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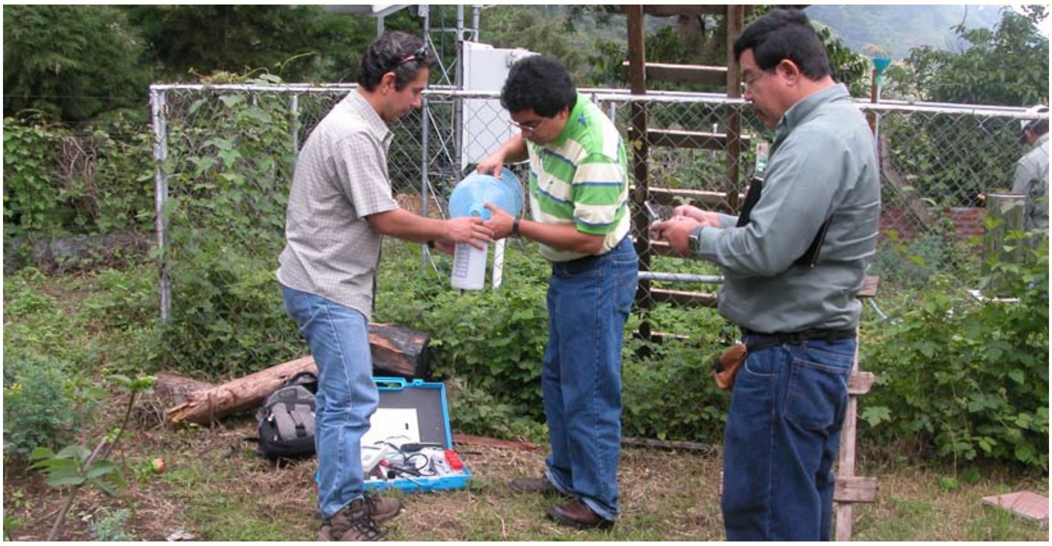
## In this Issue





*GNIP sampling at Boqueron, El Salvador. The network celebrates 50 years (Photo credit: T.Vitvar).*

## From the Section Head

In the 2010–2011 biennium, one major focal area for the Isotope Hydrology Section will be groundwater assessment — particularly regional and/or transboundary aquifers. These are geographically large aquifers, and assessments using physical hydrology are fraught with complexities and uncertainties. As these aquifers generally contain fossil water which is tens to hundreds of thousands of years old, isotopic age determination provides a cost and time effective means of aquifer assessment and modeling. Recent developments in sampling and measuring Kr-81 from researchers at the Argonne National Laboratory and University of Illinois, Chicago have made it possible to more easily use isotopes of krypton — a dissolved gas in groundwater — for dating groundwater up to about a million years old. In particular, these developments include a new technique called Atom Trap Trace Analysis (ATTA) for measuring small concentration of Kr-81 using about 50–100 litres of water sample, rather than the thousands of litres required before. Kr-81 ages allow us to go beyond the age range of about 40 000 years previously possible using carbon-14, and help build better groundwater models. This approach was recently implemented in the Nubian aquifer in northern Africa (see p. 2). Aquifer systems targeted for 2010 include parts of the Nubian aquifer in Libya, the Guarani in Latin America, and possibly the Northwestern Sahara and Mekong aquifers.

In 50 years, the global network of isotopes in precipitation (GNIP) has gathered around 120 000 monthly isotope records from more than 900 meteorological stations (p. 9). This and related work using stable isotopes is becoming much easier with laser spectroscopy machines, which mark the dawn of a new era in stable isotope hyrology. The IAEA has assisted more than 20 developing countries in acquiring a machine, and trained over 40 technicians in its use (p. 13).

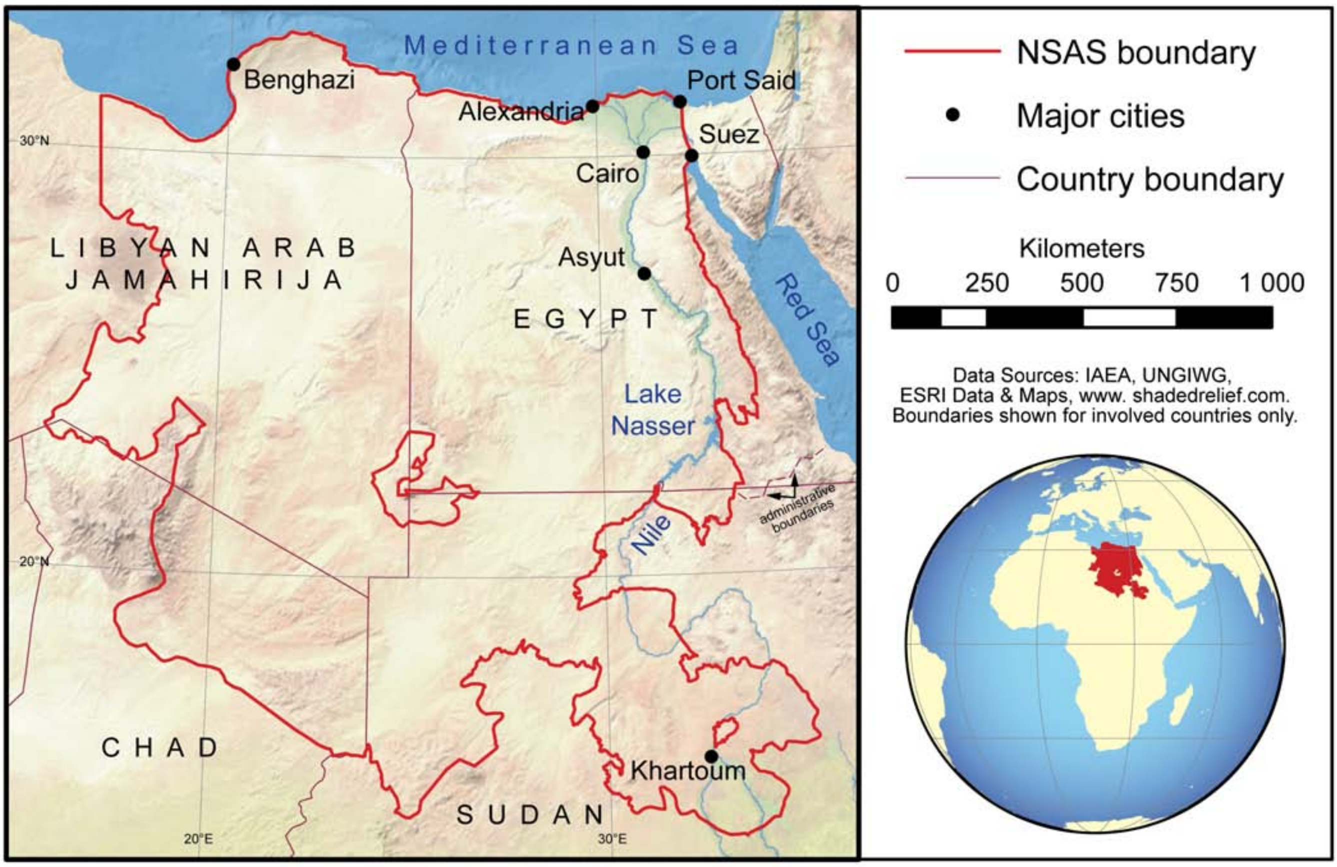
P. Aggarwal

IAEA
Water Resources Programme

# New Light Shed on the Nubian Aquifer

*By P. Gremillion, (IAEA, IHS)*

*The IAEA project can serve as a framework on which to build a programme of data sharing and cooperative monitoring of the Nubian Aquifer aiding Member States in improving their water resources assessment capabilities.*




*Map showing location of the Nubian Aquifer (Credit: S. Terzer).*

The IAEA/UNDP/GEF project on the Nubian Sandstone Aquifer System (NSAS) has as its primary objective the development of a four country cooperative strategy for the rational management of this transboundary aquifer system. The NSAS — underlying Egypt, Libyan Arab Jamahiriya, Chad, and Sudan — is a single, massive reservoir of high quality groundwater, yet has very different characteristics in each country; and each country has different development objectives for the aquifer. An essential first step in developing management strategies for the system is to understand both the transboundary and local effects of recovering water from the aquifer under present rates of withdrawal as well as development scenarios well into the future. This understanding is being gained through development of a numerical model of the aquifer system.

The NSAS model had to meet several unique criteria. It had to be conceptually simple to accommodate limited information on aquifer hydrogeology and sparse observations of water levels. The model also had to provide realistic estimates of a very large aquifer spanning approximately two million square kilometres. And perhaps most important, the model had to earn the approval of national coordinators and technical experts from the four participating countries.

## Model Configuration

The process of developing and calibrating the model involved the participation of all four countries at every step, starting with a training workshop in modelling techniques conducted in Vienna in March 2009 and culminating with a final modelling meeting in Vienna in August 2009. Mr. Clifford Voss, a research hydrologist at the United States Geological Survey, led the modelling effort in collaboration with Mr. Pradeep Aggarwal, head of the Water Resources Programme. Mr. Voss was assisted by Ms. Safaa Soliman, Associate Professor, Research Institute for Groundwater, Water Research Centre, Egypt.

The IAEA model relied extensively on data collected for the previous modelling work of the Centre for Environment and Development for the Arab Region and Europe (CEDARE),

*Participants in the five day inception meeting for the Nubian project, held in Tripoli in July 2006.*

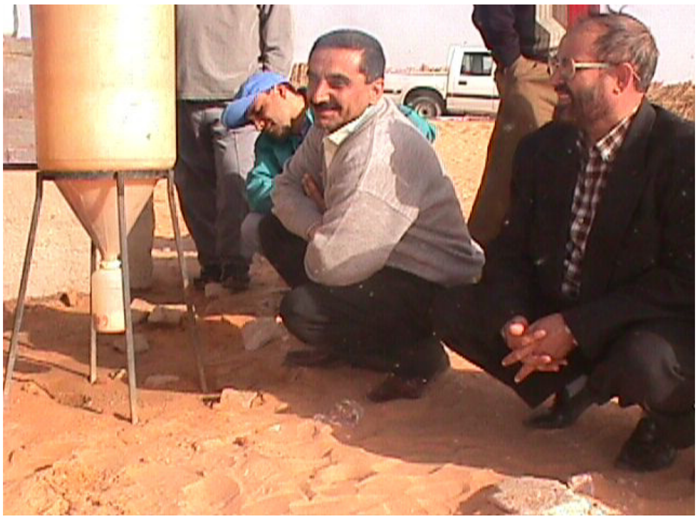
however the IAEA model took a fundamentally different approach. The CEDARE model represented the aquifer system as a two dimensional model in two layers: in the north, the confined Nubian Aquifer is defined as the lower layer and the Post-Nubian Aquifer as the unconfined upper layer, and in the south only the unconfined Nubian Aquifer is represented. This approach did not permit consideration of vertical flow in the system and knowledge of the extent and physical characteristics of the confining unit separating the upper and lower areas was too limited to model the system accurately.

In contrast with the CEDARE model, the IAEA model is three dimensional and treats the entire aquifer system as a single homogeneous, but anisotropic unit. The nature of the anisotropy is high horizontal conductivity and low vertical conductivity. This produces the effect of relatively easy horizontal movement of water and limited vertical movement of water. Slow water movement in the vertical direction is an effective way to simulate the presence of a confining unit in the absence of detailed information on the precise extent of the confining units themselves.

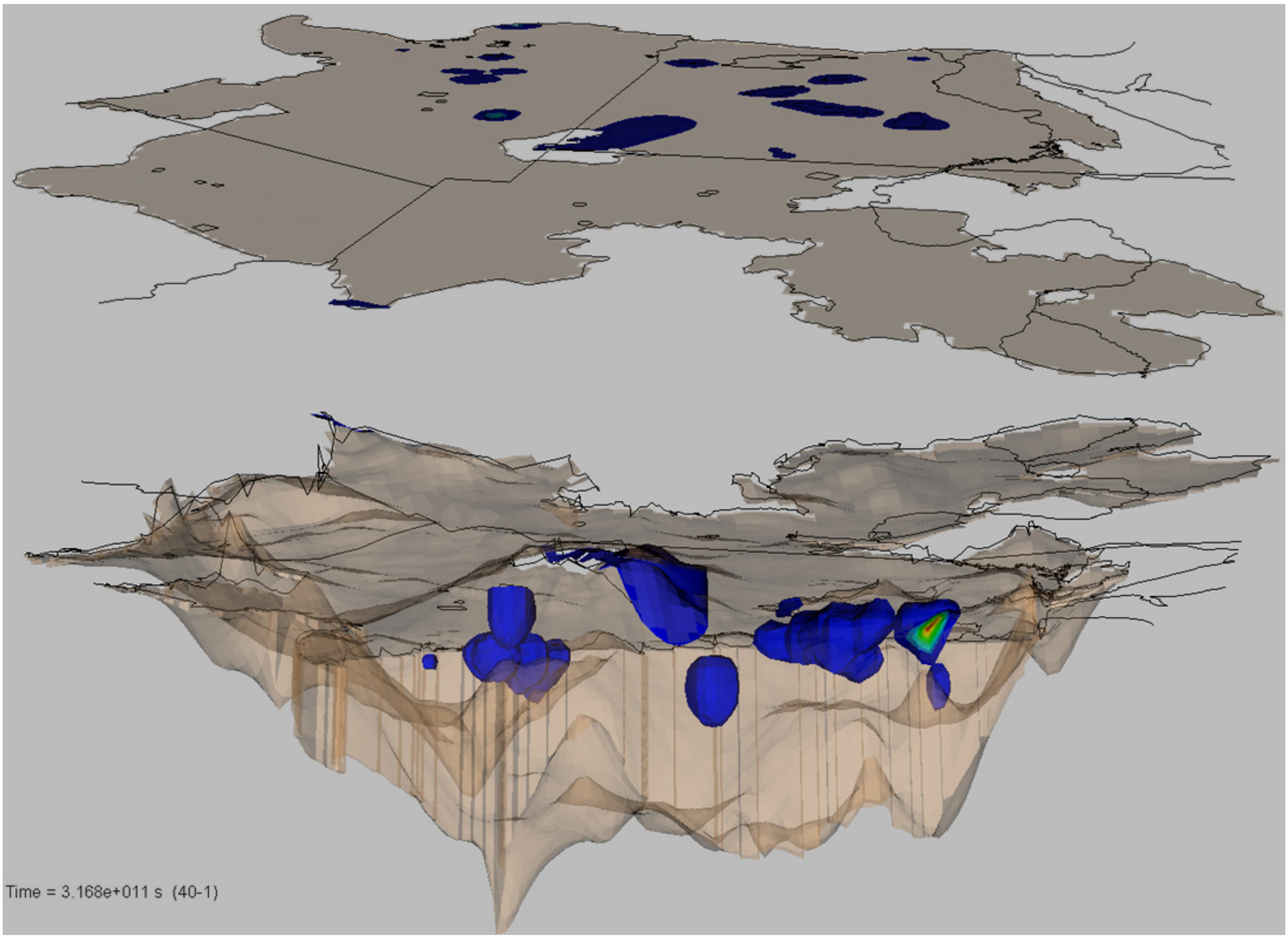
The IAEA model was constructed as a finite difference model using the Modflow groundwater simulation code with an ArgusONE graphic user interface. The grid cells are 20 km by 20 km in plan view. In the vertical dimension the network is 20 cells thick, with cell height depending on aquifer thickness. The geometry of the model was built using CEDARE data for basement topography and recent shuttle radar data for land surface topography. The regional extent of the NSAS in the current model differs from that in the CEDARE model. The model is broader due to inclusion of a southeastern lobe of the aquifer system in Sudan, including Khartoum, a small increase in the southwest to oases in Chad, and an increase to the west in Libyan Arab Jamahiriya to natural hydrogeologic aquifer boundaries.

## Model Calibration

The model calibration process was innovative and took advantage of existing data, while overcoming some severe limitations in water level data availability. The basic premise in calibration was that over geologic time, the aquifer filled to land surface during wet periods and drained during dry periods. The most recent wet period ended with deglaciation about 10 000 years ago. There is general agreement among experts that the aquifer has not been recharged in any significant way since deglaciation. Properly calibrated, a 10 000 year simulation starting with water at land surface should result in aquifer water levels at modern elevations. Observations of modern water levels were taken from existing well records prior to the start of water production pumping in the 1960s and from elevations of oases and sabkhas, which are surface expressions of the aquifer's water table.



*Sampling in a deep bore hole of the Nubian Aquifer for carbon-14 using a traditional precipitation system. The precipitate is collected in the one litre bottle on the bottom (Photo credit: B. Wallin).*




*Oblique views of the geometry for the earlier two dimensional CEDARE model (above) and the three dimensional IAEA model (below). Pumping areas are shown in blue. Two dimensional models must assume that effects of pumping reach through the entire thickness of the aquifer. For thick aquifer systems, the three dimensional model can provide a more accurate depiction of the local influences of pumping.*

The model was calibrated to present water levels through varying horizontal and vertical hydraulic conductivities, and total storage through specific yield and the compressive storage coefficient. Hydraulic conductivities represent resistance of flow through the aquifer and the specific yield and storage coefficient represents the uptake and release of water from the aquifer material itself due to changes in aquifer pressure. Once the 10 000 year aquifer response was calibrated, the model was further calibrated to historical water level declines at three pumping centres in Libyan Arab Jamahiriya and Egypt. This allowed for a separate determination of the specific yield and compressive storage components of total storage. The porosity of the aquifer, which affects flow velocity through the system, was set at a fixed value for the entire system and any effects of spatial variation in porosity were accounted for in hydraulic conductivity terms.

## Unique Strategy

A unique strategy was available to calibrate aquifer porosity, which affects flow velocity through the system. This was done using isotopic ages of groundwater. In the past, a number of studies have indicated that groundwater age in the NSAS reaches up to about 40 000 yrs, as indicated by the presence of measurable carbon-14 activity in deep groundwater samples. However, using krypton isotopes ($^{81}$Kr), groundwater recovered from production wells near oases in the western desert of Egypt has been estimated to vary in age from about 200 000 to 1.5 million years. To resolve this discrepancy, three samples of groundwater from Sudan were collected and carbon-14 was analyzed with conventional methods used in the past — in which 50-200 L of water was chemically treated to extract carbon — and by accelerator mass spectrometry (AMS), for which only one liter of water is required, and no chemical treatment in the field is needed.

Results indicated large discrepancies between conventional and AMS measurements. In particular, AMS measurements for a sample of groundwater indicated an age beyond the carbon-14 dating technique (~50 000 years) whereas the traditional, chemical extraction technique indicated an age of about 20 000 years. The lower age estimate is likely due to contamination with atmospheric $CO_2$ during sampling and extraction processes. AMS measurements are much more reliable as they do not require chemical treatment of large samples. It was, therefore, concluded that existing carbon-14 data from the NSAS for deep wells (showing ages of 20 000 – 40 000 years) is unreliable and these samples likely have ages of greater than 50 000 years. Therefore, krypton ages were considered to reflect real groundwater ages and are used in the current model.

## Anticipated Transboundary Impacts

The calibrated model was run for an interval of three million years, with wet and dry periods simulated using approximate paleoclimate records. The three dimensionality of the model permitted the use of ‘particle tracking’, or tracing the movement of individual water parcels through the modelled aquifer system. This enabled estimation of the age of water at any location and time during the simulation. By adjusting porosity, the model was calibrated to correctly predict the ages of dated water, while providing visualization of groundwater recharge and discharge locations as well as subsurface flow paths.

The effects of pumping from production wells in various locations were simulated using a fully calibrated model. The model was run both with calibrated parameter values and with a range of possible parameter values. There is generally high drawdown in the immediate vicinity of production wells and little effect from pumping further away. The model results were consistent with observations of pumping effects that have been made in and around production well fields in Libyan Arab Jamhariya and Egypt.

## Finalization of the Model

Work is still underway on the IAEA model in three areas: additional testing of the model by the IAEA, formal adoption of the model by host countries, and preparation of the model for local use. Currently, the IAEA is working with the model to check that results are robust. This is done through varying factors in the model, such as boundary conditions on the Mediterranean Sea, the Nile connection, and the aquifer in Sudan, and observing the effects on results. Once this work is completed, the IAEA will officially release the model and its results.

At the four country meeting to discuss modelling results in August 2009 there was consensus among member countries that the modelling approach was valid and the results are reasonable. Over the next several months the model will be reviewed by national experts and discussed in stakeholder forums at national meetings in Egypt, Libyan Arab Jamhariya and Sudan. Chad will work on an individual basis with stakeholders and ministry personnel to discuss the model.

> *...there was consensus among member countries that the modelling approach was valid and the results are reasonable.*

The final phase of modelling will be to turn the model over to the member countries for use in making practical management decisions. This may start with a hands-on workshop focused on using the model at a local scale. A key aspect of this will be to refine portions of the model with a finer-scale grid size in pumping areas and in areas with more detailed knowledge of hydrogeologic conditions. Finer scale modelling will permit, among other things, the rational design of well fields to minimize the environmental impacts of development.

Ultimately, the model can serve as a framework on which to build a programme of data sharing and cooperative monitoring of the NSAS. Success in developing the model as a four country effort was based on shared participation of the countries and transparency in the modelling process. Continued participation by the four countries in sharing monitoring and production data, and in the planning process for new development of the aquifer, aid in assuring that all countries maintain awareness of the impact of development on both transboundary and local aquifer development.

*For further information, please contact P. Aggarwal at p.aggarwal@iaea.org or P. Gremillion at p.gremillion@iaea.org*

*Sampling work underway at the Nubian Aquifer (Photo credit: B.Wallin).*

# Krypton-81: An Improved Tool for Dating Old Groundwater

*By N.C. Sturchio and R. Yokochi, University of Illinois at Chicago, USA*
*Z-T. Lu, Argonne National Laboratory (ANL) and University of Chicago, USA*
*R. Purtschert, University of Bern, Switzerland*

*The Water Resources Programme will launch a new activity this year using krypton-81 to date very old groundwaters. New and less complicated technology will make sampling and testing easier and complement existing information to aid in management of some of the world's largest transboundary aquifer systems.*

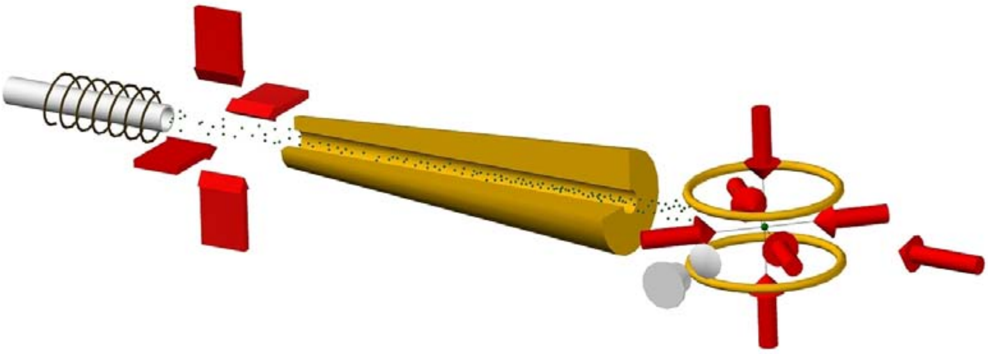
Over 1.5 billion people depend on groundwater as their primary source of drinking water. Some major aquifer systems are dominated by water with little or no measurable $^{14}C$, implying residence times exceeding ~40,000 years. Examples of such very old aquifer systems are the Great Artesian Basin of Australia, the Nubian Aquifer of Egypt-Libyan Arab Jamahiriya-Chad-Sudan, and the Guarani Aquifer of Brazil-Argentina-Paraguay-Uruguay. Knowledge of residence time distributions is required to construct and validate numerical hydrodynamic models that can be used for developing groundwater management strategies, ensuring optimal use of these precious, ancient water resources. Isotopic tracer measurements using cosmogenic $^{81}Kr$, made available in recent years through developments in analytical technology (Du et al., 2003) enable unprecedented insight into residence times beyond those accessible through $^{14}C$ measurements alone. Measurements of $^{81}Kr$ may now provide validation of more accurate, three dimensional hydrodynamic models for old groundwater in major aquifer systems around the world.

*Nubian Aquifer water being sampled from well #6 at Farafra Oasis, Egypt, for $^{81}Kr$ analysis. A plastic tube was inserted into the discharge pipe to minimize the risk of air contamination during sampling (Photo credit: Zheng-Tian Lu).*

There are few isotopic tracers available which can define residence times greater than those accessible with $^{14}C$ (half-life = 5730 years); these include radiogenic $^{4}He$, $^{36}Cl$ (half-life = 301 000 years), and $^{81}Kr$ (half-life = 229 000 years). In principle, each of these tracers can be used to provide quantitative constraints on residence time distributions in very old groundwater systems, yet each has its own particular complications in terms of measurement and/or interpretation.

Helium-4 is a stable nuclide produced by alpha decay of the U- and Th-series nuclides. It is mainly generated within minerals from which it escapes into the pore water of the aquifer. Measurement of $^{4}He$ concentrations and isotope ratios in water using mass spectrometry are now routine. Accumulation of $^{4}He$ in aquifer water can thus be used to model groundwater residence time, provided accurate assumptions are made about the rate of supply of $^{4}He$ to the pore water from the solid phase, as well as the rate of gain and/or loss of $^{4}He$ by advection and diffusion from or to surrounding formations or the atmosphere (Torgersen and Clarke, 1985; Bethke et al., 1999).

Both $^{36}Cl$ and $^{81}Kr$ are cosmogenic radionuclides that can be used to estimate groundwater residence times. Whereas $^{36}Cl$ has been applied in numerous groundwater studies since its measurement by accelerator mass spectrometry first became a routine practice in the 1980s, $^{81}Kr$ measurements remain technically challenging, and only ten measurements have so far been published for groundwater. Chlorine-36 is produced by cosmic ray spallation of $^{40}Ar$ in the atmosphere (mainly in the stratosphere). The global average production rate of $^{36}Cl$ is about 20 to 30 atoms $m^{-2}$ $s^{-1}$ but is geographically heterogeneous, and its atmospheric residence time is relatively short (~2 years). It mixes with marine chloride in the troposphere and is transported to the ground surface by precipitation and dry deposition where it is flushed into aquifers along with recharge water. Significant complications are involved in the interpretation of $^{36}Cl$ data because of uncertain initial $^{36}Cl$ /Cl ratios,



*Schematic of the atom trap apparatus at Argonne National Laboratory. The length of the apparatus is approximately two meters.*

subsurface production of $^{36}Cl$ by neutron capture on $^{35}Cl$, and the addition of stable Cl from old, saline pore fluids (Phillips, 2000). Despite these problems, $^{36}Cl$ data have provided useful validation of hydrodynamic models in several locations, including the Milk River aquifer (USA-Canada), the Great Artesian Basin (Australia), and the Nubian Aquifer (Egypt) (Phillips et al., 1986; Torgersen et al., 1991; Patterson et al., 2005).

Krypton-81 is formed by spallation and neutron activation of stable Kr isotopes in the atmosphere; with a global production rate of about $1.2 \times 10^{-6}$ $^{81}Kr$ atoms $cm^{-2}$ $s^{-1}$; the atmospheric ratio of $^{81}Kr/Kr$ is about $5 \times 10^{-13}$, in good agreement with theoretical secular equilibrium values (Collon et al., 2004). Major advantages of $^{81}Kr$ for groundwater studies, in contrast to $^{36}Cl$, are that the initial ratio ($^{81}Kr$ / Kr) is distributed homogeneously in the atmosphere and $^{81}Kr$ has negligible subsurface production. Thus, changes in the $^{81}Kr$ /Kr ratio in groundwater aquifers can be attributed entirely to $^{81}Kr$ decay, groundwater mixing, or diffusive exchange with aquitards, and are not affected by salinity or degassing. It is anticipated that, because of these favorable characteristics, $^{81}Kr$ will eventually become the tracer of choice for determining residence times of very old groundwater, in the range of about $10^4$ to $10^6$ years.

*With continued improvements... the encouraging prospect now exists for routine measurements of $^{81}Kr$ in groundwater.*

A promising new technique called Atom-Trap Trace Analysis (ATTA), which was developed at Argonne National Laboratory in the United States of America, uses a magneto-optical atom trap for atom-counting of both $^{81}Kr$ and $^{85}Kr$ (Chen et al., 1999; Du et al., 2003) (above figure ). ATTA's first application to hydrology was a study of $^{81}Kr$ extracted in the field from six samples of Nubian Aquifer groundwater (each sample with a size of about 2000 kg), where a range of apparent residence times from $2.0 \times 10^5$ to $1.0 \times 10^6$ years was found to be in agreement with results of hydrodynamic models and $^{36}Cl$ residence time estimates (Sturchio et al., 2004; Patterson et al., 2005). Since the Nubian Aquifer study was performed, improvements in the efficiency of ATTA have reduced the sample size requirement to about 100 L of water, with potential for further improvement.

Hydrophobic membrane contactors and a vacuum cylinder extraction system have been used by our research team for field extraction of Kr from groundwater for use in $^{81}Kr$ analysis (Fig. next page). The extracted gas sample can also be used for $^{85}Kr$ and $^{39}Ar$ analyses if needed (Corcho et al, 2007). Purification of Kr for analysis by ATTA is done using a combination of cryogenic distillation and gas chromatography (Yokochi et al., 2008).

With continued improvements in the ATTA technique, and the planned establishment of additional ATTA facilities in Europe and Asia, the encouraging prospect now exists for routine measurements of $^{81}Kr$ in groundwater. It is anticipated that this capability may lead to a breakthrough in understanding the dynamics of very old groundwater systems.

The Isotope Hydrology Section is planning new activities in cooperation with the authors of this article to use this promising technique in exploring other major aquifer systems, including the Guarani, the Northwest Sahara Aquifer System and systems in southeast Asia. The technology has been refined — the drastic reduction in the size of water sample required for measuring has simplified the procedure considerably — and field instruments are in place. The IAEA is now ready to apply this dynamic dating tool, and is in the process of fixing concrete plans in regards to times and locations. The technique is also expected to support the existing Nubian Aquifer modelling information discussed in the previous article.

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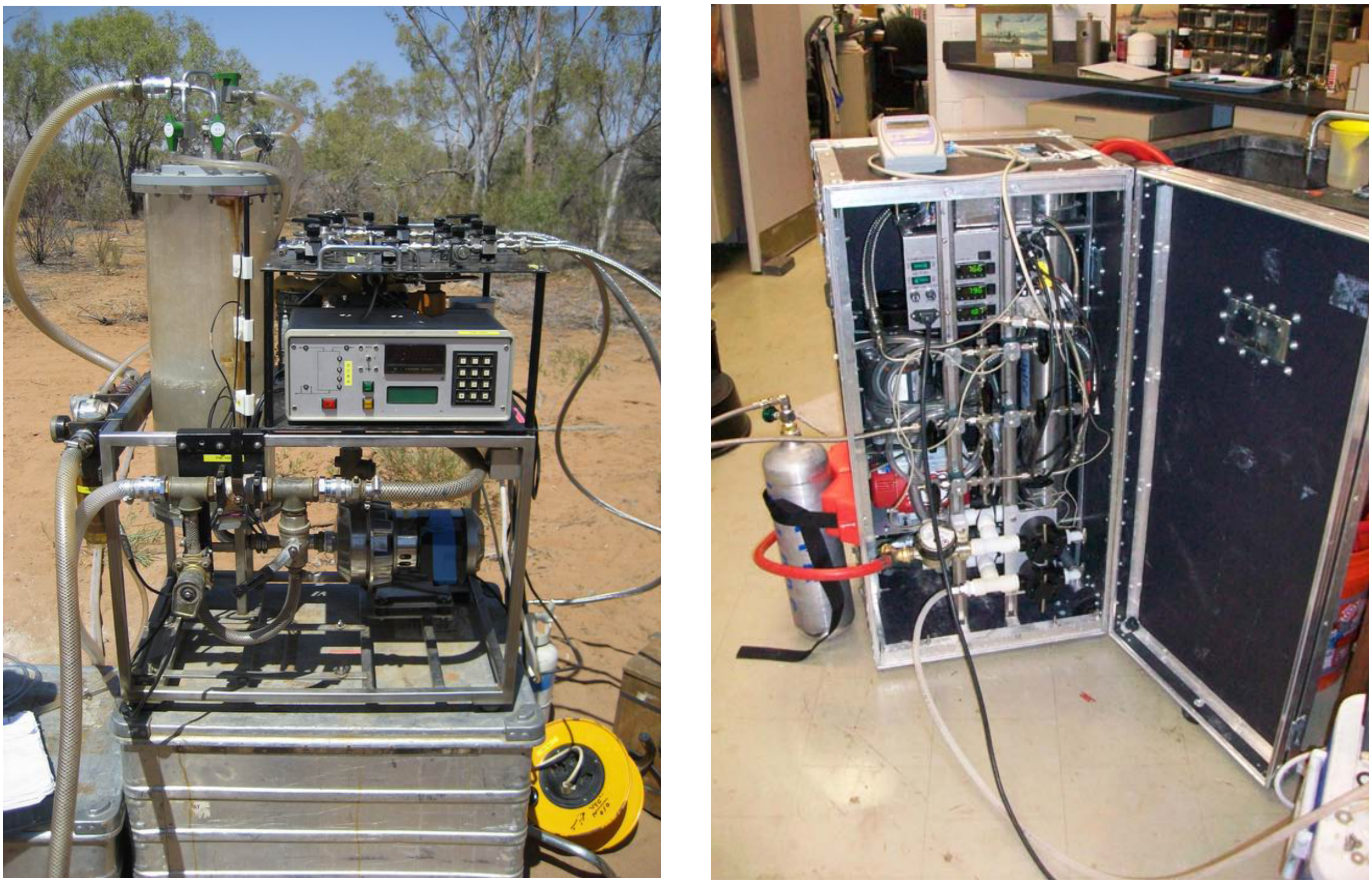


*Vacuum cylinder extraction system (left) and hydrophobic membrane-contactor apparatus (right) used in extraction of dissolved gases from groundwater for analysis of noble gas radionuclides (Photo credit: (left) Roland Purtschert and (right) Reika Yokochi).*

# Global Network of Isotopes in Precipitation goes Golden

*By M. MacNeill and L. Araguas (IAEA, IHS)*

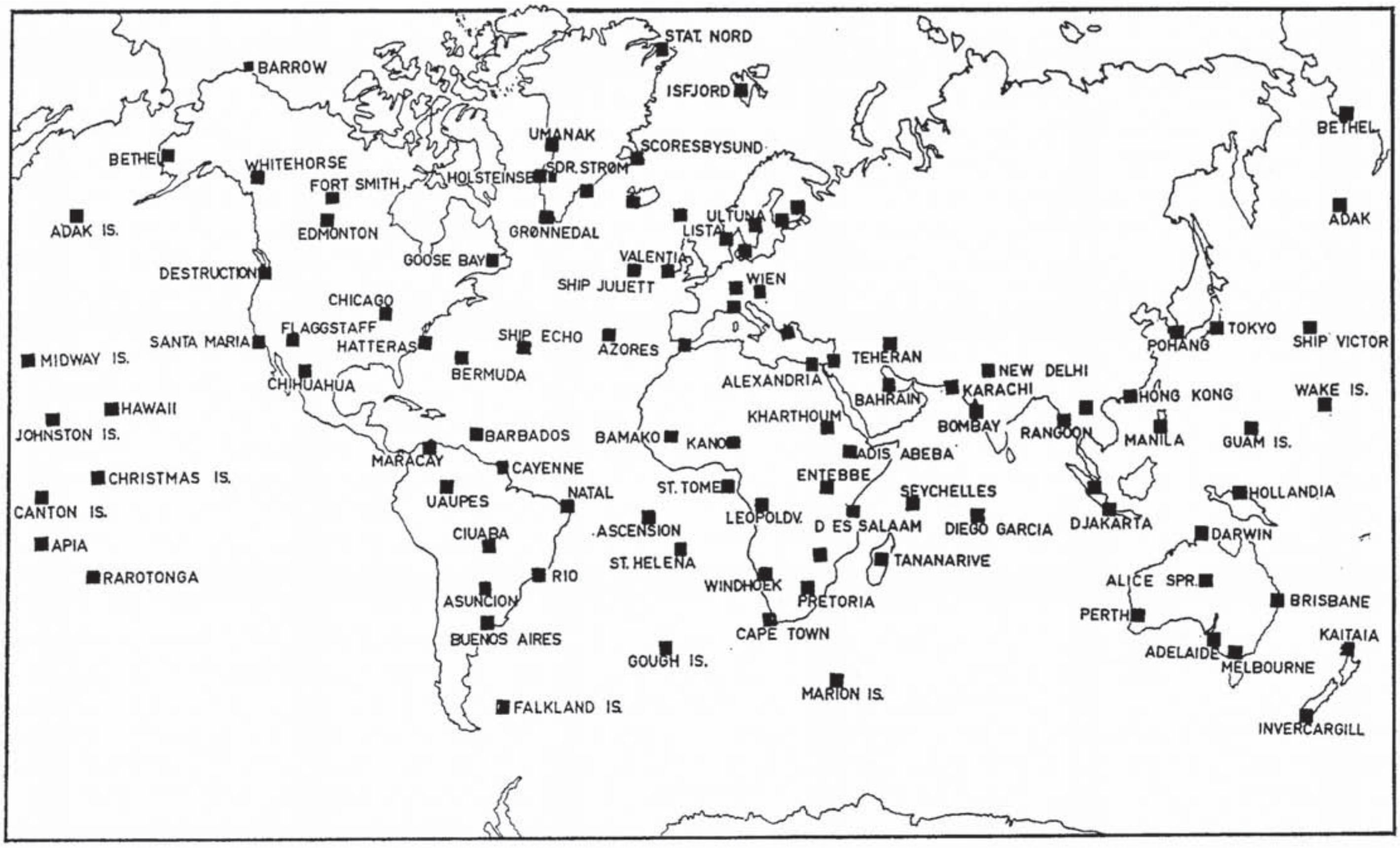
*One of the main programmes that distinguished the Isotope Hydrology Section's early years has matured through many changes over the past 50 years to become a cornerstone of the section and the most comprehensive collection of isotope data on atmospheric waters in the world.*

A letter dated 30 March 1960 by Mr. D.A. Davies, Secretary-General of the World Meteorological Organization (WMO) in Geneva, to Mr. Henry Seligman, Deputy Director General of the Department of Research and Isotopes (now called the Department of Nuclear Sciences and Applications) of the — at that time — young IAEA, set the stage for what has today become the world's largest and most comprehensive collection of isotope data in atmospheric waters, the Global Network of Isotopes in Precipitation (GNIP).

The letter stated the "willingness (of WMO) to cooperate with the IAEA in the above programme and to urge meteorological services and other agencies in Member countries to collect the required samples of rain water and to send it to you".

The cooperation of WMO, which operates a global network of stations for meteorological observations, was necessary to collect precipitation samples around the world for isotopic determinations, as the IAEA intended to do. This programme was initiated following a recommendation made in 1958 by a Scientific Advisory Committee composed of Fritz Begemann, Erik Eriksson and Hans E. Suess, three scientists rich in ideas on the potential of isotope applications in hydrology. They realized the need to collect systematic isotopic data on precipitation which recharges — directly or indirectly — all freshwater systems. In fact, isotope hydrology was still taking its first steps, after its birth in the first half of the 1950's at the University of Chicago through the work of Harold C. Urey and Willard F. Libby, both Nobel laureates, and their groups.

At the time the committee suggested that isotopes could provide information on water residence time in, and evaporation losses from, lakes and reservoirs, groundwater age and aquifer dynamics, continental water balance, age of hot spring water, and mixing time of the ocean. "For the coming decades it can be anticipated that hydrological information of the type listed above will become increasingly




*One of the first GNIP maps as printed in the first Agency publications on GNIP and in Willi Dansgaard's groundbreaking 1964 seminal paper.*

valuable for many countries with limited water supplies," wrote the committee. "A more complete knowledge of the world-wide variations in the isotopic composition of water would greatly facilitate the interpretation of local conditions."

A document by the same group in May 1959 stated: "The study of the distribution of hydrogen and oxygen isotopes in rain, in rivers, in groundwater and in oceans is by far the most important line of research in two large groups of problems which are intimately connected with the circulation of water in nature. One is the proper use of continental water sources for technical and agricultural production, the other is the disposal of radioactive wastes on land and in the sea. Such quantitative data are still virtually non-existent even on a global scale, though the accurate knowledge of water circulation processes in nature is of fundamental importance to modern civilization."

*Tritium and stable isotopes of water have been systematically used since the early 1960s for water resources inventory, planning and development...*

In those years, Bryan R. Payne was appointed head of the newly formed Isotope Hydrology Section of the IAEA, with the mandate of implementing the programme delineated by the Scientific Advisory Committee. Payne carried out the duty diligently; eventually involving the IAEA in supporting the application of isotopes in field studies in Member States and creating a reputation for the IAEA as the main world forum for discussing practical and scientific aspects of isotope techniques in hydrology.

GNIP has been always a core activity of the IAEA isotope hydrology programme, and expectations for the programme were very high when it started. If some of the applications envisioned at the time proved to be more complex than expected and difficult to implement, many other unexpected uses developed.

The cost of the new IAEA/WMO Isotopes-in-Precipitation Network — as it was called till mid 1990s — was estimated in the Advisory Committee's 1958 summary to amount annually to 67 000 US$, with an initial investment of 122 000 US$. The committee also recommended construction of a laboratory for isotopic analysis of samples, "and its optimal floor space would be in the order of 450 m$^2$." The Isotope Hydrology lab originally started out in 1962 in a cramped space in the basement of the IAEA Headquarters on the Kärtnerring in Vienna; a building which had hosted the Russian Headquarters before becoming the Grand Hotel.

The main initial equipment included proportional gas counters for tritium and carbon-14. In fact, the Isotope Hydrology lab is the only UN laboratory at a headquarters due to the need to avoid possible tritium contamination derived from the nuclear research activities at Seibersdorf's laboratories; in addition, the massive building above provided a good shielding from cosmic rays. The first mass spectrometer for stable isotopes was put into routine operation in 1970; prior to that, stable isotope measurements were processed at Willi Dansgaard's laboratory in Copenhagen. The lab moved to the current Vienna International Centre in 1979, where it has occupied 840 m$^2$ of space in floor -1 of the G Tower.

## The beginning

Tritium and stable isotopes of water have been systematically used since the early 1960s for water resources inventory, planning and development, which remains the main focus of the network.

When GNIP began, it focussed primarily on tracing tritium released into the atmosphere through thermonuclear testing; the committee trio emphatically stated their support for sampling temporarily abundant tritium: "It cannot be foreseen for how long this situation will prevail in the future and it is therefore felt that the sampling of water and the determination of its tritium concentration on a large scale should be given high priority," said the committee.

Robert Brown in of Chalk River Laboratories, Ontario, Canada, had already recognized elevated tritium counts as

## Editor's Note

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

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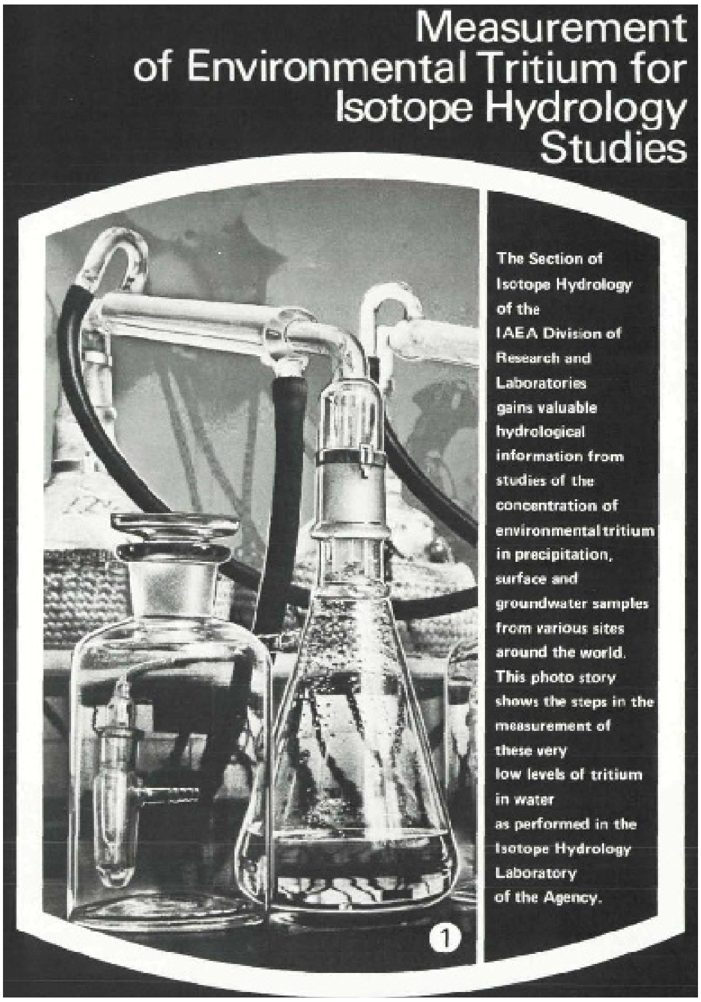


*Cover of the 1973 IAEA bulletin, explaining the method of tritium measurement.*

a golden opportunity to gain valuable information about atmospheric circulation. Brown created the only complete set of tritium data fully covering the rise of thermonuclear tritium content, which peaked in 1963. Brown also regularly monitored local precipitation from 1953 until 1969 and beyond. Brown's measurements have been used as a measuring stick ever since. Measurements of tritium concentration in rains were also carried out in Libby's laboratory in Chicago, but in a less systematic manner and not as continuously as those of Brown.

Tritium (along with carbon-14) proved to be an excellent tracer to profile ocean dynamics, including ocean circulation, and was also great for understanding interatmospheric connections. The tritium information gathered at that time is still useful today, though tritium levels have since returned to pre-thermonuclear levels and have lost usefulness as a tracer of global patterns; the monitoring of stable isotopes of oxygen has become much more important. Tritium has evolved to have a classical application in source recharge, dynamics and dating of groundwater, for which GNIP will always be needed.

It soon became clear that oxygen-18 ($^{18}O$) and deuterium ($^{2}H$) provide useful information as well, and they were included in sampling and testing. Interest in stable isotope data has increased for hydrological application verification and improvement of atmospheric circulation models, the study of climate change over different time periods, and ecological research. It is now routinely used in the disciplines of palaeontology, landscape ecology, anthropology, plant physiology, animal migrations, food webs, food authentication and forensics.

The first evaluation of stable isotope GNIP data by Dansgaard in 1964 — probably the most cited paper in isotope hydrology — led to identification of main factors controlling spatial variability of stable isotope ratios in precipitation on a global scale. The first tritium data evaluation by Schell et al. (1974) had similar objectives. More recent evaluations are credited to Rozanski et al (1991) for tritium and Yurtsever and Gat (1981), and Rozanski et al. (1993) for stable isotopes.

An important aim of the original plan was to make a large database available for any country wishing to apply isotope techniques for hydrological research, and the laboratory would allow the IAEA to assist countries in determining the isotope composition of water samples with the aim of drawing conclusions on present and future water supplies. The Scientific Advisory Committee suggested tritium concentrations in rain water should be collected from a network of about 100 stations once a month (65 over continents and 35 over the ocean), while river water samples should be collected from about 40 stations on 20 major rivers and surface ocean water samples from about 50 stations (every three months).

## Beyond expectations

GNIP outpaced the committee's suggestions; it began with 151 precipitation stations in 1961, peaking at about 220 active stations in 1963/64, with the number falling off in the 1970s after thermonuclear tritium in the atmosphere depleted. It grew once more because all applications based on stable isotopes rose in importance. Stable isotopes provide unique insights into hydrological and climatic processes at the local, regional and global scales. Water isotopes 'naturally archived' in polar ice caps, lake sediments, spelaeothems and groundwater aid in reconstructing past hydrological conditions, and aid in the study of causes behind current climate change.

Today the GNIP database has grown to include about 900 historical and current stations around the world, producing over 120 000 monthly records, far beyond the dreams of the committee when it first proposed the network in 1958. Several laboratories are now involved in determinations, and measuring techniques are faster.

Interest in stable isotope data has also increased for verification and improvement of atmospheric circulation models, the study of climate change over different time periods, and ecological research.

Other parts of the Scientific Committee vision, such as sampling in rivers, were realized much later. The Global Network of Isotopes in Rivers (GNIR) was first launched in 2007 to complement the GNIP programme, and monitors about 20 large rivers from headwaters to deltas, as suggested in the committee's original document.

A step beyond what the Committee envisioned was the development of Moisture Isotopes in the Biosphere and Atmosphere (MIBA), which started with a consultants meeting in 2003, and focuses on the regular sampling of isotopic composition of water in plant stems and leaves, as well as in soil and atmospheric vapour.

The Committee could not visualize the global computerization which was yet to come, leading to a system called WISER, through which Member States are today readily able to access all databases and even use information to examine local patterns.

Some things have stayed the same, however. The programme still runs on a voluntary basis. Also, the standard operating mode of collecting monthly samples at IAEA/WMO stations was the only mode until about 10 years ago, and remains important, though it has now expanded to include bimonthly samples, precipitation events, monitoring of water vapour, Antarctic ice, etc. The rest of the programme has remained the same: sampling and shipping instructions are provided, some samples are measured in the IAEA laboratory, and some in cooperating laboratories.

Isotope data will continue in the future to provide an important link to understanding climate change impacts on the water cycle. The need for GNIP to provide global data, therefore, will continue to exist. Improved understanding of isotope–climate relationships also are likely through weekly or daily collection of GNIP data. This higher frequency of data gathering will be facilitated by the wider availability of laser spectroscopic analysis of isotopes. Hydrological applications of isotope data as a 'global' reference for river and groundwater investigations may reduce somewhat in favour of more local monitoring of precipitation.

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*A last century etching of the lighthouse and fort on the island of Valentia. The Valentia meteorological station has been participating in the GNIP network since it began.*

# Lessons Learned on Isotope Analysis using Laser Spectroscopy

*Participants of the three day Coordination and Operational Requirements for Isotope Hydrology Laboratories Meeting in December 2009 (Photo credit: Maureen MacNeill).*

A technical meeting on the operation of the laser absorption stable isotope analyzer was organized by the WRP as part of activities aimed at improving the analytical capability of water isotopes in Member States. Under the heading 'Coordination and operational requirements for isotope hydrology laboratories', the three day meeting was specifically planned for counterparts and users of the recently developed laser absorption spectroscopy system. Eighteen participants from 15 countries, including several observers, attended the meeting. The two main objectives of the meeting were: a) to share experiences and lessons learned on the installation and operation of the laser analyzer, including both laboratories with previous experience in isotope analysis by Isotope Ratio Mass Spectrometry (IRMS) and new groups which have recently embarked on the analysis of oxygen-18 and deuterium in water samples with the laser absorption instrument, and; b) provide assistance in the overall analytical performance of the laboratory by aiding in calibration of the internal water isotope standards of each laboratory, using IHL facilities.

Based on participant presentations at the meeting, and from experience gained over the last two years at the Isotope Hydrology Laboratory and six training courses held at the IAEA headquarters, a technical document containing practical troubleshooting hints and tips was jointly compiled and revised. A document with specific recommendations and advice on installation and operation of the analyzer will be posted after a critical review on the WRP web page (www.iaea.org/water). This will join other new materials recently available online, including the latest off-axis analyzer installation and operation procedures, as well as an excel spreadsheet template for post-processing data. An installation video and an IAEA training course series document will be added soon.

During the meeting, 51 internal laboratory water standards provided by 15 participant laboratories were analyzed in duplicate with mass spectrometry and laser spectroscopy. Both methods showed good agreement in isotope results. For each water standard brought to the meeting, the best estimate of the isotope ratio for oxygen-18 and deuterium, and associated uncertainty, were provided. All participants gained experience in isotope data processing and estimation of associated uncertainty for each isotope determination. It is expected that further dissemination of laser based analyzers will increase the number of water research groups able to conduct stable isotope analyses on a routine basis with high accuracy, avoiding delays in obtaining isotope results derived from lengthy shipping and customs procedures. At present, about 25 laser analyzers have been provided through Technical Cooperation Projects and more than 40 technicians have been trained in their operation. Additionally, the WRP provides a set of materials (video, technical procedure and a spreadsheet for isotope data post-processing) to facilitate use of this technology.

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# Catchment Dynamics of Rivers Unravelled by Isotopes

The 4th and last Research Coordination Meeting (RCM) on 'Isotopic Age and Composition of Streamflow as Indicators of Groundwater Sustainability' provided a synopsis of findings about the amount of groundwater supplying rivers and its travel time in the subsurface from the point of infiltration to its exit in a stream in 14 river basins of size between 1000 and 100 000 km$^2$ in various geographical and geological settings.

Analysis of discharge records over at least five years showed an average of about 60–70% of baseflow in most catchments, ranging from about 30% in basins with runoff dominated by wet seasons (Morocco, Ghana, Pakistan, Vietnam) to 80% in karst systems dominated by subsurface flowpaths (Turkey). Stable water isotopes revealed that quick shallow groundwater contributions to rivers contain waters up to two years old, while a detailed analysis of nested subcatchments (Brazil, Slovakia, Serbia) indicated that smaller headwater subcatchments with portions of fractured bedrock might contain relatively older groundwater than larger downstream subcatchments supplied by quick groundwater contributions coming from shallow alluvial sediments.

Tritium and chlorofluorocarbon provided information about the contribution of slower groundwater flow components, providing an accurate reflection of catchment geology and ranging up to 50 years in terms of residence time (i.e., the effect of large storage in Turkish karst or Argentinian Tertiary sediments). Relatively lower residence times were observed in some larger catchments (i.e., Danube near Vienna), indicating a dominant groundwater contribution through tributaries instead of direct exfiltration. Thorough collaboration by all participating teams allowed for application and cross-comparison of identical isotope and conventional techniques in all catchments.

*Tritium and chlorofluorocarbon provided information about the contribution of slower groundwater flow components...*

The geological control of groundwater contributions to streams and the key role of multi-isotope approaches for dating younger and older groundwater components were highlighted and in the meantime have become the standard approach within the hydrological community. Recommendations to support river basin management, including how to express the amount and age of river baseflow in terms of indicators of aquifer sustainability, will be made in 2010 — the last year of the Coordinated Research Project (CRP). The CRP has made use of the recently established Global Network of Isotopes in Rivers (GNIR) and provided further valuable data to this database. The results of this CRP may also be integrated into the ongoing CRP on 'Estimation of Groundwater Recharge and Discharge by Using the Tritium-Helium-3 Dating Technique'.

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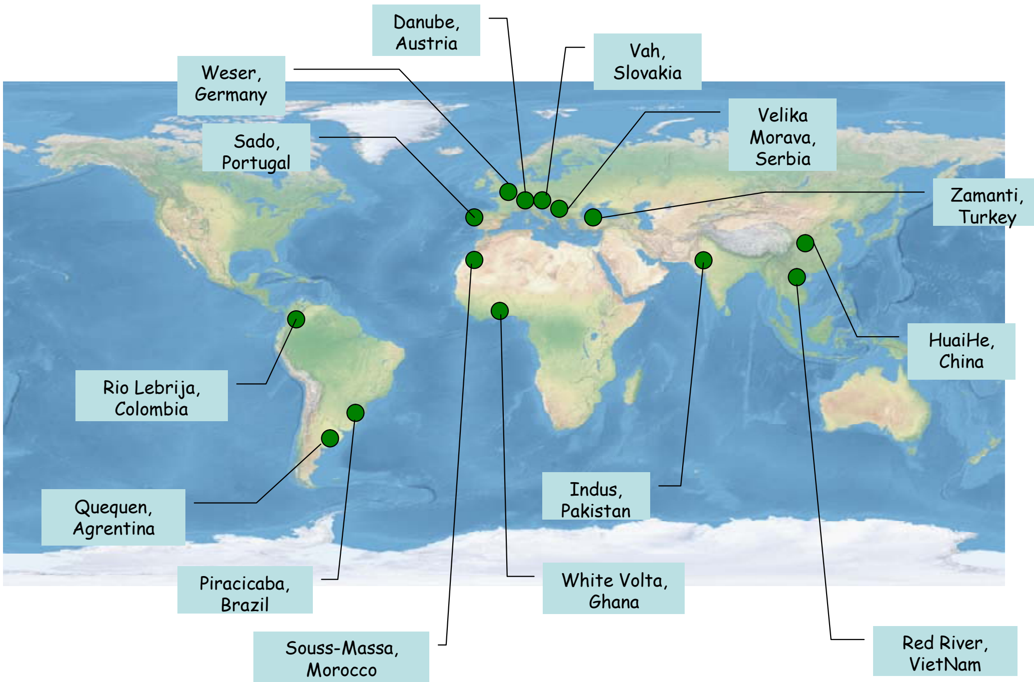


*Illustration of the study sites investigated as part of the CRP 'Isotopic Age and Composition of Streamflow as Indicators of Groundwater Sustainability' project.*

# Latin American Project Making Gains

*Field work involving sampling for chemistry and isotopes, conducted as part of a workshop within project RLA/8/041 (Photo credit: L. Araguas).*

The Second Coordination Meeting of Project ARCAL XCII was held in San Jose, Costa Rica from 19 to 23 October 2009. The project aims at implementing isotopic tools for evaluation of coastal aquifers. The workshop was organized by the Government of Costa Rica through the National Ground Water, Irrigation and Drainage (SENARA) branch, in coordination with the IAEA. This event was attended by delegates from all areas of study, the Government of Spain and the IAEA.

Project RLA/8/041 began in 2007 and comprises seven study areas in six countries. Although all aquifers are located in coastal areas, they differ from each other in many respects. For example, the two aquifers in Costa Rica feature alluvial sediments in small basins (85 and 236 $km^2$), the aquifer in Cuba is in a karst landscape, in Ecuador the aquifers are located in a semiarid area, the aquifer in Argentina has many urban and agricultural pollution problems, metamorphic and sedimentary rocks play an important role in the dynamics of the aquifers in Peru, and in Uruguay there is evidence of active seawater intrusion.

By December 2009, the IAEA had provided basic field equipment for counterparts, including a laser absorption instrument for analysis of deuterium and oxygen-18. With these tools counterparts have been able to advance field work plans, including the collection of samples. There have been 450 samples of water analyzed for deuterium and oxygen-18; 5% of them have also been analyzed for tritium, noble gases or CFCs.

Knowledge transfer has been a key part of project RLA/8/041. Twelve training sessions have been funded (including fellowships and scientific visits) in areas such as assessment of karst aquifers, development of mathematical models for aquifers, use of specialized software in hydrogeology, groundwater vulnerability assessment, installation of monitoring networks in coastal aquifers, with emphasis on chemistry and isotope sampling, and laboratory procedures for analysis of deuterium and oxygen-18. The training sessions have been conducted in Argentina, Austria, Spain, Uruguay and Venezuela.

Expert visits to study areas have also been funded by the project. These visits were carried out through 11 missions. Topics addressed include detailed planning of sampling campaigns, processing and interpretation of chemical and isotopic information, development and calibration of mathematical models for groundwater, integration of geographic information systems (GIS), application of nitrogen-15 and oxygen-18 in the assessment of nitrate origin in groundwater, evaluation of seawater intrusion, and urban hydrology.

Preliminary results have given rise to four hydrogeological conceptual models for the same number of study areas. For the others, it is necessary to conduct additional sampling campaigns. End phase project activities include: estimation of the mean residence time of groundwater in Costa Rica, measurement of nitrogen-15 and oxygen-18 in nitrates in Argentina, additional analysis of noble gases and CFC's in Peru, additional analysis of deuterium and oxygen-18 in Uruguay and Ecuador, and improvement of the hydraulic characterization of the aquifer in Cuba.

It is hoped that project results will be used by participating countries in adopting strategies to control overexploitation of groundwater and limit pollution in the study areas. The project will continue in 2010, and the final coordination meeting will be in October 2010 in Guayaquil, Ecuador.

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# Evaluation of Quality and Quantity of Groundwater Seepage in Kuwait Bay

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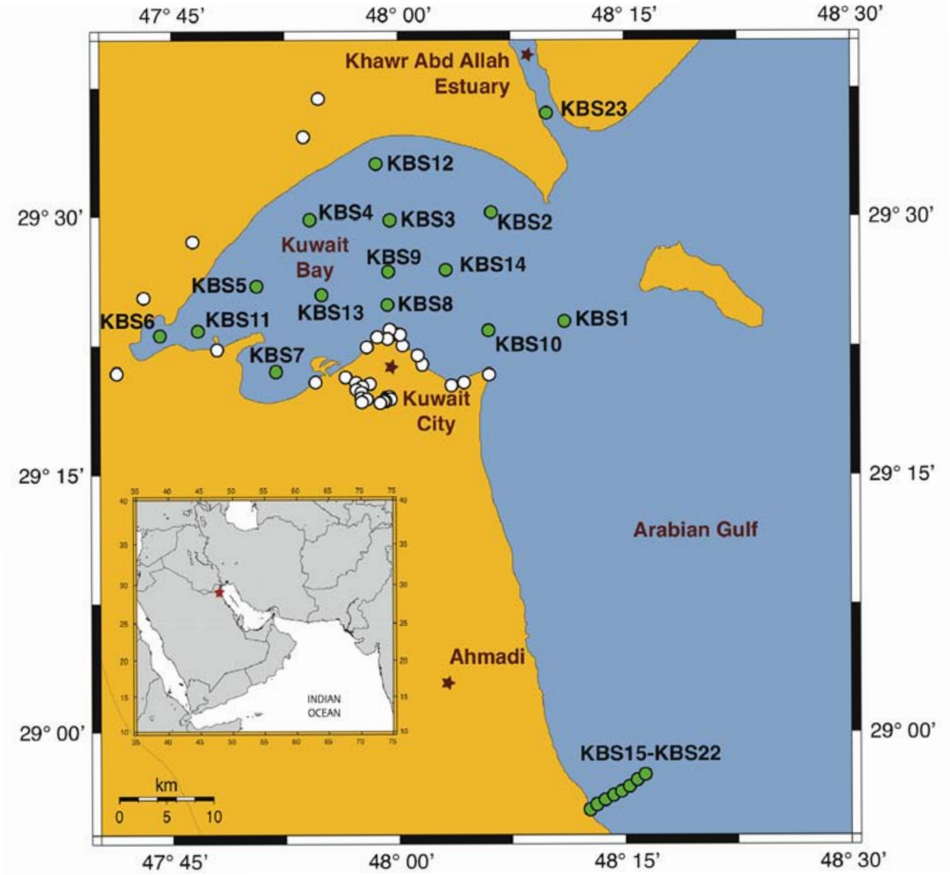
*Kuwait Institute for Scientific Research*

*This study provides the first estimates of submarine groundwater discharge (SGD) in Kuwait Bay using isotope tracers.*



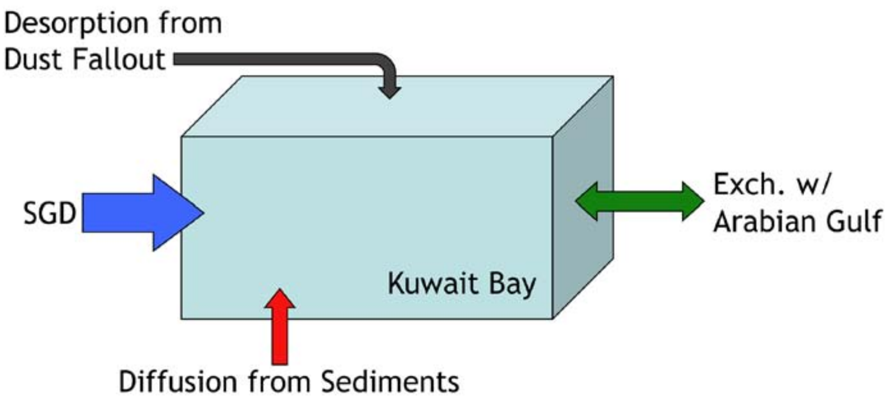

*Locations for surface (green circles) and ground water (white circles) sampling sites in Kuwait Bay.*

The flow of groundwater into the sea, which is known as submarine groundwater discharge (SGD), is an important phenomenon that has proven impacts on the chemistry of coastal waters. Having stated that, SGD can be a significant component of the elemental budget of Kuwait Bay (KB). In an effort to support sound management of the bay, this study provides the first estimates of SGD to KB and the Kuwait coastline in the Arabian Gulf. Using radium as a tracer for groundwater, estimates of SGD rates ranged from 1.1 to 2.8 × $10^7$ $m^3$ $d^{-1}$ (55 to 150 $m^3$ $m^{-1}$ $d^{-1}$) for KB and 0.65 to 1.3 × $10^7$ $m^3$ $d^{-1}$ (65 to 125 $m^3$ $m^{-1}$ $d^{-1}$) for the Arabian Gulf. Based on average groundwater concentrations around the bay, SGD adds about 1000 tones $d^{-1}$ of nitrate into the bay. The extreme aridity of the Gulf region has been a major factor in the setup of the radium budget in the following ways: (1) dust storms greater than 5 g $m^{-2}$ $d^{-1}$ have the potential to add significant quantities of radium to coastal waters, and hence should be accounted for in this and similar environments; (2) seawater evaporation during hot and dry periods may lead to density driven exchange between surface water and groundwater, and; (3) urbanization driven recharge dominates SGD's temporal trend. Signs of SGD impact on bay characteristics were examined. Overall, temperature, nitrate and chlorophyll-a have shown temporal and spatial trends similar to radium.

## Project Description

The study adapted the use of naturally occurring radium isotopes as tracers to quantify the SGD to the bay. (Moore et al., 2006; Charette et al., 2004). More specifically, the box model approach (equation below) was selected to avoid the potential effects of SGD from the opposite shorelines of the bay on the radium gradient.

$$^{226}Ra_{SGD} = \underbrace{\left[\frac{\left(^{226}Ra_{KB} - {}^{226}Ra_{AG}\right) \times V_{KB}}{t_{KB}}\right]}_{F_{Mix}} - F_{Sed} - F_{Dust}$$



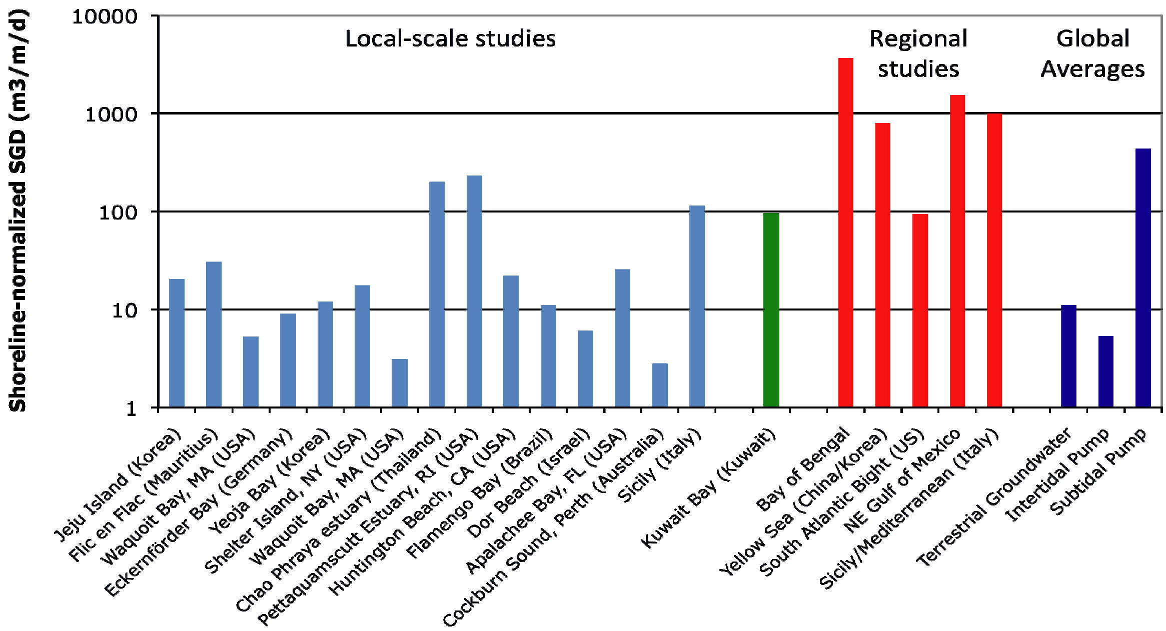

*Simplified box model for determining SGD via $^{226}Ra$.*

where $^{226}Ra_{KB}$ is the average concentration of $^{226}Ra$ within Kuwait Bay, $^{226}Ra_{KB}$ is the $^{226}Ra$ concentration of the Arabian Gulf waters that enter Kuwait Bay through tidal exchange, $V_{KB}$ and $t_{KB}$ are the volume and residence time of water in Kuwait Bay, respectively. Together these terms are solved to determine loss via mixing ($F_{Mix}$).

The approximately 14 months field activities included KB, Arabian Gulf and ground water sampling along with well drilling. A total of 12 seawater sampling campaigns were conducted, resulting in the collection of 176 samples (fig. opposite page). These samples were collected for oceanographic characterization of bay water, determination of radium content for mass balance calculations, and determination of trace elements content as ancillary information. Two groundwater sampling campaigns were conducted, resulting in the collection of 48 radium samples, 45 major elements samples and 23 trace elements samples (fig. opposite page).

## Results and Recommendations

Using the above approach, this study produced the first direct estimates of SGD to KB and the Kuwait territorial waters of the Arabian Gulf. After accounting for additional sources and sinks, the radium mass balance in combination with a measured $^{226}Ra$ groundwater average of 170 dpm $L^{-1}$ resulted in submarine groundwater discharge rates that ranged from 1.1 to 2.8 × $10^7$ $m^3$ $d^{-1}$ (55 to 150 $m^3$ $m^{-1}$ $d^{-1}$) for KB and 0.65 to 1.3 × $10^7$ $m^3$ $d^{-1}$ (65 to 125 $m^3$ $m^{-1}$ $d^{-1}$) for the Arabian Gulf. The average radium derived SGD for KB falls within the median SGD for a number of locations with a wide range of geologic and climatologic characteristics and SGD reports significantly higher than other arid regions (fig. below). Large scale urban irrigation in Kuwait City and suburban areas partially explains these differences. In addition, the relatively large scale of application in this report (i.e. compared to other arid region reports) allowed for the accounting of SGD occurrence a




*Shoreline length normalized SGD for a wide range of global studies, including this study. Korea refers to the Republic of Korea.*

significant distance beyond the intertidal zone.

The extreme aridity of the Gulf region has been a major factor in the setup of the radium budget, the following are necessary considerations for SGD estimation in such arid conditions: (1) dust storms greater than ~5 g $m^{-2}$ $d^{-1}$ have the potential to add significant quantities of radium to coastal waters. This source must be accounted for when using radium isotopes as a tracer of SGD in this and similar environments; (2) seawater evaporation during hot and dry periods may result in hypersaline conditions within coastal waters, which in turn may lead to density driven exchange between surface water and groundwater within the shallow superficial aquifer, and; (3) irrigation of landscapes and private gardens in coastal megacities in arid regions dominates the typically limited natural recharge, which in turn leads to controlling the levels and their periodicity of the groundwater beneath these cities.

*...it is recommended that an overall budgeting of the bay's nutritional and elemental inputs and outputs be conducted.*

The above SGD rates combined with average groundwater concentrations around the bay enabled estimates of SGD elemental input to the bay, out of which nitrate, with approximately 1000 tones $d^{-1}$, is very alarming. Signs of SGD impacts on bay characteristics were examined by looking into temporal and spatial correlations between $^{226}Ra$ activities and bay water characteristics. Overall, temperature, nitrate and chlorophyll-a have shown temporal and spatial trends similar to those of radium. Nonetheless, other inputs (e.g. seweage) to the bay with temporal trends similar to radium might be responsible for some of the observed impacts. Recommendations for further studies and reduction of potential impacts of SGD were made.

Even though this study showed that large elemental mass is reaching the bay via SGD, the significance of such information can be judged only within the context of the overall budget of the bay. Accordingly, it is recommended that an overall budgeting of the bay's nutritional and elemental inputs and outputs be conducted. In such a study, obtained estimates of elemental inputs to the bay through SGD should be utilized in the calculation of non-point sources to the KB. If such a study deems such inputs to be excessive and show that SGD is playing a significant role in this excessiveness, the following measures are recommended: (1) leakage control, increased water tariff and increased public awareness to reduce SGD, and (2) monitoring and regulating potentially polluting activities to enhance the quality of SGD.

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# Isotope Hydrology Goals Supported at General Conference

The goals of the Isotope Hydrology Section will be given a push forward with adoption of a resolution at the 53rd General Conference, held in September 2009. The resolution, entitled "Strengthening the Agency's activities related to nuclear science, technology and applications" supports goals such as:

- Strengthening collaboration with other national and international organizations to fully use isotope and nuclear techniques in water resources development and management;
- Upgrading of selected laboratories and aiding Member States in adopting new and less expensive analytical techniques, including laser-based ones;
- Continuation of work on groundwater management, most especially fossil resources — including mapping — in collaboration with other international and regional organizations;
- Strengthening of activities which contribute to understanding climate/water cycle relations in an effort to better predict and mitigate water related natural calamities, and to contribute to the success of the International Decade on Freshwater.

The resolution further requests continuation of support for human resourced development and training so that local hydrologists can provide Member States with appropriate tools and practices. Implementation of these goals is meant to be reported upon by the Director General to the Board of Governors and the General conference at its 55th session in 2011.

# Isotope Hydrology Used to Improve Drinking Water Supply in Southern Madagascar

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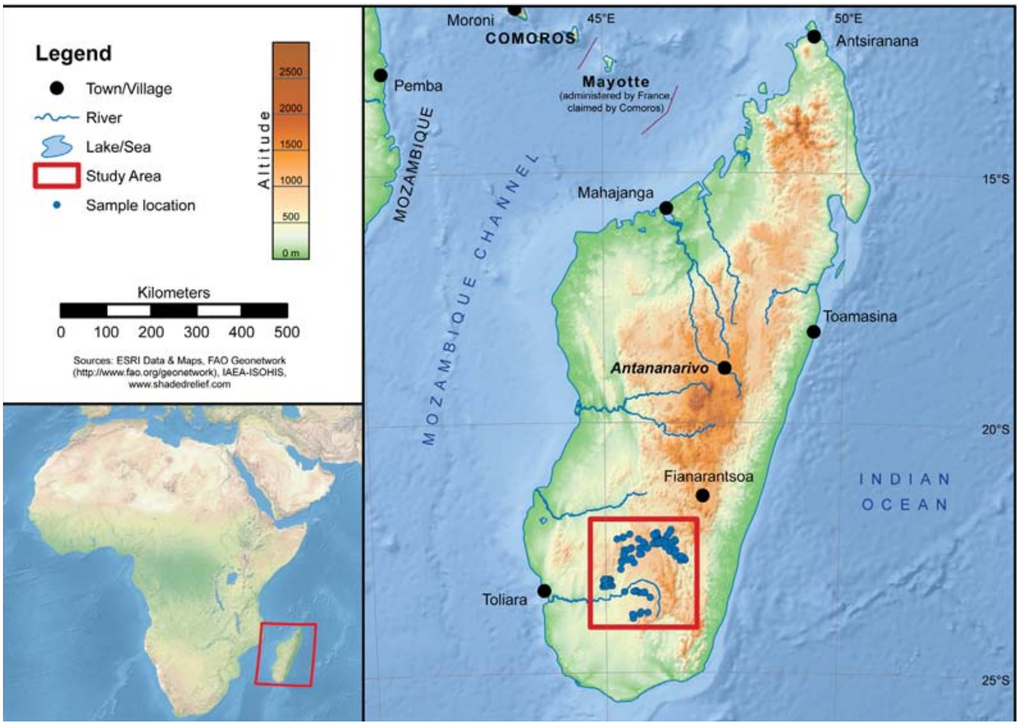
*Isotopes have been used in hydrogeological studies, together with hydrochemistry, to characterize aquifers in Tianarantsoa and Toliara provinces to investigate pollution sources and contribute to a safer water supply.*




*Map showing sampling points on the island.*

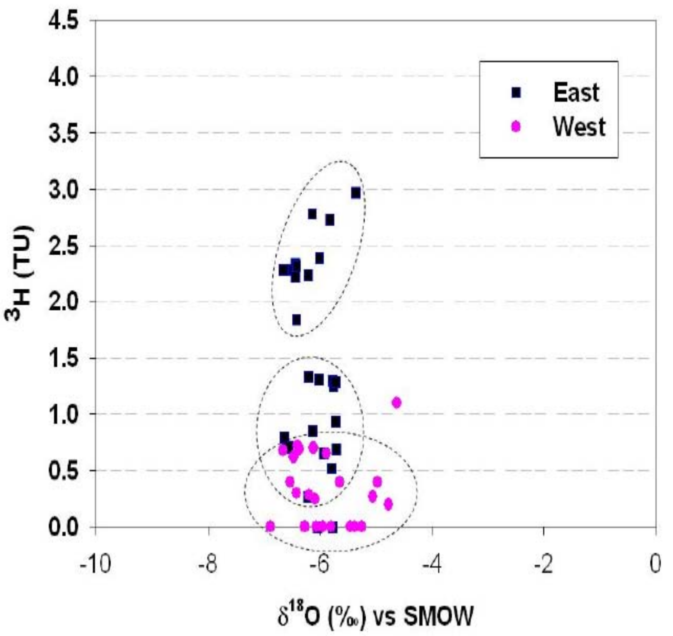
Madagascar is an island state (surface area: 587 000 km$^2$), located about 300 km off the southeastern coast of Africa, near Mozambique (see above map). In Madagascar, water-borne diseases are often responsible for sickness and death, especially in children. About a quarter of all deaths among children (24%) are caused by diarrheal diseases, according to a Madagascar Ministry of Health survey in 2000 (USAID, 2009).

Only 30% of Madagascar's population, or 67% and 16 % respectively in urban and rural areas, have access to potable water (ANDEA, 2007). This situation has left the population susceptible to diarrheal diseases, especially in the rural area, such as in Fianarantsoa and Toliara provinces [the study areas of TC isotope hydrology projects MAG8004 and MAG8006]. The supply of safe drinking water has thus become one of the greatest national priorities in recent years. The major potable water source is groundwater, while surface waters represent supplementary sources (BGS, 2002).

## Objectives

Isotopes have been used in hydrogeological studies in Madagascar, together with hydrochemistry, to characterize aquifers in Fianarantsoa and Toliara provinces in order to investigate vulnerability to pollution and contribute to water resource management for a safe drinking water supply. These studies have been supported by two IAEA Technical Cooperation projects, MAG8004 (2005-2007) entitled 'Integration of Isotope Techniques for Ground Water Exploitation, Phase II' and MAG8006 (2007-present) entitled 'Use of Isotope Techniques in Studies for the National Programme of Borehole Drilling in the Provinces of Fianarantsoa and Toliara'.

The two TC projects have been jointly conducted by the Madagascar National Institute of Nuclear Sciences and Techniques (L'Institut National des Sciences et Techniques Nucleaires de Madagascar: Madagascar-INSTN), responsible for scientific and technical elements, and by the




*Spatial variations in tritium and $^{18}O$ contents suggest the presence of groundwater bodies with different residence times.*

Directorate of Water and Sanitation of the Ministry of Energy and Mines (la Direction de l'Eau et de l'Assainissement du Ministère de l'Energie et des Mines), in charge of fieldwork logistics and database activities.

## The study area

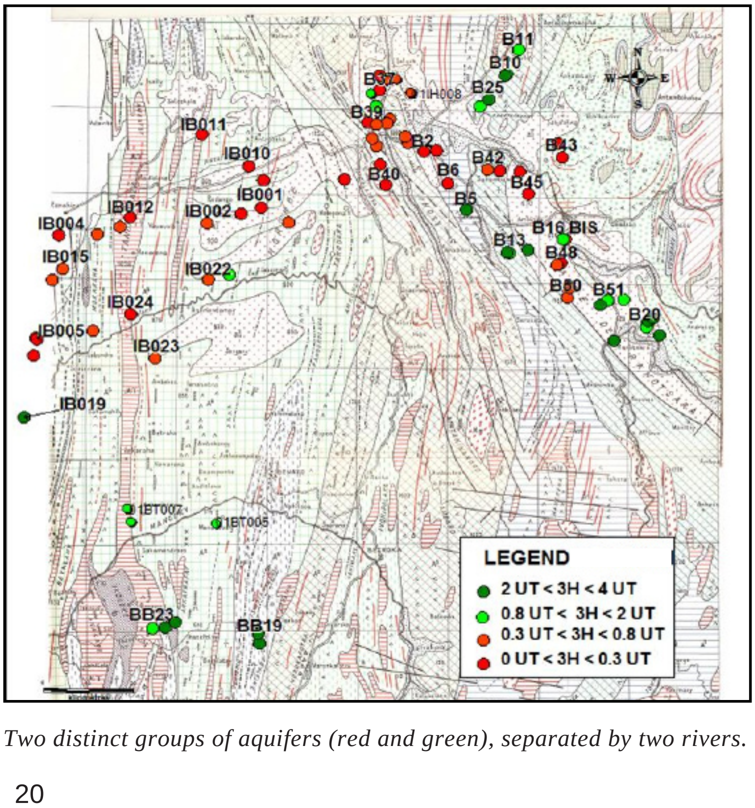
The study area covers Fianarantsoa and Toliara provinces, which are located in the southern part of the main island. The climate is diverse in Madagascar, with dry (May-October) and rainy seasons (November-April). The Ihorombe region has a tropical climate throughout the year, with low annual precipitation (800 mm) and an average temperature of 19-28°C, with maximum temperatures reaching 28-35°C. In Madagascar, the high plateau region is characterized by Precambrian crystalline basement rocks, primarily granite, gneiss and schist.

Sedimentary basins in coastal lowlands and intermontane valleys in the plateau are composed of younger rocks and alluvium, respectively. Volcanic rocks with basalt are also found (BGS, 2002). The study area can be divided into four regions from west to east in terms of morphology: (a) the lateritic plateau of Horombe, at an altitude of between 1000 and 1100 m; (b) the Ihosy drainage, moving from the north toward the Mozambique Channel area, connected with the Zazafotzy plain in the north, and bordering the Ranotsara plain; (c) the high relief area of Lez, with a slightly decreasing altitude toward the southern city of Ihosy; and (d) the Ranotsara plain, of lacustrine origin. Drainage extends to the Indian Ocean and to the Mozambique Canal, following the relatively straight divide. The region consists of three basins: the Zomandao, the Onilahy, and the Mananara, where the Sahambano and Menarahaka rivers drain.

## Field and laboratory works

Field work started with the collection of 25 well water samples in 2006 to investigate hydrogeologic conditions at the study site (Fig. below). Two, more extensive sampling campaigns were conducted in May and June 2008, when 76 groundwater, 2 river water and 5 rainwater (December 2007-May 2008) samples were collected. Madagascar's new Isotope Hydrology Laboratory, INSTN, was able to analyse some of the tritium ($^3H$) results, as well as undertaking hydrochemical analysis.

Tritium concentrations in groundwater enable the estimation of groundwater recharge timing (pre or post-bomb testing after 1952). Spatial variations in tritium groundwater concentrations (fig. left) suggest two distinct groups of aquifers — A (green in fig. below) and B (red in fig.below) — separated by two rivers, the Ihosy and the Menarahaka. The distinct differences in tritium values may be due to the presence of the Ranotsara fault (which runs northwest to southeast) between the two groups of aquifers. West of the rivers (aquifer B), tritium values in groundwater are basically zero, suggesting hydrological isolation from atmospheric input in this part of the study site, where the




*Two distinct groups of aquifers (red and green), separated by two rivers.*

climate is arid. In contrast, east of the rivers (group A), most tritium concentrations are higher, which may be due to the regular input of rainfall. Residence time is considered to be more than 50 years (prior to 1952). The spatial differences in tritium values was further examined by a plot of tritium versus stable oxygen isotopes of water (fig. opposite page left — $^{3}H$ vs $^{18}O$), and suggest that A group aquifers (east of the rivers) can be divided into two subgroups. This analysis also suggests that tritium is a powerful tool in characterizing aquifers in this study. Further data analysis would enable clearer characterization of the aquifers. Groundwater is considered to be more vulnerable to contamination if recharge occurs at a higher rate. In the project study site, zone A, which is hydrologically less isolated, may thus be susceptible to contamination.

## Main outcomes of the projects

Results from the two projects started to reveal characteristics of the aquifers. There are two main types of aquifers: those relatively hydrologically isolated and possibly not highly affected by industrial and other developmental activities and those other with a higher rate of recharge, and thus more vulnerable to pollution. In addition, the hydrogeological studies included in these projects show that the capability of analyzing tritium and hydrochemical samples is growing at the Madagascar-INSTN laboratory.

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# News in Brief

## New Developments

• The isotope hydrology section will soon release a pocket sized booklet to accompany the Introduction to Water Sampling and Analysis for Isotope Hydrology DVD, which details procedures — through video and oral explanation — required to produce high quality water samples. This brochure will be published in a smaller (pocket size) format so that users can carry it with them to the field and have it on hand to guide them step-by-step through the sampling procedure. The DVD and booklet together are meant to aid practitioners and researchers in hydrological work, to efficently gather information and thus enhance knowledge of particular water supplies. Proper water sampling is central to virutally all activities in isotope hydrology. It is important that equipment be properly calibrated, that samples are not contaminated, and that they are collected in such a way that the information drawn from them is accurate.

## New Staff Members

• Mr. Paul Gremillion joined the Isotope Hydrology Section as a consultant in July 2009. Mr. Gremillion is on leave for one or two years from Northern Arizona University (NAU), where he is an Associate Professor of Environmental Engineering. He has a background in water quality management and ecosystem restoration. His current research involves the use of lake sediment cores to reconstruct patterns of mercury deposition on landscapes. Prior to joining NAU he managed large scale wetlands restoration projects in Louisiana. His dissertation research involved using stable isotopes to understand how the hydrology of rivers is affected by urbanization. While he is in the IHS, Mr. Gremillion's activities will include work on the Nubian Sandstone Aquifer project and the Nile River Basin project.

• Mr. Charles Dunning joined the Isotope Hydrology Section as a Water Resources Advisor in January 2010. Mr. Dunning has transferred to the section from the US Geological Survey, Wisconsin Water Science Center, where he was an Assistant Director and managed science teams focusing on groundwater, regional and national assessments, and mercury in the environment. His academic training is in geology, and civil and environmental engineering. Mr. Dunning will have a lead role in the IAEA Water AVailability Enhancement (IWAVE) Project during his time in the section.

## Departing Staff Members

• Ms. Ravina Brizmohun was a consultant in the section between January and October 2009. She previously worked in the National Environmental Laboratory of the Ministry of Environment in Mauritius (where she has since returned), and was formerly involved in a TC project in Mauritius. In the section, she provided support on technical cooperation projects in Africa and Asia and was involved in the compilation of isotope data for projects in Africa.

- Mr. Clifford Voss from the US Geological Survey (USA) worked in the Isotope Hydrology Section for a few months on the Nubian Sandstone Aquifer project. He is a senior scientist at the USGS National Research Program and Executive Editor of the Hydrogeology Journal — the official journal of the IAH (International Association of Hydrogeologists). Mr. Voss is a quantitative hydrogeologist specialized in groundwater modelling, and he consults and teaches worldwide. Ms. Safaa Soliman, a groundwater modelling specialist from Egypt worked with Mr. Voss on the Nubian project.

- Ms. Safaa Soliman, from the Reasearch Institute for Groundwater in Egypt, worked in the Isotope Hydrology Section for 4.5 months on the Nubian Sandstone Aquifer project, together with Mr. Clifford Voss. She is an associate professor and specialist in groundwater modelling, teaching courses in groundwater modelling in Egypt. She is working on the modelling of the Nubian Sandstone Aquifer.

## Obituaries

*Herbert Tatzber*

- Herbert Tatzber, a colleague at the Isotope Hydrology Laboratory in Vienna passed away on 29 December 2009 at the age of 55, after a long and serious illness. Mr. Tatzber was born in 1955 in Vienna. After graduation in Vienna he worked for few years as nuclear engineer at the planned Austrian nuclear power plant in Zwentendorf. After it was decided the power plant would not be put into operation, Mr. Tatzber joined the IAEA Isotope Hydrology Laboratory. This took place in December 1979, just after its move to the Vienna International Centre. In December 2009 when he passed away, he had just completed 30 years of service for the IAEA. In the laboratory he was initially responsible for tritium and $^{14}C$ analysis using gas proportional counting and liquid scintillation counting. Due to his excellent technical skills and absolute reliability, he was responsible over many years for preparation of all internal laboratory tritium calibration standards and of test materials for international tritium interlaboratory comparison exercises. In the last 14 years he additionally took over responsibility for preparation and shipment of stable isotope reference materials. His careful approach at work and technical experience very much facilitated the strong and successful involvement of the laboratory in the development of new international reference materials such as VSMOW2.

He was an exceptional example of kindness and was ready to help for anybody at anytime. His friendly personality and cooperativeness, together with his modesty, will be remembered gratefully by everybody who ever worked with him. He leaves behind his wife Henriette, son Martin and daughter Isabella.

- Etienne Roth, a great contributor to isotope hydrology, was born in Strasbourg in 1922, just few years after the return of Alsace to France at the end of WWI. He joined the French Commissariat à l'Energie Atomique in 1946 and one year later was sent to Canada to complete his scientific training, working with Prof. Harry Thode, founder of sulphur isotope geochemistry. Mr. Roth returned to the CEA in France, working on mass spectrometry and the production of heavy water. The mass spectrometer that he built was able to detect small variations of deuterium content in natural waters, which led him to work in isotope hydrology. In collaboration with L. Facy, L. Merlivat and G. Nief, he contributed to understanding the mechanism of hail formation through radial deuterium content variations in hailstones (1962-1963): this remains one of the most elegant studies of meteoric waters made with stable isotopes. Some of the best determinations of isotope fractionation factors in water evaporation and ice sublimation were carried out in his laboratory by Liliane Merlivat, Michel Majoube and Guy Nief in the years 1967-1971, and the applications of isotopes to meteorological and climatological investigations were continued by his collaborators, Liliane Merlivat and Jean Jouzel. In 1970, together with R. Hagemann and G. Nief, Mr. Roth was the first to determine the absolute deuterium content of VSMOW (Vienna Standard Mean Ocean Water) and SLAP (Standard Light Antarctic Precipitation), prepared by Prof. H. Craig following an IAEA request; the Agency distributes these reference waters for international intercalibration of deuterium and oxygen-18 measurements. Mr. Roth also contributed to the discovery of the natural uranium fission reactor in Oklo, Gabon. Mr. Roth passed away in March 2009 in Paris, leaving behind his wife Françoise and four daughters: Catherine, Elisabety, Marianne and Brigitte.

- Heribert Moser (8 April 1922, Munich-8 June 2009), was a key figure in isotope hydrology at the international level. He engaged in mathematics and physics studies (1949) and later got his doctorate in Raman spectroscopy from Ludwig Maximilian University (LMU) in Munich. After his postdoctoral lecture qualification (1954) he lectured at LMU, and also taught physics and mathematics at Gisela secondary school in Munich. In 1951, a fruitful cooperation between physicists and geologists started, which in 1957 became the basis for a ‘research centre for radiohydrometry’, led by the LMU Institute for General and Applied Geology and Minerology. Work was mainly done in the area of development of isotope hydrology methods to research the movement and age of groundwater and its application to the issue of acquiring drinking water, groundwater protection and the dissemination of pollutants in water. In 1967, the research institute became attached to the ‘Institute for Radiohydrometry’ Gesellschaft fuer Strahlenforschung — GSF (the Association for Radiology Research), today called the Helmholz Zentrum Muenchen, Deutsches Forschungszentrum fuer Gesundheit und Umwelt (Helmholz Center Munich, German Research Center for Health and Environment) in Neuherberg. During this time Mr. Moser became the institute’s head. When he entered retirement in 1987, the institute had nearly 60 employees in comparison to just a few in the young days of radiohydrometry. The interdisciplinary cooperation between physicists, geologists, chemists and engineers under the roof of one institute was novel in comparison to other working groups.

The Institute for Radiohydrometry carried out jobs over a wide palette of geoscientific research and applications. Mr. Moser cultivated successful cooperations with national and international partners. Mr. Moser’s activities led to an established reputation for the Institute for Radiohydrometry and the field of isotope hydrology. This was also expressed in long cooperation with the Isotope Hydrology Section of the IAEA in Vienna. He and his group were IAEA TC experts in many projects — especially in Latin America. In 1978 the German Gesellschaft fuer Strahlenforschung hosted the IAEA Isotope Hydrology Symposium in Neuherberg. In 1983-88 Germany financed a IAEA coordinated research programme to apply isotope techniques in hydrology in Latin America, for which the German scientific counterpart was Mr. Moser’s isotope hydrology group in Neuherberg. In 2003, he was granted an honorary doctorate from the TU Bergakademie in Freiberg.

## Meetings

The Water Resources Programme was represented by Mr. Tuerker Kurttas at the Fifteenth Conference of the Parties (COP-15) to the United Nations Framework Convention on Climate Change (UNFCCC) held in Copenhagen, Denmark from 6-18 December 2009. Kurttas was joined by representatives of the Department of Nuclear Energy and the Department of Nuclear Sciences and Applications.

The IAEA distributed information about its role in climate change mitigation at an exhibit stand, which proved to be an effective channel of communication. IAEA representatives stated that many more party delegates stopped by than at previous COPs, with most of them engaging in discussions and collecting displayed material. The stand provided factual information on nuclear energy for the mitigation of climate change, as well as on IAEA activities regarding adaptation to climate change and the science behind it.

Material at the exhibit included a joint NA/NE brochure entitled ‘Climate change and the atom’, which discussed IAEA activities in relation to mitigation, adaptation and the science of climate change. The Water Resources Programme additionally provided folders containing various pamphlets and leaflets on its work. Publications on energy planning and mitigation of climate change and leaflets explaining the use of isotope tools in the fields of food and agriculture, as well as material on case studies were also available at the stand.

*Climate change issues are highlighted during a side event. Students ask for a ‘fair, ambitious and legally binding’ agreement in Copenhagen (Photo credit: T. Kurttas).*

# Seychelles Aquifer Studied to Assess Water Quality

*The increasing demand for good quality water to meet human consumption and economic development needs led to a request to initiate a TC project aimed at evaluating the potential of La Digue aquifer.*

*By R. Brizmohun, National Environmental Laboratory of the Ministry of Environment, Mauritius and E. Sacchi, Universita degli Studi di Pavia, Pavia, Italy*

*The PUC team at work during the April 2009 monitoring and sampling campaign (Photo credit: E. Sacchi).*

La Digue is the fourth largest inhabited island of the Seychelles, lying east of Praslin and west of Felicite Island. The island is only 14 km², with most of its surface covered by tropical forests of uncommon beauty. The steep hillsides, reaching 333 m a.s.l. are constituted of granitic rock. In the western part, an oval shaped plateau area covers a surface of 1.87 km², with a mean elevation of 3.5 m a.s.l. The plateau is bordered to the east by the sea and to the west by two rivers which collect surface runoff from the hills. The population, about 2000 people, mostly live in the west coast villages of La Passe and La Réunion in the plateau area. The main economic activities of the island are tourism and, to a smaller extent, agriculture.

Traditionally, the Seychelles Islands rely primarily on rain and surface water for human requirements. In the case of La Digue, rainwater cannot be stored because there is no suitable topographic setting for a dam. Therefore, despite high precipitation (averaging 1250 mm but reaching up to 2400 mm in rainy years) the island needs to integrate its water supply with groundwater (accounting for about 50% of annual consumption), and water from a desalination plant.

The exploited aquifer is made up of quartz sands and gravels, covered by calcareous sands and gravels, for a total deposit thickness varying from 12.5 to 17.5 m. This points to an infilled shallow coastal lagoon — probably flooded several times during the Quaternary by sea water — as the origin. It is mainly recharged by local infiltration on the plateau area and by rivers bordering the plateau to the east.

Several boreholes were excavated on the island to prospect for water (Institute of Hydrology, 1978; McCarley and Lindberg, 1987). Pumping tests conducted during these surveys indicate transmissivities ranging from 300 to 800 m$^2$/day, depending on location; higher close to the ridge and lower on the seaside.

Pumped groundwater is treated using aeration prior to mixing with other sources, which contributes to a reduction in its negative characteristics; then it is distributed. Nevertheless, the PUC faces strong opposition to groundwater use by the island's people, mainly because of its odour and hardness. Following a request by the local counterpart, the IAEA initiated a TC project aiming at evaluating the potential of the La Digue aquifer in 2007.

*Preliminary results indicate that the La Digue aquifer indeed hosts groundwater of poor quality.*

## Project Objectives

The objectives of this project are to understand the reason behind undesirable groundwater characteristics, to support local capabilities in setting up a monitoring programme to keep groundwater quality evolution under control, to assist in identification of suitable locations for a new pumping station, and to evaluate the possibility of increasing recharge.

In order to successfully achieve the objectives of the project, three expert missions have been conducted, a set of monitoring activities has been implemented, and an hydrochemical and isotopic survey has been conducted (Photo left).

The investigation, focusing both on groundwater and river water, consists of monitoring water levels and main hydrochemical parameters, determining groundwater hydrochemical and isotopic characterisation, undertaking hydrochemical sampling and characterisation of river water, using the same hydrochemical and isotopic parameters analysed in groundwater, and assessing the inland penetration of sea water through river channels and in the marsh area.

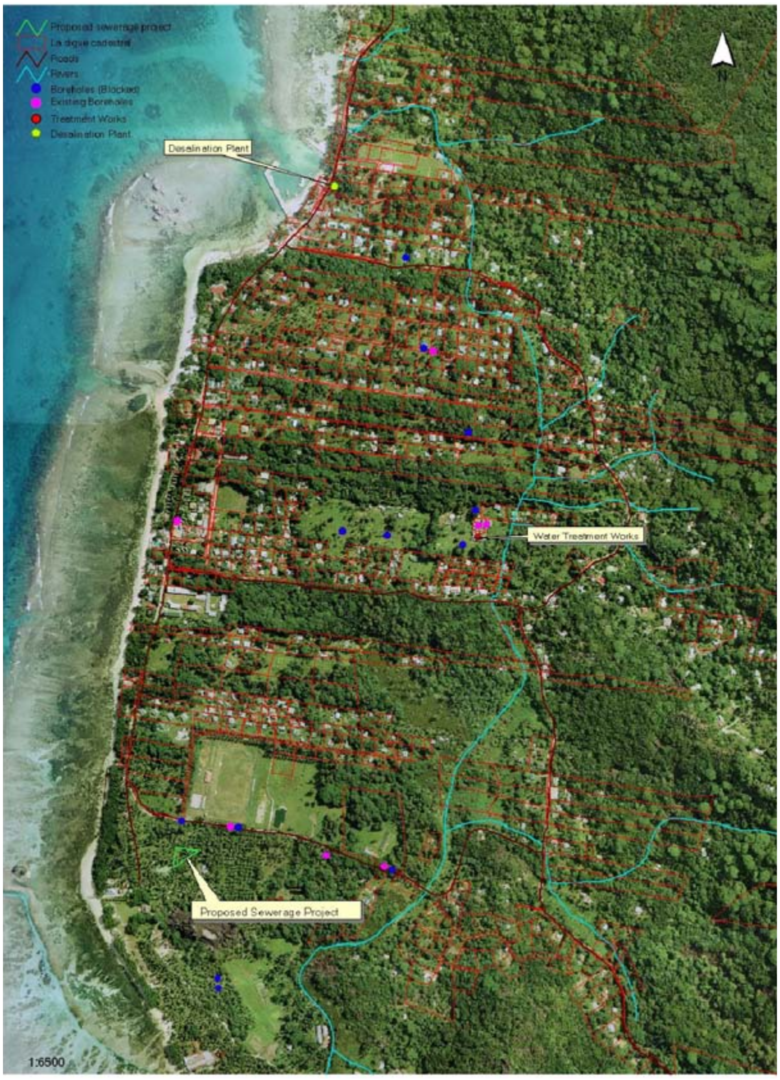
## Preliminary Results

Preliminary results indicate that the La Digue aquifer indeed hosts groundwater of poor quality. Electrical conductivities range from 0.4 to more than 30 mS/cm. The presence of brackish water is detected at shallow depths as well as far inland. In addition, redox potentials are generally low, testifying to the presence of $H_2S$ and heavy metals.

Water table depth is 0.80 to 1.5 m below ground surface and only 1–2 m above sea level. Contour maps indicate that during the rainy season, the aquifer is recharged by local infiltration and by the two rivers bordering its east end. On the other hand, during the dry season, the rivers probably drain the aquifer, inducing an inversion in the flow direction and causing sea water intrusion in the coastal area. Sea water intrusion may also be enhanced by overpumping, as the current pumping station abstraction is beyond the recommendation rate set in 1987 (800 kl/day, Alcindor et al., 2007). In addition, most streams feeding the rivers have water drawn away for human consumption, therefore reducing natural recharge of the aquifer.

Finally, human pressure is high in the plateau area, where most small hotels and tourist facilities on the island currently exist. Sewage water is not collected and households are only equipped with sewage tanks. During the rainy season, the water table level rises, often causing the tanks to overflow. Despite strong anthropogenic pressure, nitrates are not commonly observed among main groundwater constituents, possibly because the low redox potential favours denitrification. Nevertheless, the isotopic composition of dissolved nitrates clearly indicates an origin from leaking septic tanks.

During the expert missions, it was noted that sea water penetrates along the ends of the river during high tide (photo next page). In the past, river mouths were equipped with




*Arial map of the study area (credit PUC).*

*Sea water penetrating into the river channel during high tide. The river mouth was once equipped with non-return gates which prevented this ingression from occurring (Photo credit: E. Sacchi).*

non-return high tide gates which would allow excess fresh water to discharge into the sea but prevent sea water from penetrating inland. Unfortunately in the 1990s the gates ceased functioning and were never replaced. Conductivity measurements performed with increasing distance from the sea — at low tide and after a conspicuous rain event — indicate the river water is still highly saline and stratified. Since brackish water is flooding the marsh area located east of the L'Union Reserve and is not fully flushed away during rain events, a serious concern has arisen about its possible infiltration into the recharge area of the aquifer and close to the actual pumping station. It is believed that replacement of the gates, an easy and low cost intervention, would ameliorate the quality of water extracted from the existing pumping station.

Areas favourable for new wells have been identified. These are located east of the rivers and far from the marsh area, at higher elevation with respect to the plateau area. The aquifer there, although possibly of reduced thickness, is mainly made up of sands from erosion of the granitic ridge, and carbonates are absent, as indicated by the acidic pH (6.65) and low conductivity (0.33 mS/cm).

Finally, due to its unfavourable natural characteristics and anthropogenic pressure, use of the plateau aquifer as a storage facility is not without major drawbacks. Rainwater harvesting is an important low cost alternative and should be implemented with government support. In addition, in order to preserve groundwater quality, a sewage collection system should be constructed together with a sewage treatment plant, the location of which is presently being investigated. Treated water could be used for agriculture or for reinjection into the La Digue aquifer in order to prevent seawater intrusion.

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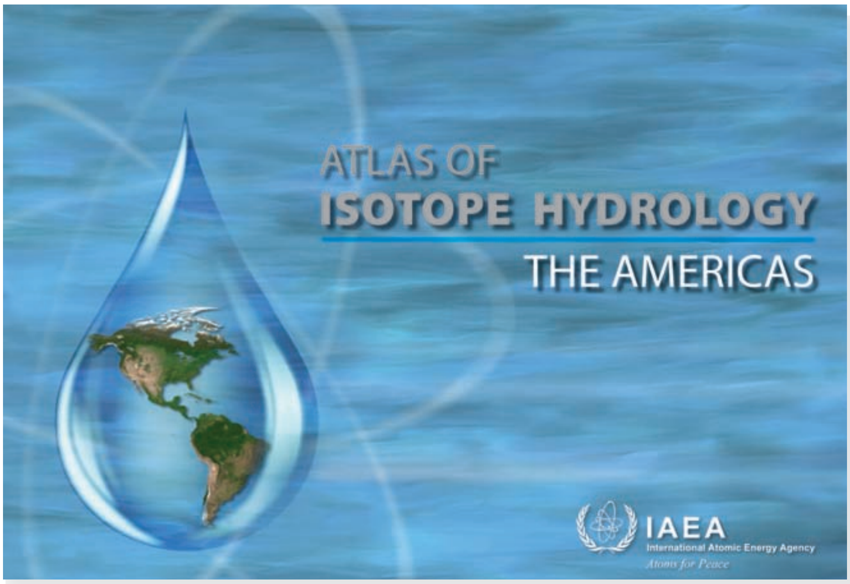
# Atlas of Isotope Hydrology — The Americas Completed

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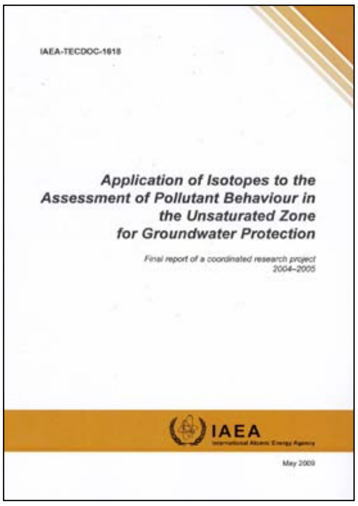
The Atlas of Isotope Hydrology – The Americas was completed in 2009, following the release of two previous atlases in 2007 and 2008, covering Africa and Asia and the Pacific. This isotope hydrology atlas focuses on projects in IAEA Member States in the Americas, where environmental isotopes were used to assess water resources in terms of quantity or quality. It presents location maps of study areas, summary statistics and relevant data plots. About 19 000 isotope records from 150 projects carried out between 1968 and 2008 in 23 Member States are included.

For each country, a physiographic map is provided that shows major water bodies, locations of stations in the IAEA/ WMO global network of isotopes in precipitation (GNIP) and project study areas. For each project, a map of the study area is provided, together with data tables and plots for median and mean values of $\delta^{18}O$ and $\delta^{2}H$, average annual precipitation and air temperature, tritium and radiocarbon values. The information presented in this series of atlases is a valuable reference for scientists and practitioners in the fields of hydrology and water resources.

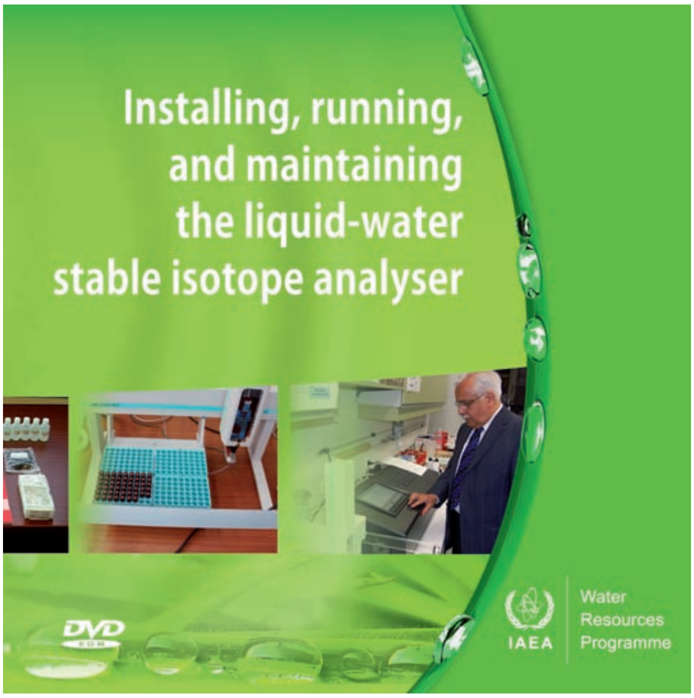
# IAEA–Tecdoc Released on Unsaturated Zone Studies

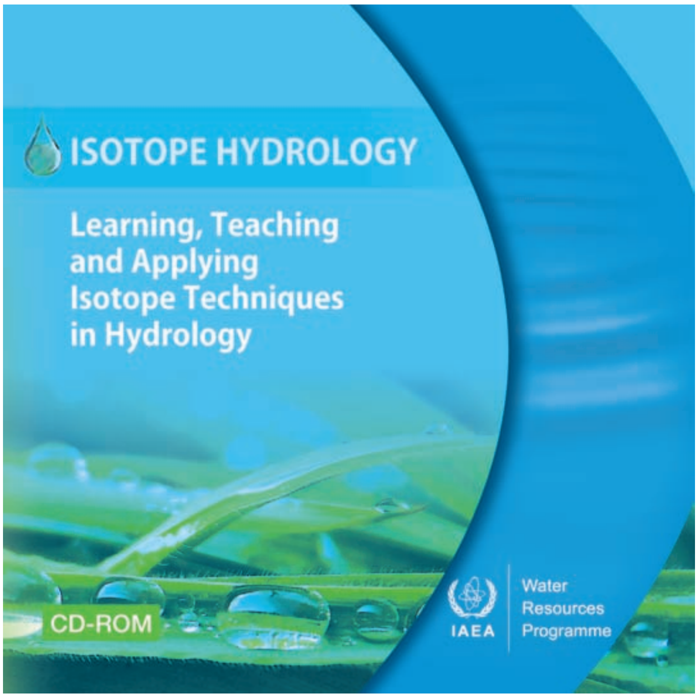



IAEA-TECDOC-1618: Application of Isotopes to the Assessment of Pollutant Behaviour in the Unsaturated Zone for Groundwater Protection is based on the findings of a coordinated research project (CRP) conducted by the IAEA with the pupose of studying what isotopic and other ancillary data are required to help understand migration of potential contaminants through the unsaturated zone (UZ) into underlying groundwater. This publication contains the reports of 10 projects and a summary of the accomplishments of individual projects presents results obtained from the field sites, located in different climatic conditions. The information was gathered using equipment to monitor and sample water and solute transport through the unsaturated zone. A number of isotope and hydrochemical tools have been used to study groundwater recharge and transport of pollutants in this zone. The information gained from these studies has led to a better understanding of flow and transport processes, which is essential to assess vulnerability of groundwater to contamination.

The 10 projects covered climates ranging from humid to arid, and water table depths from the near surface to over 600 m deep. The studies included measuring movement of water, solutes and gases through the UZ using an assortment of isotope and geochemical tracers and approaches. Contaminant issues have been studied at most of the ten sites, and UZ was found to be very effective in protecting groundwater from most heavy metal contaminants. The publication is expected to be of interest to hydrologists, hydrogeologists and soil scientists dealing with pollution aspects and protection of groundwater resources, as well as counterparts of TC projects in Member States.

# Two New Titles Released




The Isotope Hydrology section has released two titles: Installing, running and maintaining the liquid-water isotope analyser is being released for the first time. This multimedia DVD contains a training document, and other useful laser absorption analysis resources. A key item is a 45 minute video demonstrating how to assemble a DT-100 analyser from start to finish. The Learning, Teaching and Applying Isotope Techniques in Hydrology is an updated version of a previous CD-Rom, including a more user-friendly menu and updated software, as well as French and Spanish versions of the six UNESCO/IAEA volumes used as teaching material for isotope hydrology. The CD-Rom is designed as a resource for self-learning, teaching or practicing isotope hydrology, and also contains two geochemical modelling programmes of the United States of America Geological Survey. Some elements of each are accessible on the Isotope Hydrology website (www. iaea/water.org). For further information, please contact T. Kurttas (t.kurttas@iaea.org), L. Araguas (l.araguas@iaea. org) or B. Newman (b.newman@iaea.org).

# Meetings in 2010

- Research Coordination Meeting on Geostatistical Analysis of Spatial Isotope Variability to Map the Sources of Water for Hydrology and Climate Studies, Vienna, Austria, 15-19 March.
- Research Coordination Meeting on Isotope Methods for Assessing the Impact of Climate Change on Water Resources in Snow, Glacier and Permafrost Dominated Areas, Vienna, Austria, 23-27 August.
- Final Research Coordination Meeting of the CRP on Isotope Techniques for the Evaluation of Hydrological Processes in Wetlands, Vienna, Austria, September.
- Technical Meeting on Integration of Isotope Data in Rainfall-Runoff Models for Characterizing Watershed Hydrology, Vienna, Austria, October.
- Research Coordination Meeting on Tritium-$^{3}$He Dating and Noble Gas Techniques in Water Resources Management: Recharge, Infiltration Conditions and Groundwater Balance, Vienna, Austria, 8-12 November.

## Impressum

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