

Newsletter of the Isotope Hydrology Section
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IAEA representatives attended the 5th World Water Forum held in Istanbul, Turkey, from 16–22 March. (Photo credit: T. Kurttas).

From the Section Head

A team from the IAEA's Water Resources Programme (WRP) joined water specialists in Istanbul, Turkey, during the world's biggest water event of the year, the 5th World Water Forum. The forum, aimed at water experts and decision makers, was held from 16–22 March. The IAEA joined a display organized by UN Water, allowing visitors the opportunity to become familiar with various UN programmes. Deputy Director General Mr. W. Burkart was on hand, and participated in the World Water Forum ministerial meetings. The IAEA's exhibit included handouts and equipment, which drew many visitors. The WRP also contributed to a technical session on hydrological data requirements for water resource management. Another high point in 2009 has been the completion of the 5th laser training course. Approximately a year after launching training and distribution of a new laser spectrometer, the section is receiving overwhelmingly positive feedback from counterparts. The instruments have lower initial and maintenance costs, are easy to operate, and allow countries the opportunity to analyse more samples much faster than before. Member States have been provided with this instrument through technical cooperation programmes, enabling more researchers to determine isotope ratios independently. Two items are being released to support users in this venture: a new IAEA Training Course Series publication about laser spectroscopy installation, analysis and testing, and a multimedia DVD, including a video demonstrating assembly, operation and maintenance. Finally, the series of publications on isotope hydrology atlases will be expanded this year with a new edition on the Americas.

P. Aggarwal

'Fact Before Act' Approach Gathering Steam

By M. MacNeill (IAEA, IHS)

The IAEA presented the water management potential of isotope hydrology to experts in the subject at the world's biggest water event.



Photo credit: T. Kurttas

More and more government bodies and decision makers are adopting a 'fact before act' approach to planning, a trend that was clearly evident at the 5th World Water Forum in Istanbul, according to IAEA Deputy Director General W. Burkart, and one that should support the work of the WRP. "I was very pleased at the conference to see there is a general trend towards better understanding at a political level. The first step to mitigation of something is to understand it fully... this approach is more prevalent than before," said Mr. Burkart.

The IAEA was part of the experience of water in its broader context at the World Water Forum. Isotope hydrology is a large stroke on a vast canvas of water issues and solutions. Through exposure to the 33 058 participants who attended the World Water Forum (making it the world's biggest water event), the WRP was able to express the role it can play within a canopy of interdependent actors, who in order to meet growing demands on the world's water supplies and the chain of effects following it, are going to have to work together as a team.

"The most important sources, in areas where there is not enough water, are groundwater resources. It is clear we need isotope techniques to understand them, so we can make good use of them and exploit them sustainably. This is done by knowing not only the size, but the dynamics, such as regeneration capabilities. All these questions require isotope hydrology to gain a more quantitative and qualitative understanding," said Mr. Burkart.

The World Water Forum – organized every three years by the non-governmental World Water Council and the country hosting the event – ran this time under the theme 'Bridging Divides for Water'. World Water Day, held parallel to the World Water Forum on 22 March, ran under the theme 'Shared Waters, Shared Opportunities'.

The Isotope Hydrology Section was well represented at the forum, which was attended by Mr. Burkart, as well as Mr. P. Aggarwal, Mr. T. Kurttas and Mr. L. Araguás-Araguás from the Isotope Hydrology Section. Mr. Burkart and Mr. Aggarwal participated in ministerial sessions during the last four days of the forum. The WRP contributed to a technical session on hydrological data requirements for water resource management which drew nearly 75 participants. It was a great opportunity for the IAEA's work to be presented at a high profile event. The IAEA booth was among 21 other members of UN-Water, granting visitors the possibility to quickly and easily find out about all UN programmes related to water and explore what each has to offer. Mr. Frederik Pishke, UN-Water Advisor at the UN-Water Secretariat in the United Nations Development of Economic and Social Affairs stated, "From a public relations perspective, I think the UN-Water pavilion was very successful. It was a clear demonstration that organizations in the UN system are working together on water. We are clearly well entrenched in UN activities," said Mr. Burkart, adding that the WRP stand was a popular spot. Mr. Araguás-Araguás said that it was an opportunity for the WRP to present its role within the UN structure to water professionals. Many visitors were interested in the

role the IAEA plays within a water resources regime, and wanted some explanation of what exactly the IAEA is doing, continued Mr. Araguás-Araguás. He said the IAEA's exhibit, which also included information on the work of the soil and water management programme, called Nuclear Applications in Food and Agriculture, can be considered a success because of the hundreds of visitors who came to the booth seeking information on IAEA programmes. Over 400 leaflets, folders and handouts were distributed, and demand was great for audiovisual and educational materials. Many people expressed an interest in the displayed equipment and especially in the performance and availability of laser isotope analysis, as well as in the water age show. The exhibition was recorded by several local television crews.

The goal of isotope techniques is to provide a bridge between science and real-life issues through partnerships. "Water specialists are realizing that environmental isotopes can provide unique information about groundwater resources that cannot be easily obtained using other means," said Mr. Araguás-Araguás. When decision makers are aware of various options, they can consider information provided by isotope tools before making a choice. "Often decisions are made without sufficient information on water resources. Isotopes can help provide information to make proper decisions....The IAEA has a particular niche in assisting countries to build their scientific capacity. We have added value," stated Mr. Kurttas.

The WRP also works extensively with transboundary aquifers, such as the Nubian Sandstone Aquifer System, the Guarani Aquifer System and the Trifinio, to name a few, coinciding with the World Water Day focus on transboundary waters. With over 263 transboundary lakes and river basins within the borders of 145 countries, and ever growing water needs, the necessity for peaceful cooperation grows. Isotopes can help define areas of recharge and discharge as well as cross-boundary groundwater flow and river-aquifer interactions. "The sharing of resources is a challenge, but also an opportunity to meet development aspirations. With isotopes providing key information, a comprehensive assessment of resources can provide unbiased information, and help match science with policy formulation," said Mr. Aggarwal.

The World Water Forum ministerial meeting — which involved eight round tables and included 84 ministers and 19 vice-ministers of water — focused on topics included in the IAEA's WRP for 2010–2011, including adaptation to climate change and a clearer understanding of the water-energy nexus, a subject close to the heart of Mr. Burkart, who contends the link between water, energy and food is poorly understood. For example, when people think about

biofuels, they think of land use, but may not realize that a tomato requires 1/6 the amount of water compared to a bioenergy crop, he said. Even burning coal requires a lot of water, for mining and milling. "These tradeoffs are poorly understood and not clearly taken into account." Participants of the ministerial meeting, through contentious discussion, agreed that stronger coordination and integration of water and energy sectors should occur at national levels. Other points which found common support included basin scale integrated water management and use, and development of a scientific basis to assess the water footprint of energy.

The Ministerial Declaration adopted as a result of these debates includes reconfirmation of the 'desire' to reach internationally agreed upon goals such as the Millennium Development Goals, as well as the resolve to "strengthen the understanding of the impacts of global changes on water resources, natural hydrological processes and ecosystems", "develop, implement and further strengthen transnational, national and/or sub-national plans and programmes to anticipate and address possible impacts of global change" and "support scientific research, education, development and adoption of new technologies and broadening of technological choices in the field of water".

In general, the World Water Forum provided an opportunity to promote partnerships with other agencies as well as to support interest among individual countries in isotope technology. Participation in the World Water Forum allowed basic information about nuclear and isotope techniques to be presented to a broad audience of water specialists, including how these tools can be integrated into a larger framework of water resources management. "It is important to disseminate the value of what we do," said Mr. Kurttas. "People are missing opportunities."

"There is still a lot to be done," added Mr. Burkart. "Large parts of the world are not yet fully mapped; in Africa, Latin America, Asia, lands where billions of people live, it is not understood how the hydrological cycle functions below the feet of the people. We would like to bring these capabilities to the Member States, and offer technical support, so they can map their own groundwater." ■

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5th World Water Forum in Istanbul



IAEA Water Programme Conducts Laser Absorption Stable Isotope Analysis Training



Participants are instructed on how to assemble the laser analyser in the Isotope Hydrology Laboratory (Photo credit: M. MacNeill).

Nine participants from eight countries completed the IAEA training course on the use of the laser absorption based liquid water stable isotope analyser during the week of 18–22 May, 2009. This was the fifth time the course has been held, resulting in over 30 new users in Member State laboratories being trained in the operation of the instrument. Participants in this course utilized new

IAEA multimedia training materials (see separate article in this issue of the newsletter) as well as hands on instruction to learn how to install, operate, and maintain the instrument. Lectures, demonstrations, and practical computer work were also used to increase participants' knowledge of how the instrument works and how to produce high quality analytical results.

By the end of the week, all participants were able to prepare and run their own sets of samples, and post-process their results to generate $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values on the VSMOW scale. By participating in the training course and learning how to use the IAEA laser absorption analysis procedure and spreadsheet, participants gained the knowledge and confidence to be able to make sound stable isotope measurements when they return to their laboratories. ■

New IAEA Resources for Stable Isotope Analysis of Liquid Water Samples Using Laser Absorption Spectroscopy

By B. Newman, T. Kurttas, A. Tanweer and P. Aggarwal (IAEA, IHS)

A new training booklet and multimedia DVD will ensure maximum potential for equipment recently adopted by Member States to improve their water isotope analytical capabilities.

The IAEA WRP will soon be releasing a set of materials to support greater use of laser absorption instruments for $\delta^2\text{H}$ and $\delta^{18}\text{O}$ analysis of liquid water samples. The instruments use off-axis integrated cavity output spectroscopy to measure absolute abundances of ^2HHO , HH^{18}O , and HHO via laser absorption. The current materials focus on the Los Gatos DT-100 analyser and materials for the Picarro cavity ringdown analyser may be developed in the future. Laser based instruments have much lower initial and maintenance costs than mass spectrometers and are substantially easier to operate. They have the potential to bring about a paradigm shift in isotope applications by enabling many more researchers in all fields to measure isotope ratios by themselves.



The DT-100 liquid water stable isotope analyser. Autosampler, vacuum pump and Drierite column are shown in the background.

New addition to the training course series

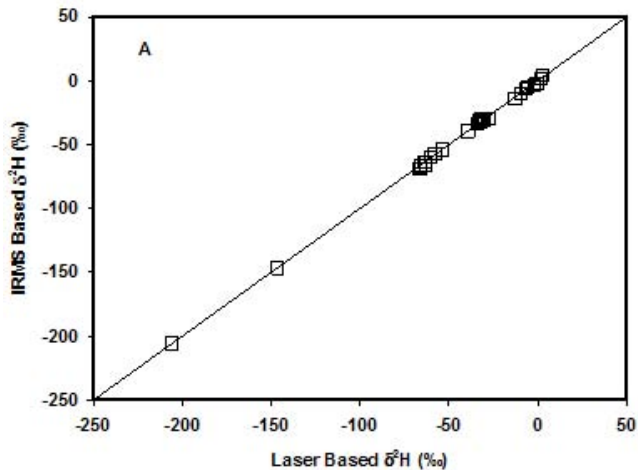
The first item to be released will be a new addition to the IAEA Training Course Series entitled Laser Spectroscopic Analysis of Liquid Water Samples for Stable Hydrogen and Oxygen Isotopes. Available in hardcopy or PDF, this document describes extensive laboratory testing performed by the IAEA using the DT-100 analyser as well as procedures for installation and analysis. The report presents results from more than a year of performance testing using three different Los Gatos instruments and a wide range of

standards and natural samples. Direct comparisons between results from the laser instrument and conventional IRMS are presented. Test results using a number of natural and synthetic water standards and samples with a large range of isotopic values demonstrate adequate precision and accuracy (e.g. precision of 1‰ for $\delta^2\text{H}$ and 0.2‰ for $\delta^{18}\text{O}$), indicating that the instruments will be suitable for a wide range of hydrological studies. As part of the performance testing, more than 1000 measurements of secondary standards and natural waters were made to examine reproducibility and for comparison with conventional IRMS results. Additional analyses were made to examine instrument performance over a wider range of isotope values using a set of labelled waters with very positive isotope values. A brief summary of some of the testing results is presented here.

Comparisons were made between laser instrument results for two secondary standards and a well characterized groundwater sample with accepted 'known' values based on repeated IRMS measurements. Nearly 200 laser analyses of each water type were made on 29 different days for two secondary standards (std7 and std9) and a natural water from the Great Artesian Basin, Australia (GAB, with a salinity of approximately 1100 mg/L). Each run consisted of different combinations of secondary standards and GAB water. Measured molecular ratios ($^2\text{HHO}/\text{H}_2\text{O}$ and $\text{H}_2^{18}\text{O}/\text{H}_2\text{O}$) of std7, std9 and GAB water varied in a narrow range of less than 0.3% from the mean value. The long term averages of calculated δ values for these runs are shown in the table. The laser based results are in close agreement with the accepted values for both $\delta^2\text{H}$ and $\delta^{18}\text{O}$ for all three water types.

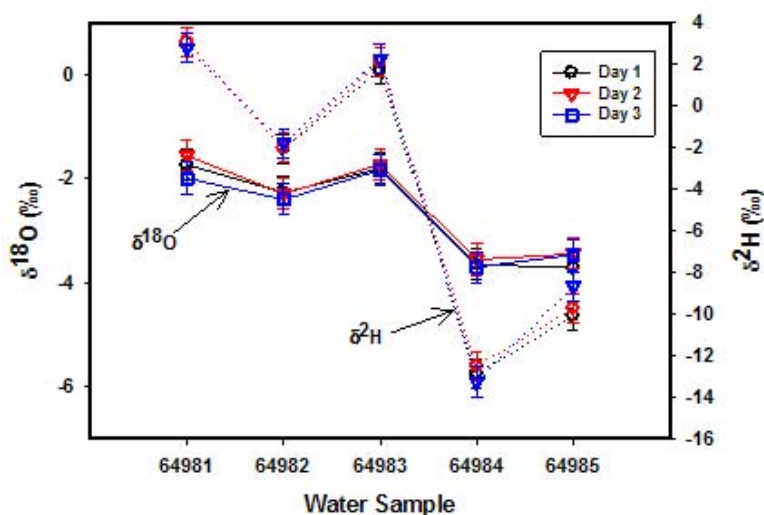
Comparison of $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values of secondary standards (std7, std9) and GAB water from laser isotope analysis (average of 196 measurements) against previously determined values. All δ values are expressed in ‰ with respect to VSMOW.

Sample	Accepted $\delta^2\text{H}$	Laser $\delta^2\text{H}$	Accepted $\delta^{18}\text{O}$	Laser $\delta^{18}\text{O}$
std7	-4.1±1.2	-4.1±1	-0.07±0.03	-0.1±0.2
std9	-189.1±0.9	-188.8±1	-24.8±0.03	-24.7±0.2
GAB	-38.6±1.4	-38.9±1	-5.8±0.1	-5.8±0.2



Comparison of measured $\delta^2\text{H}$ values of 33 natural water samples from various parts of the world using IRMS and laser spectroscopy (all data in ‰ relative to VSMOW). The analytical uncertainties are less than the symbol size.

In another test, samples from 33 natural waters with a wide range of isotope values from various parts of the world were analysed in our laboratory using laser and mass spectrometric techniques. The results plot on the 1:1 line, indicating excellent agreement between the laser based analyses and IRMS. Differences between laser and IRMS based values are typically within method uncertainties. The reproducibility of measurements for five natural water samples run on three consecutive days is shown. Each water type was analysed once every day. For all samples, the standard deviations ranged from 0.2–0.7 for $\delta^2\text{H}$ and 0.1 – 0.2 for $\delta^{18}\text{O}$ over the three day period. These results indicate the technique has good reproducibility over consecutive days, since standard deviations would be considered acceptable even for a single run within a given day.



Reproducibility of $\delta^2\text{H}$ (dotted line) and $\delta^{18}\text{O}$ (solid line) values over a three day period using five natural waters.



Cover of the liquid water stable isotope analyser multimedia DVD.

Multimedia DVD will aid users

The second item to be released is a multimedia DVD containing the training document described above, as well as 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. By viewing the video and using the IAEA Standard Operating Procedure (SOP), users should be able to install the system in less than two hours. The video also shows how to perform typical maintenance operations such as syringe changes and cleaning of the sample line, as well as basic operation of the analyser. A PDF of the SOP is also included on the DVD. This procedure includes detailed step-by-step descriptions of instrument and autosampler installation, maintenance procedures, and information on how to operate the instrument and run samples. It also contains a detailed description of how to post-process instrument data files to produce $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values on the VSMOW scale using the companion IAEA post-processing spreadsheet (also included with the DVD). The SOP should be a handy reference while using the instrument. The spreadsheet allows users to convert quickly isotope absolute abundance data included in instrument output files to $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values on the VSMOW scale. The spreadsheet also allows evaluation of the quality of calibrations as well as the precision and accuracy of results with only a minor amount of cutting and pasting. Full release of the training document and multimedia DVD is expected later this year. All materials will be available on the IAEA Water Resources website at <http://www.iaea.org/water>. ■

For further information please contact B. Newman at b.newman@iaea.org

Isotope Hydrology Applied to Characterize the Transboundary Aquifers Shared by El Salvador, Guatemala and Honduras

By M. Buch, the Trifinio Commission, Esquipulas, Guatemala
L. Toro, T. Vitvar (IAEA, IHS)

The information obtained on the characteristics and current status of the aquifers located in the transboundary area known as El Trifinio is helping local stakeholders and national authorities to establish constructive dialogue between interested parties and promote the peaceful use of water resources shared by the three countries.



Rio Lempa at Concepción, Ocotepeque province, Honduras (Photo credit. M. Buch 2009).

A hydrological study just completed as part of Technical Cooperation Project RLA/8/038 was carried out on the Upper Lempa River Basin, a transboundary area known as El Trifinio and recognized as a zone of special interest by the three countries sharing the basin: Guatemala, Honduras and El Salvador. The Trifinio area extends over 4343 km²; of which El Salvador occupies about 29.5%, Honduras 11.6% and Guatemala 58.9% .

The governments of the three countries agreed to establish the Comisión Trinacional del Plan Trifinio in this environmentally valuable and sensitive area, a platform created to promote development of boundary areas and directly managed by the respective national deputy presidents. This commission works under the slogan 'Water without borders', recognizing the importance of water resources for these three countries. In its strategy for development of Trifinio, it assigns the highest value to water as the resource with the greatest impact on life, society, food production and the environment.

The hydrogeological study

With IAEA assistance through TC project RLA/8/038, local counterparts of the three countries conducted a number of field campaigns from 2006 to 2008 aimed at characterizing the hydrology of both surface and groundwaters in the Upper Lempa River Basin. The studies were coordinated by the commission and implemented by respective national counterparts with a water resources issues mandate. The institutions involved, contributing more than 30 professionals from several scientific and managerial fields, were:

(1) Honduras: (a) National Enterprise of Electrical Energy, (b) Directorate of Mining, Secretariat of Natural Resources and the Environment and (c) National Meteorological Service.

(2) El Salvador: (a) National Service of Territorial Studies, Ministry of the Environment and Natural Resources, (b) Executive Commission for Hydroelectricity of the Lempa River, (c) National Administration of Aqueducts and

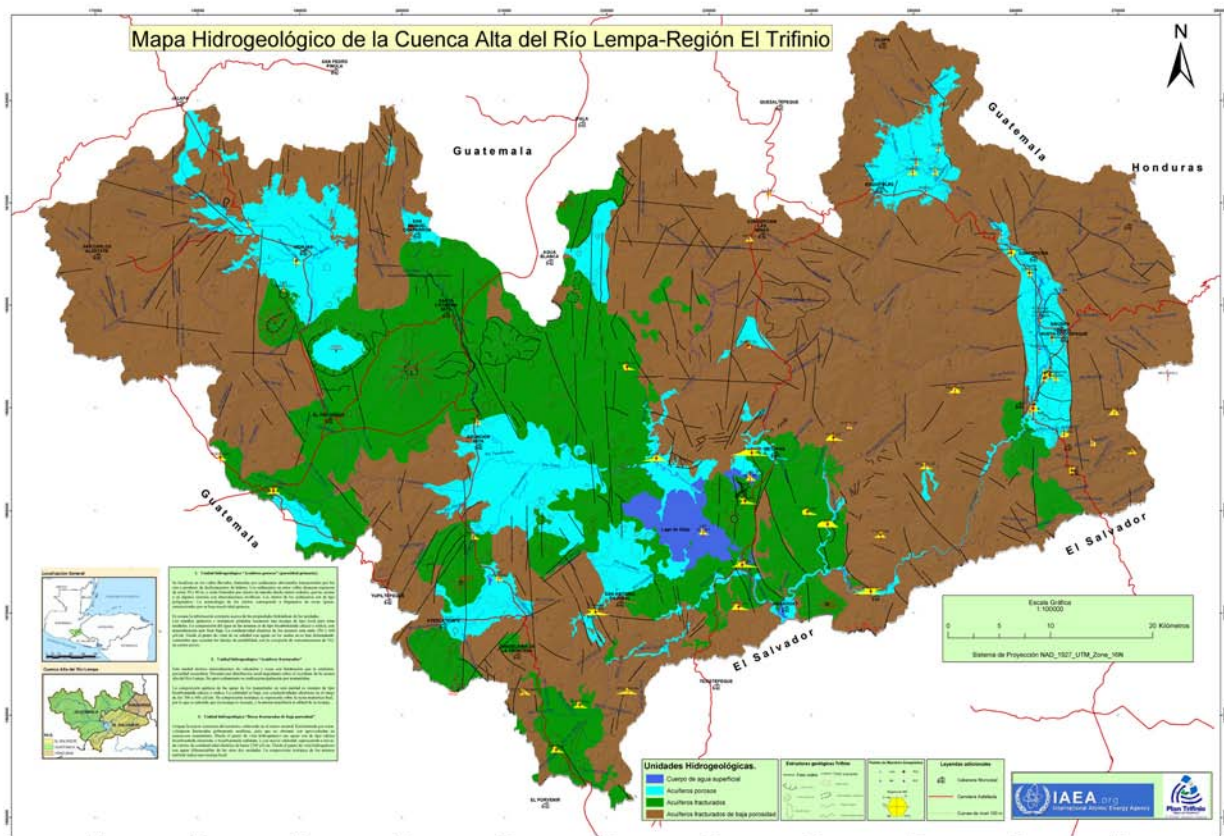
Sewage, (d) University of El Salvador and (e) Ministry of Agriculture and Cattle Ranching.

(3) Guatemala: (a) National Institute for Seismology, Vulcanology, Meteorology and Hydrology and (b) Ministry of Communications, Infrastructure and Housing.

Owing to the limited amount of hydrological information available, the first phases of the TC project consisted of field work campaigns aimed at creating and updating a comprehensive inventory of water points, mostly springs, dug wells and drilled wells. Basic physical and chemical parameters were measured in the field for about 140 samples, representing surface waters and about 110 groundwater samples. A few geophysical campaigns were also carried out in selected areas. Additionally, precipitation, surface and groundwater samples were collected for analysis of environmental isotopes. About 230 $\delta^{18}\text{O}$ and $\delta^2\text{H}$ analyses were carried out at the existing stable isotope laboratory in El Salvador.

The hydrological and hydrogeological field work resulted in the production, for the first time, of a hydrological map of the Trifinio area with a scale of 1:100 000. The initial work of the mapping exercise involved the homogenization of existing geological descriptions of different geological units in the Trifinio area.

This work enabled definition of the main aquifer units and assessment of geological factors controlling surface runoff and groundwater flow patterns. Hydrogeological studies showed the importance of significant fracture systems, which create deep circulation of groundwater in certain areas, and the existence of both local and regional flow systems. Respective conceptual flow models were developed, showing that main discharge points took place through springs and other structures in certain valleys. Groundwater–surface water interaction was observed in certain areas, although additional work is still in progress on this issue. Information on the isotopic content of baseflow and local precipitation is helping in the assessment of the importance of groundwater discharge. This extensive review of the Trifinio area's hydrogeological setting concluded with the definition of three main types of hydrogeological unit:



Hydrogeological map of the Upper Lempa River Basin, generated as part of project RLA/8/038.

(1) Porous media aquifers

Thirteen units were identified and mapped in fluvial valleys and terraces. These units are mostly formed by alluvial sediments transported by rivers, or are the result of landslides. Sedimentary units reach thicknesses ranging from 30 m to 80 m and have a very heterogeneous grain size distribution, mostly formed by fragments of igneous rocks. Hydrochemical and isotope data confirmed the meteoric origin of these waters: their fast dynamics are the result of local recharge. The dominant hydrochemical facies of these waters is calcium bicarbonate with low mineralization (250–600 $\mu\text{S}/\text{cm}$). Nitrate levels are above the drinking limit at only a few locations.

(2) Fractured aquifers

This hydrogeological unit type is formed of volcanic rocks affected by intense fracturing, mainly in the western part of the Trifinio area (Guatemala). Groundwater usually manifests itself in the form of large springs. The dominant hydrochemical facies of these waters is also calcium bicarbonate with low mineralization (300–600 $\mu\text{S}/\text{cm}$). Stable isotopes helped in estimating the recharge area altitude of various springs.

(3) Low porosity fractured rocks

These units (approximately 10) extend over most of the Trifinio region, especially in the eastern part. These volcanic rocks, although also affected by fractures, provide poor conditions for groundwater flow. The local population nonetheless exploits most of the existing springs. These waters show a more complex geochemical evolution, with electrical conductivity reaching values of up to 1200 $\mu\text{S}/\text{cm}$ and chemical facies ranging from calcium bicarbonate to calcium bicarbonate/chloride. Environmental isotopes revealed that most of these waters also derive from local recharge.

The preliminary results of this project have shown the chemical and isotopic similarities between most surface waters and groundwaters, suggesting both a fast dynamic for most systems and the relevance of local sources of recharge. Most of the identified shallow aquifers are isolated and the baseflow of the Upper Lempa River is maintained through discharge by aquifers located in Guatemala.

This study also provided information on chemical and isotopic changes over time in a few springs and shallow groundwaters monitored in dug wells. However, study

results have not been completed since the seasonal variations of isotopes in precipitation are still being characterized at a number of meteorological stations contributing to the Global Network of Isotopes in Precipitation. Groundwater discharge in a number of springs and changes in piezometric levels are also being monitored as part of the second phase of the study. The next phases of the project involve the characterization of deep groundwaters (below 100 m) and issues related to groundwater quality.

The results of the first phase of the project, including the hydrogeological map of the Trifinio area and the identification of main aquifer units and their features within the studied area, have been compiled in a final report that has been delivered to local authorities. Delivery of the report was attended by local and national authorities, local communities and stakeholders, as well as representatives of the IAEA. During the event, the need to support current efforts in addressing proper assessment of the Trifinio region's valuable water resources for the three countries was stressed. The IAEA is also providing support for the second project phase through TC project RLA/8/045. ■

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Editor's Note

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Contributions to the newsletter are welcome.

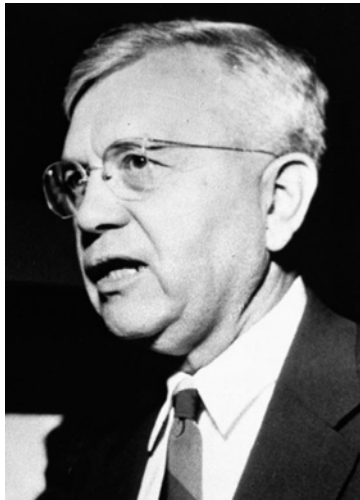
Reference Materials that Made History in Isotope Geochemistry

By R. Gonfiantini,

Istituto di Geoscienze e Georisorse del CNR, Pisa, Italy

The ideas, scientific interest and commitment of some of isotope hydrology's founding scientists led to the creation of reference materials still used to guide the field today.

Harold C. Urey was a visionary and a pioneer in the world of isotope geochemistry; the scientist who first entered the vast field of this new science. The story goes that he was in Zürich, Switzerland, to deliver a seminar on his classical theoretical study of light element isotope fractionation. The study was published in 1947, the same year as a similar study by Jacob Bigeleisen and Maria Goeppert Mayer. Urey demonstrated that the $^{18}\text{O}/^{16}\text{O}$ variation regarding temperature for the water-carbonate system is about 0.2‰ per °C. In a discussion with Peter Niggli, a renowned Swiss mineralogist who was present at Urey's seminar, the idea was put forward that marine organisms, through the oxygen isotopes of the calcium carbonate forming their skeleton, could record the temperature of the ocean in which they had developed – including the temperature of ancient seas, providing that the isotopic composition of the fossil skeleton was preserved and that of the sea had not changed. This discussion took place in the late 1940s. This was the idea at the root of paleotemperature determinations. Back in his institute at the University of Chicago, Urey started to work on the method. Some of his students helped him, many of whom were to become famous isotope geochemists in their own right, such as Samuel Epstein, Harmon Craig, Irving Friedman, and Cesare Emiliani. The gas mass spectrometer for accurate measurements of small isotope ratio differences was effectively already available: this was the mass spectrometer developed by Alfred O. Nier at the University of Minnesota during the 1940s. Indeed, it was clear that the measurements had to be comparative, i.e. relative to a CO_2 reference sample that had to be run alternately with a CO_2 sample derived from CaCO_3 .



*Harold Urey (1893-1981),
Photo credit: NASA.*

This was achieved by means of:

- A double inlet system to house both the sample and the reference;
- Capillary leaks to obtain a non-fractionating flow (viscous flow) from the two gas reservoirs into the mass spectrometer ion source, so that sample and reference would not become enriched in heavy isotopes during the measurement (as in the case of molecular leaks);
- Electromagnetic valves to switch rapidly from reference to sample and vice-versa;
- A double collector to measure simultaneously the ion beams of two different isotopic species — in this case C^{16}O_2 and $\text{C}^{16}\text{O}^{18}\text{O}$, and;
- A resistance bridge, by which part of the signal of the most abundant isotopic species was used to compensate for the signal of the less abundant species, the null point being read with the help of a vibrating reed electrometer.

The development of such a mass spectrometer, thanks to Nier (1940) and Nier et al. (1947), with improvements from Urey and his group (McKinney et al., 1950), was certainly a fundamental step, but even more important were the ideas, scientific interests and commitment of Harold Urey and his collaborators in marking the birth of a new field of science dealing with the application of isotopes of light elements to geochemistry and environmental research. Later — often several years later — isotope techniques were introduced into other fields, such as biochemistry, medicine, food investigations, and so on, using basically the same instrumentation and methods as in geochemistry.

The measuring technique described above requires the use of reference materials. I will briefly describe some of the materials that were initially selected as references and, for intercomparison purposes, the role they played in the development of isotope techniques, as well as how they continue to be adopted as references — despite the fact that they are no longer available.

PDB, V-PDB and NBS-19 (TS)

For estimating paleotemperatures, we needed a technique to extract CO₂ from CaCO₃ with an oxygen isotope composition that is strictly bound to that of the carbonate, a problem which was solved by treating the carbonate with 100% phosphoric acid (McCrea, 1950). Thus, the calcite of the rostrum of a Cretaceous belemnite (*Belemnitella americana*) from the Peedee formation of South Carolina, thereafter known as PDB, was adopted as the reference for fixing the paleotemperature isotopic scale:

$$t (^{\circ}\text{C}) = 16.5 - 4.3(\delta_{\text{C}} - \delta_{\text{w}}) + 0.14(\delta_{\text{C}} - \delta_{\text{w}})^2$$

where δ_{C} is the difference in parts per 1000 between the ¹⁸O/¹⁶O ratio of the sample CO₂ versus the PDB CO₂, both CO₂ types being extracted from CaCO₃ with phosphoric acid, and δ_{w} is the difference in the ¹⁸O/¹⁶O ratio of CO₂ equilibrated at 25°C with the water in which the organism has grown and PDB CO₂ (Epstein et al., 1951, 1953). With the above equation, the δ ‰ notation was introduced for the first time in geochemistry and it has been widely used ever since to express isotope variations in natural compounds. The choice of PDB was convenient for immediate needs, but less useful as a reference for both oxygen and carbon stable isotopes in the long run. From the beginning, PDB was available in limited amounts and was, in fact, soon exhausted. Other belemnites from the same formation were used¹, but there is no published record of the tests that most probably were performed to verify whether their isotopic composition was the same as that of the original PDB. Belemnite rostra are, moreover, isotopically inhomogeneous, as radial variations occur due to seasonal changes in temperature during belemnite growth. They also contain some organic matter that has to be destroyed by heating in a helium stream before treatment with H₃PO₄.

In order to overcome the problem of measurement intercalibration, the US National Bureau of Standards (formerly NBS now NIST: National Institute for Science and Technology) set aside a CaCO₃ sample from the Solnhofen Limestone (a Jurassic limestone formation at Solnhofen, Bavaria, Germany), which was calibrated by Craig (1957) with respect to PDB and distributed by the NBS under the code NBS-20. NBS-20, however, was also not entirely satisfactory. Irving Friedman's laboratory reference, prepared from a slab of white marble that formed part of a discarded toilet seat (and was thus known at first as TS), calibrated with respect to PDB (Friedman et al.,

1982), was the material used from that time on to convert mass spectrometric results versus V-PDB; the V stands either for Vienna, where the IAEA is located, or Virtual, because V-PDB is a reference material that physically does not exist². V-PDB is geochemically a convenient reference material, as its isotopic composition is close to that of marine limestone, which constitutes the most abundant CaCO₃ reservoir within the Earth's crust.

The material prepared by Friedman is now distributed for intercalibration by the IAEA and NIST under the code NBS-19. By international agreement, its δ values with respect to V-PDB are exactly -2.20‰ for the ¹⁸O/¹⁶O ratio and +1.95‰ for the ¹³C/¹²C ratio. Thus, the 'true' reference material is NBS-19.

SMOW, V-SMOW and SLAP

The history of water reference samples is also somewhat complicated. Before 1961, almost every laboratory had its own reference for each isotope, and results were not easily comparable. For example, Epstein and Mayeda (1953) used the CO₂ extracted from PDB with H₃PO₄ as a reference for $\delta^{18}\text{O}$ values of water samples, simply because CO₂ equilibrated with ocean water at 25°C has an ¹⁸O/¹⁶O ratio close to that of CO₂ extracted from PDB. For $\delta^2\text{H}$ values, however, Friedman (1953) used as a reference a sample of distilled Lake Michigan water, which was probably the natural choice for a laboratory located in Chicago. Around that time the NBS put aside two water samples for intercomparison purposes, labelling them NBS-1 and NBS-1A. The first was collected from the Potomac River, near Washington, D.C., which again appears to be a natural choice, with the NBS located in close proximity. We must thank Craig for defining a virtual reference water, which he called SMOW (acronym of Standard Mean Ocean Water), whose isotopic composition with respect to NBS-1 is (Craig, 1961a):

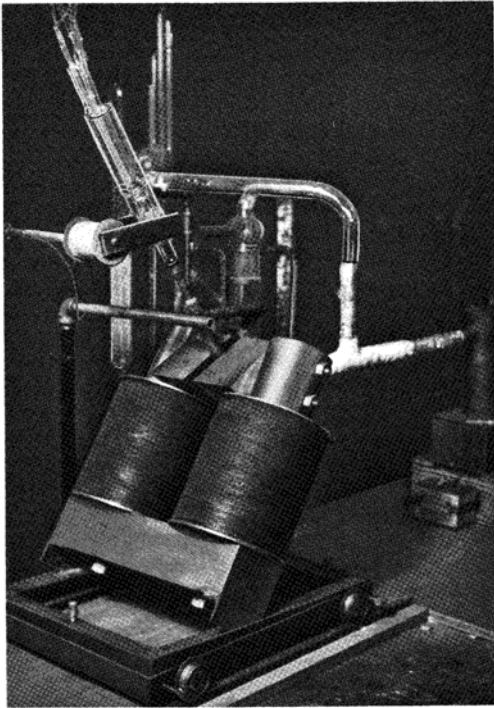
$$(^{18}\text{O}/^{16}\text{O})_{\text{SMOW}} = 1.008 (^{18}\text{O}/^{16}\text{O})_{\text{NBS-1}}$$

$$(^2\text{H}/^1\text{H})_{\text{SMOW}} = 1.050 (^2\text{H}/^1\text{H})_{\text{NBS-1}}$$

Craig's definition was promptly accepted by the isotope geochemistry community, not only because it shed light

¹ In 1959, I received some fragments of a sample called PDB-2 for intercalibration purposes.

² Some isotope geochemists seem reluctant to use the prefix V for the reference materials. I would like to stress that the prefix should not be construed as an appropriation by IAEA. The prefix simply implies that the measurements have been calibrated using materials distributed by the IAEA and NIST, and that results are converted with respect to the reference materials using the differences and procedures agreed upon by the international geochemical community (Gonfiantini et al., 1995).



The Nier mass spectrometer.

on the existing confusion, but also because it was already clear that $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values strictly correlate in natural waters (Craig, 1961b) and therefore need to be expressed with respect to a common reference water. SMOW was the ideal solution because the ocean can be considered isotopically homogeneous; it contains about 97% of the water present on the Earth's crust, and is the major source and sink of waters taking part in the hydrological cycle. Soon, however, it became clear that the use of NBS-1 would introduce an additional uncertainty because its isotope ratios are rather different from those of SMOW. Thus, the need for a water sample with the same isotopic composition as SMOW was recognized. Some doubts were also raised about its state of conservation. In 1967, at the request of the isotope geochemistry community, and with IAEA support, Harmon Craig undertook the preparation of several tens of litres of 'real' SMOW at the University of California, San Diego, a project which was completed a couple of years later³. Craig's prepared SMOW was considered, by international agreement, to be identical to the defined SMOW, disregarding a small difference in $\delta^2\text{H}$ (-0.2‰ according to Craig). The new water reference was called V-SMOW. Together with V-SMOW, another water reference was prepared for intercalibration purposes. This

³ Craig collected the main batch of water used for preparing SMOW in the Pacific Ocean at latitude 0° and longitude 180° in July 1967. The water was distilled before use.

second water reference was intended for the normalization of δ scales, or, in other words, for fixing the so-called stretching factor of δ scales. This is necessary because the range of natural water isotopic composition is wide: about 60‰ for ^{18}O and 500‰ for ^2H . The ultimate objective was to help laboratories overcome systematic errors that may affect the whole analytical procedure.

The new reference water, whose δ s had to be very negative, i.e. close to the lower end of the variation ranges of natural waters (V-SMOW being close to the upper end), was prepared by melting ice from the Plateau Station in Antarctica⁴; its name thus became SLAP, an acronym for Standard Light Antarctic Precipitation. V-SMOW and SLAP were distributed to more than 50 laboratories. Results showed that agreement improved considerably with a common stretching factor. The exact δ values of SLAP versus V-SMOW, assigned by international agreement, are (Gonfiantini, 1978): $\delta^{18}\text{O}_{(\text{SLAP/V-SMOW})} = -55.5\text{‰}$, and $\delta^2\text{H}_{(\text{SLAP/V-SMOW})} = -428\text{‰}$.

At the time V-SMOW and SLAP were prepared, ^{17}O was rarely used, so that the $^{17}\text{O}/^{16}\text{O}$ difference between V-SMOW and SLAP had not been measured. There was no doubt, however, that the $^{17}\text{O}/^{16}\text{O}$ of V-SMOW would also correspond to that of mean ocean water, and that the $\delta^{17}\text{O}/\delta^{18}\text{O}$ of SLAP versus V-SMOW would obey the mass dependent relationship. This was later confirmed by Jabeen and Kusakabe (1997), who found $\delta^{17}\text{O}_{(\text{SLAP/V-SMOW})} = -28.58\text{‰}$.

Craig's V-SMOW was on the brink of exhaustion, thus the IAEA undertook the preparation of V-SMOW-2, which became available in 2004.

CDT, V-CDT and IAEA-S-1

The reference material for reporting sulphur isotope variations, limited until recently to the $^{34}\text{S}/^{32}\text{S}$ ratio, is troilite (FeS) from the Canyon Diablo iron meteorite, Arizona. Meteoritic sulphur shows a narrow range of isotopic variation and its isotopic composition is close to the mean isotopic composition of terrestrial sulphur, as shown in the pioneering studies of Harry G. Thode and his group at McMaster University (McNamara and Thode, 1950). These were the main reasons for selecting Canyon Diablo troilite, CDT, as reference material. Recently, however, it has been proven that CDT is not isotopically homogeneous (Beaudoin et al., 1994). The IAEA has found a remedy.

⁴ The ice was collected by Edgar Picciotto, Université Libre de Bruxelles.

In the late 1980s, at the request of IAEA, Brian W. Robinson and Carl A.M. Brenninkmeijer at the Institute of Geological and Nuclear Sciences in Lower Hutt, New Zealand, undertook preparation of a synthetic Ag_2S with a $^{34}\text{S}/^{32}\text{S}$ ratio as close as possible to that of CDT (Robinson, 1995), with the addition of two more Ag_2S materials for δ scale normalization. The sulphur isotope ratios of CDT (not only $^{34}\text{S}/^{32}\text{S}$, but also $^{33}\text{S}/^{32}\text{S}$ and $^{36}\text{S}/^{32}\text{S}$) are, in fact, at about the middle point of the natural variation range, so two materials — one with δ close to the lower end and the other with δ close to the upper end of the range — are desirable. The first material, called IAEA-S-1, was ready in 1987, and its $\delta^{34}\text{S}$ value versus V-CDT was fixed at exactly -0.30% by international agreement.

As in the past, the name of the reference has now changed from CDT to V-CDT to indicate that it refers to a Canyon Diablo troilite that exists only virtually through IAEA-S-1. Again, this implies that the true reference material is IAEA-S-1.

The other two materials prepared by Robinson and Brenninkmeijer, IAEA-S-2 and IAEA-S-3, have $\delta^{34}\text{S}$ values of $+22.66$ and -32.30% versus V-CDT, respectively (averages of results obtained in two different laboratories), as reported by Ding et al. (2001). As yet, however, for the purpose of scale normalization, there is no official international agreement or consensus on the values of IAEA-S-2 and IAEA-S-3.

Ding et al. (2001) also report values of $\delta^{33}\text{S}$ for IAEA-S-1, IAEA-S-2 and IAEA-S-3 versus V-CDT, which are: -0.05 , $+11.56$ and -16.50% , respectively.

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Isotopes Demarcate Precious Water Resources in Mauritius

By R. Brizmohun, (IAEA, IHS) and E. Sacchi, Università degli Studi di Pavia, Pavia, Italy

Isotope hydrology is helping to address contamination issues threatening precious groundwater resources in this small island State.

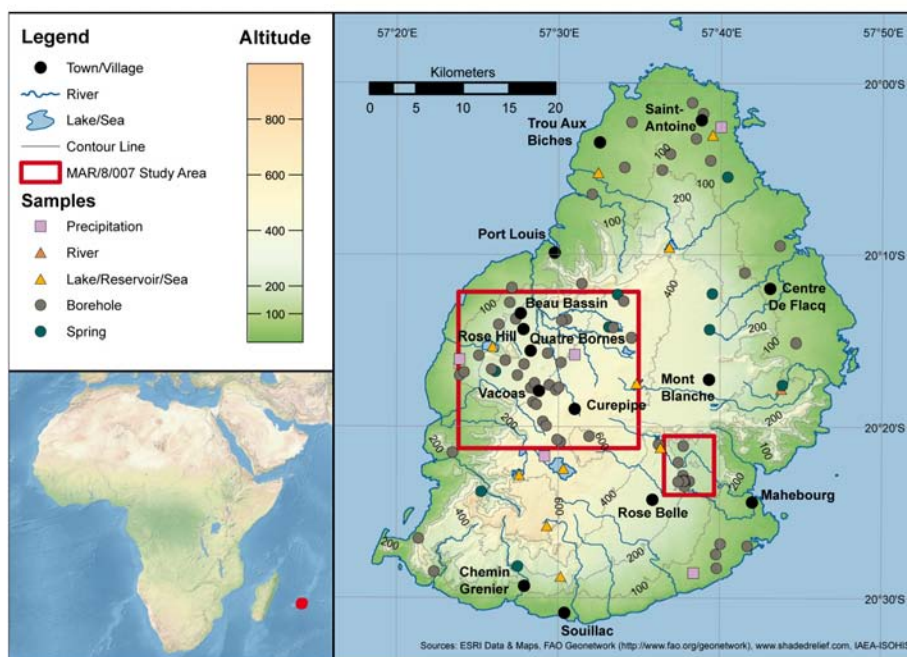


The Central Plateau area and the western region aquifers. Potential sources of nitrate pollution include agriculture (sugar cane cultivation) and urban settlements. (Photo credit: E. Sacchi, 2009).

Mauritius is a small, developing island State, and thus highly vulnerable to environmental threats. As a result, water resource management is one of the main concerns of the island people. Mauritius is heavily dependent on groundwater for drinking purposes; 50% of that demand is met by the island's system of aquifers. The consumption of water for domestic purposes in Mauritius is about 200 litres per day per person, hence groundwater is considered very precious and it is crucial to address issues around its use and ensure its protection. The growth of industrialization, the flourishing tourism industry, and the increasing use of chemical fertilizers and pesticides, coupled with other human and land based activities will undoubtedly affect the island's groundwater resources. The demand for water in Mauritius is increasing, alongside the risk of groundwater pollution from municipal and industrial wastes. It is therefore deemed imperative to understand the origin and recharge dynamics of groundwater as well as its circulation patterns in order to identify existing or potential sources of groundwater contamination. Isotopic studies on the island funded by the IAEA date back to 1976. A preliminary study was originally carried out to make a reconnaissance of the environmental isotope content of

surface and groundwater of the island in order to assess whether the spatial and temporal variability of isotopic content is broad enough to apply isotopes as a tool in groundwater research.

The variability of oxygen-18 and deuterium in rain was found to be high, and the pattern showed some regularity, forming the basis for hydrological applications of these isotopes. Relatively enriched $\delta^{18}\text{O}$ values were observed during the winter season when there is low rainfall, while depleted $\delta^{18}\text{O}$ values were measured during summer (high rainfall). In addition, when rainfall was low, there was a slight increase in $\delta^{18}\text{O}$ values due to the evaporation effect. When $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values between groundwater taken from wells and those from rainfall were compared, it indicated that groundwater in Mauritius is mainly replenished during the summer season. The $\delta^{18}\text{O}$ values of groundwater were found to be typical for summer rain, that is $\delta^{18}\text{O} < -2\%$. One remarkable additional outcome of the project was the identification of an important hydraulic connection between surface waters and groundwater. Previous studies had concluded that the regularities and variability of stable isotopic contents of surface waters and groundwater



Map showing sampling points around the island.

confirmed the potential for the application of isotope techniques in water resources development in Mauritius. Isotopic techniques could be used to measure replenishment of groundwater and reservoirs, water balance of reservoirs, hydraulic connections between water bodies, delineation of aquifers and origin of groundwater (Fröhlich, 1993). With this background, and the quest to identify sources of groundwater contamination, project MAR/8/007 was initiated in 2007. Two sites were identified, namely the western region and the area near the Mare Chicose landfill.

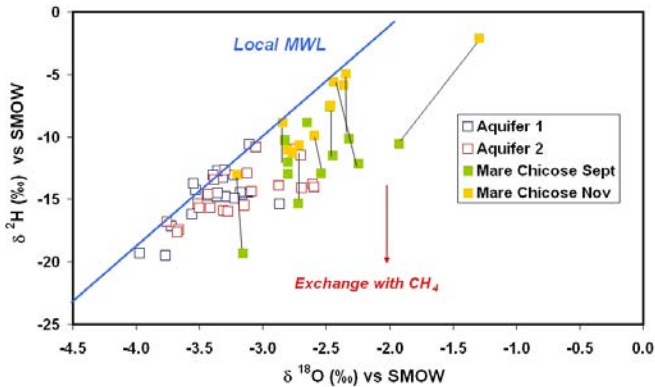
The western aquifers of Mauritius

The western aquifers of Mauritius extend from the central plateau area (mean elevation 300–400 m.a.s.l.) to the sea. This site was chosen following concerns raised regarding the degradation of groundwater quality in some selected boreholes in that region. The aquifers are constituted of basaltic lava flows, and more specifically by two superposed basalt layers (intermediate basalts, 3.5 to 1.5 million years old and recent basalts, 1.5 million years to 25 000 years old), of similar hydraulic conductivity, separated by a thin (<10 m) and discontinuous layer of weathered clayey rocks, behaving as an impermeable layer. According to previous studies, the aquifers are recharged in the Central Plateau area, where precipitation is higher than 2500 mm per year (Giorgi et al., 1999). Discharge occurs close to the sea at lower altitudes, where springs are present. At Flic-en-Flac (western coast), a submarine discharge area was previously studied with IAEA involvement (Burnett et al., 2006). Fourteen boreholes were sampled during three sampling

campaigns (rainy season, winter and summer) and analysed to provide hydrochemical characterization (major ions and trace elements) and microbiological assessment (TC and E. coli). Stable isotope analyses (^2H , ^{18}O and ^{13}C) were also performed. Stable isotopes proved to be rather homogeneous, ranging from -4 to -3‰ for $\delta^{18}\text{O}$ and from -20 to -9‰ for $\delta^2\text{H}$. This observation supports the concept of a common recharge area for the aquifers located in the Central Plateau. The distribution of $\delta^{18}\text{O}$ ratios versus altitude revealed two different trends, indicating enrichment along the flow down to about 250 m. a.s.l., and depletion at lower altitudes. This may indicate an upwelling of deeper water circulating in the intermediate basalts. Indeed, this is the altitude at which natural discharge of the aquifers occurs, according to literature (Giorgi et al., 1999), where fractures are present and the impermeable layer separating the two lava flows is absent. The results of this investigation were successful in defining groundwater quality, assessing possible interconnections between the two aquifers, identifying possible pollution sources and validating the general groundwater circulation model.

The Mare Chicose landfill area

The Mare Chicose landfill, which is the only landfill on the island, has been operating for 10 years and is considered a 'hotspot' regarding groundwater pollution. The landfill leachate is collected and taken to a wastewater treatment plant; in addition a gas extraction system coupled to a burning torch collects the produced methane. At the Mare Chicose area, samples were collected from 12 points (3



Stable isotope composition of samples from the western aquifers (Aquifers 1 and 2) and from the Mare Chicose landfill area. Lines connect samples from the same boreholes to show the displacement affecting the hydrogen isotope composition, likely due to exchange with methane.

in the groundwater leakage detection system, and 9 in boreholes surrounding the landfill) during two sampling campaigns (rainy season and summer). Hydrochemical analysis revealed that groundwater contamination from the landfill leachate could be occurring. Stable isotopes of the water molecule show strong variations between the two sampling campaigns. In November, the data plot was close to the local meteoric water line. However, in September, most of the data plot was below the line. In addition, careful observation of the $\delta^2\text{H}$ versus $\delta^{18}\text{O}$ levels in each well unveiled vertical displacement, indicating that the isotope composition of groundwater was influenced by methane produced within the landfill.

Such displacement can only be caused by a large amount of CH_4 escaping to the outside. Wells impacted by gas migration do not correspond exactly to those impacted by leachate contamination. Indeed, while liquid contamination follows the direction of groundwater flow and is therefore highly predictable, gas migration can occur in any direction. Results of the investigation have shown that the western aquifers are not adequately protected against possible contamination by pollutants from the surface. Infiltration seems to be rapid and to take place throughout the aquifer's outcrop, favoured by the presence of vertical fractures in the basalts. Concerning the Mare Chicose landfill site, investigation results will be useful in ensuring more environmentally safe systems. Project results thus show how important groundwater monitoring is in tackling the long term evolution of groundwater quality and in providing the ability to implement quickly remedial actions in the case of contamination. ■

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Isotope Hydrology to Improve Water Management in Asia

By R. Brizmohun, (IAEA, IHS)

IAEA project addresses the issue of water management in 16 countries in Asia that have been put under increasing pressure due to rising demand.

It is a known fact in today's world that groundwater and surface water resources are under severe pressure due to a number of factors such as population growth leading to rising demands for food, increasing urbanization, and industrialization, among others. Pressure on the Asian continent — which supports more than half of the world's population with only 36% of the world's water resources — is comparably high. The RCA project 'Assessment of Trends in Freshwater Quality Using Environmental Isotopes and Chemical Techniques for Improved Resource Management' addresses the increasingly important issue of water management in 16 countries in Asia. The project's

overall objective is to improve management of freshwater resources in the region through utilization of isotope techniques. The initial step to achieving the goal of sound scientific understanding of various components of the water cycle, trends in water quality, and setting up of early warning indicators for corrective management decisions was made in RCA project RAS/8/097. The long term observations made as a result of this project are expected to benefit the region and its countries enormously in the realm of policy decision making. The new project attempts to fill gaps still existing in information availability, and expand efforts in the development of a fully fledged regional database on water

quality for the benefit of policy makers and researchers alike. As part of the project, the IAEA/RCA Executive Meeting 'Application of Isotope Techniques to Solve Hydrological Problems' was held on 20–24 April 2009 in Kuala Lumpur, Malaysia. Eighteen participants from 12 countries attended the meeting, including Bangladesh (2), China (1), India (2), Indonesia (1), Republic of Korea (1), Malaysia (3), Myanmar (1), Pakistan (1), Philippines (1), Sri Lanka (2), Thailand (2) and Vietnam (1). The IAEA was represented by Mr. P. Aggarwal, Isotope Hydrology Section Head (Technical Officer) and the project coordinator was Mr. M. A. Choudhry (Pakistan). The purpose of the meeting was to discuss emerging issues and needs in water resource development and management with senior executives and professionals of participating RCA Member States and provide them with knowledge about the importance of isotope techniques in understanding surface water, groundwater and inter-aquifer hydraulic interactions, as well as the delineation of pathways of recharge flow and contaminant migration in groundwater. The participants involved were not necessarily familiar with the application of isotopic methodologies, but are responsible for the management of groundwater resources in their country. The aim was to understand better their needs, and for them to provide feedback regarding what isotopic and geochemical information is most useful in developing appropriate monitoring and amelioration strategies.

Each country representative presented a country report highlighting the status of local water resources, issues

and problems in water resource development and management, common remedial actions, and adaptation and integration of isotope techniques. The main themes of the presentations were groundwater–surface water contamination, interaction and management. Individual country presentations were further categorized into six common themes: anthropogenic contamination, geogenic contamination, sustainability, surface water–groundwater interaction, groundwater salinization, education and training. The meeting was useful in identifying country specific problems and common regional themes. It was also a means to disseminate information on the role of isotope techniques to participants through lectures and case studies. It provided a forum to discuss specific country problems in detail and to suggest appropriate isotope methodologies to be adopted in order to solve hydrological problems. Member State requirements were discussed in order to help fine tune national and regional activities. Participants, especially end user executives, viewed this IAEA/RCA project as highly worthwhile, and appreciated the support of the IAEA. ■

Reference

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Eighteen participants from 12 countries attended the meeting 'Application of Isotope Techniques to Solve Hydrological Problems' in Malaysia. (Photo credit: M.A. Choudhry).

News in Brief

New Developments

- A second guidebook in the series on dating of groundwater is being produced. This guidebook, focusing on ‘old’ groundwater will include all topics related to time determinations in groundwater systems circulating on timescales longer than approximately 1000 years. Tracers able to derive this time information are ^{14}C , ^{81}Kr , ^{36}Cl , some nuclides of the U/Th decay chains and the radiogenic noble gases, most prominently helium. Theoretical background for the guidebook was derived from meetings held in December 2008 and June 2009. This follows the first guidebook on ‘Use of Chlorofluorocarbons in Hydrology’ available at <http://www-pub.iaea.org/MTCD/publications/publications.asp>.
- The WRP is close to releasing its new web page design. For several months, the section has been working on the creation of a new, dynamic layout and structure. New features include direct access to a collection of technical documents related to isotope hydrology as well as symposia, monographs, newsletters, fact sheets, brochures, videos, and learning tools. A project in which symposia and monograph documents on isotope hydrology and related fields from 1963 to the present day are being scanned and stored — accessible after the release of the new web site — will be a great tool for the isotope hydrology community, and preserve the heritage of the science. Many of these documents are out of print or otherwise unavailable. The web site project is part of an overall reworking of IAEA sites by individual sections, as well as a department wide web presence restructuring.

New Staff Members

- Ms. Ravina Brizmohun joined the Section as a consultant in January 2009. She previously worked in the National Environmental Laboratory of the Ministry of Environment in Mauritius, and was formerly involved in a TC project in Mauritius. In the section, she is providing support on TC projects in Africa and Asia and is involved in the compilation of isotope data for projects in Africa. Ms. Brizmohun’s interests include water resource management, especially the use of environmental isotopes in groundwater.
- Mr. Clifford Voss from the US Geological Survey is working 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). Cliff is a quantitative hydrogeologist specialized in groundwater modelling, and he consults and teaches worldwide. Working with Cliff on the Nubian project is Ms. Safaa Soliman, a groundwater modelling specialist from Egypt.

- Ms. Safaa Soliman, from the Research Institute for Groundwater in Egypt, is working 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 on groundwater modelling in Egypt. She is working on the modelling of the Nubian Sandstone Aquifer.
- Mr. Spyridon Kleitsas joined the Isotope Hydrology Section in December 2008, and is currently working on project management for ongoing Global Environment Facility projects. More specifically, he is working on the Nubian Sandstone Aquifer project and the Adding the Groundwater Dimension to the Nile River Basin project. Before coming to Nuclear Applications for Physical and Chemical Sciences, Mr. Kleitsas worked for six years with the TC programme of the IAEA, focusing on strategy and policy development, resource mobilization and programme management.



Departing Staff Member

- After 37 years of distinguished service, Mr. Ahmad Tanweer retired from the IAEA in June 2009. A native of Pakistan, Tanweer joined the IAEA in 1971

as a technical staff member of the Isotope Hydrology Laboratory. A diligent and meticulous analyst, Tanweer made a number of contributions to the field of isotope measurements. During his long career, he worked with oxygen, hydrogen, carbon, and sulphur stable isotopes and tritium. Tanweer also coordinated the arduous task of reference material distribution. Some of his more important achievements include the development of a manganese reduction method for deuterium analysis of water samples. He also contributed to the refinement of the zinc reduction method and to developing a procedure for brine analysis. Tanweer was always ready to take on new challenges, which made him a natural choice for testing the newly invented laser absorption machine for stable isotope analysis. Without previous experience with lasers, Tanweer happily took on the challenge and through his perseverance, conducted some of the key experiments which led to a more robust and reliable instrument that is now being used widely throughout the world. Tanweer also helped develop training materials for this machine and participated in training scientists from a number of countries. Through his kind nature and gentle demeanor, Tanweer was always ready to work with and assist his colleagues in many aspects of isotope analysis. Yet, Tanweer is truly proud of his other achievements in life—the two children that he and his wife raised. As he enjoys his second career by splitting his time between Vienna and London, we wish Tanweer a long and healthy retirement and look forward to his continuing contributions to the work of the IAEA.

Obituary

- Tad Florkowski was born in Krakow, Poland, in 1928, and graduated in 1957 from the AHG University of Science and Technology in Krakow. His scientific career was centered from the beginning on applications of nuclear physics. In the 1960s he was very active in promoting geophysical and industrial applications of nuclear methods. Mr. Florkowski worked in the IAEA Isotope Hydrology section over two periods — 1964–1969 and 1977–1984. During his posting in the 1960s, he was responsible for the Isotope Hydrology Laboratory and contributed to establishing tritium and ^{14}C low level counting methods. After returning to Krakow in 1969, he established the environmental isotope laboratory at the Institute of Nuclear Techniques (then based at the AGH University) in Krakow, with assistance from the IAEA. The years which followed saw this laboratory become a leading centre of isotope hydrology applications in Poland and elsewhere in Europe. Mr. Florkowski served as executive director

of the institute until his return as head of the IAEA laboratory in 1977. Mr. Florkowski was responsible for moving the laboratory from its old location on Kaertner Ring to the VIC's new premises. Tad passed away on 22 September 2008, leaving his wife Barbara, son Maciej and daughter Barbara.

Meetings

- The WRP hosted a technical meeting on the state of the art of catchment scale residence time conceptualization, modelling and analysis on 19–21 January. Twenty-eight participants discussed a wide range of topics related to watershed hydrology, including isotope and geochemical methods, as well as modelling approaches. The workshop began with a series of invited presentations on how to quantify transit times and transit time distributions and key uncertainties and how to represent them, how to deal with transit times in watershed hydrology models and related mixing assumptions, how to think about transit times as landscape scaling metrics, and the importance of old (residence time greater than a few years) groundwater inputs to streams. Extensive discussion time was devoted to identifying knowledge gaps and the types of studies necessary to move the field to a new level. One major topic of discussion was how to reconcile various terms used in the literature to describe watershed characteristics such as residence times, transit times, age, tracer age, etc. A key output of the meeting was the production of a draft opinion article intended to be published in the international journal *Hydrological Processes*, which seeks to articulate the current state of watershed/catchment hydrological knowledge and identify areas which require more insight and further study.
- The 2nd Research Coordination Meeting (RCM) of the Coordinated Research Project (CRP) 'Quantification of Hydrological Fluxes in Irrigated Lands Using Isotopes for Improved Water Use Efficiency' was held in Vienna from 4–6 May. The overall objective of the CRP is to enhance the application of water use efficiency techniques in irrigated lands at the field and basin scales in Member States. The objective will be met through development and implementation of isotope methods for quantification of two of the major fluxes (deep percolation and evaporation) that control the water balance of irrigated lands, and therefore, are a measure of the degree of water use efficiency. RCM objectives included reviews of accomplishments and descriptions of plans for the next phase of the CRP, as well as discussions on how to coordinate better various projects to support broader CRP goals, including

synthesis of results. Projects from nine countries focused on isotope data collection from rainwater, percolation water, groundwater, atmospheric vapour, soil moisture and plant water samples, as well as meteorological and geochemical data.

- An IAEA–US State Department Argonne National Laboratory regional training course on isotope techniques was held from 11–22 May at Argonne, USA. This advanced regional training course on the use of isotopes and related hydrogeochemical and modelling tools for river basin management, including river–groundwater interactions, was organized following earlier collaborative training events at the laboratory. It was open to participants from Latin American countries with experience and involvement in hydrological issues at a national level, involving assessment and evaluation of water resources or their management. Fifteen participants attended the course, coming from Argentina, Brazil, Chile, Colombia, Costa Rica, El Salvador, Honduras, Panama, Peru, Uruguay and Venezuela. Lectures were given on tools, approaches and methodologies available to hydrologists to help them better characterize river basin hydrology, both above and below the Earth’s surface. Along with the IAEA’s Mr. Pradeep Aggarwal and Mr. Luis Araguás-Araguás, other lectures were given by Mr. George Leavesley, Mr. Robert Michel and Mr. Neil Sturchio.

- A consultants’ meeting on the Guarani Aquifer System (GAS) was hosted by the IAEA in Vienna from 2–5 June. The meeting reviewed and consolidated conclusions reported by different groups involved in the study. At the same time, other hydrological issues were identified for future work. Presentations covered various aspects required for the development of a sound conceptual model for the GAS, including geological and hydrogeological settings, hydrochemistry, isotopes, numerical modelling and groundwater management issues. The meeting also provided the opportunity to address a number of open issues which were not fully addressed in the reports presented to the Secretariat of the Guarani Project. The IAEA has been providing technical assistance for integrated study of the GAS since 2001. This has included the use of isotope and hydrochemical tools in characterizing the main hydrogeological features of this continental scale aquifer. This large aquifer is shared by Argentina, Brazil, Paraguay and Uruguay. The IAEA contribution to this project — additionally funded by the Global Environment Facility, the World Bank and the Organization of American States — focused on a number of hydrological issues relevant to consolidating a sound conceptual model describing the functioning of the GAS, and setting the foundation for development of a water resource management programme. ■

WRP at the European Geosciences Union in Vienna

By M. MacNeill, (IAEA , IHS)

The European Geosciences Union (EGU) annual General Assembly, held at the Austria Centre from 20–24 April, allowed specialists from all fields of earth, planetary and space sciences to exchange ideas and information at a professional level. Insiders got the chance to see what colleagues are doing in parallel fields.

Technological advances in measuring, mapping and exploring sciences in everything from geology to meteorology, from hydrology to astrophysics were on display at the EGU. Climate change, ocean acidification, the role of CO₂ in geological systems, CO₂ storage, pollution and health, renewable resources and low carbon energy options were subjects of deep discussion. New insights and information swapping were the order of the day. With 45 000 members, the EGU is the second largest association of geoscientists.

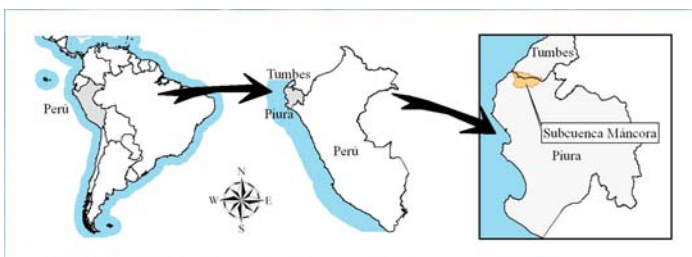
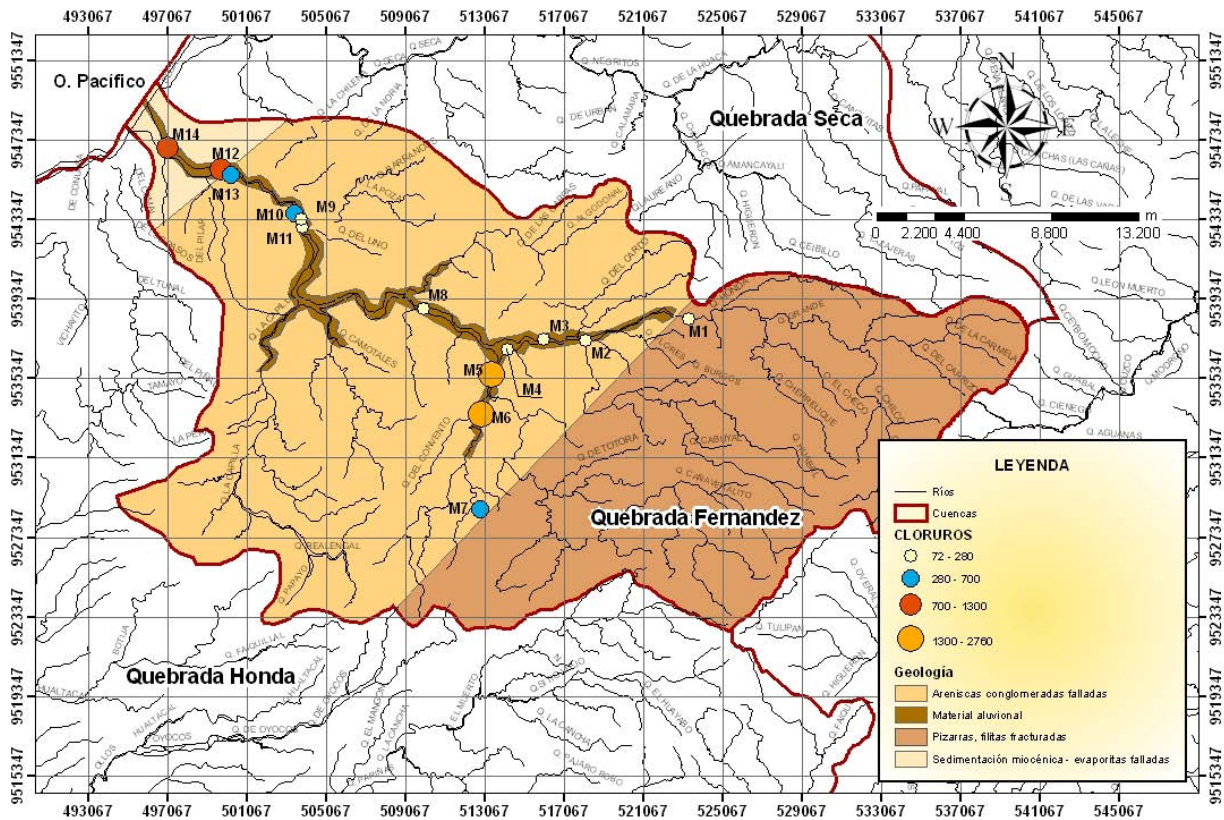
The WRP display attracted many visitors interested in discussing the realm of isotope hydrology. They were particularly interested in the material made available by the section at its stand, including postcards, bookmarks, newsletters, pamphlets, books and audiovisual material.

There was also ample opportunity to disseminate information on new developments in isotope applications and analytical developments, including laser spectrometry. The WRP facilitates the use of laser spectroscopy for isotope analysis, including testing and adaptation of the laser spectrometer, training courses, a procedure for data collection and interpretation, and a DVD guide to installing and operating the instrument. ■

Isotopes and Chemistry Used to Study Coastal Aquifer Vulnerability in Peru

By T. Vitvar (IAEA, IHS), I. Benavent Trullenque and A. M. Paulini Palacios de Silva, Instituto de Hidráulica de la Universidad de Piura, Peru

Isotopes are being used to uncover the reason behind salinization of the Mancora aquifer.



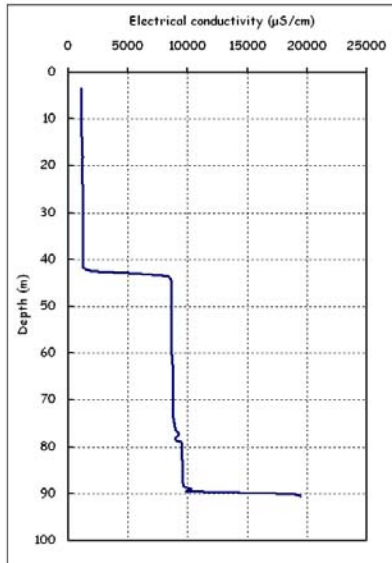
Location of the Mancora aquifer and geological map of the study area with sampling points and chloride concentrations (in mg/L) in sampled waters.

In 2007, PER/8/015 project The Mancora Aquifer: Development of a Management Plan with the Aid of Hydrochemical and Isotopic Methods to Prevent the Intrusion of Sea Water was launched by the Institute of Hydraulics of Piura University. This project seeks to discover whether the Mancora aquifer in northern Peru is affected by marine intrusion, and if so, what the main impact is on vulnerability of the crucial drinking water resource in an area with rapidly growing freshwater demand. The study area

corresponds to the approximately 600 km² Quebrada Fernandez catchment, which is defined by three major geological formations, including: (a) outcrops of Paleozoic metamorphic rocks of the Cordillera de Amotapes in the east,



A new 100 m deep piezometer, installed with financial support of the Piura regional government. (Photo credit: T. Vitvar).

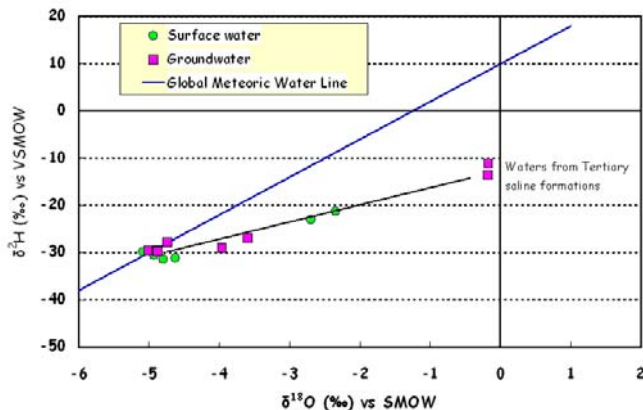


Profile of electrical conductivity in the piezometer.

representing the major recharge zone, (b) Tertiary sediments of the Talara and Salina formations with high salinity and dominant Ca–Na–SO₄ waters in the middle, and (c) the Mancora aquifer, formed by the Quaternary alluvial in the west. The Mancora aquifer is being tapped through two drinking water wells operated by the company EPS Grau, and provides the Mancora village area with drinking water amounting to approximately 50 L/s from about 30 m depth. Two major field campaigns have been conducted by the Piura University team during both the dry (January 2008) and humid (June 2008) seasons. These campaigns covered 14 sampling points and applied water chemistry (analyses performed in the Piura University laboratory) and water isotopes (analyses performed in Mexico and

Argentina), as well as CFC measurements at selected springs and wells (analyses performed in the IAEA Isotope Hydrology laboratory) and Cl/Br ratio determination. In the second half of 2008, a nearly 100 m deep multilevel piezometer was drilled through a collaboration between the Piura University project team and the regional government of Piura province, with the aim of better understanding the impact of Tertiary saline formations on the hydrochemical and isotopic evolution of groundwater along the major flow path toward the Quaternary alluvial formation. Preliminary data analysis showed no marine intrusion into the Mancora aquifer — neither the isotopic composition of the wells close to the coast, nor the chloride content or Cl/Br values indicate mixing with seawater. The dominant characteristics of groundwater are rapid recharge, increasing CFC age and increasing groundwater salinity along the main flow path from east to west, naturally changing from Ca–HCO₃ affected water in the recharge zone to Na–Cl and Na–Ca–SO₄ affected water due to dissolution of gypsum, precipitation of calcite and exchange of cations through the Tertiary saline formations. First profile measurements by the new piezometer near production wells revealed that the saline formations are located at a depth of approximately 40 m.

Preliminary stable isotope data show that direct recharge into the fractured Tertiary aquifers occurs in the southern part (well M5 and springs M6 and M7), adding water affected by evaporation with higher salinity. The reason for enriched isotope values in samples from this southern zone is being investigated. One of the sampled wells shows an impact from infiltrated river water. This indicates that although the Mancora aquifer water supply does not face marine intrusion, it may be affected either by infiltration of contaminated river water, or, in the case of extensive pumping, by intrusion of saline water bodies or dissolution from the Tertiary formations. ■



Water stable isotope data from the Mancora area sampling campaign June 2008.

For more information, please contact T. Vitvar at t.vitvar@iaea.org

Goals Agreed Upon at a Regional Technical Cooperation Project in Uganda

By M. Ito (IAEA, IHS)



Group photograph of participants at the Entebbe meeting. Mr. C. Tindimugaya, Mr. A. Ayenew Bekele and Mr. K. Francis are missing. (Photo credit: M. Ito).

A TC project on isotope hydrology in Africa, entitled Building Capacity in Support of Regional and Sub-Regional Water Resources Planning, Development and Management in Africa (RAF/8/048), started in 2009.

The project is aimed at building and strengthening capacity in the application of isotope techniques in water resource management, not only through training, which is a major component of the project, but also by developing a university module in isotope hydrology, supporting selected institutes/laboratories that will assume a leading role in the region (regional designated centres) and enhancing quality control/quality assurance practices for isotope analysis in laboratories.

National project coordinators, or those representing the national project teams, from Burkina Faso, Egypt, Ethiopia, Ghana, Kenya, Morocco, Tunisia and Uganda met in the first coordination meeting — hosted by the Government of Uganda — in Kampala, Uganda, in April 2009.

At the meeting, participants identified similarities and differences in the goals of participating countries. They sought, and agreed on, common goals for the project. Participants expressed a desire for cooperation among counterparts, including a willingness among countries more advanced in isotope hydrology to support those less advanced in the field. At the same time, barriers to cooperation in areas such as travel (of experts) and transport (of samples to be analysed) between countries in eastern and western Africa were pointed out and should be taken into consideration when facilitating activities.

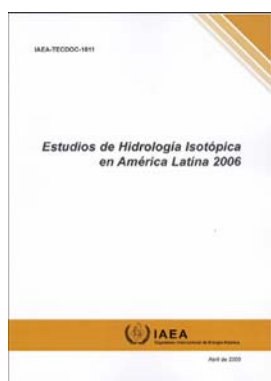
The Government of Uganda invited meeting participants to visit the laboratory of the Ministry of Water and Environment, Directorate of Water Resources Management in Entebbe, where the meteorological station is also operated. The present project is designed to be conducted through the initiative of participating countries, for the benefit of African countries. ■

For further information please contact M. Ito at m.ito@iaea.org

Meetings in 2009

- Technical Meeting on the State of Catchment Scale Residence of Time Conceptualization, Modelling and Analysis, Vienna, Austria, 19–21 January.
- 2nd Research Coordination Meeting on Optimization of Irrigation Water Use Efficiency by Using Isotope Techniques to Evaluate Water Flux Below the Root Zone in Flood and Drip Irrigation, Vienna, Austria, 4–8 May.
- Consultant's Meeting on Developing Opportunities for Using Isotopes in Regional Water Management Initiatives: the Guarani Aquifer, Vienna, Austria, 3–5 June.
- Consultant's Meeting to produce a TECDOC on Isotope Methods for Dating Old Groundwater, Vienna, Austria, 3–5 June.
- Research Coordination Meeting to Develop Isotope Methods for the Assessment of Groundwater Sustainability by Age Dating of Base Flow, Vienna, Austria, 28 September–2 October.
- Research Coordination Meeting on use of Environmental Isotope Tracer Techniques to Improve Basin-scale Recharge Estimation, Vienna, Austria, 19–22 October.
- Consultant's Meeting to Produce a Guidebook on the Use of Isotopes for Monitoring Artificial Recharge and Aquifer Storage Schemes, Vienna, Austria, 16–20 November.
- Technical Meeting on Coordination and Operational Requirements for Isotope Hydrology Laboratories, Vienna, Austria, 2–4 December.

New Technical Document



IAEA-TECDOC-1611: Estudios de Hidrología Isotópica en América Latina 2006 compiles the most important results and achievements obtained during implementation of Technical Cooperation project RLA/8/031. Under this project, 11 aquifers in Chile, Colombia, Costa Rica, Ecuador, Nicaragua, Peru and Uruguay were studied using hydrogeochemical and isotope

tools. Most of the studies involved both a technical counterpart with experience in the use of isotopes and related hydrogeochemical tools, as well as counterparts from institutes with a mandate at national or local levels on water resource management.

The studies addressed key hydrological aspects such as origin and magnitude of recharge, groundwater dynamics, nitrate pollution, interaction between surface and groundwaters, and water quality issues. It is expected that dissemination of the achievements of this project will promote the initiation of additional hydrological studies among decision makers on water resource issues in Latin America, leading the way to improved assessment of groundwater resources at different levels. During the last few years, several Latin American governments have expressed concern about the poor understanding of aquifer systems and their role in guaranteeing a supply of good quality drinking water in many large urban centres. The results presented in this publication highlight how information obtained in these studies can help in defining policies leading to better characterization of these water sources and optimization of both surface water and groundwaters.



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