evaporation losses and protection against contamination. Upstream pollution is prevented through community regulation of land-use in the catchments and human activity is restricted to downstream areas. The system can be created locally with indigenous tools employing locally available unskilled workforce at a very nominal cost and serves perennially without need for special maintenance skills other than periodic cleaning and repairs.

The system has served the needs of the mountain communities over centuries meeting satisfying the water quality and public health norms at least cost and is particularly suitable to offer decentralized solutions for land locked mountain communities across the developing world very reliably and cost effectively.

Roof-top rain water harvesting to recharge groundwater reservoir of a group of houses

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Artificial recharge (AR)/groundwater recharge (GR) refers to the natural replenishment of an aquifer by percolation of surface run-off, stream flows, or melting snow into the ground. Rainwater harvesting and groundwater recharge promise to be a potential solution for effective increasing the utilization of surface run-off and hence, to augment the freshwater supplies in urban areas at lower costs. AR of rainwater also helps to qualitatively improve contaminated groundwater aquifers by reducing the concentration of pollutants through dilution effects. Large urban centers are the single largest users of freshwater for domestic purposes. Most of the cities and towns in India face acute scarcity of water in both terms of quantity and quality. Roof-top Rain Water Harvesting (RRWH) requires connecting the outlet pipe from the roof top to divert collected water to existing well, tube well, bore well or a specially designed well. Urban housing complexes and institutional building having large roof area or a group of residential buildings can be utilised for the purpose. The Central Groundwater Board of India has suggested several methods of RRWH for individual houses and multistory buildings only. We have designed RRWH techniques for housing complexes that is useful for a group of residential buildings. Rain water is the purest form of natural water. It can be used as recharge water without any treatment. The water used for this purpose can be taken from any source but it must be pure like drinking water or rain water. It should not have even soil, sand and silt in it. Recharge water should be surely silt free. If germs are present, it should be chlorinated, ozonized or irradiated before using as recharge water.

Arid zone water management

Abstracts

Groundwater explotation in an arid zone in relation to the recharge in a central region of the Argentine Republic

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Objective: To obtain a sustainable management of the subsurface hydric resource in the area under study considering the best profitable use of the resource in relation to the recharge. This is an advance based on a regional understanding of the geology, the aquifer system and its relation with the hydrodynamics.

Methods: The behavior of the system is analysed in respect to different exploitation alternatives in order to know which are feasible under a series of physical, technical and economical restrictions. This process analyzes the results of supposed simulation scenarios of the resource exploitation with the purpose of determining the quality of the additional groundwater obtainable from the system with an adequate management of the recharged volumes.

Results: By means of the application of the proposed methodology it is possible to abtain a sustainable meliorated utilization of the resource by balancing the recharge by taking advantage of a reduction of the ground water discharge by evaporation.

Conclusions: The environmental deterioration permits to state that the exploitation of the hydric resource under the present model should be minimun if the conservative extraction requisites proposed in the simulations are fulfilled and provided a correct management of the ground water resource. The application and control of the proposed methodology will determine an optimization of the recharge of the system.

Large scale recharge modelling in an arid area

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A three-dimensional transient groundwater flow model for the Nubian Aquifer System in the Western Desert of Egypt and the adjacent countries was developed and used to calibrate groundwater recharge of long-term time horizons. The input-data of the area of about 2 million km^2 were held in a GIS that allows an implementation of the numerical groundwater model in different modelling systems. Long-term groundwater recharge and aquifer porosity were calibrated by using the results of recent geological research which indicated that some lakes had existed about 6,000 years b.p. in the southern part of the modeled area as well as sabkha sediments in the northern part. The simulation results of the last 25,000 years indicated that a recharge rate of 10-50 mm/year was enough to maintain the aquifer in a nearly filled up condition during the wet period. The decline of groundwater surface started about 19,000 years ago, but it was slowed down and completely interrupted by regional infiltration during the wet period (ended 2,500 years ago). It took about 5,500 years after the start of the second wet period to return to the nearly filled up condition and since then the groundwater levels went down for more than 4,000 years. In this period natural discharge was not completely balanced by recharge. Simulation results also indicated that in both wet and dry condition periods, groundwater flow from the aquifer to the Nile River has occurred in the area between Dongola and Aswan where the hydraulic conditions are favourable before the construction of Aswan High Dam. The amount of Nile water seepage into the aquifer was very low and only possible in the area south of Dongola. After the construction of the dam, rising water level in Nasser lake increased nile water seepage into the aquifer. Recharge from the Nile water and percolating rainwater in the southern part of the aquifer are minor if compared to the sum of present natural and artificial discharge of the aquifer. The present groundwater management has to take into account, that there is not enough recharge in the southern part to cover the discharge of the oasis in the northern part. If the groundwater extraction in the oasis is further increased, the groundwater levels will descend to economically unreachable depths.

Qanat a Traditional Method for Water Harvesting In Arid and Semi – arid Regions of Iran

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Iran is lake of water resources, especially in its arid regions. So the management of water resources in these areas is very important.

The arid and semi – arid regions in Iran are mainly located in center and southeast of Iran. This paper investigated reasons of destruction and reclamation methods of Qanats in Dahak River basin. Qanats are a traditional method for water harvesting in arid and semi – arid regions in Iran and some arid regions in world. Qanats play important role to ground water utilization in arid and semi – arid regions of Iran, especially in Dahak River basin.Dahak River basin located in Southeast of Iran and Northeast of Lout plain, with total area 98000 ha, the annual precipitation is 155 mm, the average evaporation from water surface 1375 mm.

Case studies

Abstracts

Infiltration Mechanism of Artificial Recharge of Groundwater – a Case study at Pingtung Plain, Taiwan

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The purpose of the study is to discuss the infiltration mechanism of artificial recharge of groundwater with high-infiltration basins. The hydrogeologic parameters were collected to estimate the conceptualized physical model of study area. A numerical simulation model, Tough2, was used to simulate the infiltrating behavior of artificial recharge into underground aquifer. Four groundwater observation wells (MW-1, MW-2, MW-3, MW-4) in the field site were observed. The results showed that the groundwater level of simulation and observation in two wells, MW-1and Mw-2, are matched very well respectively. The observed groundwater level is higher than the simulated groundwater lever in MW-3, which is located in the edge of artificial recharge lake. This might be caused by portion of the infiltration followed the well border into the well screen. The groundwater level in MW-4 is lower than other wells caused by the well permeability of the well location. The result of this study was also predicted that the variation of the groundwater level will be reached a steady state after ca. 47 hours from the beginning of infiltration.

Groundwater resources management on the urban environment – case study in Dire Dawa Town

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The study area, Dire Dawa town and its vicinity, is found in the Eastern part of the country at a distance of 520 Km from Addis Ababa, 18km away on the Harer-Jijiga high way, at latitude 9° 11` N, and longitude 41° 52`E within the Awash River basin at the foot of Wabi shebelle-Awash Basin divider escarpment.

Dire Dawa is one of the oldest urbanized towns in the country, where the population is increasing constantly, and has reached 270,000 in 2003. As a result, some of the boreholes that are sources of water supply of the town are contaminated with different sources of pollutants such as urbanization of domestic and industrial wastes. The coverage of population in Dire Dawa with safe water is about 68% and urban sanitation 75% coverage level.

The chemical, physical and biological processes in addition to the geological formation and man-made factors influence the hydrochemical variation of groundwater both spatial and temporal in quality directly and indirectly. As a result of disposal of liquid, gaseous and solid wastes, chemical substances and/or waste generated from industries, agricultural activities, households, market centers, institutions, garages, fuel stations and the health centers are the main sources of pollutants that may affect the quality of water in the area.

Due to the fact that, the upper sandstone aquifer at Dire Dawa town is vulnerable to pollution due to the high to moderate permeability of the alluvial sediments overlying the main aquifer. High concentration of nitrate is directly related to high population density, urban agriculture and industrial areas. The high concentration plume is flowing along the groundwater flow direction, mainly at shallow well of the alluvial aquifer in the inner part of the town. So modelling is very important to identify the extent and contaminant zone of the aquifer in order to take remedial measures by the concerned organization.

Domestic-scale ASR with rainwater at Kingswood, South Australia

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Rainwater derived from roof surfaces can offer sufficient quantities of good quality water if it can be successfully harvested, particularly in developing nations where alternative sources are often contaminated and require costly pre-treatment.

A two year demonstration project is currently underway to investigate the operational performance of domestic-scale aquifer storage and recovery (ASR) with rainwater. A shallow alluvial aquifer in the southeast Adelaide metropolitan area was targeted after an earlier regional assessment had suggested it could be a good opportunity for ASR.

Two wells, located 5 meters apart, were installed to a depth of 24 meters. Their yields range from 0.9 to 1.1 L/s, with an ambient salinity of 2200 to 2500 mg/L TDS and depth to groundwater level at 12 meters. The run-off from a single dwelling 250 m^2 has been plumbed to the ASR well under gravity feed via a 4 m^3 storage tank and 100 μm filter. Flow rate, volume, piezometric head, electrical conductivity and temperature are monitored continuously and the quality of the influent and recovered water measured periodically.

After the first full 12 months of operation, 100 m^3 has been injected with no observable clogging. Although the salinity of the groundwater has been reduced, it is not yet sufficiently fresh to be useful for irrigation supplies due to mixing losses and the effect of regional groundwater drift. Productive use of the groundwater could be expected once greater volumes have been injected, however the supply is limited by available roof area and rainfall variability. The main challenge is therefore to meet operational performance criteria under the current constraints.

Subsurface residence time of hyporheic ground water and mixing with alluvial ground water

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The north- western Indian State of Haryana is a part of Indo- Gangetic alluvial plains and has two distinct topographical and hydro- geological settings: high water yielding fresh groundwater areas and saline groundwater regions where aquifers of relatively poor transmission characteristics occur. About two third of the state geographical area is currently underlain with saline groundwater and the situation is deteriorating further due to disproportionate pumping vis- a- vis groundwater recharge. In most of the marginally saline groundwater regions, low discharge shallow cavity wells are used for irrigation which are inexpensive abstraction structures without a strainer. Deep tubewells are not feasible in such regions due to increasing groundwater salinity with depth while many shallow tubewells are abandoned due to upconing of salts from the deeper layers during pumping. Under these conditions, it is imperative not to disturb the saline water but to selectively skim fresh water accumulated over the native saline groundwater and by enhancing groundwater recharge.

The paper discusses the features of a combined skimming cum recharging system proposed and field tested for saline groundwater regions of Haryana. The system, consisting of two cavity tubewells installed in fresh and marginally saline groundwater zones at 7 m and 40 m depth respectively, can be operated separately or together to obtain groundwater of different qualities. The other component of the system is a recharge chamber which contains a graded sand- gravel filter and facilitates recharging of one or both cavities with filtered surface runoff during the rainy season. Salient results on performance evaluation of the system through pumping and recharging studies, periodical observations of groundwater levels and quality and resistivity surveys are presented in the paper. It is reported that recharge rates through injection in cavity wells were low at about one quarter of the pumping rates due to shallow groundwater conditions and were also influenced by the efficiency of recharging filter.

Artifical Recharge issue in Cho Shui Alluvial Fan

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Objective: The prior study of Artifical Recharge Characteristic in Choshui Alluvial Fan.

Methods: Artifical Pond experiment in Cho Shui Alluvial Fan

Numerical Simulation

Evaluation of the benefits for the recharge

Clogging effects

Abstracts

Characterisation of physical and geochemical processes causing turbidity and well clogging in a dual porosity Chalk aquifer: South London Artificial Recharge Scheme trials

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Objective: Turbidity was found to be a significant issue during the South London Artificial Recharge Scheme trials in the dual porosity Chalk aquifer. The turbidity of abstracted water exceeded the drinking water prescribed concentration value of 1 NTU for up to 1 week following injection of mains water, typically reducing from maximums of >100 NTU. As a result the turbidity and associated clogging issues were investigated in some detail during the abstraction and recharge testing programme.

Methods: Sequential results of step test hydraulic analysis were used to track changes in clogging whilst the turbidity responses were recorded by data logger from a turbidity meter accurate to 0.01 NTU.

Results: Scanning electron microscope (SEM) and chemical analysis identified the turbidity solids to be calcite ($CaCO_3$), alumino-silicates (clays) and some $Fe(OH)_3$. PHREEQC geochemical modelling of the mixing of injected water with the native groundwater produced results that were consistent with this mineralogy and showed that precipitation of both $CaCO_3$ and $Fe(OH)_3$ was the thermodynamically favoured outcome of mixing the two waters. Consequently it was possible to conclude that the fundamental cause of the turbidity was mixing of mains water with native groundwater.

Conclusions: Three separate causes of turbidity were identified: (a) mixing of injected water with groundwater with a response period of 1 day to 1 week; (b) short duration (<3 hours) disequilibria responses in the aquifer caused by the transition from no flow to pumped flow; and (c) fracture network development by scouring when boreholes are pumped at higher rates for the first time. Precipitation of turbidity minerals in the fine grained chalk matrix was shown to be the likely cause of the partial clogging of the aquifer that occurred immediately during the first injection cycle. Thereafter clogging fluctuated during each recharge cycle, but improved during the recharge testing programme as the aquifer became progressively conditioned to mains water consistent with the PHREEQC modelling results. Experience showed that turbidity could be satisfactorily managed by pumping at high rates for short durations in order to scour precipitated minerals from the fracture network and then restricting operational pumping to rates less than that scoured pumping rate.

Laboratory column studies of the effects of effluent pre-treatment, soil type and water depth on clogging during soil aquifer treatment (SAT)

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Objective: A sound understanding of soil clogging processes is fundamental in the design of a proposed soil aquifer treatment (SAT) trial at Alice Springs, Northern Territory, Australia (details are given in the abstract by Knapton et al).

Methods: A multi-factorial column experiment was undertaken to assess the effect of effluent pre-treatment and soil type. Four water types ranging from primary treatment through to potable were passed through 'loam' and 'sand'. Additionally, for one soil and effluent-type the effects of ponding depth (10, 30 and 50 cm's) in constant temperature and glasshouse environments were evaluated. In all, 34 columns were operated simultaneously for four cycles of 7 days wetting followed by 7 days drying. Hydraulic and water quality data were measured on a regular basis and at the end of the experiment columns were dissected to quantify levels of microbial activity in the soil.

Results: For a given soil type, infiltration rates were negatively correlated with particulate and nutrient levels in the source water. Surprisingly, the loam had significantly less clogging (when defined as the ratio of final to initial hydraulic conductivity) than the sand, and quasi steady-state conditions were achieved sooner. Polysaccharide concentrations were similar across water types, and across soil types when account of the specific surface area is made, suggesting the soil's capacity to support microbial growth is limited. The extent of physical clogging on the other hand is strongly determined by the source water quality. However biological clogging, indicated by polysaccharide concentrations in column material, was found to depend more strongly on the specific surface area of the soil than on water type.

Conclusions: Overall, these results demonstrate the primary treatment of effluent at Alice Springs will lead to excessive clogging in either soil type. Secondary treatment produced acceptable infiltration rates. Basins made of the loamier of the two soils are likely to be more effective in trapping particulates near the surface, thereby allowing more effective restoration capacity and simpler operational management. However, this would coincide with significantly lower infiltration rates.

Biological structure of sandy littoral sediments

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At Lake Tegel, Berlin, bank filtration is used for drinking water extraction. However, the detailed infiltration and clogging processes as well as the carbon turnover in the upper sediment layer of the littoral zone under principal natural conditions is not completely understood.

The aim of this study is therefore to investigate the saisonal dynamics of the main effective biological and physico-chemical processes at a fine depth-integrated scale. The biocoenosis of the interstitial plays a key role for the biological efficiency of the water purification process influencing and causing clogging phenomena and being responsible for the carbon transfer and turnover.

The Poster-Presentation will give insight into the variations of the spatial structure of the hyporheic interstitial and its biocoenosis, as a basis for understanding the biological functioning of bank filtration mechanisms.

Experiments to determine clogging and redevelopment effects at laboratory scale

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Objective: Aquifer Storage and Recovery (ASR) can be a useful tool in countries with distinct rainy seasons to store water in rainy season and be used in concluding dry seasons. In India, ASR is used to store water (e.g. in Orissa) or to improve the groundwater quality of saline aquifer (e.g. in Haryana). Surface water, which is polluted by soil particles, nutrients, pollutants and microorganisms, is reaching the aquifer by direct infiltration through ASR-wells. Besides the quality problem of the stored water, the infiltration of the polluted water leads to clogging of the aquifer next to the ASR-well which is caused by physical deposition of fine particles, geochemical reactions and biological processes. The objective of this study is to investigate combined clogging effects of surface run-off water. It is embedded into the idea to secure a long life time of the well use in developing countries when using pollutant surface water as infiltration source.

Methods: Laboratory experiments have been carried out at soil columns using natural storm water run-off to find out the effects of single clogging processes and the effect of back-washing. By back-washing suspended particles can be withdrawn from the aquifer matrix. For that reason run-off water was infiltrated into the soil column in several cycles interrupted by pumping.

Results: The laboratory experiments showed that the biological clogging process is most significant to the reduction of aquifer conductivity at a temperature of 20°C. The biological clogging was found on the first 20 cm of the soil column and back-washing was hardly unable to withdraw particles or other materials. The entrapment of gas bubbles has a large effect. But it is reversible and back-flushing has some influence on raising the conductivity. Clogging by infiltrated particles has the lowest effect. The deposition of particles takes place mainly in the dead-end-pores and does not affect the active pore volume very much. Particles which were deposited in the active pore volume were washed off the soil column by back-washing or were redeposited into the dead-end-pores.

Conclusions: Laboratory experiments showed that biological processes have a very large impact on clogging while using storm water run-off for direct infiltration by ASR-wells. Biological processes complicate the improvement of aquifer conductivity by back-washing. Physical deposition has a minor effect and particles can be withdrawn from the aquifer. A probable reason is that physical deposition of particles takes place more in the dead-end-pores than in the active pores. Numerical modelling is necessary to calculate the effects of clogging and redevelopment so that a management plan can be developed which secures a long life time of ASR-wells.

Changes within bacterial community structure during artificial groundwater recharge with humic lake water

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Objective: The objectives of the research are to study changes in microbial community structure during simulated artificial groundwater recharge and the ability of microorganisms to degrade natural organic matter in the saturated zone. Humic lake water will be used as water source for the recharge process. In Finland, the main purposes of groundwater recharge are the removal of natural organic matter (NOM) and stabilisation of seasonal temperature variations to produce high quality drinking water and to minimise destruction of water distribution networks. The content of NOM in Finnish water bodies is high and seasonal temperature variations are up to 20 oC. Thus, clogging of the porous media might limit artificial groundwater recharge.

Methods: Simulation of artificial recharge will be carried out in five 50 cm long (diam. 4,8 cm) laboratory columns and one 18 m long (diam. 30 cm) column. The columns will be filled with sandy material originating from a Quaternary glacial deposit, an esker, in the First Salpausselkä region of Finland. Within the next years, a full-scale infiltration plant will be built in the area of sand sampling. The columns will be feed with the same humic lake water also to be used in the full-scale recharge process. So far, the humic lake water has been used for drinking water production in a conventional drinking water plant. At the present moment, the columns are taken into operation. Following physicochemical parameters will be monitored: TOC, DOC, dissolved oxygen, temperature, pH and iron. Conservative tracer tests with chloride will be done to determine the flow regime within the columns. Different flow rates will be used in the small columns. The microbial community structure will be analysed by amplifying 16S rDNA genes with PCR following DGGE to separate different DNA segments. Additionally, changes in the microbial community will be studied by cell counts and FISH.

Experimental Investigation into the Effect Grain Size of Porous Media Have of Biological Clogging

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Objective: The clogging of porous media, by way of filtration of suspended solids, geochemical and biological processes posses a significant problem to the long term sustainability of artificial recharge operations. Of theses processes biological clogging is the least understood. While grain size and carbon concentrations are know to impact on biological clogging, the extent to which it does is not well defined. Laboratory column experiments were used in order to define the degree of biological clogging that may be encounter by injecting waste water, investigating variations in the grain size of porous media as well as the amount of injected nutrients.

Methods: Laboratory columns were packed with three pure silicate sands of grain sizes ranging from coarse grained (0.71-0.25mm), medium grained (0.3-0.125mm) and fine grained (0.106-0.056mm). The solutions leached through the columns included two synthetic nutrient solutions with TOC concentrations of 2mg-C/L and 12mg-C/L and a real tertiary treated effluent. Saturated hydraulic conductivity was recorded along the length of the columns over the experimental period. Polysaccharide and biomass concentrations were obtained by destructively sampling the columns at the end of the experiments.

Results: For coarse grained columns leached with real tertiary treated effluent there was no observed reduction in saturated hydraulic conductivity (Ks), while Ks did decrease by 1-1.5 orders of magnitude in columns packed with fine grained porous media. Similar trends were observed in the columns leached with synthetic nutrient solutions however the overall reductions in Ks were greater. The Ks reduction for coarse grained was approximately 1 order of magnitude, while for fine grained columns there was a 2.5 order of magnitude reduction in Ks. It was observed that for both synthetic nutrient solutions and real tertiary treated effluent leached through coarse and fine sand there was approximately 1 to 1.5 order of magnitude reduction in the saturated hydraulic conductivity. The polysaccharide concentrations at the inlet of the columns were concurrent with the observed reductions in Ks. Polysaccharide concentrations in the fine grained columns were generally twice as high a polysaccharide concentrations in coarse grained columns. The polysaccharide concentrations were also 1.5-2 time greater in the columns leached with synthetic nutrient solutions.

Conclusions: The grain size of porous media does affect the degree of biological clogging. Significant Ks reductions and high polysaccharide productions are observed within finer grained porous media. This may be due to smaller pore size and greater surface area for bacterial growth within fine grained porous media. Synthetic nutrient solutions generally yield higher polysaccharide concentrations and greater reductions in Ks. This is mostly likely attributed to the source of organic carbon present in the synthetic nutrient solutions.

Clogging processes of the littoral zone of Lake Tegel used for bank filtration

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Clogging phenomenon of the interstitial is regularly observed in sand filters as well as in infiltration basins, and up to know several mechanisms can be distinguished like physical (input of fine sediments, building of gas bubbles), chemical (precipitation mainly of carbonates) and biological processes (excretion of extracellular substances by algae and bacterias). As a consequence water permeability of the interstitial can be strictly reduced. In natural lenitic littoral zones (lake shores) clogging too occurs and will regulate carbon turn over processes, which are not yet sufficient described and quantified. Building up of POC by primary production, mineralization of POC by detritivorous consumer, production and uptake of DOC and losses of carbon to the atmosphere (as CH_4) and to the groundwater (as DOC) are main processes. Investigations are carried out at the littoral zone of Lake Tegel to analyse the carbon turnover processes, and data are presented concerning the infiltration rate and DOC input, the passive transport of POC downwards in sediment as well as of POC build up by bioproduction. In the first centimetres of the sediment occur very intensive turnover processes occur and we must assume micro zones of the fauna and flora due to the oxygen gradient. The transport of FPOM is significantly reduced to water flow due to clogging processes.

Geochemistry during infiltration and flow

Abstracts

Anaerobic Ammonia Oxidation during Sub-Surface Transport

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Objective: A set of experiments was completed to evaluate anaerobic ammonia oxidation as an important removal mechanism during groundwater recharge. In addition, several experiments were done to evaluate the conversion of nitrite to nitrate as the rate limiting step for anaerobic ammonia oxidation.

Methods: Soil column studies and batch tests were used to evaluate anaerobic ammonia oxidation in saturated soil systems. Soil columns were operated with a feed mixtures of nitrate plus ammonia and then converted to a feed mixture of nitrite plus ammonia. In addition, one column was operated with nitrate or nitrite to evaluate the bioavailability of ammonia adsorbed on the soils. Batch tests were also done with different nitrogen compositions and the rate of nitrogen gas production was evaluated. In addition, manganese oxide coated soils and and divalent manganese were added to batch tests to evaluate potential mechanisms for the conversion of nitrate to nitrite.

Results: Nitrogen removal was sustained in soil columns fed nirate plus ammonia or nitrate only for over 500 days without the addition of supplemental organic carbon. The nitrogen removal efficiency decreased gradually with time in the soil columns and the decrease could not be attributed to changes in operating conditions. The decrease in removal efficiency was greatest in the column that was fed nitrate only as adsorbed ammonia became exhausted from the soil. When one column was converted to a feed composition of nitrite plus ammonia, the nitrogen removal efficiency increased from less than 30% to greater than 95% in less than 20 days. As the nitrogen loading was increased to the soil column, the nitrogen removal efficiency continued to exceed 90% with a feed composition of ammonia and nitrite. The observed mass nitrogen removal rate with a feed composition of ammonia and nitrite increased by a factor of 12 as compared to the mass removal rate with a feed composition of ammonia and nitrate. Batch experiments to evaluate potential manganese nitrogen interactions did not demonstrate any significant impacts from manganese oxide coated soils or from the presence of divalent manganese. During batch tests, Initial concentrations of nitrite or nitrate exceeded 100 mg-N/L and there was no apparent effect of nitrogen composition and elevated nitrite concentrations were inhibitory.

Conclusions: Anaerobic ammonia oxidation was demonstrated as sustainable removal mechanism for nitrogen removal during groundwater recharge. When both ammonia and nitrate are present in the absence of oxygen, nitrogen removal is possible by anaerobic ammonia oxidation. The presence of ammonia is not always detected in the liquid phase since adsorbed ammonia is bioavailable and can support anaerobic ammonia oxidation. The conversion of nitrate to nitrite was the rate limiting step in the soil systems studied. An unknown soil component is believed to be involved in the conversion of nitrate to nitrite and further investigations are necessary to determine the unknown soil component.

Geochemical evaluation of artificial recharge to intermediate flow systems in a carbonate aquifer from northeast Mexico

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Artificial recharge of groundwater has been implemented to replenish extracted groundwater in a coal mining area of northeast Mexico, a semi-arid area where alternative water sources are scarce. The main aquifer of this region is overlying by a coal seam and surface coal mining requires dewatering the aquifer around the open-pit mining areas. Extracted groundwater ($29x10^6$ m^3/year) is injected at two sites located downgradient after atmosphere interaction which produces temperature and gas exchange modifications. The main purpose of this paper was to use the PHREEQC (Parkhurst, 1995) geochemical model to determine whether the mixing between natural groundwater and recharge water is causing adverse impacts on the aquifer or native groundwater quality.

The general hydrogeochemical conceptual model was determined from 70 groundwater samples taken in different parts of the aquifer. Samples were obtained from active wells, springs, lagoons in abandoned open pits and recharged water just before its injection. Temperature, specific electrical conductivity (SEC), Eh (Pt-electrode), pH and dissolved oxygen (DO) were measured in the field using an in-line flow cell. Alkalinity was also measured in the field by Gran tritation. Samples for major anions were taken in 500 ml bottles, for major cations, silica and trace elements were filtered with a 0.45 μm membrane filter and acidified with ultra-pure nitric acid (1 ml acid per 100 ml sample) and stored at 4o C until analyzed. Analytical methods used for major anions are compatible with those reported in APHA (1995); major cations measurements were done by atomic absorption. Calculated ionic balance was within 5% in 100% of the samples. A complete suite of trace elements were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) although only a few (Ba, Fe, Mn, Sr) were used in the present investigation; accuracy of ICP-MS analyses was controlled using duplicates, blanks and appropriate laboratory standards. Geochemical evaluation of the artificial recharge was made after the determination of a geochemical conceptual model.

Results indicate saturation of calcite, dolomite, barite and chalcedony, and without relation to salinity or groundwater flow. Supersaturation of carbonates and goethite was detected in some samples, especially in recharge water and lagoons. Subsaturation of gypsum, strontianite, celestite, rhodochrosite and siderite is also a common characteristic.

Geochemical modeling results suggest that mixing between original aquifer water and recharge water precipitate calcite, goethite, barite and chalcedony. Calcite shows the largest amount of precipitation and represents the major cause of permeability reduction around the injection sites or the major actual artificial recharge consequence. Clogging derived from suspended matter incorporated along the open channels will also contribute to reduce the recharge site efficiency.

Hydrochemical evaluation of Surface and groundwater quality at the coastal Basin (Syria)

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Major dissolved constituents (Ca^{++}, Mg^{++}, Na^{+}, K^{+}, $Fe^{++,+}$, Cu^{++}, HCO_3^{-}, SO_4^{2-}, Cl^{-}, PO_4^{3-}, NO_3^{-}, NH_4^{+}, F^{-}) have been determined in 66 water samples (54 of groundwater, and 12 of surface water) from the major region of the central coast basin. Most of these samples have been taken from groundwater of the carbonic consolidated aquifer (Limestone's and Dolomites of the Jurassic and Cenomanian/Turonian period). The specific characteristics of these hydrochemical groups seem to be related to the lithology of aquifers (dolomites aquifer =Mg/Ca > 1). The elevated Na^{+}, Cl^{-}, and SO_4^{-} content of the water is attributed to interaction of marls in the aquifer. The relation between the lithology of the aquifer and hydrochemical composition of groundwater should be confirmed by systematic sampling. The ground water from the chalks in the area has a higher content of Mg, SO_4^{-}, Cl^{-} and NO_3^{-}. The elevated contents of Na^{+} and Cl^{-} seem to be related to a higher portion of interbedded marls in the Cenomanian/Turonian aquifer in the south western part of the coastal mountains, occurring in the outcrops in the area near Myssiaf and Dreikich. The seasonal variations of the HCO_3^{-} and Mg^{++} Concentrations suggest that the content of HCO_3^{-} and Mg is related generally to the retention period of the groundwater in the aquifer. Mixing of hydrochemically different ground waters occurs as a consequence of a hydraulic connection between separated groundwater bodies by the weeding out of separating aquicludes, or by the change in the formations of an aquifer. With the natural recharge the mixing between surface and groundwater may be caused artificially in boreholes by hydraulic connection of separated aquifers. An obvious influence of surface water can be seen in samples sources and boreholes sitnated in the range of infiltration of rivers which is indicated by an elevation of the groundwater level (NO_3^{-}, PO_4^{3-}, Na^{+}, Cl^{-},...) in the vicinity of river or dams. Alteration by the chemical composition contamination of the groundwater is often occurred by biogenesis pollution in wells situated in outcrop areas of the aquifer in the vicinity of villages and rivers. Pollution indicated by an elevated NO_3^{-}, PO_4^{3-}, SO_4^{--}, Na^{+}, Cl^{-}, K^{+}, COD, Cu^{++}, $Cr^{4,6+}$…content has been noted particularly in outcrop areas of grand towns and its canalization's (Tartous, Banias,....). Regional varieties of chemical composition of the groundwater are found to be related to differences in the lithology of the aquifer and influences of rocks overlying or underlying the aquifer. In dolomites aquifers a relation is assured between the concentration of the groundwater, particularly the Mg^{++} and HCO_3^{-} content, and the retention period of the ground water in the aquifer. Mixing of natural waters of different chemical compositions could be recognized in same cases by hydrochemical characteristics. Most of groundwater samples represent the carbonate consolidated aquifer of Limestone's and Dolomites rocks of Jurassic-Cenomanian/Turonian period. Polluted shallow and deep groundwater by the infiltration of polluted surface water with high chemica1 composition of NO_3^{-}, SO_4^{--}, NO_2^{-}, PO_4^{3-}, F^{-}, Na^{+}, Cl^{-}, $Cr^{4,6+}$, Cu^{++}... etc is resulting with bad quality and unacceptable chemo-physica1 property. Chloride-sodium chemical type due to the Salinization of groundwater (sallow groundwater) from the sea water encroachment was observed at North with South Tartous (El-Hamidieh). The problem related to pollution of both surface and groundwater systems is becoming One central problem in the management of water resources in this region (and other regions) of Syria.

The behaviour of trace species during Aquifer Storage and Recovery (ASR): a case study using reclaimed water in a carbonate aquifer at Bolivar, South Australia

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Utilisation of reclaimed waste water in artificial recharge takes advantage of an available resource to augment groundwater resources, while also reducing the discharge of nutrient rich waste water to surface or coastal waters. However, the affects of geochemical processes following the introduction of a foreign water body into an aquifer must also be considered. A full-scale Aquifer Storage and Recovery (ASR) field trial at Bolivar, South Australia was used to investigate the behaviour of trace species, arsenic, nickel, aluminium and zinc in a carbonate aquifer. These trace species were present in the reclaimed waste water injectant and in the native groundwater. Therefore potential concentrations changes may be due to mobilisation from the aquifer itself, or conversely, attenuation processes. This paper examines the changes in aqueous concentrations of these trace species through the ASR cycle, the likely mechanisms and the consequences of these changes on the utility of the recovered water as an irrigation supply.

The injected aluminium (0.008 $mmol.L^{-1}$) was predominantly in the particulate phase while the remaining species of interest were largely soluble. The soluble aluminium (0.002 $mmol.L^{-1}$) and nickel (0.0004 $mmol.L^{-1}$) concentrations injected were generally greater than in the ambient groundwater (0.0005 and 0.000010 $mmol.L^{-1}$ respectively), while the injected arsenic (0.03 $mmol.L^{-1}$) and zinc concentrations (0.0009 $mmol.L^{-1}$) were comparable to the ambient condition (0.05 $mmol.L^{-1}$ and 0.0010 $mmol.L^{-1}$ respectively). Overall, the recovered water quality indicated that particulate aluminium was removed but soluble aluminium remained unaltered, nickel was also unaltered, zinc was effectively attenuated and arsenic was mobilised (average increase of 0.2 $\mu mol.L^{-1}$). Removal of particulate aluminium was achieved through physical processes such as filtration or adsorption during the injection phase. Zinc attenuation, also occurred during the injection phase, and was attributed to precipitation of zinc carbonate. Arsenic was mobilised upon injection with the subsequent redox conditions controlling the aqueous concentration. Nonetheless, the recovered water remained compliant with Australian irrigation quality guidelines despite the slight increase in arsenic concentration. In addition, the treatment capacity of the carbonate aquifer was illustrated with the attenuation of injected aluminium and zinc.

Long-term impact of stormwater infiltration on groundwater quality: ASR in Melbourne

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Objective: In the light of the drought in 2001-2003 that afflicted much of Australia the need for water reuse was formulated in the Green paper (DSE, 2003) and the aim of a 20% reuse rate for Melbourne are strived for. This comprises reclaimed water as well as a better management of stormwater runoff. Up to now very little emphasis on investigating the feasibility of using stormwater for ASR in Melbourne has been done. The three main issues that have to be addressed are the quantity of stormwater that can be infiltrated, the long-term quality changes to the groundwater system implemented with it and the clogging of bores and infiltration basins. Our main focus will be the question whether ASR systems could degrade groundwater quality in the long-term, either through pathogens, nutrients or other contaminants.

Methods: As to date there is limited monitoring data of Melbourne's groundwater quality the first step will be to determine a couple of possible ASR sites. Secondly column and batch studies with aquifer material are going to be undertaken to shed light on the transport processes involved with stormwater infiltration, using actual and synthetic stormwater based on collected samples.

Results: With the aid of these findings a model for long-term predictions is to be developed, which could be used for recommendations regarding actual implementation.

Conclusions: A key issue is the need for thorough groundwater research and investigation so that long-term, sustainable performance of stormwater infiltration and reuse can be addressed at the outset in order to help move towards a sustainable urban water cycle.

Health aspects

Abstracts

Nomograms to predict water quality improvement for management of aquifer recharge

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A simple nomogram was developed to describe the number of log-removals of pathogens and biodegradable organics between injection and recovery wells for simple Aquifer Storage Transfer and Recovery (ASTR) projects and between the bank and production wells in bank filtration projects. The method assumes a homogeneous isotropic aquifer of uniform thickness and porosity with uniform ambient hydraulic gradient, constant rates of pumping, and constant exponential rate of biodegradation, and linear adsorption isotherm. Only two non-dimensional parameters were found to be required to define log-removal or biodegradation during transport through the aquifer to the recovery well. These describe advective transport due to pumping wells and due to the regional hydraulic gradient respectively. These parameters uniquely defined the ratio of minimum travel time to the time for one-log removal, which thereby defined the number of log-removals of the contaminant reaching neighbouring wells

The method was applied to a case study in the Bandung Basin, Indonesia to derive safe distances for down-gradient wells from wells in which stormwater was to be injected for nine hydrogeological zones in the basin. Recharge enhancement was being considered to help address the groundwater overdraft in the basin. While the approach is very simple, it was adequate to demonstrate that in each of these zones the rate of groundwater flow was high in relation to rate of pathogen die-off, so that runoff from the ground surface should not be admitted into wells. However roof-runoff, piped directly to a well, was likely to yield water suitable for injecting into the aquifer without adverse impacts on the quality of neighbouring wells. Although the model is very simple, it may be useful as a planning tool or to assist in designs of MAR projects.

Are there Limits to Cyanobacterial Toxin (Microcystin) Elimination by Sand Passage?

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Objective: Cyanobacterial toxins are substances with high acute and chronic toxicity produced by cyanobacteria or "blue-green-algae" that can be observed in surface waters world wide. In case of cyanobacterial blooms that occur frequently in case of elevated nutrient loading high concentrations of cyanobacterial toxins occur with microcystins being the group of substances most frequently found. Under normal conditions over 90 % of the toxins are contained within the cells. There have however been reports on high extra-cellular concentrations e.g. in case of aging populations and / or sudden cell lysis.

Sediment or sand passage has shown to be effective in eliminating cyanobacterial cells as well as microcystins from surface water in many cases. In order to ensure toxin elimination for drinking water production, however, elimination has to be secure under a variety of conditions met in the field. For this reason different worst case scenarios were simulated within the interdisciplinary NASRI research project (Natural and Artificial Systems for Recharge and Infiltration) dealing with river bank filtration processes. The aim was to identify the basic conditions under which sand and sediment passage can securely eliminate microcystins from surface water so that no further drinking water treatment has to take place.

Methods: The UBA's experimental field on the outskirts of Berlin offers a unique possibility of simulating bank filtration, artificial recharge and slow sand filtration on a technical scale. One part of the site is a storage reservoir (pond) with a water volume of about 3500 m^3 with an adjacent artificial aquifer consisting of sand and gravel. Additionally the surface water can be conducted into 4 infiltration basis each with a square basal surface of 100 m^2. Two of these basins are sealed by concrete at the bottom with a sand depth of 0.8 m and two have a direct contact to the underlying sediments and can be operated as infiltration ponds. For smaller scale experiments three enclosures with a surface area of 1 m^2 and otherwise same sediment structure are installed in one of the infiltration basins. The whole site is separated from the surrounding aquifer by a layer of clay thus forming an independently operable hydraulic system so that experiments with toxic substances can be carried out without adverse effects on the environment.

Experiments were carried out on one of the sealed infiltration ponds as well as in the enclosures. For simulation of worst case scenarios high extra-cellular microcystins extracted from a mass culture of Plankthothrix agardhii were applied to virgin sand without previous microcystin exposure and collmation layer (schmutzdecke). Further experiments investigate toxin elimination under anoxic and anaerobic conditions as well as under low temperatures.

Results: From the data available so far, a substantial reduction of extra-cellular microcystins (maximum concentration after 80 cm sediment passage or 6 h travel time: 15 % of input concentration) due to biological degradation was observed even under unfavorable conditions (high filtration velocity, missing schmutzdecke, virgin sand). There are however indications that elimination is retarded under anoxic and anaerobic conditions. As these conditions are frequently met in bank filtration settings further investigations are currently being carried out.

Conclusions: Sand and sediment passage have shown to be secure drinking water treatment methods with respect to microcystins even under some unfavourable conditions. Precautions however have to be taken in cases where groundwater conditions are anoxic or anaerobic. Here travel times for secure toxin elimination are longer and careful monitoring is recommended.

Interactions of indigenous groundwater bacteria with enteric viruses, as microcosms versus individuals, during water quality improvement by aquifer storage and recovery (ASR)

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Aquifer Storage and Recovery (ASR) is not only a method of water storage and reuse, but also as a method of water quality improvement. Reclaimed water, injected and stored in aquifers can be extracted with a higher level of water quality due to the action of indigenous groundwater microbes. Studies of the interaction between indigenous groundwater microbes and enteric viruses have repeatedly shown viral decay over time in groundwater when indigenous groundwater bacteria are present. Further investigations of this interaction have shown a small percentage of indigenous groundwater bacteria may be responsible for this observed decay. Each active bacteria result in the decay of the enteric viruses, poliovirus type 1, coxsackievirus B3 and adenovirus, each in their own specific way. Decay rates varied not only amongst each active groundwater bacteria, but also amongst each virus tested. These indigenous groundwater bacteria interact as a whole groundwater microcosm, resulting in a much greater decay rate than when tested individually. Investigations of the mechanisms of decay for each active bacteria and the interaction of all active bacteria as a whole microcosm will give further insight into what is actually happening in situ during ASR. Results could be applied to risk prediction for water reclamation to ensure reclaimed waters pose no public health risk once recovered from storage after a prescribed period of time.

Removal Mechanisms of Effluent Organic Matter During Soil Infiltration In Artificial Groundwater Recharge Systems

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Objective: The fate of effluent organic matter (EfOM) during artificial groundwater recharge (AR) has been intensively studied during the last decades. The persistence of organic carbon during AR is of concern since it can potentially elevate dissolved organic carbon concentration in receiving aquifers, affect the transport of pollutants in the subsurface, or limit a co-metabolic removal of trace organics. Previous research has demonstrated that the fate and transport of organic carbon during AR is primarily determined by biological and physical processes. A novel approach was developed in this study to investigate the bioavailability of organic carbon being introduced into AR systems by monitoring soil biomass growth response during the infiltration of effluent derived organic carbon substrates. The approach combined soil microbiological parameters (aerobic mineralization potential, universal biomass activity measured as dehydrogenase activity and total viable biomass) with advanced chemical organic carbon characterization (organic carbon fractionation, size exclusion chromatography). Specific objectives of the study were: (1) to determine the fractions of organic carbon, which are removed by biodegradation and adsorption, respectively; (2) to quantify physical and biological organic carbon removal kinetics; (3) to identify the factors impacting biological removal kinetics organic carbon in AR systems; (4) to locate where biological removal of organic carbon occurs in AR systems; and (5) to provide recommendations regarding operation and design of AR systems to enhance organic carbon removal. This study was part of a tailored collaborative research project funded by the American Water Works Association Research Foundation (AwwaRF) and the U.S. Environmental Protection Agency.

Methods: In this study we differentiated between three organic carbon fractions (hydrophobic acids (HPO-A), hydrophilic organic carbon (HPI) and colloidal organic carbon) that constitute the bulk of EfOM. To assess the bioavailability of the organic carbon fractions, biologically acclimated column systems were employed simulating soil infiltration under saturated aerobic flow conditions. Organic carbon removal was studied using conventional and advanced chemical analysis (dissolved organic carbon, specific UV absorbance, size-exclusion chromatography) in combination with soil bio-community characterization tools (phospholipid extraction, dehydrogenase activity and substrate induced respiration). The adsorption potential of the organic carbon fractions was quantified using abiotic batch and column experiments. Abiotic conditions were established using low biomass containing sand and sodium azide. Results from laboratory experiments were compared to investigations at full-scale AR sites in Arizona and California. Field sites differed in both, wastewater pre-treatment and EfOM composition as well as geohydrological conditions. The field sites were characterized in terms of EfOM composition as well as organic carbon removal and soil biomass depth profiles.

Results: Results indicated that organic carbon removal correlates well with biomass activity and the presence of total viable biomass in the soil infiltration layer (0-30 cm). This finding emphasizes that biodegradation was the leading process for organic carbon removal and that biodegradable organic carbon concentrations were limiting soil biomass growth during soil infiltration. All three carbon fractions showed a significantly different availability to

biological decay. Biological removal kinetics for the individual fractions were modeled using a first order kinetic approach and compared well to the overall removal behavior of the combined EfOM from which they were isolated. The majority of mineralization occurred in all column experiments and at all field sites in the upper 15 cm. Below that depth, biomass activity decreased rapidly to background levels independent of loading rates or the length of wet/dry-cycles.

Conclusions: Soil biomass proved to be a good indicator to locate where organic carbon degradation occurred in laboratory and under field site conditions. These findings stress the importance of the upper infiltration layer for the biological attenuation of organic matter. Adsorption experiments using sand media showed that physical removal was relatively less important for all three organic carbon fractions. Results of this study suggest that total viable biomass (measured as phospholipid extraction) could serve as a useful tool to estimate biological removal of organic carbon in AR systems. Findings of this study contribute to an improved understanding regarding the mechanisms leading to attenuation of organic carbon during soil infiltration under saturated aerobic flow conditions.

Development of fresh water sources in some parts of the arsenic contaminated areas of West Bengal (eastern India) through artificial recharge: a remote sensing and geographical information system based approach

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The presence of arsenic in groundwater has been reported from several countries of the world like the U.S.A., China, Chile, Nepal, Thailand, Bangladesh and India. In India, the chronic arsenic toxicity is reported from eight districts, from Malda to South 24 Parganas through Murshidaad, Nadia and North of 24 Parganas on the eastern bank of Bhagirathi river and Bardhaman, Haora and Hugli districts from western bank of the river and this entire area belongs to the state of West Bengal (W.B.) of eastern India. In this region about 1.2 million people are suffering from arsenic contaminated water. Arsenic affected area forms a part of the Ganga-Bhagirathi delta comprising thick succession of quaternary sediments. The deltaic alluvial plain bears the reflection of depositional and erosional history of the rivers and their numerous distributories. The delta and flanking areas forming the Bengal basin can be divided in to different forms i.e. deltaic upland, barind, upper and lower delta plain of meander belt and delta front. The higher incidence of arsenic in ground water is restricted within the upper delta plain with a series of meander belts. The conspicuous levees along the Bhagirathi and other rivers, as well as the inter-distributory levees are other geomorphic features which could be related to fluvial process of distributories in the upper delta plain. They were formed under varying hydrodynamic condition in a fluvial regime. Abandoned meander scrolls are the most common form and could be related to flood plain formation in the upper delta. Composition of the sediments changes laterally across the delta plain even within a few meter to several hundred meters. This may explain the apparent discontinuity of the arsenious aquifers and non arsenious aquifers due to overlaps from one meander to another.

Most of the arsenic affected areas are located in the upper delta plains and in southern part of the delta in the south. The sediments of the plain (upper delta) consist of several sequences of peat, organic matter, clay, sand, and silt. The delta in the south, consists of tidal mud, distributor levees and inter-distributory marshy complex formed in a fluvio estuarine and marine environment under the influence of fluctuating sea level in the Tertiary and Quaternary. The major drainage in the area under study, Hoogly (a stretch of Bhagirathi) river has a low sinuosity value of 1.14 which is significantly less than a meandering river with the sinuosity value of 1.50. This particular aspect has a direct correlation with the location and distribution of high arsenic concentration in the groundwater. The arsenic concentration is mostly high (>0.05mg/l) in the levees of abandoned meander belts. The relatively younger floodplains do not show high concentration (>0.05mg/l) of arsenic in the groundwater. Again, amongst the older flood plains which are consisting of almost continuous clay bed(s) / layer(s) are free from high arsenic concentration in groundwater. Here the shallow aquifers are unconfined by nature and deep aquifers are confined. In fact, the aquifers change gradually open to semiconfined character towards the south. The meanders, levees and flood plains with their sediment characteristics varying from sandy, silty to clay size with varying landcover/landuse practice are clearly discernible in the satellite imageries (IRS IC/ID LISSIII and PAN merged data) and field verifications are performed for confirmation. In the above backdrop present investigation comprising a part of Nadia district (W.B.) involves satellite remote sensing aided by geographical information system (GIS) technique to generate

composite map(s) (Scale, 1:25.000) to delineate the sites for (1) artificial recharge ultimately to dilute/flush out arsenic contaminated groundwater by fresh water(obtained through natural precipitation), (2) water harvesting structures for surface water storage development and for (3) fresh groundwater exploration. Older meander belts, geomorphic lows and palaeochannels (excluding that of older meander belts and scrolls) are the suitable sites for artificial recharge, water harvesting structures and for fresh water exploration respectively. Deeper aquifers present in the relatively older flood plains consisting of clay beds are also suitable for freshwater exploration. Changes in landuse can offer excellent clues for sitting water harvesting structures as well.

Prediction of transport and fate of pharmaceuticals during bank filtration

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Objective: Pharmaceutically active substances and metabolites are reported at concentrations up to the microgram/L-level in pore water from the unsaturated and in groundwater samples from several locations world wide. Among the compounds detected in groundwater are clofibric acid, propyphenazone (mild analgesic), diclofenac, ibuprofen (both anti-inflammatory drugs), and carbamazepine (anti-epileptic drug). Among the most important input paths of drugs are excretion and disposal into the sewage system. Groundwater contamination is likely to be due to leaky sewage systems, influent streams, bank filtration, and irrigation with effluent water from sewage treatment plants.

Methods: In field studies investigating groundwater sampled at a bank filtration site at Lake Tegel (Berlin, Germany), clofibric acid was found at concentrations up to 290 ng/L, propyphenazone up to 250 ng/L, whereas concentrations of diclofenac were around the detection limit. These occurrences led to further investigations regarding the fate and transport of these pharmaceuticals in groundwater. We conducted laboratory soil column experiments with sandy sediments and corresponding water from the Berlin area. Furhtermore, transport models are based on these field studies and lab experiments.

Results: Results of the saturated column experiments show that clofibric acid exhibits no degradation and almost no retardation (Rf=1.1) whereas ibuprofen is biodegraded (>90 %) under aerobic conditions. Diclofenac as well as propyphenazone are retarded whereas significant degradation was not observed for both pharmaceuticals. Carbamazepine shows no degradation in the soil column experiments but significant retardation under the prevailing conditions.

Conclusions: Transport models show that the mobility of clofibric acid is characterized by advection whereas mobility of ibuprofen is controlled by retardation and degradation under aerobic conditions. These results explain, why the concentrations of pharmaceuticals in groundwater exhibit high variations and what pharmaceutics might be expected even in deeper aquifers.

Retention of Cryptosporidium oocysts in different filter sands during slow sand filtration

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Objective: These experiments were carried out to investigate the Cryptosporidium oocysts reduction efficiency of different filter sands during artificial groundwater recharge by gravel pre-filtration and slow sand filtration.

Methods: In a half-technical outdoor test plant (Lysimeter) the method of artificial groundwater recharge using a two-stage filtration (gravel pre-filter and slow sand filter) was reproduced. The test plant (basin size: 4 m^2) simulated realistic field conditions and operating stages close to practice. Only the thickness of the sand filter was low for the investigation of optimization possibilities. Three filter sands with different effective grain sizes (d_{10}) and particle-size distributions were used (sand 1: d_{10}=0.28 mm, sand 2: d_{10}=0.12 mm, sand 3: d_{10}=0.15 mm). Under defined conditions three operating stages close to practice were investigated, and the reduction efficiency of the filter sands was compared against one another. During the experiments microbiological parameters (Cryptosporidium oocysts, Clostridium perfringens, Coliforme) and relevant hydrochemical parameters were measured.

Results: Gravel pre-filtration (grain size 8 – 16 mm) already caused a distinct reduction of Cryptosporidium oocysts. During the second filtration step the three tested filter sands were not able to retain the Cryptosporidium oocysts completely in all operating stages (start-up stage, stage with supernatant, start-up stage after dry stage). Filter sands with a small effective grain size (d_{10}–value) are more suitable for avoiding oocysts break through. Increased specific discharge (Darcian velocity) e.g. in start-up stages after dry stages could cause a remobilisation of retained oocysts which leads to increased oocyst concentrations in the initial filtrate. A connection between the concentrations of Cryptosporidium oocysts and Clostridium perfringens spores was not found.

Conclusions: The two-stage filtration by gravel pre-filter and slow sand filter during the artificial groundwater recharge causes a distinct reduction of oocysts. The thickness of the filter sand should be large and the specific discharge (Darcian velocity) small to achieve a high reduction of Cryptosporidium oocysts. The following underground passage acts as an additional purification step after the filtration.

Injection well issues, aquifer storage and recovery

Abstracts

ASR well field optimization in unconfined aquifers in the middle east

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Storage of large quantities of potable water has become more important over the last years in the Middle East. Unconfined aquifers allow to store potable water for strategic purposes. The operational requirements for the recovery of water in emergency situations involve high abstraction rates over long durations. The approach utilized involves numerical simulation, groundwater information analysis, GIS capabilities and extended aquifer characterization tools that are linked to a single shared database. A 3-dimensional hydrogeological model was developed to characterize the aquifer conditions. Hydrodynamic test analysis was used to identify the dynamic conditions of the aquifer and to estimate well efficiencies. Subsequently a 3-dimensional numerical model was generated and calibrated with the newly derived field data. Sensitivity analysis was carried out to account for local heterogeneities. A typical surficial aquifer in the region may display a relatively thin saturated thickness compared to the overall thickness of the aquifer including the unsaturated zone. This fact can limit recovery with high abstraction rates for long durations. Thin saturated thickness raises concerns over wells running dry on recovery. In order to maximize recovery rates, an ASR well field optimisation has to be carried out. A 3-dimensional numerical model was generated including the thick unsaturated zone and populated with aquifer properties developed from advanced geophysical logging. The number of wells needed, well spacing, pumping and injection rates were determined for large well fields by numerical modelling. The key factors that need to be accounted for and their effects on the operational scheme of the aquifer storage and its economical feasibility will be described. This work allows insight into the requirements necessary for the design of large ASR well fields in unconfined aquifer conditions.

A Comparison of the Operational Performance at Ten ASR Sites located within the United States, Australia, and England

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Objective: In support of Everglades Restoration in South Florida, USA, the U.S. Army Corps of Engineers and the South Florida Water Management District have made an effort to review field data from operating Aquifer Storage and Recovery (ASR) sites across the USA, Australia, and England. This field data review was completed with two main objectives. First, the ASR operating data was reviewed to evaluate operational similarities and differences. Second, the ASR operating data was reviewed to identify fatal flaws that could be avoided for the proposed Everglades ASR program while still enhancing the existing groundwater resources of South Florida.

Methods: The U.S. Army Corps of Engineers contacted numerous ASR owners and developers across the USA, Australia and England to request key ASR operating data. Over thirty ASR project sites were contacted and agreed to send data. The data sent by the ASR proponents varied in importance and scale as well as format (e.g., hard copies vs. electronic data deliverables). At the time of this abstract, data from ten sites had been reviewed and analyzed.

Results: The ASR operating data from the ten project sites include a variety of purposes, hydrogeologic environments, and performance. In general, a majority of the sites have been successful in meeting the initial ASR project objectives, however, a few of them have experienced ongoing operational problems. Two sites have identified geochemical issues as major constraints.

Conclusions: The review of data from existing ASR project sites was a beneficial learning experience for the Corps project team members. Lessons learned from operating sites provide an invaluable source of knowledge for anyone planning a new ASR project. From the data review, it is apparent that geochemical considerations may be a key component in planning for the proposed Everglades Restoration ASR program. For ASR restoration sites involving recharge of natural systems, the recovered water quality may be key determining factor in project performance.

Aquifer Storage Recovery (ASR): an economic analysis to support use as a strategic managerial tool to balance a city's desalinated water production and demand

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Objective: Most cities around the globe are faced with the same challenge - the year round availability of adequate freshwater. The quality, quantity, reliability and economics of the supply become measuring sticks for success. In the city of Sharjah in the UAE, as in other regional countries, the creation of large buffer storages for its desalinated water production is a well-recognized need for optimizing its water resource management. In the face of expensive surface tanks offering limited storage, the use of Aquifer Storage Recovery (ASR), a technique for storing very large quantities of water in aquifers, has been evaluated here to support economic decisions towards its use in balancing the city's desalinated water production and demand.

Methods: To evaluate the use of ASR in this manner, the production versus demand charts for the city were analyzed to identify the times and quantities of recharge and recovery. Daily and seasonal variations were plotted. A number of scenarios were created for varying degrees of strategic (crisis management) and seasonal support (cost reduction) objectives. The detailed economic evaluations included considering in each case, the storage size and related ASR facility costs, the recharge water source and related plant and operating costs. Taken into account were the reductions in production when desalination units are down for maintenance, unforeseen breakdowns and short period demand increases. To meet these challenges, options evaluated for building ASR capacity included utilizing surplus production, dedicated desalination units or purchasing from a national grid. For streamlining the comparisons, all scenarios were presented using Equivalent Annual Cost (EAC) calculations. Detailed, actual and known costs were input.

Results: The results obtained were put through decision tree software analysis, assigning the calculated costs and probabilities to each of the envisaged scenarios. Each node branched to options with related cost impacts, so as to arrive at a justifiable conclusion – in this case, an ASR recharged with a dedicated RO plant and sized to fully meet annual seasonal shortages and cover 25% of a crisis situation. A sensitivity analysis, varying the probability assumptions, showed the cut-off probability at which the suitability of this chosen scenario of would become questionable.

Conclusions: The conclusions drawn clearly demonstrated the viability of Aquifer Storage Recovery as a reliable and economic building block of an overall water resource management strategy.

Water quality changes during Aquifer Storage and Recovery (ASR): results from pilot Herten (Netherlands), and their implications for modeling

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ASR (Aquifer Storage and Recovery) is a water management technique to store superfluous water in an aquifer for use during future needs. In the Netherlands this technique is currently under investigation for application to drinking water. In this case it is crucial – for the economic feasibility – that the drinking water injected remains of high quality, meeting all drinking water standards without necessitating a costly post-treatment.

The quality changes of drinking water during a recent ASR test in a sandy aquifer of Tertiary age (159-170 m – LS), in the Southern Netherlands are shown, discussed and modelled.

The composition of the oxic drinking water, after injection into the deep anoxic aquifer, changed mainly by redox reactions with organic material, pyrite and a manganous siderite. As a result, concentrations of SO_4, Fe, Mn, H, As, Co, Ni and Zn rose, and those of O_2, NO_3, SiO_2 and HCO_3 dropped. These reactions decreased during successive ASR-cycles thanks to leaching, coating with ironhydroxides and a concomitant pH increase. Tests were carried out with adding O_2 and $NaNO_3$ to the injection water, in order to speed up the inactivation of reactive aquifer components. A stronger leaching resulted, however, in a strong pH decrease which mobilized even more Fe and Mn. It is concluded that adding oxidants should be accompanied with adding NaOH to keep the acidity low.

An important observation is that an anoxic zone developed around the bore hole wall during the storage phase of ASR. This is explained by decay of micro-organisms that develop during the injection phase of ASR. Upon recovery the water affected by this decay and by anoxic reactions with the aquifer, needs to be diverted from the drinking water mains.

Even more important is the observation that during prolonged pumping iron and manganese, which dissolved into the drinking water more remote from the ASR well, were clearly immobilized in the most aerobic zone. The latter is situated in between the ASR proximal zone (where anoxic conditions arise during storage, as mentioned above), and the outer zone of the ASR bubble, where the reactive aquifer components are still abundant and uncoated by iron(hydr)oxides.

This immobilization is supposed to be due to the sorption processes active during On Site Iron Removal (OSIR). As a result, with increasing ASR cycles a rising and ultimately very high recovery efficiency is attained.

The water quality changes observed have been modelled with a new version of the Easy-Leacher model (EL-ASR 2.0). The crucial changes in the ASR-proximal zone and the effects of OSIR needed to be implemented in this model, in order to obtain a good fit with the field data.

Effect of Drilling, Completion and Operational Procedures on ASR Well Performance in Unconsolidated Aquifers

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The aim of this research is to evaluate what is currently known about the effects of different drilling techniques, well completion designs, redevelopment techniques and other forms of maintenance, on the performance of ASR wells completed in unconsolidated formations. The key driver is to avoid excessive clogging that leads to reduced injection rates and increased frequency of unclogging. Other problems can also arise (eg. excessive sand production). The goal is to understand the impact of these different influences on the recharge capacity of ASR wells over the long-term.

A literature review is currently underway which takes in ASR, injection and conventional production wells. Case studies are being sought on: well operation problems and how these have been solved; comparative studies where different drilling methods or well completion techniques have been used and rates of clogging rate or well yield observed; and innovative borehole design techniques.

The literature appears to be deficient in quantitative evaluations of the effects on performance of design and construction of ASR wells in unconsolidated aquifers. However, some design and construction aspects of production and injection wells in unconsolidated formations have been found to enhance well performance remarkably. For instance, recharge rates of Dutch drill holes have increased from 25 m^3/h to 400 m^3/h (at the same pressure differential), by simply scraping the borehole wall after rotary drilling. Other examples include a new strategy, based on the use of high-pressure jets to inject a mixture of chemicals, as well as the enlargement of well diameters, which is thought to be effective in rehabilitating severely clogged wells.

Based on the results of this literature review, knowledge gaps are being identified and a research program devised to address these.

Modelling aspects and groundwater hydraulics

Abstracts

Simulating Effect of successive cycles in Aquifer Storage and Recovery well in India

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A Volkswagen funded research project at Balsamand, India has investigated the viability of aquifer storage and recovery (ASR) of reclaimed water in a brackish aquifer. The field trials involved the injection of 0.8 ML and recovery of 0.8 ML of reclaimed water in four successive cycles (0.2ML in each cycle for injection and recovery) into a highly brackish aquifer. Through intensive monitoring an understanding of movement, mixing and water quality changes of the injectant in the aquifer has been developed. Modeling using Hydrus-2D of the changes in pressure heads as observed in the piezometer (10 m away from the ASR well) have a fair good relation with the experimental data. The study showed that the recovered water met the guidelines for unrestricted irrigation. The quality of water improved with successive number of cycles particularly with TDS and suspended particles. There clogging was observed and the cost of the operation was found to compare favorable with conventional alternatives.

Fate and transport of DOC and nitrogen species in 2-D soil aquifer treatment (SAT) model

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Soil aquifer treatment (SAT) is a promising technique for wastewater reclamation and reuse using natural remediation process in the aquifer. This treatment strategy takes an advantage of physicochemical and biological processes in the subsurface. The efficiency of SAT is governed by (i) aquifer characteristics, (ii) source water characteristics, and (iii) operation condition. Two dimensional SAT model was designed and manufactured to see the major mechanism of SAT in both unsaturated and saturated aquifer. The dimension of the model is 4-m in horizontal, 2-m in vertical, and 10-cm in width. As groundwater is induced to flow in half parts of the model, the unsaturated and saturated aquifers are divided. As we load effluent of membrane bioreactor into the SAT basin with the cycle of 4-days loading and 3-days drying, we monitored the fate and transport of the influents in terms of DOC and nitrogen species, such as ammonium and nitrate. DO was also monitored considering those parameters. DOC and ammonium were considerably removed or oxidized by the respective microorganisms in unsaturated aquifer, and by dilution in saturated aquifer, but nitrate was somewhat increased. This result implies that nitrification is rather dominant than denitrification in the system because of high DO concentration in the source water. From this result, we will be able to predict how the SAT source water affects to the established groundwater.

Application of most recent borehole geophysical logging for aquifer characterization

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The purpose of this article is to illustrate the applications of the most recent borehole geophysical measurements for the evaluation of the aquifer characteristics and its suitability for an aquifer storage and recovery (ASR) project.

Amongst the many properties required for aquifer characterization are total porosity, lithology, grain size and grain sorting, fracture density, aperture and directions, free and capillary bound water, lithologic saturation, water quality and aquifer transmissivity.

Advanced geophysical logging methods are rarely used in the water industry. In this article, we will present the application of Litho-density, Neutron, Array Induction, Elemental Capture Spectroscopy, Nuclear Magnetic Resonance, and Formation Micro Imager for the deduction of aquifer properties.

As well, we will present the inversion methodology through the simultaneous Elemental Analysis solver for the integration of the above mentioned measurements into an optimized solution for the rock and soil characteristics in saturated and unsaturated conditions. Step by step analysis of the individual measurements will be presented, as well as the integration of these individual measurements into the final solution.

The aquifer properties derived from the log interpretation will be used to populate a 3-dimensional numerical model. The methodology offers opportunities to increase the vertical resolution of the aquifer structure (identification of multi-layer systems) and will strongly enhance the quality of numerical modeling.

Groundwater recharge assessment in Kangavar basin, Kermanshah, Iran

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Groundwater resources, because of its importances in agriculture plays a key role in irrigation sector in Iran. The consuption has increased in recent years meeting about 80 percent of water requirements of the country. Dependence on groundwater has increased due to rise of population and also introdution of high yeilding variteis crops, which requires a assured, availabe and timely water supply. This reliability on groundwater as the most dependable source for irrigation and other uses has led to its over explotation in the most parts of the country, in both hard rock terrain and alluvial formations. With ever increasing demands on water resources, artificial recharge of groundwater is gaining importance as one of the strategies of water management in this country. Application of artificial recharge offers a great scope for the arid and semi arid regions as the water available in time of plenty can be stored in this manner for utilization in times of shortages. The choice of particular method of recharge is governed by local geology, topography and soil conditions etc. The percolation of water into zone of saturation is mainly depending on nature of lithologs and ultimately the thickness of alluvial burdenand ultimately the hydrogeological conditions.

In this study attempt has been made to delineate hydrogeological conditions of Kangavar basin to asses artificial recharge by evaluating:

-Geology of the area

-Availability of suitable sites, mainly from topographical and cultural consideration.

-Presence of suitable source of supply water.

-Lithological composition, thickness and permeability characteristics of geological formations by application of geoelectrical method and using tube wells data.

-Groundwater balance studies.

-Groundwater flow patterns and fluctuation of water table.

-Hydrodynamic conditions in the aquifer.

-Cost benefit considerations.

-Need for artificial recharge.

Groundwater Mathematical Modeling of Sujas Basin Zanjan Province Iran

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Groundwater Models are simple representation of actual physical processes and suitably constrained differential equation that describes groundwater behavior in a system of interest. This model enables us to test hypothesis to predict the relative effects to management strategies and to perform sensivity analysis. A three-dimensional, numerical groundwater model of the Sujas aquifer in the Zanjan province of NW Iran was developed to help estimate groundwater availability and water levels in response to pumping and potential future droughts. The model includes historical information on the aquifer and incorporates results of new studies on water levels, structure, hydraulic properties, and recharge rates.

Modeling the size of microbiological protection zones around phreatic sandy aquifers in the Netherlands

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Artificial aquifer recharge with surface water might result in the introduction of pathogenic microorganisms in the soil. During soil passage from the infiltration site to the abstraction well, microorganisms will be removed. Recently, a model has been developed that calculates the removal of viruses during soil passage. This model can be used to calculate the size of protection zones around abstraction wells. The aim of the current study was to calculate the size of protection areas around oxic and anoxic sandy aquifers without confining layers using a virus infection and transport model. The maximum allowable virus infection risk was set at 10^{-4} per person per year at the 95%-confidence level.

Model results demonstrated that for phreatic oxic sandy aquifers in the Netherlands, protection areas with a residence time of 50 to 100 days are needed to prevent that the maximum virus infection risk will be exceeded. This is 0.83 to 1.67 times the current guideline of 60 days. In contrast to oxic aquifers, phreatic anoxic sandy aquifers without confining layers need protection zones of 567 to 898 days to stay below the maximum virus infection risk. This is 9.5 to 15 times the current guideline. However, only three phreatic anoxic sandy aquifers without confining layers are present in the Netherlands. The results imply that for artificial recharge of surface water, oxic aquifers are preferred over anoxic aquifers. In order to keep an artificial aquifer recharge site oxic, it is recommended that soil sludge is removed and the infiltration water is pretreated to remove most of the organic material. A sensitivity analysis of the model demonstrated that the calculated protection zone was most sensitive for the virus inactivation rate and collision efficiency. Values of both parameters were predicted from values obtained in two field studies. It is unknown if the predicted values can be used at other locations as well. As a result, the reliability of the model is currently unknown. Therefore, it is proposed to perform field studies to calibrate and validate the model.

Overall, we conclude from our study that around phreatic oxic sandy aquifers, the size of the protection zone necessary to prevent that the maximum virus infection risk will be exceeded, is much lower than around anoxic aquifers. The model used in this study can also be used to calculate microbiological safe distances between the artificial recharge and the abstraction well. Model results, however, should be used as an indicative rather than as an exact value.

Modelling parameter estimation by tracer experiments in the porous aquifer of Ljubljansko polje

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Objective: Human activities in the area of the Hrastje waterworks of Ljubljana threaten groundwater quality. A numerical groundwater flow model was established for the wider area of the Ljubljansko polje aquifer. A lack of experimental data on solute transport leads to unreliability in the transport model and its predictions of pollution scenarios. The transport model needs to calculate reliable scenarios of pollution dispersion, which can only be achieved with the application of real transport parameters.

Methods: These could be provided from tracer experiments in the Ljubljansko polje aquifer. First, a small tracer test with potassium bromide was conducted in the Hrastje waterworks area, followed by a multi-tracer experiment (potassium bromide, uranine, microspheres and tinopal CBSX) in the broader area of the Ljubljansko polje aquifer. Tracer test design considers differences between pollutant spreading in the unsaturated and saturated zones of the aquifer. Therefore, the tracer injection was performed as spreading on the surface (injection to the unsaturated zone), as well as injecting directly into the saturated zone through observation wells.

Results: Only potassium bromide and uranine gave successful results. Both tracers indicate the dominant groundwater velocity of about 20 m/d. The tracer experiment with uranine has shown sharp differentiation in the field and relatively long retardation times. The dispersivity depends on the length of the flow path and varies from 10 m at short distances to 100 m at long distances.

Conclusions: Results of the multi-tracer experiment improved the flow and transport model. All together, this will enable better knowledge of the hydrodynamic conditions in the Ljubljansko polje aquifer, which will yield more effective measures for waterworks protection. Consistent implementation of these measures will improve the groundwater quality in the Hrastje waterworks.

On the Construction of Flowpath Vector Fields

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Objective: MODFLOW probably is the most used code for setting up groundwater models worldwide. Several software shells have been wrapped around MODFLOW, making it even more popular: Processing MODFLOW in Europe, VisualMODFLOW in Canada and GMS in the United States, just to name the most prominent products. Using these packages, several pre- and postprocessing steps are simpler to perform and the presentation of model results is visually more impressing. Nevertheless the connection with other programs is still sometimes awkward or impossible. A prominent example is that flowpaths or streamlines, calculated as post-processing, can not be transferred to GIS-programs, which are often used for data representation within application projects. In the paper a solution for this problem is given.

Methods: A software coupling with interfaces, written in MATLAB, is presented, which can be applied to produce flowpaths as vector fields from a MODFLOW model. The main task of flowpath calculation is performed by MODPATH, a MATLAB module transforms the results in a format which can be used by other programs. The details are outlined in the paper. Another task, which can also performed by a MATLAB module, is to transfer flowpath starting positions from Processing MODFLOW's PMpath to MODPATH.

Results: The software connection has been used during the interdisciplinary NASRI research project (Natural and Artificial Systems for Recharge and Infiltration) dealing with river bank filtration processes and during the KORA research project (Kontrollierter natürlicher Rückhalt und Abbau) dealing with natural attenuation processes in the subsurface. Examples of vector fields in final SURFER graphs are presented. SURFER is one of the most popular programs used for GIS and data representation in the geosciences.

Conclusions: Flowpaths as vector fields, used for an optimal visualization of groundwater flow in the subsurface, can be constructed for use in GIS programs. Model output can be presented together with maps or measured data fields. The advantage of the vector representation is that the graphic is scalable without loss of resolution. Another advantage of the described procedure is that flowpaths are obtained as one-dimensional line-elements. This allows the further treatment of one-dimensional transport and even reactive transport models along the flowpath. This opens the way to examine complex biogeochemical systems in combination with transport more easily.

Robustness of Microbial Treatment during Groundwater Recharge

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Objective: The hypothesis that travel time during sub-surface transport is related to surface area contact was evaluated for groundwater recharge systems. The hypothesis that microbial activity was related to surface area was also evaluated.

Methods: Both mathematical modeling and soil column experiments were done to evaluate the hypotheses. A hydrological analysis of the relationship between surface and travel time was done for common aquifer materials assuming different distributions of particle sizes. For a constant hydraulic gradient, the surface area was normalized to travel time. Soil column experiments were done with two different sizes of commercailly available silica sand sieved to a narrow particle size. Dextran was used as a model compound to simulate transformations of refractory organic matter during sub-surface transport. The columns were operated over a range of residence times to evaluate the relationship that microbial activity is a function of particle size. The results were verified using a biofilm model after microbial constants and biomass density were indepently determined.

Results: A relationship between surface area and travel time was determined for common aquifer materials. For a constant hydraulic gradient, the relationship does not show significant variations for aquifers materials consisting of silts, sands or gravels. When surface area is normalized to travel time, there is less than a factor of two variation in surface area for a given travel time assuming a constant hydraulic gradient. The results of soil column experiments support the hypothesis that microbial activity is a function of surface area. During the majority of sub-surface transport when substrate concentrations are low, the microbial density is low and diffusional mass transport resistance is negligible. Independent verification of microbial parameters during sub-surface transport was done and the microbial model was able to predict soil column performance without parameter fitting. Uniform substrate fluxes resulted in greater biomass accumulation as a function of surface area.

Conclusions: The robustness of microbial removal mechanisms during sub-surface transport during groundwater recharge has been observed around the world. The results of this study provide a potential explanation for the robustness of these removal mechanisms. Within the time scale of most groundwater recharge systems, the variations between surface and travel time are not significant enough to cause major variations in microbial treatment for common aquifer materias.

Case studies on water infiltration processes in the unsaturated zone with a multi-dimensional multiphase flow model

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Objective: Water infiltration in the unsaturated zone and its further movement to the groundwater table is of major importance for aquifer recharge concerning water quantity and water quality. If complex aquifer systems which consist of different layers, low permeable lenses and preferential flow pathes are considered, the flow and transport processes in the unsaturated zone are very complex and of course multi-dimensional, and they can considerably be influenced by small-scale heterogeneities.

The flow processes in the unsaturated zone are mostly modeled with a one-dimensional Richardson model concept in medium and large-scale domains. With this approach, lateral flow processes and their influences on the aquifer recharge can not be described in an adequate way.

Methods: Multi-dimensional two-phase flow models consisting of the phases water and soil air simulate the flow processes in the unsaturated zone and the groundwater with the same model concept and include the horizontal spreading of infiltrating water. Up to now, such model concepts have hardly been used for large-scale hydrological questions, but for small-scale problems, for example in the context soil remediation or local contaminant infiltration. A two-phase model concept is part of the modeling system MUFTE-UG. MUFTE stands for Multiphase Flow Transport and Energy model and contains different physical model concepts and discretization techniques for multiphase systems in porous and fractured-porous media. UG is the abbreviation of Unstructured grids, and this toolbox provides fast solvers based on parallel adaptive multigrid methods.

Small-scale heterogeneities of permeability fields can be generated with geostatistical methods.

Results: In this contribution, different case studies on water infiltration processes in the unsaturated zone and their further movement to the groundwater table will be carried out using the two-dimensional two-phase flow model of MUFTE-UG. The influences of different layers and low permeable lenses including effects of small-scale heterogeneities will be investigated for small and medium-scale domains and compared with simpler approaches.

Conclusions: Depending on the complexity of aquifer geology, we expect significant differences in the flow processes and the aquifer recharge between the two-dimensional two-phase flow model concept and simpler approaches.

Advanced well performance and aquifer test analysis required to obtain reliable aquifer and well performance hydraulic parameter values in a dual porosity aquifer: Examples from artificial recharge trials in South London

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Objective: The classic dual porosity characteristics of the Chalk aquifer of South London present both advantages and pitfalls to artificial recharge investigation interpretation. Perhaps the biggest pitfall comes from the common but inappropriate use of a homogeneous porous radial drawdown model to determine hydraulic parameters. In South London this would have led to derivation of aquifer storage coefficients that are magnitudes greater than true values and overestimates of the total recharge capacity of the South London area in error by a similar margin. Conversely, the fracture system sustains very high well yields (up to 30 Ml/d per well) that has the advantage of significant reduction in artificial recharge testing costs per Ml/d supplied compared to lower yield boreholes with poorly developed fracture networks. Providing sufficient and well designed aquifer test monitoring data are obtained, relatively simple straight line dual porosity aquifer analysis techniques can be applied to determine the effective fracture radius of a well, the fracture network transmissivity, the fracture network storage, and the critical parameter of matrix storage.

Results: Good case study examples from recent artificial recharge investigations in South London are presented to illustrate dual porosity hydraulics in aquifers and how to effectively analyse drawdown and draw-up responses.

Conclusions: Accurate matrix storage values determined from advanced hydraulic analysis are required to correctly calculate aquifer recharge scheme capacities in dual porosity aquifers. However knowledge of the ratio of fracture transmissivity to matrix transmissivity is also informative as experience in South London has shown that the matrix rather than the fracture network is prone to clogging during artificial recharge. Consequently aquifer testing data available prior to artificial recharge testing can be used to estimate the reduction in well performance of a well in response to clogging from artificial recharge injections. Similarly over-estimates of river depletion and derogation of other groundwater supplies can be avoided if dual porosity aquifer models are applied.

Simulation modeling of salient artificial recharge techniques for sustainable groundwater management

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Excessive exploitation of groundwater resources has resulted in groundwater lowering, with concomitant problems of land subsidence and saltwater intrusion in both developed and developing nations. Artificial groundwater recharge and rainwater harvesting have emerged as two basic techniques for sustainable management of shrinking freshwater resources. Numerical modeling is a vital tool for the quantitative analysis of groundwater systems, which is not subject to many of the restrictive assumptions required for analytical solutions. In the present study, an attempt has been made to explore some suitable artificial recharge techniques using simulation modeling for reversing the groundwater lowering in a groundwater basin of Kochi Prefecture, Japan. A transient, two-dimensional FEM-based groundwater-flow model was developed for this basin, which was successfully calibrated and validated. The validated groundwater flow model was then used to examine the efficacy of some feasible artificial recharge techniques. Based on the results of this study, two recharge techniques namely “subsurface barrier” and “river modification” are selected as promising remedial measures for depleting groundwater resources. The effect of the proposed subsurface barrier was found to be limited both in terms of areal extent and the extent of groundwater rise, but a weir of height 4.5 m from the dry period water level in a perennial river bordering the basin was found adequate to meet the current groundwater demand. However, the combined application of these two techniques is recommended in order to ensure long-term sustainability of the scarce groundwater resources.

NASRI

Abstracts

Investigation of the hydraulic and hydrochemical conditions in the infiltration zone during bank-filtration in Berlin

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Objective: The infiltration of surface water into the aquifer is restricted to the narrow stripe of shore, since thick layers of low-permeability organic mud inhibit the infiltration at greater water depths. The shore, however, is strongly clogged, because the surface water system is slow-flowing and resembles lakes rather than rivers. The clogging layer is therefore never scraped off, neither artificially or naturally. Due to higher contents of organic carbon and finer grained material, this zone is more reactive and plays a vital role in the elimination of potential water contaminants such as pathogens, nutrients, organic carbon and others. The aim of this study was to focus on the near-shore zone and investigate the infiltration process at the surface water-groundwater interface in detail in terms of both, hydrochemical and hydraulic processes.

Methods: Cores were taken in 1, 20 and 40 m distance from the shore at Lake Wannsee. The cores were described lithologically. Darcy experiments of the entire cores and core sections were undertaken parallel to sieving in order to derive hydraulic conductivities. The geochemical properties (organic carbon, inorganic carbon, cation exchange capacities, total and reducible iron and manganese contents, total sulphur content) of the cores were determined. Two cores were turned into columns run under similar conditions as in the field in order to understand the hydrochemical processes occurring in the first meter of flow. The extent of the organic mud was mapped at Lake Wannsee and slug and infiltration tests were conducted in a raster near the shore.

Results: First results of the ongoing work suggest that the hydraulic conductivities decrease with distance from the shore. The mud occurs from approximately 50 m distance from the shore. The hydraulic conditions are unsaturated on the first tenths of meters. The hydrochemical analysis of the near shore columns revealed more reducing conditions in the columns than in the groundwater below the lake, reaching as far as towards sulfidic conditions. This suggests that a re-oxidation may take place in the unsaturated parts of the aquifer. These preliminary results still require further validation.

Conclusions: The infiltration is restricted to areas uncovered by low-permeability mud close to the shore. These clogging zones are more reactive than the aquifer itself, due to higher proportions of finer grained and organic material. The hydrochemical conditions of the clogging layer seem to reach sulfidic conditions, whereas the groundwater below the unsaturated zone is aerobic again. This suggests a possible re-oxidation due to an input of oxygen to the shallow groundwater caused by strongly alternating groundwater-levels.

Evaluation of the hydrochemical conditions during bank filtration and artificial recharge in Berlin

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Objective: The objective of the study is to evaluate the hydrochemical conditions during bank filtration and artificial recharge, in particular with regard to the redox state of the system. Redox conditions are a crucial factor in bank filtration, since they affect the behaviour of various potential contaminants such as nitrate, sulphate, heavy metals, absorbable organic halogens and pharmaceutically active compounds (PhAC's). The aim is to identify and quantify the major hydrochemical processes occurring during the infiltration of surface water into the groundwater at 3 field-sites in Berlin.

Methods: Transects with piezometers oriented in flow direction were installed between surface water and an exemplary production well as well as inland of the production well. Monthly sampling over 2 years was conducted by the Berlin Water Company (BWB) and samples were analysed for physico-chemical properties as well as major anions and cations at BWB. In addition, selected wells were analysed for delta-^{34}S and delta-^{18}O of sulphate and delta-^{13}C of bicarbonate as well as for T/He to obtain groundwater ages.

Results: The redox conditions are more reducing at the bank filtration sites, mainly as a result of the longer travel times. They show a strong seasonality, in particular at the artificial recharge site, which is mainly caused by the seasonal temperature changes and the resulting differences in microbial activity. Rather than showing a typical redox zoning with more reducing conditions in greater distance from the surface water, the redox zones show a horizontal layering, with more reducing conditions in greater depth. This is believed to be an effect of the strongly alternating water-levels, caused by irregular pumping regimes. The hydrochemical data clarified that at the bank filtration site, the infiltrate becomes considerably older with depth in the aquifer. While a number of substances used more intensively in the past are present in higher concentrations in greater depth, younger sewage indicators dominate in the shallower bank filtrate. These finding are consistent with age dating results at the sites.

Conclusions: The bank filtrate undergoes hydrochemical changes during infiltration. The redox conditions are influenced by (i) operational factors, (ii) seasonal temperature changes affecting the microbial activity and (iii) travel times of the infiltrate. In addition, the bank filtrate is becoming increasingly older with depth, thereby reflecting the historical changes of the surface water composition with regard to some minor water constituents.

Degradation of microcystins under aerobic and anaerobic conditions

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Objective: Toxic cyanobacterial blooms occur worldwide in surface waters with microcystins as one of the most potent and frequently found group of toxins. When using surface water infested with toxic cyanobacteria as source for drinking water (e.g. via bank filtration) elimination must be ensured under all conditions.

Previous studies have shown that biological degradation is the most important elimination process for microcystins in porous media without significant clay content as it is usually used for bank filtration or artificial recharge. As part of the research project NASRI (Natural and artificial systems for recharge and infiltration) laboratory batch experiments are therefore conducted by the working group "environmental microbiology" of the Technical University Berlin in cooperation with the drinking water section of the Federal Environmental Agency (UBA). The aim is to study the kinetics of microcystin degradation under aerobic and anaerobic conditions with emphasis on the processes that lead to anoxic degradation of microcystins.

Methods: The first batch experiments are conducted with a crude extract of a mass culture of Planktothrix agardhii cultivated at the UBA's experimental field in Marienfelde (Berlin). Microcystins are extracted by repeated freeze-thawing a cell concentrate obtained by centrifuging the culture. After centrifuging the extract again it contains microcystins in concentrations of 50 mg/L amongst other water soluble cell properties. This centrifuged extract is then brought into contact with an inoculum derived from natural sandy bank material from a lake in Berlin with frequent cyanobacterial blooms (Lake Wannsee) together with a fresh sample of the cyanobacterial mass culture. One parallel is kept aerobic by allowing contact to the natural atmosphere, the other is held strictly anoxic under N_2/CO_2-atmosphere.

Results: The results obtained so far show complete degradation of microcystins under aerobic as well as under anaerobic conditions with more rapid degradation under aerobic conditions. Even under aerobic conditions however a lag phase of 2 days with only little degradation (10%) is observed. After the 2nd day, however, 99.9% of the microcystin present is degraded within 2 days.

Conclusions: As demonstrated by previous investigations microcystin degradation is possible under aerobic conditions. The lag phase observed has also been described before however without detailed explanation. In some cases no lag phase was observed at all. Further experiments concentrate on the reason for this lag phase which can be due to i) time needed for adaptation of the microorganisms to microcystin degradation, ii) the fact that microorganisms first degrade more easily degradable substances present (katabiolitic repression) or iii) N-limitation. Therefore experiments are conducted in presence of ammonia and easily degradable carbon sources under aerobic conditions. Anaerobic degradation of microcystins has not been demonstrated so far. Therefore further experiments concentrate on settings with sulphide reduced medium to ensure anaerobic conditions throughout the experiment.

Fate and Transport of Pharmaceutical Residues during Bank Filtration

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Objective: Bank filtration and artificial ground water recharge are important, effective, and cheap techniques for surface water treatment and removal of microbes, inorganic and (some) organic contaminants. However, its purification capacity varies and is limited for different contaminants. After detecting a number of pharmaceutical residues in groundwater samples from a bank filtration site in Berlin, Germany, the research on these compounds was focused on their transport behavior during the infiltration process. The investigations are a part of the interdisciplinary research project called NASRI (Natural and artificial systems for recharge and infiltration) that started in May 2002.

Methods: For this research two bank filtration sites at lakes Wannsee and Tegel in Berlin, Germany, were equipped with several monitoring wells. These so called transects were sampled monthly and analyzed applying solid-phase extraction, chemical derivatization and gas chromatography-masspectrometry (GC/MS) with selected ion monitoring (SIM).

Results: In these investigation six pharmaceutical residues were detected up to the μg/L-level in Berlin's surface waters. During the bank filtration process, the analgesic drugs diclofenac and propyphenazone, the antiepileptic drugs cabarmazepine and primidone and the drug metabolites clofibric acid and 1-acetyl-1-methyl-2-dimethyl-oxamoyl-2-phenylhydrazide (AMDOPH) were observed to leach from the surface water into the groundwater aquifers. They also occur at low concentrations in receiving water supply wells. The antiphlogistic drug indometacine and the blood regulating drug bezafibrate have also been detected at concentrations up 100 ng/L in the surface water but they are efficiently removed and were not detected behind the first two monitoring wells.

Conclusions: Recapitulating the results, bank filtration is able to the decrease concentrations (e.g. of diclofenac, carbamazepine) or even to remove some of the pharmaceutical residues (e.g. bezafibrate, indometacine). Moreover, the antiepileptic drug primidone was identified as being an excellent tracer of sewage contamination's in surface and groundwater.

Transport and Attenuation of Antibiotic Residues during River Bank Filtration in Berlin, Germany

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Objective: Bank filtration is an important, efficient and low-cost technique for surface water treatment and well-proven for removal of microbes, inorganic and some organic contaminants.

In an interdisciplinary project, entitled "Natural and Artificial Systems for Recharge and Infiltration" (NASRI) the fate and transport of some new emerging contaminants during bank filtration are investigated at lake Tegel and lake Wannsee in Berlin, Germany.

Methods: Within this project, different surface and ground water samples were analyzed monthly for 18 antibiotic substances. A multi method was developed for the determination of trace levels of antibiotics from various prescriptions classes (macrolide antibiotics, sulfonamides, fluoroquinolones, penicillins and tetracyclines) in water. The samples are analyzed by solid-phase extraction and high-pressure liquid chromatography-electrospray-tandem mass spectrometry (LC/ESI-MS/MS).

Results: Six antibiotic substances, including the macrolides clarithromycin, roxithomycin and erythromycin (measured as metabolite dehydro-erythromycin), the sulfonamide sulfamethoxazole, the sulfonamide synergist trimethoprim and the lincosamide clindamycin, were detected in Berlin surface water. These residues are important for bank filtration, which is frequently used for drinking water production in Berlin. The studies within the NASRI project have shown that bank filtration was able to remove trimethoprim, clarithromycin and roxithomycin efficiently and to decrease the concentrations of clindamycin and dehydro-erythromycin significantly. Sulfamethoxazole was generally found at higher concentrations in surface and ground water than all of the other compounds. It is the only antibiotic that also occurs at significant concentrations (mean value of 8 ng/L) in the receiving water-supply wells.

Conclusions: Generally, antibiotic residues are only found at trace-levels in the water-supply wells. Thus, bank filtration has proven as being an efficient method for the removal of most of the antibiotic residues by natural attenuation. It can be a useful tool for the pre-treatment of contaminated surface water in drinking-water supply.

Modelling transient horizontal redox zoning at bank filtration

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Objective: Modelling is applied to a bank filtration site at the east bank of lake Tegel (Berlin, Germany) used for drinking water supply. Water infiltrates into the aquifer at the shore of the lake, passes through a sandy glacial Quaternary aquifer and is extracted by a well gallery 100 m from the shore. At the first part of the passage the aquifer is unconfined, whereas in the second part (near the wells) the aquifer is horizontally divided by a glacial till. Part of the water extracted from the gallery comes from below the lake, infiltrated at the opposite (western) shore. Another part comes from the landside, east of the extraction gallery. 13 observation wells are aligned as a transect between the bank and Well No. 13, roughly following the flow paths. An appropriate hydraulic and geochemical modelling approach has been developed in order to....

Methods: Hydraulic modelling: The groundwater around lake Tegel is extracted by 8 well galleries, resulting in abstraction dominated watersheds. Gallery West is modelled with MODFLOW using a steady-state watershed as boundary condition calculated by another flow model. Flow paths are determined and the extent of the glacial till is hydraulically conditioned by means of instationary hydraulic heads. A transient water balance is calculated using MT3DMS.

Transport modelling: Travel times and mixing are modelled with MT3DMS using B-, Cl-, Isotopes, Temperature and AMDOPH as tracers. Temperature modelling is crucial as it affects reaction velocities and also reveals short-term flow conditions as it is measured daily.

Geochemical modelling: Based on the hydraulic and transport model, a multi-component reactive transport model PHT3D is used to simulate the relevant redox processes. Infiltrated water is rapidly depleted from O_2 and NO_3- reacting with DOC as well as sedimentary POC leading to Mn and Fe reduction deeper and further downgradient. A raised O_2 input at the free groundwater surface is induced by entrapped air because of an oscillating water table. This is modelled by a fictive O_2 oversaturated recharge at the top. The transient redox zones are modelled from the transient interaction of infiltration, groundwater dynamics, temperature and O_2 input.

Results:

Part of the water extracted east of lake Tegel infiltrates at the opposite site of the lake.

The extent of the glacial till could be specified.

Conservative tracers and redox conditions could be modelled with the current approach.

Temperature modelling is crucial as it affects reaction velocities and also reveals short-term flow conditions as it is measured daily.

Estimating of the solute transport parameters retardation factor and decay coefficient of pharmaceutical residues using the program visual CXTFIT

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Objective: Currently, many investigations are carried out to minimize the risk of break through of critical substances into the raw water for drinking water supply. One part of these studies is the determination of the transport behavior of pharmaceutical residues in test sand filters, so called enclosures, equipped with sampling points at various depths.

Methods: Using this equipment, the breakthrough curves were determined for carbamazepine, primidone (both antiepileptic drugs), clofibric acid (a metabolite of blood lipid lowering agents), diclofenac, ibuprofen (both analgesic drugs) and for sodium chloride, used as a conservative tracer. The evaluation of the retardation and decay was performed by using the software Visual CXTFIT.

Results: It was observed that the transport of carbamazepine was two times longer than that of primidone. After a month the time delay between carbamazepine and the tracer sodium chloride is 15 days.

Conclusions: It can be concluded that the determination of retardation factors and decay coefficients in an enclosure is a good method for the prediction of the transport behavior of dissolved substances in the groundwater and to estimate the phase shifts between different substances or conventional tracers.

Hydrogeochemical Changes of Seepage Water during Artificial Recharge of Groundwater in Berlin, Germany

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Objective: The present study is aimed at (i) identifying the transient saturated and unsaturated hydraulic regime below a recharge pond and (ii) to characterize and understand the dynamics of hydrogeochemical changes of the seepage water which result from changing hydraulic conditions and from seasonal temperature variations.

Methods: A detailed monitoring program was initiated for a duration of one year. Therein, the pond water, groundwater and water extracted from four ceramic suction cups located in different depths below the pond were analysed for major ions, dissolved organic carbon (DOC) and dissolved oxygen (DO) on a weekly base. Water contents and pressure heads at two different depths below the pond were recorded continuously by TDR (Time Domain Reflectometry) probes and tensiometers respectively. The temperature of the pond water and the groundwater as well as the groundwater level below the pond were continuously measured on a daily base with data loggers.

Results: During recharge the hydraulic regime immediately below the pond is characterised by cyclic changes between saturated and unsaturated conditions.,. These changes, which occur during each operational cycle, result from the repeated formation of a clogging layer at the pond bottom. The hydrogeochemical analyses shows that during the summer period nitrate and manganese reducing conditions dominate beneath the pond as long as water saturated conditions prevail. Iron and sulphate reducing conditions occur in zones of lower hydraulic conductivity. The formation of the clogging layer leads to a steady decrease of the infiltration rate, which ultimatively causes a shift to unsaturated conditions below the clogging layer. Atmospheric oxygen starts then to penetrate from the pond fringes into this region, leading to (i) the re-oxidation of the previously formed sulphide minerals and (ii) an enhanced mineralisation of sedimentary particulate organic carbon. The latter leads to an increased carbonic acid production and subsequent dissolution of calcite. During winter, dissolved oxygen is not entirely consumed during saturated conditions as very low surface water temperatures are leading to a decrease of microbial activity. During unsaturated conditions DO concentrations below the pond increase. Simultaneously an enhanced inorganic carbon production is observed but not as intense as during the summer period. During both saturated and unsaturated conditions, nitrate appears to be produced while the seepage water travels from the pond to the groundwater monitoring well.

Conclusions: This study shows that during the summer period, the spatial and temporal development of different redox environments are not only considerably impacted by the different hydraulic situations below the pond, but also by non-uniform flow conditions due to the heterogeneity of the sediment's hydraulic properties. During the entire winter period, the redox-state below the pond is characterized by aerobic conditions and the different hydraulic situations are only affecting the availability of oxygen. As a site effect of decreased biodegradation rates, nitrification of sedimentary bound nitrogen can now be observed because nitrate is not immediately consumed, as it is the case during summer.

Statistical description and analysis of a bank filtration system

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Objektive: This statistical analysis of the bank filtration system at Lake Tegel is part of the NASRI project of the KompetenzZentrum Wasser Berlin (2001-2005). The main objectives were to uncover existent patterns of indictors during bank filtration and to verify connections between the different variables collected in the framework of the project. Special attention was paid on the redox zones and the reduction of measured pharmaceuticals.

Methods: To uncover where the different redox reactions take place, a cluster analysis using inputs and products of the redox reactions as clustering variables was performed. Then, running a regression analysis the reduction of the pharmaceutical Carbamazepin dependent on the estimated travel time, temperature, electric conductivity and UV254 is analyzed. By performing the regression separately for every redox zone formed by cluster analysis, the influence of proceeding redox reactions on the reduction of Carbamazepin should be made visible.

Results: Four redox zones whose boundaries are moving downwards during winter time could be identified through cluster analysis. In the first two zones O_2 and NO_3 are reduced, whereas in the third and fourth zone Mn, Fe and NH_4 are appearing in rising concentrations. A significant influence on the reduction of Carbamazepine could only be proved for the estimated travel time.

Conclusions: Since in this analysis the travel time of filtrated water is the only influential factor on the reduction of the pharmaceutical Carbamazepine, no statements on what is happening with this pharmaceutical during bank filtration can be made. Further investigation is needed.

Simulating bank filtration and artificial recharge on a technical scale

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Objective: The UBA's experimental field on the outskirts of Berlin offers a unique possibility of simulating bank filtration, artificial recharge and slow sand filtration on a technical scale. The aim of the paper is to introduce this site to scientists concerned with water infiltration processes for future cooperation.

Methods: The site consists of a storage reservoir (pond) with a water volume of about 3500 m^3 with an adjacent artificial aquifer consisting of fine and coarse gravel. Additionally the surface water can be conducted into 4 infiltration basis each with a square basal surface of 100 m^2. Two of these basins are sealed by concrete at the bottom with a sand depth of 0.8 m (here infiltration can be regulated by 3 parallel drainages) and two have a direct contact to the underlying sediments and can be operated as aquifer infiltration ponds. For smaller scale experiments three enclosures with a surface area of 1 m^2 and coarse sand filling are installed in one of the infiltration basins. The whole site is separated from the surrounding aquifer by a layer of clay thus forming an independently operable hydraulic system so that experiments with toxic substances can be carried out without adverse effects on the environment. Additionally large scale columns with a total length of 30 m can be used for longer term groundwater transport simulation. A variety of physico-chemical parameters (e.g. pH, temperature, oxygen, redoxpotential, electrical conductivity, TOC, total bound nitrogen (TN_b) as well as fluorescence for determination of algal biomass) can be measured continuously and observed online. For characterization of groundwater flow tracer experiments have been carried out. Currently the site is being used by the working groups of the interdisciplinary NASRI (Natural and Artificial Systems for Recharge and Infiltration) project for experiments on the elimination of a variety of substances (cyanobacterial toxins, viruses, bacteria, drugs, organic trace compounds) during sediment passage.

Results: As the aquifer sediment is gravel the travel times for the bank filtration passage range from a few days to a maximum of 3 weeks depending on the pumping rates at the drainage pipes. In the enclosures and infiltration ponds contact times of a few hours can also be simulated. Usually the redox conditions are strictly aerobic. By addition of nutrients to the water reservoir anoxic to anaerobic conditions can also be induced. In the large scale columns contact times of up to 3 months can be simulated.

Conclusions: The UBA's experimental field site can be used for technical scale experiments on elimination of substances that are hazardous to environment or health by sediment passage that can not be carried out otherwise. The setting focuses on short travel times as these are common along many river bank filtration sites. By controlled variation of flow velocities and redox conditions the site can be adapted to a large variety of settings.

Fate of bulk organics during bank filtration and groundwater recharge of wastewater-impacted surface waters

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Objective: This research study is part of the NASRI project of the Center of Competence for Water Berlin. As part of this project the TU-workgroup studies the removal of bulk organics (dissolved organic carbon (DOC), effluent organic matter (EfOM)) at three field sites with different characteristics and in two soil column systems. Since the processes during infiltration are very complex, it is difficult to predict bulk organic composition in the bank filtrate or to estimate important factors of influence for the degradation. There are indications that bank filtration under anoxic/anaerobic conditions provides different removal of organics compared to aerobic bank filtration. In addition to the redox state, factors such as retention time, temperature, initial degradable carbon concentration, soil properties, and hydrogeological conditions may affect the final concentration. The factors of influence and the fate of these bulk organics are studied in the field and in long-term experiments.

Methods: For the field monitoring three field sites in Berlin were chosen, one artificial recharge site and two bank filtration sites. A significant influence of treated wastewater on the surface water is given at all field sites. Soil column studies were conducted on a 30 m long column system, which was operated with original surface water. This column system was used for long term experiments (retention time = 30 d) on a simulated one-dimensional aquifer. Furthermore, 9 columns (length 1 m, retention time 6 d) were operated to study the importance of different redox conditions on the degradation of bulk organics. The monthly analytical program of the field and column samples is comprised of DOC, UVA, and LC-OCD.

Results: The long-term monitoring of the surface water confirmed stable concentrations of DOC in the lake and some seasonal changes. The residual of the dissolved organic carbon after infiltration is comparable under aerobic (groundwater recharge) and anoxic (bank filtration) conditions. Statistical analysis of the kinetics reveals that aerobic degradation seems to be faster than anoxic or anaerobic degradation. Aerobic field wells and column tests show a fast DOC-degradation within a month, while anoxic conditions appear to require up to 6 months. The results of the LC-OCD analysis show clearly that the fraction of polysaccharides is completely removed very fast at all field sites (only minor filtration effects in abiotic column) whereas other fractions (humics, humic hydrolysates) exhibit only partial removal. The results of the soil column experiments support these findings and reveal more details about the redox sensitivity of bulk organic removal.

Conclusions: Aerobic and anoxic underground conditions during infiltration can lead to about the same residual DOC but the study indicates significant differences in the kinetics of DOC-removal depending on the redox conditions. The LC-OCD analysis reveals that the change in character is comparable under different redox conditions and that the fraction of polysaccharides is removed very fast.

Bakterien

Regional issues and artificial recharge case studies

Abstracts

Basin artificial recharge and groundwater mound formation: A case of the Rokugo alluvial aquifer, northern Japan

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Objective: We discuss the formation (growth and decay) of groundwater mound induced by basin artificial recharge concerning typical groundwater cycle in the aquifer of alluvial fan.

Methods: Field observation and measurement is performed by using artificial recharge basins, piezometers and observation wells.

Results: Infiltration rate is 10 - 20 centimeters per hour and raising amount of water table is ca. 3 meters.

Conclusions: Basin arificial recharge is effective in the area in Japan where has three key words such as alluvial fan, paddy field and snowfall.

Identification of groundwater recharge conditions in shallow crystalline basement rock aquifers of the southwestern Nigeria

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Objective: Groundwater recharge conditions in the crystalline Basement of southwestern Nigeria are a crucial factor for understanding the groundwater flow regime. It is therefore the overall aim of this research to get adequate information on groundwater isotopic and chemical characteristics with possible origin dynamics and infiltrating conditions.

Methods: For the purpose of the present study several hand-dug wells and some boreholes (tapping groundwater at relatively deeper level) have been sampled for chemistry and stable isotopes. Temperature, pH, electrical conductivity (EC) and alkalinity test were measured in the field using portable (battery-operated) meters. As a reference to groundwater of the study area actual precipitation have been sampled from two different stations for chemical as well as isotope analyses. Analyses of the stable isotopes were jointly performed at the Isotope Geochemistry Laboratory, Monash University, Australia and Centre for Environmental Research (UFZ), Leipzig-Halle, Germany. Stable isotopes ratios are expressed as delta in per mil (i.e. δ‰) relative to VSMOW (Vienna Standard Mean Ocean Water). The isotope precision of measurement based on VSMOW is ±0.15 ‰ for ^{18}O and ±1 ‰ for ^{2}H.

Results: Radiometric dating indicates that the Basement rocks of southwestern Nigeria is polycyclic and has responded to several tectonic events with differing intensities from Archean to late Proterozoic (Pan African). Results of the present study shows groundwater isotopic signature range from -19.2 to -11.5 ‰ for δ2H (with mean of -15.7 ‰) and -3.6 to -2.2 ‰ for δ18O (mean: -3.0 ‰) as against rainwater (δ^2H: 0.8 ‰, $\delta^{18}O$: -1.0 ‰). A plot of δ^2H against $\delta^{18}O$ show that the isotopic composition of groundwater cluster closely around a regression line defined by the equation: $\delta^2H = 8.6\ \delta^{18}O + 10$

This is in agreement with the meteoric line of Dansgaard (1964) for the northern hemisphere and almost falls perfectly along the Mean Meteoric Water Line of Craig (1961) except for the different gradient. The majority of the water samples are having deuterium excess less than 10. This was interpreted as indicating similar recharge conditions for the groundwater of this area and that mainly from precipitation. The low deuterium excess in the groundwater of the study area are also indications of enrichment by evaporation.

Conclusions: The knowledge of the groundwater infiltration conditions are crucial to quantifying recharge. The groundwater infiltration conditions are indicated by isotope signal of samples from the basement/weathered regolith aquifer beneath the study area. The alignment of the groundwater samples with the global Meteoric Water Line (MWL) underlines their meteoric origin.

The “careos alpujarreños”. A historical example of artificial recharge previous to century XIV applicable to the century XXI

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Objective: A study of an ancient system of artificial recharge implanted by Arabs in the South face of Sierra Nevada has been carried out. The system was designed to make use of the defrosting water coming from the mountain range and to direct it to the aquifers by means of drains known as "acequias de careo".

Methods: The work has had an important field component and a summary of historical chronicles.

Results: The systems of drains have been reconstructed, appreciating that great part of them agrees with the existing ones at the present time. The system implanted by Arabs of recharge of aquifers by means of drains implies that already the Arabs had a developed mentality for the artificial charge of Aquifers.

Conclusions: Although the Arabs had a polished and developed technique, specially as far as an organization and a fare distribution of the benefits, the application of SAT techniques can considerably improve the effectiveness of these pioneering facilities. It is possible to emphasize that the advantage of the water of defrosting for the artificial charge by means of systems of superficial drains can be implanted in diverse mountain ranges with irrigations installed in the mountain faces, as it can be some sectors of the Andes and the Himalayas.

Investigations of alternative filter materials for their application using slow sand filtration

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Objective: In the subproject "Limitations of slow sand filtration, possibilities of technical modifications and adaptation to local conditions", as part of a joint research project of the German ministry of education and research (BMBF), alternative low-cost filter materials will be investigated in laboratory scale experiments as well as in larger scale experimental facilities for their application using slow filtration.

Methods: Laboratory columns (length: 1 m, diameter: 0.2 m) were used as a model system of slow filtration with pre-filter and slow filter. The alternative slow filter materials crushed recycled glass, coconut fibre and pumice were investigated to test how different climatic conditions and a bad raw water quality (DOC, ammonium) affect their purification efficiency.

A well examined filter sand was used as reference material. The tests were carried out at three different temperatures (5 – 10°C, 20°C and 30°C). Coconut fibres were tested in comparison with gravel as well as an alternative pre-filter material. In a half-technical outdoor test plant (size of basins: 4 m^2) investigations on the influence of operating conditions of slow filters (filter speed, continuous or intermittent operation) on the cleaning efficiency are being carried out at the moment. In these investigations the filter materials crushed recycled glass, coconut fibres and reference sand already tested in the column experiments are used.

Results: The analysed parameters concentrate on the processes degradation (nitrate, nitrite, ammonium, sulphate, DOC, TOC) and filtration/sorption (turbidity, particulate-bound heavy metals). The results of the column experiments showed differences in the purification efficiency of the investigated filter materials depending on temperature and parameter. Compared to the gravel pre-filter the coconut fibre pre-filter e.g. better absorbs peaks of turbidity. The slow filtrates showed no great differences in turbidity. Especially at the beginning of the filter operation the coconut fibre is characterized by an increased organic output and an oxygen reduction at higher temperatures. The sand filter showed the highest head loss under all temperature conditions. Compared to the other tested slow filter materials the crushed recycled glass had the lowest elimination of heavy metals.

Conclusions: The results of the different investigations completed with literature data will allow an assessment to be made for the application of the alternative filter materials under defined conditions (temperature, raw water quality). The summary of these results can be used by engineers as a practical guideline for choosing suitable filter materials under the given local conditions.

Evaluation of the strategies for the re-equilibrium of the groundwater balance of an overexploited aquifer (Prato, Italy)

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Objective: The aim of this study is to accurately understand the hydrologic mechanisms effecting the recharge of an overexploited aquifer, such as the Prato (Tuscany, Italy) alluvial fan body, in order to evaluate strategies for the re-equilibrium of the groundwater balance. The Prato aquifer plays a key role for the water supply of the whole Pistoia-Prato-Florence urban area which counts 1 million of inhabitants for a total demand of water of more than 100 millions of meter cubes per year, for civil uses. A strong depletion of groundwater resources has been recorded over the past 50 years.

Methods: Several field tests such as piezometric survey, river infiltration tests and geophysical survey, along with continuous monitoring of the hydraulic heads, spread all over the area, have showed that, especially in the northern part of the plain, groundwater flow lines are directed towards the river, with rather low values of hydraulic conductivity occurring. A series of actions have also been taken previously, acting both on the input and the output terms of the groundwater balance equation, such as: improvement of river bed infiltration, as an essential contribution to the aquifer recharge, reducing abstractions for civil uses by differentiating public aqueduct water supply using surface water resources, complete pipeline interconnection and contribution from the Florence aqueduct, supplied by the Anconella-Arno plant. Following these actions the recharge of the aquifer have not improved significantly therefore new interventions have been planned to be taken for the re-equilibrium of the water balance.

Results: As a tool to verify and integrate these aspects a physical model has been developed and tested both in steady state and transient conditions. A new set of activities will be the input for the model, such as full capacity employ of the industrial aqueduct to enhance re-use and recycle of treated wastewater for non civil uses, reduction of uncontrolled abstractions and an Artificial Storage and Recovery (ASR) trial plant, planned to be developed on the next 12 months. A physical model simulation on steady state conditions of the planned ASR trial plant have already been performed confirming that the recharge system, especially in the northern part of the plain, requires further investigations. The results of the artificial recharge experimental programme will contribute significantly also to understand the natural recharge mechanisms, and it will be one of the key input for the transient model simulation.

Conclusions: Given the complexity of the recharge mechanisms, the physical model of the aquifer will be the tool that will allow to integrate and quantify all the elements of the system in order to point out the most effective strategy for the re-equilibrium of the groundwater balance of the Prato aquifer.

Evaluation of Infiltration Velocity Changes Induced by Sediment Accumulation on the Artificial Infiltration Basin: a case study at Pingtung Plain, Taiwan

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Artificial recharge of groundwater using infiltration basin at Wanlong Farm, Pingtung Plain, Taiwan, the purpose of the study program is to gain a better understanding of recharge system, infiltration velocity and added groundwater amount after conveying surface water to the infiltration basin.

From the designed full scale excavation area with the maximum amount of water needed to maintain a constant water level in the basin estimated to be 10,000 CMD, water supply was performed for 17 days, 14days was the normal recharge test, the other 3 days was clay added test, an average discharge of water supply was 10,000 CMD. The water level was kept at 1.7m, and average infiltration velocity was 15.2 m/day, after the silt sediment added test, the infiltration velocity was declined from 15.2m/day to 5.3m/day. The clogging is the main factor of the infiltration velocity reducing from the study. Using the soil characteristic curve by the pressure plate to find out fine sediment penetration depth is greater than 35 cm in a gravel filter.

The use of grain size filter has been designed a good performance during the operation of groundwater recharge in terms of sediment trap efficiency and maintain the permeability of underlying aquifer.

Groundwater recharge tests in NW Peloponnese's aquifer system (Greece)

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During the last decades, overpumping combined with prolonged dry periods lowered the groundwater level in Greece. Aquifer recharge is an environmentally acceptable solution and one supplemental means to restore deficient water balance.

This paper presents the results of groundwater recharge experiments of the aquifer system in the NW Peloponnese, through deep boreholes. Average annual rainfall during the past 30 years is 662 mm. Geologically, the area consists of Plio-Quaternary and alluvial deposits (conglomerates, clays, sands or sandstones), which form one multiple aquifer system. In northern part carbonate and flysch formations crop out.

Groundwater recharge experiments was carried out, through seven boreholes, during 2002. The depth of boreholes was greater than 180 m. The main objective of this project is to determine the feasibility, durability of the proposed aquifer recharge type. A preliminary hydrogeological study was carried out in order to determinate hydraulics parameters, groundwater quality and zones where groundwater recharge would be most beneficial to the aquifer system. The winter runoff of torrents and water from springs was the main source of recharge water used in the experiments, and it was transferred to each site via the existing irrigation canal network, without any treatment.

During the entire recharge period, the total volume of recharged water in seven boreholes was 137,000 m^3. The water level in the test boreholes was rising after the end of recharge experiment over 500 m from recharge boreholes. The maximum rise of the groundwater level at the end of the 63-days experiment was 45 m and the minimum 3.26 m.

The investigations have shown that the groundwater recharge through deep boreholes is one of the options available for increasing the groundwater reserves in this area. It can be concluded that this method is feasible, inexpensive and no specialized engineering works are required.

Experiments provided useful guidance with reference to setting up of a field test, data monitoring and analysis, which can be applied to other regions with similar conditions.

Improvements in wastewater quality from soil passage using infiltration galleries: case study in Western Australia

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As the demand for groundwater resources increases in semi-arid regions, managed aquifer recharge systems are becoming an increasingly practical option. In Perth, Western Australia, covered infiltration galleries are being trialled to enhance the percolation of secondary treated wastewater to allow water quality improvements to occur. The aim of this research is to investigate the aquifer characteristics controlling hydraulic residence times and water quality improvements (i.e. pathogen die-off rates; removal of chemicals of concern) as required for effective wastewater treatment.

Secondary treated wastewater is discharged at roughly 25 KL/day into a network of slotted pipes within buried trenches that contain either gravel or high void space plastic infill. The top and sides of the galleries are covered in geotextile material, while the base is an open interface several metres above the water table. One pumping well operates continuously down-gradient to control the direction of groundwater flow away from the infiltration galleries. A series of piezometers between the galleries and the pumping well allow us to monitor flow directions, conduct tracer tests, and perform in-situ microbial survival experiments.

The initial stages of this project have focused on the hydrogeological characterisation of the field site and performing infiltration tests in the sandy, unconfined aquifer. Infiltration tests conducted using a double-ring infiltrometer reveal suitably high rates of infiltration (70 times higher than the discharge rate), and only minor evidence of clogging after several hours. A simulation of the groundwater flow system has been developed using MODFLOW linked to a particle tracking code for predicting travel times in the aquifer. The model has allowed us to investigate the effects of hydrogeological parameters, well design, and the pumping rate to aid future planning and implementation. It is anticipated that water recovered from the pumping well will be suitable for non-potable reuse.

Variability and scale factors in artificial recharge from the Deccan basalts of India: a case study from Kolwan valley of Pune district in Maharashtra, India

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Objective: To describe groundwater behaviour on scales ranging from a check dam to a river basin in the Deccan basalt area of central-west India. To understand the inhomogeneity in factors controlling recharge to basalt aquifers, especially artificial recharge using spreading techniques.

Methods: Water resources development in the Kolwan valley (Walki river basin) from Mulshi taluka of Pune district in western India, is strategised on three scales. These three scales are compatible with the scales on which artificial recharge measures are undertaken in India and can be described as:

Construction of masonry and earthen checks constructed for harvesting runoff and spreading it over the surface, in anticipation of recharge to groundwater during the dry season.

A microwatershed is a small catchment of less than 20 km^2 area, considered as primary units for watershed development, wherein several individual structures, as above (check dams, commonly called percolation tanks), are located.

Several microwatersheds form a part of a small river basin that may cover areas of order of 100 km^2 form the more regional unit. Watershed management of several microwatersheds as well as construction of larger weirs and water impounding structures constitutes what is commonly referred to as river basin management.

Results: Recharge structure scale: The upstream check dam in Chikhalgaon village fills up rapidly after the onset of monsoon. It takes a few days, perhaps even a few hours, for the three check dams to fill up. They continue to top over throughout the rainy season, and hence, remain at flood level or maximum level for a period of over 100 days. In some 70 days after the cessation of rains, two of the check dams to completely empty out (no pumping) through a combination of infiltration, evaporation and some leakage. The third check dam holds water till mid February as it falls within a groundwater discharge zone. Microwatershed scale: Small checks are usually constructed along streams in microwatersheds (about 10 km^2 in area), in the form of masonry or earthen structures that are built with the intention of facilitating recharge or harvesting runoff. Water is lifted generally from structures built on the main river course (called Walki) and not from the check dams built on the microwatershed scale, although this is not adhered to generally as a rule. Preliminary data and observations clearly indicate that not all of these structures facilitate recharge because some of them are constructed in natural groundwater discharge zones where groundwater levels in the aquifer in the vicinity of the dam remain higher than the stage height of water in the dam. However, if 2 or 3 such structures are built, groundwater recharge is likely to result from one or two of such structures. River basin scale: The Walki river basin receives high rainfall, although it is quite variable, the normal rainfall ranging from as much as 2600 mm per year in the upper reaches of the basin to as less as 1300 mm in its lower reaches. The regional groundwater flow pattern follows the general topography, draining towards the river channel. However, embedded in

this regional pattern are local groundwater flow patterns picked up at the microwatershed and recharge structure scales. Land-use across microwatersheds of the river basin is quite different in response to local conditions, artificial recharge measures often influencing drastic changes in cropping pattern

Conclusions: There is a great diversity in hydrogeological conditions in the Kolwan valley and this is clearly evident from the results of the study on artificial recharge on three different scales. It is interesting to note further, that although understanding the processes of recharge on the three scales is not simple, the effects, both direct and indirect, from watershed development programmes are quite clear from the studies on the three scales. Broad water budgets on the three scales are being attempted and will be described in the detailed paper along with the results from a socio-economic survey that will help correlate augmentation of recharge with changes in livelihoods of people from the Kolwan valley.

Recharge Augmentation Through Percolation Ponds for Sustainable Irrigation Water Supply In Hard Rock Areas – A Case Study

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Objective: 1. To study the beneficial impacts of a percolation pond constructed in hard rock terrain in Tamil Nadu, India, where indiscriminate withdrawal of limited ground water resources has resulted in considerable decline of ground water levels and de-saturation of aquifers.

2. To evaluate the efficacy of percolation ponds as cost-effective ground water augmentation structures in areas underlain by crystalline rocks to ensure sustainale irrigation water supply.

Methods: 1. Collection and analysis of data pertaining to performance of wells and cropping pattern in the area prior to and after construction of a percolation pond as a pilot project by Central Ground Water Board under 'Central Sector Scheme for Recharge to Ground Water', aimed at popularising cost-effective technologies for ground water augmentation.

2. Quantification of beneficial impacts of construction of percolation pond.

Results: The analysis of field data collected after one year of construction of the structure indicated.

1) Increasing in pumping duration of irrigation wells by 14 to 22 percent per cropping season.

2) Increase in number of pumping days by 31 to 61 percent per season.

3) Increase in area irrigated by as much as 60 percent.

Conclusions: 1.Percolation ponds, suitably designed and constructed at strategic locations after detailed field investigations are effective in increasing the sustainability of ground water abstraction structures in hard rock areas due to augmentation of ground water resources.

2) When constructed in combination with other artificial recharge structures as a whole, percolation ponds could be of great help in arresting the adverse environmental impacts of over-exploitation of ground water resources, especially from weathered and fractured hard rock aquifers of very meagre ground water potential.

Experiences of Capturing Flood waters for Artificial Recharge of Groundwater in North China

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The purpose of this paper is to summarize experiences of capturing flood waters for artificial recharge of groundwater in arid and semi-arid areas in north China. Two running cases, Huangshuihe artificial recharge system in coastal area and Luohe artificial recharge system in inland area, were studied. Many works were used to capture flood waters of seasonal rivers, such as surface reservoir, barrage, underground dam, infiltration well, infiltration trench and so on. Combination of surface reservoirs and aquifers increased the quantity of groundwater resources and improved the environment. For example, the groundwater quantity in Huangshuihe increased 11~60 million m^3/a. However, some problems occurred. Infiltration capacity of riverbed in Huangshuihe decreased half because of clogging. Groundwater level in Luohe rose so high that stabilities of underground construction and high building foundation were threatened. The quality of aquifers deteriorated as the quality of recharge sources was not good enough. Problems occurred because maintenance of artificial recharge systems had not been managed well. Standardized projects are suggested on future artificial recharge systems in the middle way of 'south-north water transfer project' so that systematic experiences and theory can be gained and spread widely in China.

The Use of Aquifer Reinjection as a Low Impact Groundwater Investigation Tool – a case study from the Pilbara Region, Western Australia

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Objective: The case study presents an innovative use of aquifer reinjection as a low impact groundwater investigation tool. The Marandoo Iron Ore mine is bounded by National Park in an area of ecological and cultural sensitivity within the Pilbara Region of Western Australia. To assess the dewatering requirements and impacts of mining below the water table required an extensive investigation of the hydrogeology of the orebody and adjacent aquifers. A program involving prolonged aquifer pumping with reinjection has been adopted as a low-impact method of temporarily stressing a sensitive groundwater system.

Methods: The program has involved prolonged pumping from bores on the mining lease with re-injection of discharge into an adjacent dolomitic basin aquifer. An extensive monitoring network has been managed with the aid of groundwater loggers. The approach was adopted because it: a) facilitates a large-scale "reverse" hydraulic test in the national park without the risk of aquifer drawdown impact; b) conserves the fresh groundwater resource and prevents the unseasonal discharge of water to ephemeral drainage; and c) allows the technical feasibility of aquifer re-injection as a water management option to be assessed. The program and infrastructure were designed with the objective of 60 days continuous operation.

Results: The testing program will be completed by end 2004. The trial will provide important findings regarding a) the degree of interconnection between the major aquifers and implications for mine dewatering requirements; and b) the degree of interconnection between the shallow ecosystem dependent groundwater system and the deeper bedrock aquifers. Findings regarding the technical aspects of reinjection under prolonged mine dewatering discharge conditions will be described including the effective use of a simple in-bore device for the management of air entrainment. The extent of "permanent" clogging related to introduced sediment, chemical and biological encrustation – as assessed at the completion of the trial by multi-rate testing, CCTV surveys and chemical sampling will also be described.

Conclusions: The results are expected to definitively address the hydrogeological uncertainty at Marandoo. The combined pumping and reinjection program has proved to be an effective method of obtaining good hydrogeological data on a major groundwater system with minimal environmental impact, and it is considered that the technique could have wide application.

River / lake bank filtration and pond infiltration issues

Abstracts

Investigations on upgrading an existing bank filtration well field considering water quality aspects

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As part of the international donor- and IFI-financed Kaliningrad Water and Environmental Services Rehabilitation Project, a wellfield 30 km East of the City of Kaliningrad is being upgraded from 30.000 m^3/day to 90.000 m^3/day. The wellfield relies on recharge from a system of interconnected lakes and abandoned gravel pits that are connected to the Pregol River.

Kaliningrad is short of sources of abundant groundwater supply, a fact that was already recognised during the German period before the second world war, when the wellfield was originally established. The location of the wellfield is within the alluvial and glaciofluvial flood plain of the Pregol River, providing the possibility to abstract from highly permeable gravel and sand layers. However, the location is also associated with very high level of geogenic organic matter in surface and groundwaters.

The planned expansion of the wellfield will result in a large scaling up of the existing abstraction, thus increasing the need to shed light gaps in the present understanding of the geochemistry and hydrology of the area. The development of an overall plan for wellfield expansion, operation and maintenance must strike a balance between technical, institutional and economic considerations.

A combination of hydrological investigations and analysis of the composition, sources and variability of chemical parameters is being carried out, with particular focus on organic matter. This will support the establishment of a sustainable strategy of managing and monitoring abstraction, with benefits to human health and lifetimes of physical assets.

Ground water recharge from a lined watercourse under shallow water table condition

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Objective: The study was carried out to quantify the field groundwater recharge dynamics

Methods: Rise and fall in water table were observed in observation wells at orthogonal distances X=5,25,50 and 100 m from a 7 year old cement lined channel (Width-0.6m, Water depth - 0.37m Design discharge-0.23m^3/s) at different time intervals. The initial water table was at 2.54m depths from soil surface. The height of the bottom of the watercourse (ho) from the water table was 2.43 m.

Results: Ground water rise R and groundwater fall F increased with time at all orthogonal distances X and followed the square time root law with r2 values more then 0.95 (R=0.0366 t1/2 + 0.03514; F=-0.0474 t1/2 + 0.0754 for 5 m). The water course orthogonal reach (the value of X at which rise is more than 14 % of the total rise at 5m) was 100m.Groundawter rise rate RR and falling rate FR decreased with time following inverse square root law with r2 values more than 0.765 for X=5m. It thus showed the seepage from watercourses is mainly a horizontal infiltration phenomenon under shallow water table condition. The ground water rise and fall decreased with distance exponentially with r2 value more than 0.93 (R=0.4092 e-0.0192X and F=0.5505 e-0.0114X) Ground water rise R was higher than ground water fall up to 90 hours and then the order was reversed i.e. fall was larger than rise at time more than 90 hours.

Conclusions: The practical implications are that lined watercourses contribute to the considerable seepage and ground water recharge up to a canal reach of 100 m even in the short time interval of 170 hours.

Artificial recharge of Baghmelak aquifer Khuzestan province southwest of Iran

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Objective: The Baghmelak intermontane aquifer is surrounded by mountain ranges differentiating in lithological characteristics. This is one of the promising groundwater reservoirs in Khuzestan province in the southwest of Iran for agricultural and drinking purposes. But withdrawal of water from the aquifer is more than the rate of recharge, thus due to over drafting water level is declining and imbalance in the underground reservoir is created. Pilot survey of the area and collected hydrogeological data indicated that in order to combat progressive depletion of groundwater level and meeting the growing demand on groundwater, establishment of artificial recharge can be considered as a tool, which aims groundwater resource management.

Methods: The success of such adoption requires the integration of the available knowledge in many decipline, and the prime importance in establishment of such engineered system where surface water is put on in the ground for infiltration requires proper selection of sites for artificial recharge. Therefore, hydro-geological investigation including infiltration rate, surface geology and well logs in vicinity of three ephemeral stream draining from conglomerate highs were taken into account. In addition to hydro-geological parameters, the potential of harvesting storm waters and quality of available water has been assessed.

Results: On this background, three sites (two-basin type and a check dam) for artificial recharge was suggested in the north and the northeast of the area where coarse alluvial thickness was remarkable. On the bases of collected data, the average rate of hydraulic conductivity is 52.5 m/ day and the rate of recharge that could be achieved at the three sites is approximately 4 Mm^3 / year.

Conclusions: Implementation of such infrastructures facilitates to increase groundwater storage and mitigation of destructive flood is the side benefit. The coast of one cubic meter infiltrated water in the short term is expensive while it is the reasonable and economic way of storing groundwater in the long-term.

Sustainability of managing recharge systems

Abstracts

Sustainability of managing recharge systems: the case of the Chad Basin transboundary aquifers

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Objective: To identify the factors that affect how the aquifers in the Chad basin could be managed sustainably.

Methods: The Chad Basin transboundary aquifers are located within the geographical basin of the Lake Chad which is between latitudes 6and 24 degrees north and longitudes 10 and 23 east. This is a closed lake basin containing a freshwater lake. Greater than two-thirds of this basin is located in an arid zone, the Sahelian climatic belt of West/Central Africa.

Of all the principal aquifers of the Chad Basin, the only ones exploited are the Quaternary, the Early Pliocene and occasionally the Continental Terminal because of the latter's depth and water quality. This paper does not delve into the controversies concerning the hydrogeology of the basin but uses the Barber and Jones (1960) designations – Upper, Middle, and Lower Zones of the Chad Formation as equivalents for the Phreactic, Middle and Lower zones of Hanidu, et al. (1989) respectively.

The paper discusses factors that affect how the recharge systems in this basin can be managed sustainably by reviewing the works of several authors with respect to surface water-groundwater interactions along the two main drainage basins that contribute flows into the Lake Chad – the Komadugu-Yobe and the Chari-Logone as well as around and under the lake. The identified factors that affect sustainable management of the recharge into the Chad Basin aquifers are institutional, management approach and practices as well as climate, i.e. climatic seasons and climate change.

Results: Climate change, climatic variability in space and time as well as institutional arrangements, management approaches and practices are fundamental to the sustainable management of Chad basin transboundary aquifer recharge systems.

Analysis of feasibility and effects of artificial recharge on some aquifers, by modeling of integrated management in Medio Vinalopó basin (Alicante, Spain)

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Objective: The main objective of the study is the optimization of management in Medio Vinalopó basin, by using a management simulation code (AQUATOOL-SIMGES) applied to some different scenarios. It also try to test the effects on aquifers exploitation rates and the feasibility and impacts of artificial recharge with external excess water from Jucar system, as a possible alternative.

Results: The most probable scenario attending to the National Hydrologic Plan includes a transfer of 80 Mm^3/y from river Jucar distributed along six months (october to march), and substitution of a part of groundwater pumped from aquifers of the system by transferred surface water. With this scheme grounwater exploitation would be highly reduced respect to current rates. Overdraft would be sustained on Sierra de Crevillente, Serral-Salinas and Umbría aquifers, and slightly on Solana and Madara ones. As regards supply guarantees, the agricultural ones would become significantly better, with reduction of deficit from 16,5 Mm^3/y to 5,9 Mm^3/y, but would not so urban ones that would get considerably worse. It is owing to the obligation to substitute some groundwater pumpings for urban supply by transferred surface water, and the proposed water regulation scheme with a 20 Mm^3 reservoir, that could not guarantee summertime supply properly, while winter excesses would be lost.

However, using those winter surpluses for artificial recharge of some local aquifers: Serral-Salinas (9,9 Mm^3/y), Jumilla-Villena (8,2 Mm^3/y) and Solana (3,2 Mm^3/y), in the way proposed in simulation 5, and keeping operative current urban supply wells, it would be possible to correct overdraft in these three aquifers. Then they would only keep affected the aquifers of Sierra de Crevillente, Umbría, and slightly Madara. But also safe yields would be increased, what would let a higher pumping rate than in other scenarios and take advantage of the regulation capacity of the aquifers for their exploitatation mainly during summertime, when there would not be water transfers. So it could be avoid the problem of not attending the whole summer's urban demands as a consequence of the insufficient regulation capacity of a transbasin concentrated in six months (october to march). It also would be reflected in a significant increase of supply guarantees and reduction of deficits with regard to the planned scenario.

A proposal of a new classification of susceptible wetlands to be recovered by means of artificial recharge techniques. Application to the Coca-Olmedo wetland complex, Duero basin (Spain)

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Objective: The main objective is to present a new classification of wetlands degraded by effect of irrigation that are susceptible to be regenerated by means of artificial recharge operations. Same as to relate precise experiences of application of the artificial recharge for environmental aims with certain political weight.

Methods: The monitoring of the evolution of several connected wetland with a linked aquifer subjected to AR operations has been carried out for two years. It has been noticed an important variation of certain dynamic parameters, mainly hydrogeological, physical, and ecological interrelated between them. With object to systematize its pursuit: the initial situation has been defined, a colour-based classification of wetlands has been proposed and a system of specific monitoring has been projected.

Results: A classification and characterization of a 60 wetlands system has been carried out as a result of a fieldwork. Most of those are desiccated at present by the effect of irrigation. Thanks to the proposed systematic it has been able to obtain some empirical experiences that allow establishing preferential immediate actuation paths. The colour-supported classification is expressive full and quite synthetic allowing to group together some genetic, functional, and preservation degree aspects. This classification although designed for the wetland system of Coca-Olmedo, may be extrapolated to numerous analogous worldwide systems.

Conclusions: Remediation of wetlands by means of operations of AR begins to receive importance once demonstrated its viability. It is possible to emphasize that the induced superficial artificial recharge is outlined like the most appropriated technique in order to compare the hydrochemical quality of of low salinity waters, with the ecological conditions of the generally saline wetlands. One is an environmental technique that counts on the power advantage to be used with political aims. Its implantation requires an accurate definition of the preoperational surroundings conditions and a suitable monitoring.

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