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Water Resources Programme

From the Section Head . . . . .

As this issue of the newsletter is being published, the 50th General Conference of the IAEA is meeting in Vienna. Isotope Hydrology has been a part of the IAEA's activities almost from the beginning of the IAEA fifty years ago. After making substantial contributions to the scientific field, the isotope hydrology portion of the IAEA's work acquired the status of a programme and was renamed the programme on water resources. This reflected both the importance of water in sustainable development and the wider role of the IAEA in enabling countries to develop their human and institutional capacity for using isotope techniques. Since then, the programme of work in water resources has focused to a large part on identifying and removing obstacles to a wider use of isotopes in water resources management. Let me highlight a few of these items here.

Strengthening the network of isotopes in precipitation, Global Network of Isotopes in Precipitation (GNIP), has been a challenge for more than two decades. This challenge arises from two basic issues: the effort needed to collect precipitation samples and the use of isotope data in hydrological and climate studies. Increasingly, data collection for hydrology and meteorology is migrating to automated and/or satellite based observation networks. Isotope data networks, however, require the availability of some infrastructure and human resource to collect physical samples. This creates substantial difficulties in building a network that can operate over a long term.

We have taken a number of steps, including the provision of small grants, to facilitate the collection and shipping of precipitation samples to Vienna for analysis. Recently, we began a collaborative activity with Dr. Tyler Coplen of the US Geological Survey to modify his design of an automated sample collector. This sample collector may be used to gather up to 96 precipitation samples at preset intervals. When available, this modified collector can ease the burden and reduce human resource requirements for obtaining precipitation samples from remote areas as well as areas where an interested community of scientists may not be available. In addition, it would allow easier collaboration with other scientific programmes which presently may not include isotope investigations in their work.

The GNIP Scientific Steering Committee has been re-constituted and presently includes Jim Ehleringer from the University of Utah, USA, John Roads from the Scripps Institution of Oceanography, La Jolla, California, USA, Tetsuo Ohata from the Japan Agency for Marine-Earth Science and Technology, Japan, and representatives of World Meteorological Organization (Wolfgang Grabs), and Past Global Changes (PAGES) (currently Georg Hoffman, Laboratoire des Sciences du Climat et l´Environnement, Saclay, in France). Interactions have also been strengthened with institutions operating GNIP stations and an attempt is being made to bring many of the station operators together on an annual basis to discuss the state of the network and its use.

The operation and management of GNIP is also impacted by the degree of use of the data for hydrology and/or climate studies for a lack of availability or use of data decreases the motivation of those who may have to invest some resources to operate a GNIP station. Over the years, we have facilitated the dissemination of GNIP data through the internet.

In addition to precipitation data, we have compiled isotope data from aquifers and rivers worldwide. These data are also being used to build thematic maps of fossil water aimed at assisting decision-makers and water authorities in adopting better practices for groundwater management. The database software has been considerably improved to make it user-friendly. We will soon release a GIS tool, developed in cooperation with the Institute of Geography at the University of Vienna, that would allow statistical data processing and plotting of data on to graphics and maps. A hard copy of all isotope data compiled from the Africa region would soon be published by the IAEA as an "Atlas" to provide easy reference to previous studies and foster greater use of the data in future research.

The ability to analyse water samples for isotope ratios is another obstacle in the wider use of isotopes in hydrology. The development of a dual-inlet gas-source massspectrometer in the 1950s heralded an explosive growth in the use of isotopes in hydrology and geology. New technological developments for isotope analysis of hydrological samples hold a great promise for revolutionizing the use of isotopes in water resources management. With extra-budgetary funding from the US Government, we are presently testing and adapting a laser isotope analysis machine. This relatively inexpensive, low-skill and low-cost instrument, compared to the dual-inlet mass-spectrometer, could be operated at a minimal cost by researchers and practitioners alike including non-isotope hydrologists, and would overcome the present barrier a wider use of isotopes in hydrology posed by a lack of easy availability of isotope analysis.

As a means to increase the integration of isotopes in hydrological investigations, we are building a partnership with other organizations, in particular the Global Environment Facility (GEF) to formulate and execute comprehensive groundwater management projects. These projects will address scientific and policy issues and demonstrate the use and value of information obtained from isotope techniques. First of these projects being implemented is in northern Africa where we are assisting Egypt, Libyan Arab Jamahiriya, Sudan and Chad to manage the shared, Nubian Aquifer. Other projects being formulated include a characterization of groundwater-surface water interactions in the Nile River Basin and an assessment of national groundwater resources in Ethiopia.

Water resources management continues to be high on the international agenda. The UN has proclaimed 2005–2015 as the UN Decade for Action "Water for Life", recognizing the growing awareness of the critical linkage between water and development. Isotope Hydrology has an important role to play in helping people manage their resources.

In this issue of the Newsletter, a number of contributions discuss the application of isotopes in coastal zones, managing aquifer recharge, groundwater contamination, etc.

I hope you find this issue of newsletter useful and informative.

Pradeep Aggarwal

News in Brief

New staff members

Mr. Kamel Zouari joined the Isotope Hydrology Section in May 2006. He was a former Professor at the Engineering School of the University of Sfax in Tunisia. His interests include the use of environmental isotope techniques for the assessment of groundwater resources of regional scale basins. He has coordinated several bilateral and regional projects related to water resources in arid regions funded by the International Atomic Energy Agency, the European Commission and UNEP. In the Section, Mr. Zouari will work on sustainable water resources management using isotope and hydrochemical techniques, mostly in African countries.

Ms. Mari Ito joined the Section in June 2006 after working on data management related to climate change in the Climate Change Secretariat. She obtained a PhD in biogeochemistry with hydrology and GIS. She previously worked on the development and implementation of several environmental and development projects in eastern Europe, Southeast Asia, Africa, and Mexico in the UN and bilateral organizations. She is interested in the interaction between water quantity and quality, environmental settings, and climate change, together with the application of GIS and the organization of data. Ms. Ito hopes to contribute to sustainable development, especially in developing countries and the countries in economic and social transition, through projects and other activities.

Departing staff members

Mr. Andrew Herczeg left the Isotope Hydrology Section in August 2006 to return to his position at CSIRO Land and Water laboratories in Adelaide, Australia. During his 1 1/2 years at the Section, he assisted with development of a number of projects such as hydrological processes in wetlands, global network for monitoring isotopes in rivers, estimating deep drainage in irrigation areas, training and capacity building and large aquifer projects such as the Nubian Sandstone Aquifer System. In addition, he managed a number of TC groundwater projects in the arid zone of Africa and the Middle East. He was also involved in planning and organizing the 2007 Isotope Hydrology Symposium.

Mr. Seifu Kebede left the Isotope Hydrology Section in July 2006 to return to the Department of Earth Sciences, Addis Ababa University, Ethiopia. Mr. Kebede was involved in compiling isotope, chemical and hydrological data on African meteoric waters under the ISOHIS programme as a Junior Professional Officer.

Meetings

The International Workshop on the Isotope Effects in Evaporation "Revisiting the Craig-Gordon Model Four Decades after its Formulation" was held in Pisa, Italy during 3–6 May 2006. Mr. Pradeep Aggarwal with 3 staff members from the Section participated in the workshop. The aim of the Workshop was to re-examine the Craig-Gordon evaporation model and review current knowledge on the isotope fractionation during phase changes of water in natural environments and laboratory experiments. Two scientific papers prepared by staff members were presented in this workshop.

A consultants meeting (CM) to "Develop Geochemical and Isotope Techniques to Evaluate the Water Flux Below the Root Zone in Irrigation Systems" was held at IAEA, Vienna (12–15 June 2006). The diminishing capacity to divert and fully utilize new water supplies is placing greater constraints on the ability of irrigated agriculture to further contribute to world food production. While there have been significant advances and innovation in irrigation methods for better yields and crop water management avoiding non-productive losses of water such as leakage from transfer systems, evaporation during application and deep drainage below the root zone have been less well studied. Deep percolation (recharge) resulting from irrigation have serious implications for sustaining groundwater irrigation, food security, drinking water supplies, and groundwater dependent ecosystems. While drainage plays an important role in preventing buildup of salts within the plant rooting zone, there can be adverse consequences manifested by water logging due to increase in water tables, salinisation, or nutrient and pesticide discharge to waterways and wetlands. Nuclear techniques are useful in quantifying deep drainage on plot to regional scale as well as in evaluation of off-site impacts.

Isotopes and geochemical techniques provide potential for improved quantification of deep drainage over time and spatial scales not afforded by conventional water balance or lysimeter studies. The use of both environmental tracers and applied tracers, while having been widely used in catchment scale studies, have not been adopted as widely in agricultural systems on a large scale.

The consultants meeting has identified a specific set of methodologies that can be tested through a coordinated research project (CRP) on a plot to catchment to regional scale. The meeting report has recommended a set of sites as a way of up-scaling the information to determine regional water balances. Incorporating the isotopic information with discharge data and water quality also form an essential part of the proposed project design.

From 29 May to 9 June 2006 a formulation meeting for a new IAEA/UNDP/ GEF Medium-Sized Project "Adding the Groundwater Dimension to Nile River Basin Management" was held at the IAEA headquarters in Vienna. The objectives of the meeting were to: i) Review the relevance and need for assessing the groundwater-surface water inter-linkages in the Nile River Basin as well as to discuss the results of the on-going IAEA technical cooperation project (RAF/8/037) that is investigating groundwater linkages with Lake Victoria and parts of the lower Nile; ii) Gain agreement amongst project partners about the objectives, expected outputs & outcomes, activities and needed inputs for the new initiative; and iii) Prepare a joint IAEA/UNDP/ GEF initiative for adding the groundwater dimension to the Nile River Basin management activities. Participants from 6 countries and representatives from relevant projects under the Nile Basin Initiative framework joined the IAEA staff and associated experts to develop this initiative. The proposal has been submitted to UNDP/GEF for review and approval.

The "Nubian Technical Baseline Meeting" was held during 8–12 May 2006 in Vienna with the participation of Nubian countries, IAEA staff and experts. The objectives of the meeting were to: i) Review and synthesize currently available technical information, with a focus on isotopic data, as a basis for updating the "baseline" knowledge of the Nubian Sandstone Aquifer System (NSAS); ii) Determine information gaps that need to be filled in order to gain better understanding of the system and to assess transboundary issues; iii) Consider strategies (sampling, monitoring, etc.) that could effectively and efficiently lead towards filling these gaps; iv) Develop concrete steps for filling these gaps in the frame of the IAEA's co-funded activities for isotopic analysis in the IAEA/UNDP/GEF Nubian Aquifer Project and in particular to support the development of a report on "Shared Aquifer Diagnostic Analysis (SADA)".

The IAEA's Water Resources Programme co-sponsored the "European Groundwater Conference" that was held during 22–23 June 2006. The Conference was organized by the Austrian

Environment Agency on behalf of the Austrian Government in its tenure of the EU Presidency. The Conference brought together an international group of over 300 groundwater specialists, policymakers and managers to focus on policy and scientific aspects of the overall EU groundwater legislative framework concerning groundwater quality and implementation of the groundwater elements of the EU Water Framework Directive. The key topic at the conference was the new EU Daughter Directive on Groundwater Protection and Management. In addition to co-sponsoring the conference, the IAEA's Water Resources Programme (WRP) provided a plenary presentation on the "Use of Isotopic Techniques for Groundwater Assessment and Management" and a booth that highlighted IAEA achievements in the field.

The 3rd International Symposium on Transboundary Water Management was held in Ciudad Real, Spain from 30 May to 2 June 2006. The meeting was hosted by the University of Castilla-La Mancha in cooperation with a number of national and international organizations and institutes, such as the UNESCO, Spain´s Ministry of the Environment, Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA), and the IAEA´s Water Resources Programme. More than 120 participants with a broad field of expertise reviewed the current status and recent developments on a number of topics dealing with management of surface waters and groundwaters shared by two or more territorial entities. Technical sessions comprised characterization of hydrological systems, recent advances on modelling, possible impact of global change in water availability and quality, legal issues such as the water law or the implications of the European Water Framework Directive, resolving historical conflicts on water, public participation in decision-making, sharing hydrological information, analysis of the economical implications of shared management, etc., The programme consisted of a number of plenary sessions, three parallel technical sessions as well as a poster session. With the assistance of the IAEA´s WRP, a pre-symposium workshop on "Applications of Isotopic Techniques for Transboundary Aquifer Management" was held during 29–30 May 2006. The value and role of isotopes to assess groundwater systems were emphasized in the workshop. Contribution of the IAEA, over the last four decades, in the field of Isotope Hydrology was highlighted.

Forthcoming

GNIP-Scientific Steering Committee Meeting

The fifth meeting of the Scientific Steering Committee of the GNIP (Global Network of Isotopes in Precipitation) will be held at the IAEA Headquarters, Vienna in November 2006. This meeting is designed to provide advice to the IAEA and the WMO on strengthening of the operational aspects related to the GNIP as well as on the related global monitoring activities, such as GNIR (Global Network of Isotopes in Rivers) and MIBA (Moisture Isotopes in the Biosphere and the Atmosphere). Review of the current status and recent developments of the programme on isotope monitoring of precipitation will be undertaken during the meeting. Also advice on activities to establish or reactivate the GNIP stations, will be sought.

A consultants meeting also related to the GNIP will be held in November 2006 at the IAEA Headquarters, Vienna. The meeting deals with the establishment of national networks for monitoring isotope contents in precipitation. The main objective of the meeting will be to provide basic information on the GNIP and relevant operational aspects to national teams leading to establishment/reactivation of national networks within the GNIP.

Editor's Note

To receive a free copy of Water & Environment News regularly, please write to:

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Contributions to the newsletter are welcome.

Submarine Groundwater Discharge: An Emerging Coastal Issue

By Willard S. Moore, University of South Carolina, USA

The direct flow of groundwater into the ocean and the recycling of seawater through coastal aquifers are processes that have been largely ignored in estimating material fluxes from the land to the sea. Submarine groundwater discharge (SGD) is becoming recognized as an important process along many coasts that leads to fluxes of nutrients and carbon that may exceed riverine inputs.

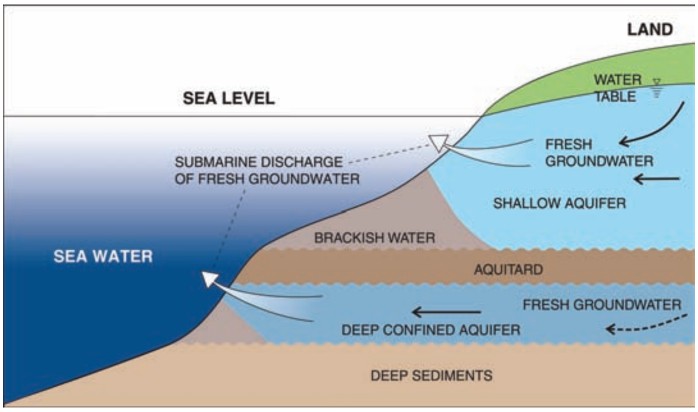

Figure 1. The interface between meteoric and seawater.

The most evident interface between terrestrial and ocean waters is the river mouth or estuary. Less obvious is the subterranean interface between terrestrial groundwater and ocean water. The direct flow of groundwater into the ocean and the recycling of sea water through coastal aquifers are processes that have been largely ignored in estimating material fluxes from the land to the sea.

Submarine groundwater discharge (SGD) includes any and all flow of water on continental margins from the seabed to the coastal ocean, regardless of fluid composition or driving force. SGD is becoming recognized as an important process along many coasts leading to fluxes of nutrients and carbon that may exceed riverine inputs. There are two issues that must be considered: (1) What is the flux of freshwater due to SGD? (2) What are the material fluxes due to chemical reactions of sea water and meteoric water with the aquifer matrix? Hydrologists are primarily concerned with the first question as it relates directly to the freshwater reserve in coastal aquifers and salinization of these aquifers. Oceanographers are also interested in this question because there may be buoyancy effects on the coastal ocean associated with subterranean input of fresh water. Chemical, biological, and geological oceanographers are more concerned with the second question as it relates directly to alteration of coastal aquifers and nutrient, metal, and carbon inputs to the ocean (and in some cases removal from the ocean).

As freshwater flows through an aquifer driven by an inland hydraulic head, it can entrain seawater diffusing and dispersing upward from the salty aquifer that underlies it. (Figure 1). Superimposed upon this terrestrially-driven circulation are a variety of marine-induced forces that result in flow into and out of the seabed even in the absence of a hydraulic head. To emphasize the importance of mixing and chemical reaction in coastal aquifers, these systems have been called “subterranean estuaries” because they are characterized by biogeochemical reactions that influence the transfer of nutrients, metals, and carbon to the coastal zone in a manner similar to that of surface estuaries. Several studies estimate that on some coastlines the flux of nutrients into salt marshes and the coastal ocean through subterranean estuaries rivals the nutrient flux to the coast by rivers or the atmosphere.

The natural supply of nutrients and carbon by SGD may be necessary to sustain biological productivity in some environments. There is also awareness that in some cases, SGD may be involved in harmful algal blooms and other negative effects. As coastal development continues, changes in the flux and composition of SGD are expected to occur. To evaluate the effects of SGD on coastal waters, it is necessary to know the current flux of SGD and its composition.

Attempts to quantify SGD have focused on three approaches: (1) using seepage meters to directly measure discharge; (2) using tracer techniques to integrate SGD signals on a regional scale; and (3) groundwater modeling. Seepage meters (Figure 2), are constructed from the top of a steel drum driven into the sediment. In the simplest application a small plastic bag collects the SGD. More advanced seepage meters are based on heat pulse and acoustic Doppler technologies or dye dilution. Tracer techniques (Figure 3) utilize chemicals (often naturally occurring radionuclides) that have high concentrations in groundwater relative to coastal waters and low

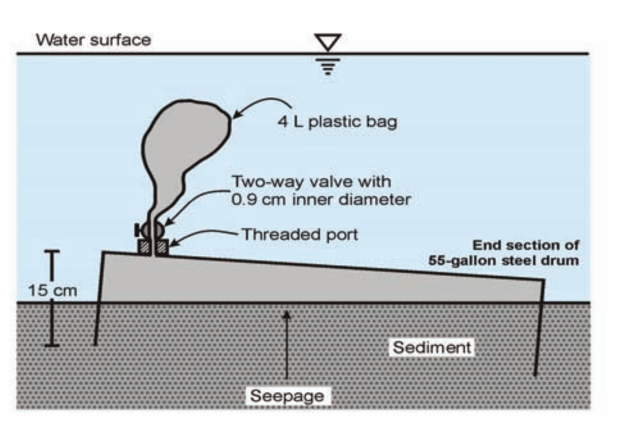

Figure 2. Manual seepage meter.

reactivity in the coastal ocean. These techniques require an assessment of the tracer concentration in the groundwater, evaluation of other sources of the tracer, and a measure of the residence time of the coastal water. With this information, an inventory of the tracer in coastal waters is converted to an offshore flux of the tracer. This tracer flux must be replaced by new inputs of the tracer from SGD. There have been several attempts to reconcile groundwater flow models with tracer-derived and seepage meter estimates of SGD; these attempts have generally failed.

An initiative on SGD characterization was developed by the International Atomic Energy Agency (IAEA) and UNESCO in 2000 as a 5-year plan to assess methodologies and importance of SGD for coastal zone management. The IAEA component included 2 technical meetings on the subject and a Coordinated Research Project (CRP) on "Nuclear and Isotopic Techniques for the Characterization of Submarine Groundwater Discharge (SGD) in Coastal Zones" carried out jointly by IAEA's Isotope Hydrology Section in Vienna and the Marine Environment Laboratory in Monaco, together with 9 laboratories from 8 countries. In addition to the IAEA, the Intergovernmental Oceanographic Commission (IOC) and the International Hydrological Programme (IHP) of the UNESCO have provided support. This overall effort originally grew from a project sponsored by the Scientific Committee on Ocean Research (SCOR) who established a Working Group (112) on SGD.

The overall objective of the IAEA CRP was to improve the capability of the Member States for water resources and environmental management of coastal areas. The specific research objectives were: i) To identify and integrate the application of isotope methods with conventional methods appropriate for detection, characterization, and quantification of submarine groundwater discharge in coastal areas. ii) To explore application of recently developed nuclear and isotopic techniques suitable for quantitative estimation of various components of SGD. iii) To develop a better understanding of the influence of SGD on coastal oceanographic processes and on groundwater regimes for better management of groundwater resources and environmental concerns in coastal areas.

This CRP brought together investigators from diverse scientific backgrounds to assess SGD in different geological/hydrological regimes and to synthesize the results into a comprehensive paper (Figure 4). The activities of the project included joint meetings

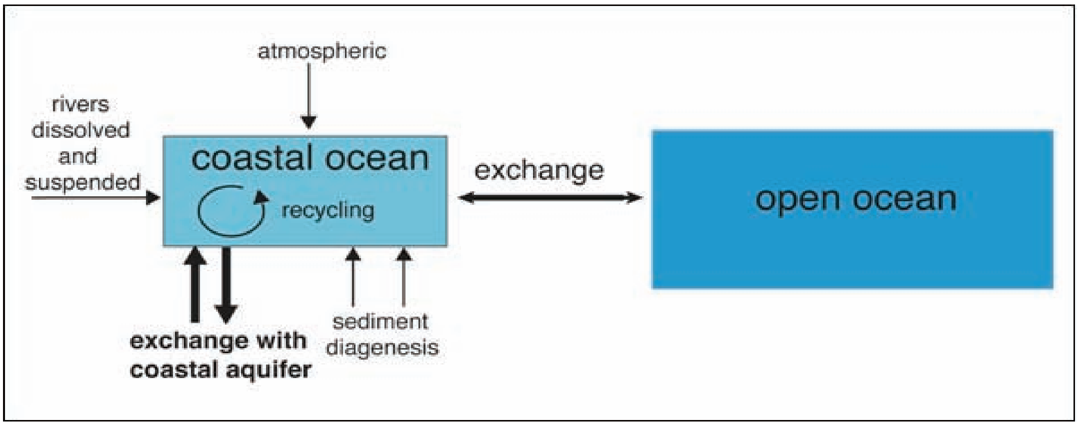

Figure 3. Strategy to determine the importance of exchange with coastal aquifers.
1. Identify tracers derived from coastal aquifers that are not recycled in the coastal ocean. Map their distribution and evaluate other sources (rivers, sediments, atmosphere).
2. Determine the exchange rate with the open ocean.
3. Calculate the tracer flux to the ocean, hence the tracer flux from the aquifer.
4. Measure the average tracer concentration in the coastal aquifer to calculate fluid flux.
5. Use the concentrations of other components (nutrients, carbon, metals) in the aquifer or their ratios to the tracer to estimate their fluxes.

Figure 4. SGD studies in progress at the Shelter Island, USA. (Photo courtesy W.C. Burnett)

(Vienna 2000, 2002, and 2005; Syracuse, Sicily, 2001; and Monaco 2004), sampling expeditions (Australia 2000; Sicily 2001 and 2002; New York 2002; Brazil 2003; and Mauritius 2005), joint analytical work, data evaluation, and preparation of joint publications. A combination of geochemical, geophysical, and hydrological techniques and models revealed substantial SGD at each site. The CRP compared different techniques and arrived at a consensus protocol for future SGD studies. As a result of this CRP as well as the SCOR, IHP, and IOC support, 43 scientific papers have been published or are in press; an additional 12 have been submitted. We anticipate that this list will continue to grow over the next few years. The products of this CRP will serve as standard reference materials in ongoing and future studies of SGD.

The overall finding of the CRP agrees with other studies of SGD, namely that it is fairly ubiquitous in the coastal zone. In unconfined aquifers SGD usually follows a pattern of decreasing flux with distance from the shore. There are temporal patterns modulated by waves and tides; not only the diurnal tidal variations, but also the spring-neap lunar cycle. Superimposed on these predictable patterns are the effects of storms and other events that may cause large SGD fluxes in a short time. Semi-confined aquifers may discharge many km offshore without a clear pattern. Detailed knowledge of subsurface geology would be required to predict where such discharge is expected. Regardless of location, however, both spatial and temporal variations are to be expected. Preferential flow paths (sometimes revealed as submarine springs) are commonly found not only in karst environments, but also in settings that appear reasonably homogeneous and isotropic. Tidal variations generally appear as higher SGD rates at low tide levels (and lower rates at high tides). However, the modulation is not necessarily linear and the relationships are not completely understood (Figure 5). In some situations the rate of SGD seems to change abruptly without an obvious cause. The composition of SGD is often a mixture of fresh and saline groundwater with recirculating seawater accounting for 90% or more of the discharge in some locations or less than 10% in the case of some offshore springs.

While each study site must be approached individually, there are a few generalizations that can be made. All the measurement techniques described here seem valid although they each have their own advantages and disadvantages. Therefore, multiple approaches should be applied whenever possible. In addition, a continuing effort is required in order to capture long-period tidal fluctuations, storm-induced effects, and seasonal variations. The choice of technique will depend, of course, not only on what is perceived to be the “best” approach, but by practical considerations (cost, availability of equipment, etc.) as well. For many situations, where calm seas prevail and the coast is not affected by significant waves or strong currents, seepage meters appear to work very well. These meters provide a flux at a specific time and location from a limited amount of seabed (generally ~0.25 m^2). Seepage meters range in cost from almost nothing for a simple bag-operated meter to several thousands of dollars for those equipped with more sophisticated measurement devices. However, labour costs to install and maintain seepage meters over a large area for more than a few days are substantial. Seepage meters are subject to artefacts but can provide useful information if one is aware of the potential problems and if the devices are used in the proper manner. This seems to be especially true in environments where seepage flux rates are relatively rapid (>5 cm/day).

Use of natural geochemical tracers, especially

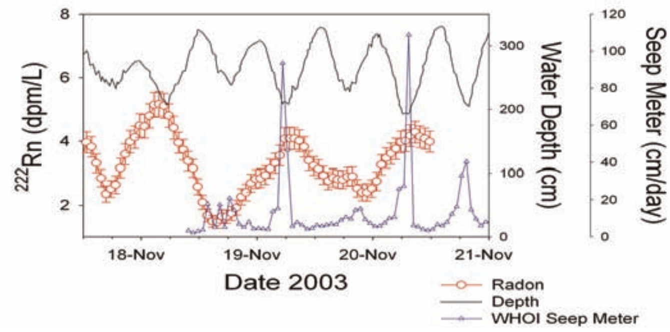

Figure 5. Variation of ^{222}Rn, seepage flux, and tide height. In general seepage and ^{222}Rn are highest at low tide, but the data are not related linearly. Note the very high seepage for the second low tides on 19 and 20 Nov., but not for the earlier low tides on these days. These early low tides were not characterized by high ^{222}Rn activities. WHOI in the figure means Woods Hole Oceanographic Institution. (Courtesy W.C . Burnett)

isotopes, involves the use of costly equipment and requires personnel with special training and experience. One of the main advantages of the tracer approach is the integration of the SGD signal through the water column so smaller-scale variations, which may be unimportant for larger-scale studies, are smoothed out. The approach may thus be optimal in environments where especially large spatial variation is expected (e.g., fractured rock aquifers). In addition to the spatial integration, tracers integrate the water flux over the time-scale of the isotope and the water residence time of the study area. Depending upon what one wants to know, this can often be a great advantage. Finally, different components of SGD can be recognized and quantified using isotopic tracers. This allows discharge from surficial and semi-confined aquifers to be separated. In all cases conclusions based on isotopic tracers depend on the validity of the models and their assumptions used to interpret the distributions. Mixing and atmospheric exchanges in the case of radon must be evaluated and care must be exercised in defining the end-members. The use of multiple tracers is recommended when possible.

Simple water balance calculations have been shown to be useful in some situations as an estimate of the fresh groundwater discharge. Hydrogeologic, dual-density, groundwater modelling can also be conducted as simple steady state (annual average flux) or non-steady state (requires real time boundary conditions) methods. Unfortunately, at present neither approach generally compares well with seepage meter and tracer measurements, often because of differences in scaling in both time and space. Particular problems can be encountered in the proper scaling and parameterizing dispersion processes. Apparent inconsistencies between modelling and direct measurement approaches often arise because different components of SGD (fresh and salt water) are being evaluated or the models do not include transient terrestrial (e.g., recharge cycles) or marine processes (tidal pumping, wave set up, storms, etc.) that drive part or all of the SGD. Geochemical tracers and seepage meters measure total flow, very often a combination of fresh groundwater and seawater. Water balance calculations and most models evaluate just the fresh groundwater flow.

Although the techniques described here are well-developed, there is no "standard" methodology. For example in karstic or fractured bedrock environments, heterogeneity must be expected. In this case it would be best to plan on multiple approaches. Rates are likely to be controlled by the presence or absence of buried fracture systems where flow is focused, or dispersed, by the topography of the buried rock surface. In such situations, integrated SGD might be assessed with dispersed geochemical tracers or described statistically from many, randomly situated, seepage measurements. In volcanic aquifers, especially young basalts, the radium signal may be low. This was found to be the case in the Mauritius study and in other studies in Hawaii. Such a situation might hamper the application of Ra and Rn tracers in these settings. In such an environment one should also confirm the spatial heterogeneity with some preliminary seepage meter deployments and geophysical techniques; and use traditional modelling approaches with caution as good results will likely require more complex models and a significant amount of data.

In a coastal plain setting without an underlying semi-confined aquifer, it is likely that the results will be more homogeneous. Seepage meters often work well in such environments where conditions are calm. These can provide good estimates that can be checked by looking for a distinctive pattern in the results. Such a pattern might, for example, consist of a systematic drop off in seepage rates as a function of distance offshore in unconfined aquifers. Simple modelling approaches (e.g., hydraulic gradients, tidal propagation, thermal gradients) can often be valuable in this type of environment. Tracers also will work very well in coastal plain environments.

This emerging field will require the expertise and viewpoints of a wide variety of coastal scientists. Some will try to understand the movement of water through anisotropic strata due to forcing by hydraulic gradients, tides, waves, storms, coastal freshwater demands, and changing sea level. Others will investigate chemical reactions among the variable composition fluids and aquifer solids and the changes these reactions cause to both phases. The present effects of the discharge on the biology, chemistry, geology, and physics of the coastal ocean must be understood. Past effects of SGD, especially during altered sea level, must be considered as well. There is little doubt that important coastal management issues will derive from these studies.

For further information please contact K.M. Kulkarni at k.kulkarni@iaea.org

Managing Aquifer Recharge : How Can Isotope Hydrology Help ?

By Jordan F. Clark, Dept. of Earth Sciences, University of California, Santa Barbara, USA

One of the emerging solutions to ever increasing water demand is a practice known as managed aquifer recharged (MAR) that involves diverting runoff water or recycled water into aquifers for storage and later extraction.

During the last 50 years, the increased demand for freshwater has created shortages throughout the world. The projected growth in population combined with a changing climate is likely to make the situation worse. New solutions are needed to meet future water demands. One of the emerging solutions is a process known as managed aquifer recharge (MAR) that involves diverting surplus runoff water or recycled wastewater into aquifers for storage and later extraction. MAR is now practised for the combined management of groundwater and surface water in many parts of the world.

While there are many potential benefits of MAR, one needs to be mindful of many potential side-effects that may arise when altering the natural water and chemical cycles within the subsurface. For example, understanding the movement and fate of injected water as well as changes to the water quality during transit through the soil and groundwater is needed. Contaminants from industry, agriculture, or municipal sources that are part of the source water supply may affect the ambient groundwater quality. The introduction of disinfection by-products, infective micro-organisms, and organic compounds with unknown health risks into groundwater supplies is a significant concern. It is paramount to understand the fate and transport of potential contaminants near MAR sites. Only from this understanding can robust and appropriate regulations be developed.

Stable isotopes of water and conservative ions are used as 'fingerprints' that can trace movement and fate of water. Also, dating with tritium and its daughter, ^{3}He, and deliberate tracer experiments are used to estimate water residence time within the subsurface. This knowledge is needed to established hydraulic connections and travel times between the recharge location and production wells. These techniques are probably the most reliable and cost-effective methods for determining travel times between recharge location and wells considering the complex hydrogeology and transport processes that exist near most MAR operations. Because of the variety of techniques and multiple manners in which each technique can be used, isotopes are well suited for site planning studies as well as for performance evaluations of young and old MAR operations. These techniques have been used and tested in the Coastal Dunes of the Netherlands, the Orange County Water District, California, The Berlin Water Works, Germany, and the Bolivar ASR system, South Australia.

The isotope techniques may be most useful in providing critical parameters for examining *in situ* water quality changes. The application of stable isotopes of carbon, nitrogen, oxygen and possibly compound specific isotopes can evaluate the rate and extent of biodegradation of contaminants and organic matter and to evaluate *in situ* biogeochemical reactions that change the quality of the recharged water within the subsurface. Many potential contaminants such as most infective micro-organisms are naturally removed or become inactive with time in the subsurface.

While many of the well characterized MAR sites in the world are in developed nations, there are numerous sites in the developing world that have equally long operation histories and are the source of a large fraction of the potable water supply. The source water for most of these sites is either surplus runoff or recycled wastewater. Examining the scale of the water quality impact as well as water balance is crucial to the viability and long-term sustainability of MAR in the water-stressed parts of the world.

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Isotopes and Geochemical Techniques in the Study of Managed Aquifer Recharge in the Middle East

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Groundwater resources in many parts of the Middle East are under increased stress owing to increased demand for water from rapid population growth in recent decades. As large volumes of water are generated seasonally in arid areas during episodic storm events that drain into lowlands and are subsequently lost to evapotranspiration, there is potential to alleviate the stress on groundwater by implementing water harvesting techniques.

Throughout the Middle East, surplus water from storms is stored in aquifers via basins or injection wells and later drawn upon via extraction wells during times of shortage. The earliest known practice of enhancing groundwater through artificial recharge dates back several millennia in the Middle East.

Although simple in concept, successful and sustainable managed aquifer recharge (MAR) is dependent upon addressing numerous technical issues. Of these, characterizing local hydrogeological conditions and the resulting distribution of recharged water within the aquifer, the degree of mixing between recharge water and ambient groundwater, and residence times within the system are fundamental to the successful management of MAR schemes. The scope of isotope applications in MAR has not been thoroughly evaluated, with few studies of this kind in arid or semi-arid climates, and fewer (if any) within the Middle East.

TC Project RAS/8/103 will assist the Member States involved to better manage aquifer recharge sceheme, through the use of isotopic techniques supported by conventional geochemical tracers.

A diverse range of case studies have been selected for investigations that encompass hydrogeological environments ranging from unconsolidated sand to karstic limestone, and water sources ranging from pristine snowmelt to treated sewage effluent (Table 1). There is an emphasis on surface spreading methods that target unconfined aquifers, although one site utilizes injection wells to store water within a

Study Site	MAR Type	Hydrogeological Setting	Monitoring locations	Tracers
Siwaqa Dam, Jordan	Recharge dam for drinking supplies (Cap=2.5X10^6 m^3)	Upper creaceous limestone	dam, observation wells and 2 production wells	Major ions, ^2H, ^{18}O, ^3H
Rajil Dam, Jordan	Recharge dam for oasis restoration (Cap=3.5X10^6 m^3)	Basalt overlying limestone	observation wells under construction	Major ions, ^2H, ^{18}O, ^3H
Wala Dam, Jordan	Recharge dam for irrigation and drinking (Cap=9.3X10^6 m^3)	Upper Createaceous limestone	dam, 3+ observation wells and 2 production wells	Major ions, ^2H, ^{18}O, ^3H, ^{14}C
Damascus Basin, Syria	7 (or more) injection sites	Alluvial sands and gravels	recharge water, observation wells and production wells	Major ions, ^2H, ^{18}O, ^3H, ^{14}C
Beryan Dam, Sana'a Basin Yemen	Recharge dam (Cap=0.22X10^6 m^3)	Alluvial sediments overlying Basalt	climate, groundwater levels, recharge water and groundwater quality	Major ions, ^2H, ^{18}O, ^3H, ^{14}C
Beih Dam, UAE	Recharge dam	Fissured limestone	observation wells	Major ions, ^2H, ^{18}O, ^3H
Tawiyaen Dam,UAE	Recharge dam for tertiary-treated sewage effluent	Fissured limestone	observation wells	Major ions, ^2H, ^{18}O, ^3H

Table 1. Several of the MAR investigation sites selected for study.

confined aquifer (Figure 1). All case studies are replenishing stressed aquifers that are used for urban and/or agricultural water supply.

A short course and workshop was conducted in Damascus during February 2006 involving all the participating countries to share the broad range of knowledge and experiences on MAR within the project team. Assistance was provided with site selection, development of monitoring programmes and analytical capabilities.

Preliminary results to date indicate that the application of isotope techniques have contributed to the understanding of the technical issues. The ultimate aims are to assess the feasibility of applying MAR schemes at various sites, to determine the site characteristics that best suit this purpose, and to promote the development of a regional capability for using isotopes and geochemical techniques to aid future investigations. Already the project has succeeded in enhancing collaboration amongst participating countries, and between the various institutions responsible for water supply and management.

Figure 1. Injection well, Damascus Basin, Syria.

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Figure 2. Participants in the Regional training course Damascus , Syria 5–16 February 2006.

Application of Isotope Techniques in Groundwater Contamination

The applications of environmental isotopes for understanding hydrological processes and tracing the sources, movement and fate of contaminants are relatively well developed. Adoption of the techniques by water resources managers and policy makers has been less successful. There are many reasons for this, such as lack of knowledge regarding the unique information provided by isotope techniques, poor access to and high cost of isotopic analyses, lack of effort to make the isotopic applications relevant, among others.

It has recently been observed that information dissemination through meetings with water resources managers and planners generally results in increased awareness and use of isotope techniques. An executive meeting under the ongoing RCA project RAS/8/097 was organized in Ho Chi Minh City, Vietnam during 23–26 May 2006. The main purpose of the meeting was to discuss the emerging issues of contamination of groundwater systems in the Member States and to provide participating end users (water resource managers) with knowledge of advantages and utility of isotope techniques in tackling the groundwater contamination problems. 23 representatives from Bangladesh, China, India, Malaysia, Mongolia, Myanmar, Pakistan, Philippines, Sri Lanka, Thailand and Vietnam participated in the meeting.

Individual participants from each of the countries presented the problems that could be categorized into common themes as follows: coastal and inland salinisation, landfill leachate, industrial and mine waste effluents, nutrients and pesticides from irrigation activities, sewage disposal into rivers, naturally high arsenic, fluoride and manganese, and overexploitation of aquifers causing induced recharge of wastewater. The conclusion of these presentations was that very often, the sustainable use of groundwater is limited by water quality rather than quantity considerations. These may be caused by ingress of poorer quality water from adjacent aquifer resulting from over-development or it may be a legacy of years of indiscriminant disposal of waste when environmental issues were not of concern. An important aspect that has not been traditionally

Participants of the IAEA/RCA Executive Meeting, Ho Chi Minh City, Vietnam.

considered is the contamination by natural sources of otherwise fresh waters. The classic case example is the arsenic laden waters of Bangladesh and West Bengal, India. New occurrences of arsenic contamination of groundwater were reported from India, Pakistan, Vietnam, China, Thailand and Myanmar. In addition, manganese occurrences were also reported from India, Bangladesh and Pakistan.

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Meetings in 2006

- Research coordination meeting on isotopic age and composition of streamflow as indicators of groundwater sustainability, Vienna, 8–2 May 2006

- Consultants meeting to develop geochemical and isotope techniques to evaluate the water flux below the root zone in irrigation systems, Vienna, 12–15 June 2006

Forthcoming

- Consultants meeting on establishment of national networks for monitoring isotope contents of precipitation, Vienna, 6–8 November 2006

- 5th Meeting of the scientific steering committee of the Global Network of Isotopes in Precipitation (GNIP), Vienna, 9–10 November 2006

- First research coordination meeting of the CRP, Geostatistical analysis of spatial isotope variability to map the sources of water for hydrological studies, Vienna, 27–29 November 2006

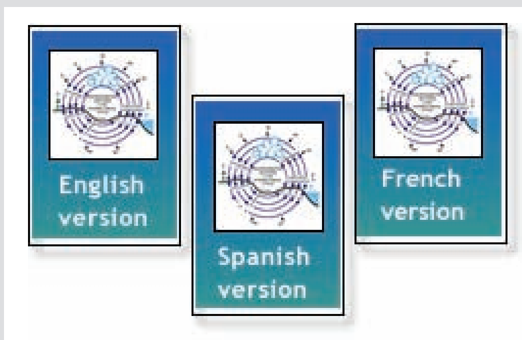
- First research coordination meeting of the CRP, Isotope techniques for assessment of hydrological processes in wetlands, Vienna, 4–8 December 2006

- Second research coordination meeting of the CRP, Isotope methods for study of water and carbon cycle dynamics in the atmosphere and biosphere, Vienna, 6–8 February 2007

On the Web

The six volumes of the “Environmental Isotopes in the Hydrological Cycle” are now available in English, Spanish and French.

These could be downloaded freely in PDF format from the Section’s website: http://www.iaea.org/water



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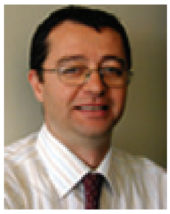

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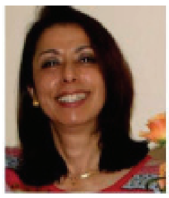

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