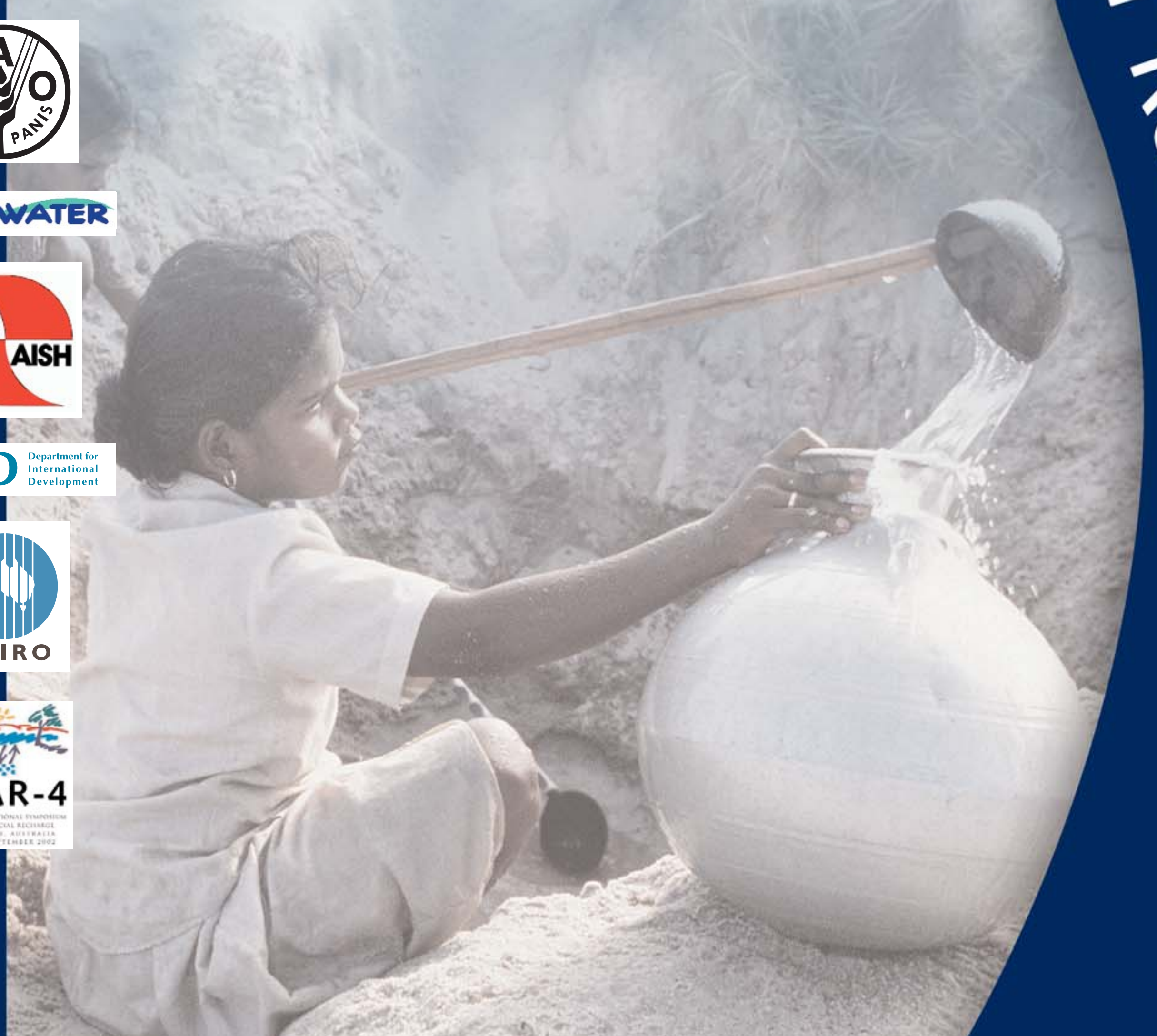
Managing Aquifer Recharge

Over 95% of the Earth's useable fresh water is stored as groundwater. This key component of the water cycle maintains soil moisture, stream flow and wetlands, and is the source of drinking water and agricultural and industrial supplies in many parts of the world.

The water flowing out of aquifers to feed springs and rivers is replenished naturally, at a rate which varies according to local conditions. Pressures of the modern world to increase water resources has led to the concept of enhancing these natural rates of recharge so that groundwater can be used more widely. This brochure describes the principles of managing aquifer recharge and lists the activities and achievements of the major international players in this important area of sustainable development.



Foreword

Peter Dillon *Chair, IAH-MAR Commission*

Many international, national and local organisations see great potential for recharge enhancement to increase the security and quality of water supplies in water-scarce areas. But if such projects are to succeed, they need to be well planned, designed and operated, and should be an integral part of catchment/basin-wide water management strategies.

A meeting of representative organisations in Paris on 25-26 April 2002, agreed to produce coherent plans and activities and to speak with one voice. As a starting point for this communication, this brochure sets out the goals of the members of this consortium. We hope that this will spark other individuals and organisations to contribute to future joint initiatives to make all new recharge enhancement projects sustainable.

Further actions include:

- Developing material on Wise Strategies for recharge enhancement in Arid and Semi-arid areas – UNESCO/IAH.
- Running a workshop on Evaluation of recharge enhancement in Arid and Semi-arid Areas – Adelaide, 21-22 September 2002. UNESCO/IAEA/FAO/IAH.
- Holding a further planning meeting at the IAH-MAR plenary during ISAR4, Adelaide, 22-26 September 2002.
- Publishing a report on enhancing recharge with reclaimed water – WHO.
- Producing a report on recharge enhancement with respect to climate change and water storage needs for water security – WHM/GW.MATE.
- Running a symposium on managing risks associated with recharge of reclaimed water – IAHS/WHO/IAH, Sapporo 7-8 July 2003.
- Producing further publications; running regional training programmes
- Facilitating data collection; monitoring and evaluation of projects
- Facilitating networking and dissemination of information via a web page and email list (www.iah.org/recharge)

Recharge in the water cycle

Natural recharge to aquifers is vital in order to maintain the groundwater and to replenish the discharges from the aquifer, either natural of resulting from Man's activities. When more water is removed from and aquifer than is replenished by recharge then the groundwater level falls and storage is depleted. Recharge occurs periodically, usually seasonally even in temperate climates, but less frequently in arid and semi-arid regions. Recharge is either natural (mainly via direct infiltration of rainfall into permeable soils but also from surface flow), or can be managed (by contour ploughing, building bunds/dams, ponds, diversion channels and wells to enhance recharge), or may be incidental (irrigation, waste water disposal, leaky pipes in cities or clearance of deep rooted vegetation).

In developing countries aquifers provide a store of groundwater, which, if utilised and managed effectively, can play a vital role in:

- Poverty reduction/ livelihood stability
- Risk reduction
- Increased yields resulting from reliable irrigation
- Increased economic returns
- Distributive equity (higher water levels mean more access for everyone)
- Reduced vulnerability (to drought, variations in precipitation)

Rainwater harvesting and managed aquifer recharge (often known as artificial recharge) contribute to the maintenance of the above benefits, particularly if practised as part of a wider approach to water resource management that addresses demand and quality dimensions as well as supply aspects.

For sustainable management of a groundwater resource, demand needs to be managed to balance the recharge to the aquifer, be it natural, managed or incidental. This balance should preferably be made on an annual basis. However, in arid and semi-arid climates a longer period of balance may occur to utilize the groundwater storage capacity to accommodate climate variability. Demand management can take many forms including more efficient use, education, moves to a lower water use economy (i.e. away from irrigated agriculture) as well as fiscal controls.

Methods of recharge enhancement

There are many methods for enhancing recharge to aquifers (see Figure), the main ones being;

- Pond or basin infiltration is used when water can be stored in an unconfined aquifer, and leakage from the pond through the unsaturated zone recharges an aquifer, which is subsequently pumped to provide a water supply. Percolation through the unsaturated zone provides relatively rapid attenuation of some contaminants in comparison with passage through the aquifer. Soil aquifer treatment (SAT) is a form of intermittent pond filtration, in which recycled water undergoes alternate nitrification and denitrification beneath a leaky pond.

- Surface and sub-surface impoundments and dams in stream beds and Wadis designed to capture or slow down, often sporadic, runoff. These are often low-technology structures, designed to meet local conditions and can be filled annually or perennially. Many small structures can help to reduce soil erosion. Silt that accumulates needs to be removed to maintain infiltration rates and can be returned to the land. Larger dams may be used to release water, in a controlled manner, to infiltrate along the streambed.

- Rainwater harvesting from roof drainage which is used to recharge aquifers via collection tanks or through sand filters.

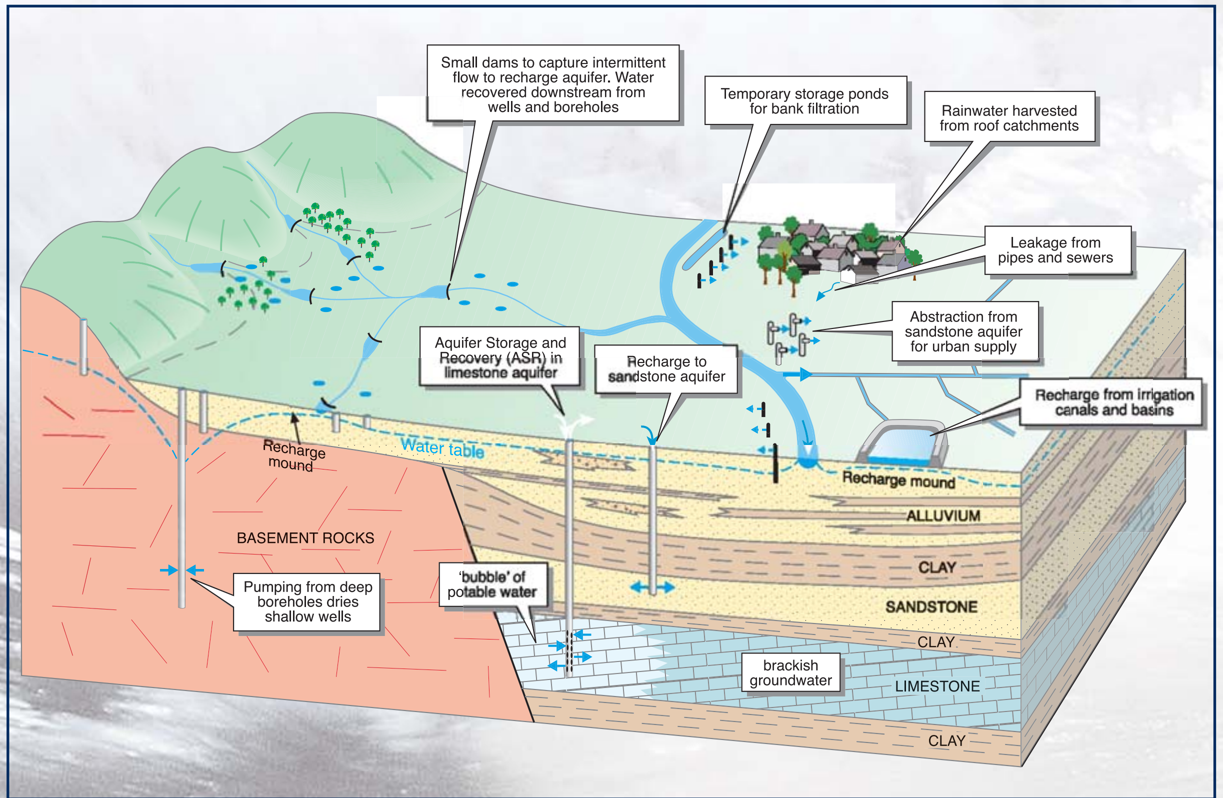
- Induced infiltration describes pumping of groundwater from aquifers that are hydraulically connected to lakes or rivers. Pumping induces seepage from the surface water into the aquifer and provides filtration of the water en-route to the water supply well. This is commonly used in alluvial aquifers in Europe for purifying water supplies.

- Aquifer Storage and Recovery (ASR) involves injecting water into a well and recovering it later from the same well. This can be performed even where the native groundwater is not fit for the intended use, such as where aquifers are saline or suffering from relic pollution, so long as the injected water after a period of storage is of suitable quality for its intended use.

- Injection and recovery from different wells has the advantage of filtration provided by passage through the aquifer. This is usually only used when the native groundwater is of potable quality, and injection helps to maintain the supply. Where unconfined aquifers have a very deep water table, surficial media are permeable, and injectant water quality has extremely low suspended solids, infiltration from dry wells may also be successful.

- All forms of irrigation and leakage from water mains and sewers are unintentional recharge enhancement, however these are rarely beneficial and are generally not managed from the perspective of enhancing recharge.

Factors to consider in all schemes include the quantity, quality and timing of available water for recharge, the depth and storage capacity of aquifers (confined or phreatic), local hydrogeological conditions, quality of native groundwater, availability of land and availability of technical expertise to construct, operate, monitor and maintain the structure. Beyond these technical issues the institutional and financial considerations may determine the success or failure of a scheme. For example, low-technology schemes are usually more successful where there is involvement and commitment of the communities that benefit.



Water harvesting and spreading basins in semi-arid conditions

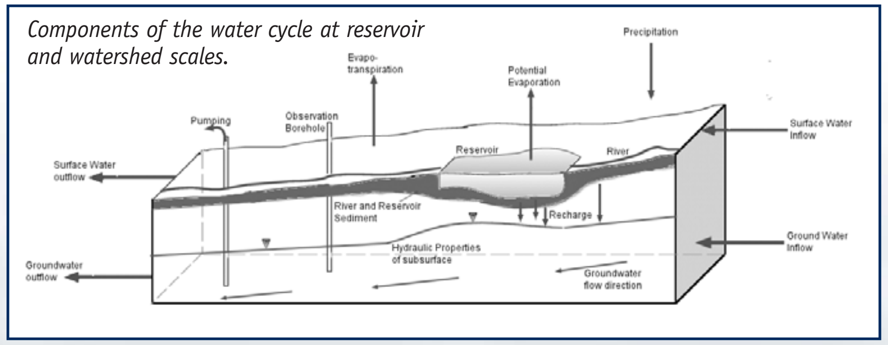
Some of these techniques have been used for centuries: simple check bunds in gullies to complex diversion and infiltration structures, as well as injection wells. Recently, there has been considerable investment in restoring and maintaining such traditional facilities as well as building new structures. Much current effort is, however, empirical in choice of sites, structures and aquifers. There have been many reported successes with locally raised water tables and wells and streams becoming perennial. Nevertheless, the management of the demand side of the water balance (groundwater abstraction) also needs to be addressed to ensure that the benefits of recharge augmentation are significant.


Percolation pond near Coimbatore, Tamil Nadu.

Augmenting groundwater resources by artificial recharge (AGRAR)

Assessing the effectiveness of artificial recharge schemes is essential. So is devising criteria to determine the cost-effectiveness of schemes at a range of scales, from individual structures to catchments and at a regional level. However, effectiveness can be difficult to measure directly. A detailed water balance study is the most common but there are other methods that will indicate the effectiveness of artificial recharge schemes, both relatively and temporally. The societal impacts also need to be checked in relation to differing management practices and the equity of benefits for existing and planned uses, and users. The key uncertainties are:

- The hydraulic effectiveness of recharge structures
- The impacts of different structural designs and management techniques
- Impacts on livelihoods



Components of the water cycle at reservoir and watershed scales.

These issues are being addressed in a three-year, DFID- funded study. Starting in July 2002, the study is based in India and Nepal, in collaboration with Government, NGOs, universities and UNESCO. Guidance materials will be tailored to the needs of end users with their full involvement to ensure knowledge is disseminated effectively and appropriately.

Further details can be found on www.iah.org/recharge/proj.html#AGRAR

Recharge enhancement for agriculture

The UN Food and Agriculture Organisation is actively engaged in promoting three methods of recharge to shallow aquifers:

- water harvesting techniques (‘run-off farming’) by which water is stored in the root-zone and excess water percolates to the aquifers.
- water management in wetlands to provide over-season storage and enhanced recession flows to contribute to recharge and provide residual soil moisture for a dry season cropping,
- construction of small reservoirs, even on permeable soils, to store water but at the same time also to recharge the local shallow aquifer.

In summary, the principles followed when applying aquifer recharge include:

- Ideally, recharge activities, including mechanised water harvesting techniques, should focus on the most favourable soil/aquifer situations and be combined with the overall resource management of the linked aquifer systems, at the watershed scale
- Full participation from the farmer’s community, paying particular attention to the role of women, through involvement during planning, design, implementation, operation and evaluation of the system.
- The investment should result in income in the short term. Water harvesting results in surplus production of grain or fodder. Artificial recharge should result in more water for irrigation and increased production.

Many field projects and, in particular, the activities undertaken in the water control component of the Special Programme for Food Security contribute to the recharge of groundwater. These projects deal with irrigation, soil and water conservation, wetland development and management including small-scale water harvesting; irrigation and drainage systems using rainfall, water runoff, small streams, shallow groundwater and simple lifting devices, such as the treadle pump; and land development and tillage systems that offer greater resilience to climatic variation.
Details can be found at the website: http://www.fao.org/spfs and http://www.fao.org/ag/agl

Artificial Recharge, Namibia

The Omaruru River Delta Aquifer (OMDEL) on the arid coast of Namibia is one of two major aquifers supplying water to the central Namib settlements. Recharge to the aquifer is from ephemeral river flow. However, on rare occasions, large quantities of floodwater pass over the riverbed and into the sea because a layer of fine silt on the surface of the riverbed impedes recharge.

Artificial recharge involves the temporary storage of ephemeral floodwaters in a large reservoir (OMDEL Dam) to allow the fine sediment to settle, with the release of clean water in a controlled manner to infiltrate over designated sites on the Main Channel. The aim is to transfer the water in the reservoir to the aquifer during a dry period. In the event of consecutive good rainy seasons, enough storage space will then be available in the OMDEL Dam, ensuring that the storage potential of the reservoir would be maximised.

The very good rainy seasons of 1997 and 2000 tested the OMDEL artificial recharge facility, with 53% of the 1997 flood event (18 Mm^3) infiltrated artificially, more than seven times the expected natural recharge. It was calculated that 29% of the water was lost to evaporation and 11% remained in the OMDEL Dam.

Aerial view of the OMDEL dam (R. Albrechts, 1994)

Looking in a downstream direction, pre-sedimentation basin in front of the flow divider with infiltration basin B in the background.
(S. Zeelie, 1997)

The International Association of Hydrological Sciences (IAHS)

The aims of IAHS include:

- The study of all aspects of hydrology
- Comparison and publication of research results;
- The initiation and coordination of research that requires international cooperation.

IAHS organizes conferences, symposia and workshops in various parts of the world, including a symposium on ‘Methodologies for risks assessment of waste water re-use on groundwater quality’ – IAHS/WHO/IAH, Sapporo, Japan 7-8 July 2003. Proceedings of these meetings are published in the so-called Red Books. Some deal with general themes related to groundwater management, like calibration and reliability in groundwater modelling (Publ. No. 237, No 265), tracers and modelling in hydrogeology (Publ. No. 262) and integrated water resources management (Publ. No. 272). Others describe processes in specific hydrological systems, like hard rock systems (Publ. No. 241) and karst hydrology (Publ. No. 247).

IAHS also publishes a scientific journal, the Hydrological Sciences Journal (HSJ) containing articles on groundwater and aquifers normally describe natural and man induced flow and water quality processes. More information about IAHS, symposia, Red Books and HSJ can be found on the IAHS website: *http://www.cig.ensmp.fr/~iahs.*

Current activities

Aquifer Storage Recovery in the UK

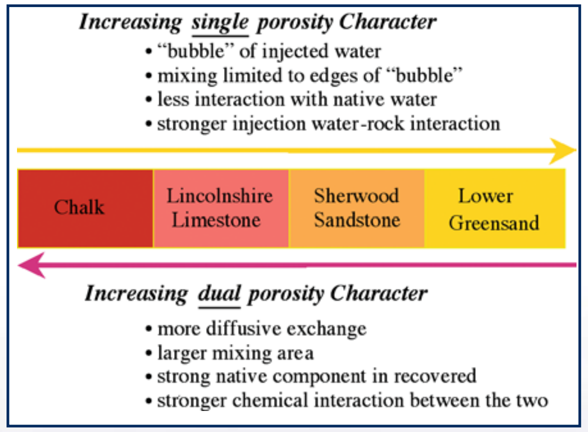
A review of the potential for ASR in the UK (1998), identified several aquifers with good potential and also drafted guidance on regulatory aspects. Several field trials were undertaken by water companies. Among the issues constraining development were:

- impacts of the dual-porosity behaviour of the Chalk and other aquifers on recovery efficiency
- geochemical interactions; water/water and water/rock in different aquifers
- environmental impacts in relation to operational cycles.

These issues were addressed by a project entitled ASR-UK through physical and geochemical modelling, the results of which are summarised at www.nwl.ac.uk/gwf/asr/asr_intro.htm

The main conclusions drawn from ASR-UK were:

- British aquifers can be considered as part of a continuum (see figure) ranging from single porosity unconsolidated aquifers to fractured dual-porosity aquifers.
- The response of these aquifers to ASR varies in a predictable manner that is controlled by the proportion of fracture and matrix porosity, both from the physical mixing and geochemical interaction perspectives.
- Simple modelling tools have been developed to assist in decision-making from the early stages of ASR schemes.



Applications of environmental isotopes to aquifer recharge studies

The application of isotope techniques to aquifer recharge studies can contribute greatly to the understanding of processes and mechanisms as well as providing solutions to particular problems. One challenge is to find the scope of generic applications, as many isotope applications are dependent on the particular case study.

Tracing enhanced aquifer recharge using isotope methods is, in a sense, the reverse of dam leakage studies in that the intention is to infiltrate as much surface water as possible into aquifer. Therefore many of the principles that are used in dam leakage studies could be adapted and applied to aquifer recharge by surface infiltration.

Numerous areas of possible application of isotope methods include:

- Infiltration basin studies and variants (e.g. arid zone water harvesting from Wadi floods). The possible tracers are ∂^2H, $\partial^{18}O$, tritium and hydro-geochemistry.
- Injection well applications – tracer tests, efficiency of injection and recovery using a conservative isotopic tracer in a mass balance approach. Flow path and travel time between injection and recovery wells (Isotope ^3H, perhaps CFC).
- Constraining water balance of infiltration basins using isotopes and solutes, thereby estimating infiltration efficiency, using the combined water, isotope and solute mass balance approach
- Managed aquifer recharge is recognised as a key element of water management strategies in arid regions (Saudi Arabia, Oman, Kuwait, Egypt, Lebanaon,). Wastewater reuse is a significant issue – therefore $\partial^{13}C$ and N isotopes in NH_4 & NO_3 are potentially useful to determine N-depletion processes, denitrification etc.
- Others include pathogen transport and viability (fate and degradation of DOC - $\partial^{13}C$, ∂^2H), dissolved oxygen consumption (oxygen-18 of DO) and mixing reaction, oxidation and reaction with pyrite and Natural Organic Matter (C and S isotopes).

Contact: Dr Jeffrey Turner, International Atomic Energy Authority.
E-mail: J.V.Turner@iaea.org Web: www.iaea.org

UNESCO - IHP

The International Hydrological Programme (IHP), UNESCO's intergovernmental scientific co-operative programme in water resources, is a vehicle through which Member States can upgrade their knowledge of the water cycle and thereby increase their capacity to better manage and develop their water resources.

It also aims to improve the scientific and technological basis for the development of methods for the rational management of water resources, including the protection of the environment. Further information can be found at *http://www.unesco.org/water/ihp/*

The UNESCO-IHP has a long history starting with the International Hydrological Decade (IHD, 1965-1974). Currently, IHP-VI (2002-2007) is in the final stages of negotiation and comprises five Themes sub-divided into 21 Focal Areas. Many the issues addressed in these Areas are of common interest to other projects and programmes related to Aquifer Recharge, some of which are described in this brochure.

Groundwater Management Advisory Team

GW.MATE is a core group of experienced specialists in the multidisciplinary and multifaceted subject of groundwater managemant. They will act globally over a period of 3-5 years to develop operational capacity and capability in groundwater resource management and quality protection.

GW.MATE are currently providing advice and assistance to World Bank-funded projects in North China Plain, Sanaa Basin-Yemen and Quibor Valley-Venezuela. the aim is to promote both technically and institutionally cost-effective supply-side management of groundwater resources through various types of relatively low-cost aquifer recharge enhancement methods, whilst simultaneously assisting the appropriate national or local government agency and water-users to constrain water demand through a wide range of demand-side management measures.

In the Sana'a Basin, for example, the advantages of constructing cascade check dams in the steeper minor wadis are being investigated. In addition to storing flashy runoff that would be lost from the catchment, or through evaporation, these structures reduce soil erosion, flood damage and the flushing of pollutants into the aquifers in the major wadis. Spring flows have also been observed downstream of several check dams, where the gradient is suitable.

Contact: Dr Stephen Foster. GW_mate@bgs.ac.uk or Kkemper@worldbank.org

The Environmental and Water Resources Institute (EWRI)

The EWRI of the American Society of Civil Engineers (ASCE) has a number of standards development Committees, including the 'Standards Committee on Artificial Recharge of Ground Water.' Outputs from this committee, organised by A Ivan Johnson, include:

- The 'Standard Guideline for Artificial Recharge of Ground Water, 2001' is available for sale by contacting the ASCE web page.
- The results of a widely circulated questionnaire published as 'International Survey on Existing Water Recharge Facilities, 1970'. Publication No. 87 of the International Association of Hydrological Sciences.
- Johnson has continued to distribute the ASCE questionnaires worldwide to scientists and scientific organisations. The ASCE/ EWRI Standards Committee is working at making all of the data available through an EWRI web page.
http://www.asce.org/instfound/ewri.cfm

The American Water Works Association Research Foundation (AwwaRF)

The American Water Works Association Research Foundation (AwwaRF) has supported, or is currently supporting, the following projects:

- Aquifer Storage Recovery of Treated Drinking Water [#713]. Published in 1996. *(Out of print.)*
- Aquifer Storage Recovery of Drinking Water From the Cambrian-Ordovician Aquifer in Wisconsin [#2539]. *Completed in 2001.*
- Water Quality Improvements During Aquifer Storage and Recovery [#2618]. *To be completed in 2003.*
- Comparing Basins, Galleries, and Shallow Wells for the Recharge of a Deep Aquifer [#2529]. *Completed in 2001.*
- Predicting Water Quality Changes From Artificial Recharge Sources to Nearby Wellfields [#486]. *Completed in 2001.*
- Augmenting Potable Water Supplies With Reclaimed Water [#371]. NRC published this work in 1998 as *Issues in Potable Reuse: The Viability of Augmenting Drinking Water Supplies With Reclaimed Water* (ISBN 0-309-06416-3). Available from the National Academy Press; website: *http://www.nap.edu*
- Soil Treatability Pilot Studies to Design and Model Soil Aquifer Treatment Systems [#901]. Published in 1998. (Order 90731)
- Investigation of Soil-Aquifer Treatment for Sustainable Water Reuse [#487]. *Phase I completed in 2000; Phase II to be completed in 2003.*

The # numbers refer to the individual projects; more information can be found on AwwaRF's web site, *www.awwarf.com*.

Health implications of groundwater recharge with treated wastewater

World Health Organization

Freshwater scarcity and saline intrusion of coastal aquifers are currently problems for many regions and are predicted to get worse as human populations increase in affected areas. Artificial recharge of aquifers with treated wastewater (both intentionally and unintentionally) is being used more frequently in many areas to restore groundwater levels and prevent saline intrusion. This practice, if not properly managed, can result in significant risks to public health, especially when the groundwater is a source of drinking water.

There is a need to evaluate best practices and develop multi-barrier approaches for safeguarding human health. Additionally, environmental and socio-cultural concerns associated with the recharge of groundwater with treated wastewater need to be addressed. With these goals in mind, WHO organized an expert consultation on health risks in aquifer recharge with reclaimed water in Budapest, Hungary in November, 2001. A report from this meeting is available at *http://www.euro.who.int/watsan/MainActs/20020416_3*

The main conclusions of this meeting were:

- the health implications of groundwater recharge with wastewater need to be further evaluated; and
- a technical report is needed to provide guidance on the best practices for protecting human health during groundwater recharge with wastewater.

WHO is currently developing a technical guidance document on groundwater recharge with treated wastewater. The draft document will be available in 2003 for public review and comment. The proposed table of contents of this report is contained in Annex 1 of the meeting report (see above).

Aquifer storage and recovery research in Australia

CSIRO

For eight years CSIRO and the South Australian Department for Water Resources have worked together to develop aquifer storage and recovery with urban stormwater runoff and reclaimed water. They store this in brackish or saline aquifers to create irrigation water supplies. Techniques have been developed to measure fate of injectant in the aquifer, anisotropy of the aquifer material at in-situ stresses, fate of colloidal material and organic carbon, the clogging potential of low-grade waters, and survival of pathogenic organisms. Together with groundwater flow, solute transport and geochemical modelling, this information has been used to develop operating practices at these sites and improve the design of new sites. Almost 1 million cubic metres/year of installed capacity is now operating from more than 6 sites and this is expected to quadruple in the next 4 years. The combined group was honoured in October 2001 with the UNESCO Great Man-Made River Prize for Innovative Water Resources Management in Arid and Semi-Arid Zones.

In addition, work is also advancing on understanding and predicting the water quality improvements that occur in aquifers during aquifer storage and recovery of water intended for potable use. The AWWARF supports this work. Further information: www.clw.csiro.au/research/catchment/reclamation

---

Key references

Artificial Recharge of Groundwater, II: 1994. Proceedings of the Second International Symposium on Artificial Recharge of Ground Water, July 17-22, 1994, Orlando, FL, United States, American Society of Civil Engineers, New York, NY, United States.

Artificial Recharge of Groundwater 1996. Proceedings of an International Symposium, Helsinki, Finalnd, Nordic Hydrologic Programme Report #38.

Artificial Recharge of Groundwater, III: 1998. Proceedings of the Third International Symposium on Artificial Recharge of Ground Water, Amsterdam, Ed Jos H Peters, Balkema.

Artificial recharge of groundwater: hydrogeology and engineering. 2002. Bouwer, H., in Hydrogeology Journal 10: 121-142.

Atelier Sous-Regional sur la Collecte des Eaux de Surface en Afrique de L' Ouest et du Centre, tenu à Niamey au Niger du 26-29 Octobre 1999 – FAO RAF, Case studies: Nigeria, Cameroon, Burkina Faso, Niger, Mauritanie, Gambie and Tchad.

Groundwater and Society: Resources, Tensions and Opportunities. 2000. Burke, J.J. & Moench, M.H. Themes in groundwater management for the 21st century. United Nations Publications.

Groundwater recharge and wells – A guide to Aquifer Storage and Recovery. Pyne R. D. G. 1995. Lewis Publishing, Florida, USA.

Guide on Artificial Recharge to Ground Water. 2000. Central Ground Water Board, Govt. of India, New Delhi.

Rainwater harvesting and Artificial Recharge to Groundwater: a guide to follow. 2000. UNESCO-IHP and Central Ground Water Board, Govt. of India.

Standard Guidelines for Artificial Recharge of Groundwater. 2001. Environmental and Water Resources Institute, American Society of Civil Engineers, 2001EWRI/ASCE 34-01.

Water Harvesting, A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production. Critchley, W., Siegert, K., Chapman, C. and Finkel, M. FAO publication AGL/MSC/17/91. Available on line at: http://www.fao.org/docrep/U3160E/U3160E00.htm. Also, training workshop on water harvesting available in 2002 on CDROM in English, French, Spanish, Arabic and Chinese: http://www.fao.org/af/AGL/ag|w/wharv.htm

International Association of Hydrogeologists Commission on Management of Aquifer Recharge. IAH-MAR

IAH-MAR aims to expand water resources and improve water quality in ways that are appropriate, environmentally sustainable, technically viable, economical, and socially desirable. It will do this by encouraging development and adoption of improved practices for management of aquifer recharge. This will be achieved by increasing awareness of MAR among IAH members, related professions and the community, by facilitating international exchange of information between members (e.g. via a web page and an email list), by disseminating results of research and practical experience (e.g. via conferences and reference database), and by undertaking joint projects and activities identified as important by its members.

Web: http://www.iah.org/recharge/index.html
Chairman: Peter.Dillon@csiro.au
Vice-chairman: i.gale@bgs.ac.uk
E-mail List: Subscribe free from web page.

4th International Symposium on Artificial Recharge of Groundwater

Adelaide, Australia
22-26 September 2002

Theme: Management of Aquifer Recharge for Sustainability

Proceedings available after conference from http://balkema.nl (see under IAH)

ISAR-4 is the fourth of a series of symposia conducted approximately every 4 years, the 3 previous ones being held in Anaheim, Orlando and Amsterdam.

Web: http://www.groundwater.com.au/conf/isar4.htm