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From the Section Head — Isotopes and Sustainable Development

Earlier this year the UN celebrated 2016 World Water Day with the theme 'water and jobs ' that focused on how achieving adequate quantity and quality of water can change workers' lives and livelihoods - and even transform societies and economies. The availability of freshwater as a basic determinant for human wellbeing is recognized in the new post-2015 Sustainable Development Goal (SDG) 6: "Ensure availability and sustainable management of water and sanitation for all". The 'water for all' goal will be achieved in large measure through increased exploitation of groundwater, with contributions from conservation and recycling. With the approval of the SDGs, the next 15 years will see a structured and sustained focus on water resource management enabled by national scientific, technical and innovation capabilities, and the IAEA's Water Resource Programme (WRP) is positioning itself to play a dynamic and substantial role in supporting the achievement of 'water for all'.

As most readers know, the IAEA-WRP works with member states to strengthen their scientific, and technical capabilities to play an innovative and increasingly vital role in water resource management. This results from establishing two key capacities: understanding and conceiving water as an integrated resource system; and developing and transferring the

knowledge and tools to mitigate constraints and realize opportunities of a single resource. The tools of choice for IAEA-WRP are isotopes and their indelible fingerprints on the water molecule that permits scientists to monitor H_2O's path through the water cycle, such as the rate at which an aquifer is recharged, how long water remains in the aquifer, it's pathway from surface to ground and it's return to evaporation and precipitation states.

Groundwater is the 'reservoir' for ninety-eight percent of Earth's available fresh water, representing about 60 times more fresh water than can be found in lakes and streams. Groundwater accounts for some 33% of total global water withdrawals and over 2 billion people rely on it as their primary water source, while over half of all irrigation water used to grow the world's food is supplied from groundwater. But these reservoirs are unseen and must be visualized through techniques and modelling that captures the mechanics of the water cycle: the pathways from the surface, the rate of recharge, the residence time and migration to oceans, lakes and springs, rates of evaporation and transpiration. Despite its dominance as the primary source of freshwater, full understanding by national water authorities of groundwater dynamics is usually incomplete and sometimes totally erroneous, which supports the need for strengthening the capacities of scientific, and technical authorities to understand these dynamics and substantiate and implement sound national water management policies and practices.

Sustainable Development Goal for Water

The new post-2015 Sustainable Development Goals (SDGs) recognize the role of science, technology and innovation (STI) in national development. By recognizing 'water for all' as a strategic goal with science, technology and innovation capabilities as a means for achieving it, the SDGs provide a framework and pathway for future cooperation with IAEA member states seeking to achieve it. The IAEA-WRP is unique in bringing STI to water management by linking research in scientific methods to technical applications, such as the study of flow and transport of groundwater by using new dating techniques. Groundwater dating provides essential knowledge for sustainable exploitation of an aquifer because it reveals the rate at which the aquifer recharges and thus gives confirmation of what volume can be removed without causing adverse effects due to lowering water tables and/or disrupting ecosystems. In this area, one innovation is the use of the isotopes of noble gases dissolved in groundwater: Helium (He), Neon (Ne), Argon (Ar), Krypton (Kr), Xenon (Xe) and Radon (Rn). The concentration of noble gases in groundwater is controlled by their solubility and are used to decipher infiltration areas or the temperature during recharge. Helium-4 accumulated in groundwater is used as a dating tool for a wide range of ages. In the case of radioactive noble gas isotopes, krypton-85 is used to date 'young' groundwater, while krypton-81 is applied to study groundwater dynamics and age in deep aquifers containing very old groundwater (up to one million years). The noble gas tools extend and enhance the routine use of radiocarbon for age estimation. The use of helium-3, along with its parent isotope tritium, provides a more accurate estimation of groundwater ages and recharge processes of modern groundwater that was recharged in the last about 100 yrs. These new techniques are at the forefront for advancing the technical capabilities in developing IAEA member states that are necessary to sustainably manage water resources and achieve SDG6 "Ensure availability and sustainable management of water and sanitation for all".

The IAEA Water Resource Programme is working to strengthen science, technology and innovation in water resources management through the introduction of new tools and methods for understanding constraints and exploiting opportunities for increasing water availability. The WRP is helping to build competent scientific and technology institutions and to foster the confidence and trust that promotes effective policies and programmes. The articles that appear in this Summer 2016 Newsletter further develop this theme and bring readers new insights into the expanding role of isotope hydrology in sustainable development. With the help of the international water community our contribution will continue to expand and help member states realize their SDG6 targets by 2030.

P. Aggarwal, Section Head, R. Kastens

'Water for All' is not truly free. It comes at the price of knowledge, technology and institutional capabilities

Strengthening National Capacity to Conduct Water Assessments

Since the early 1970s, the international water community has recognized that adequate national assessments do not exist in many countries, particularly in relation to the water residing in aquifers. These resources hold about 97% of the Earth's easily recoverable fresh water but they are often poorly understood and poorly managed. To sustainably manage water resources, it is essential to have a holistic understanding of:

- How much water exists and where it comes from;
- The quantity of water resources available for sustainable current and future uses;
- How vulnerable water resources are to pollution and climate change.

Thus, water resource assessments provide essential information and data for sustainable water 'system' management, particularly the unseen and usually uncertain parameters of groundwater. However, a comprehensive systemic approach to water resource assessment has not been attempted.

IWAVE

What is IWAVE, how and why was it conceived? The IAEA Water Availability Enhancement Project was an idea resulting from some key realizations:

- Too many stand along national and regional projects with isotopes disconnected from conventional hydrology — poor and low value results
- Inadequate understanding of water as a resource — disconnected and disjointed analysis often resulted.
- Limited collaboration within national water authorities and between member states on trans-boundary issues.
- Overall frustration that while isotopes were essential for confirming basic groundwater parameters, they were not always used effectively.

Moreover, for many years the Agency approach to capacity building for isotope hydrology focused on institutes undertaking isotopic studies on site-specific problems, often without the prerequisite or enabling information and data necessary for effectiveness. While some counterparts made significant progress, the results were often uneven with lost opportunities to realize the full potential of isotope studies, for example groundwater modelling using carbon-14 dating. Further, while some regional water projects promoted cooperation and exchange of information and expertise, many others were simply a collection of national activities without significant collaboration. And very few isotope hydrology projects approached water resource problems from a system perspective. From the technical standpoint, it was felt that a break from the business-as-usual approach to technology transfer could be desirable. Furthermore, it was recognized that greater focus on knowledge transfer, at both the national and regional levels was essential for effectively addressing the complexities and variability's of climate change and other natural phenomena affecting water resource management. USGS must also be recognised as a guiding partner in developing the methodology, as it faced similar realizations, particularly managing water as a resource

system. US Geological Survey was helpful in deriving funding from the US "Peaceful Uses Initiative" and has played a central role in each pilot exercise.

Thus, the IWAVE methodology was conceived and piloted beginning in 2010, to improve the structure, comprehension and collaboration for national water resource assessments, and better enable the contribution of isotope hydrology in:

- Philippines
- Oman
- Costa Rica

Although these pilot programmes are ongoing, in some instances the outcomes have been significant and far-reaching for the IAEA Water Resource Programme. In fact, the most sweeping and dynamic results from the pilot exercise have been unplanned: emergence of groundwater leadership, rationalizing national water management structures, delineation of distinct roles and responsibilities, identification and agreement on common priorities and action plans, and generally promoting collaboration and cooperation in management practices.

The Methodology

Each study:

- Identified national gaps in hydrological data and information;
- Determined the expertise, technology and infrastructure support required to fill identified gaps;
- Formulated and implemented the optimum methodology for utilizing isotope techniques;
- Developed an approach for collaborating with other multilateral and bilateral organizations to fill identified gaps.

Gap analysis

While each study differed in content, several gaps in hydrological data and information seem to be common, including:

- Groundwater — aquifer extent, aquifer characteristics, groundwater storage and flow;
- Water balance — runoff and recharge to groundwater, surface and groundwater interaction;
- Water use — withdrawal rate and location, consumptive use.

Elements of an integrated assessment

The IWAVE methodology follows a comprehensive master plan for identifying essential information and data requirements, prioritization and phasing of information needs, and implementing the necessary remediation, all based on broad consultation and systematic engagement. The gap analysis often leads to problem statements, situation and stakeholder analysis, and partnership building. In the Philippines, mitigation plans found action through the development of the "Investment Needs for Resource Assessment Capability in the Philippines to improve the planning and management of water infrastructure". In some instances these plans became the blue print for introducing and sustaining the capacity to implement comprehensive water resource assessments as all levels of authority. The structure and elements of the assessment is straight forward:

IWAVE Outcomes and Achievements

PHILIPPINES

The IWAVE project in the Philippines elevated technical management of water resources to the highest political level by promoting discussion of hydrological gaps, which is crucial for understanding social-economic impact, mitigating and controlling constraints and sustaining positive results. Building collaboration among water-sector agencies and experts to overcome the institutional barriers that had isolated hydrological and isotopic data, programs, and expertise is a major achievement. The IWAVE approach involved all nation-wide institutions with a mandate for water resource management, organizing joint training for multiple stakeholders, introducing data sharing exercises, fostering dialogue and collaboration, and thereby fostering a culture of collective actions and responsibility. The IWAVE project in Philippines has introduced or improved

Hydrological data and information

Surface water

Hydrographic maps and models — hydrography, storage volume and flux
Streamflow hydrographs, maps and models — discharge, channel geography, rating curves
Flood risk and drought risk maps and models — recurrence intervals, trends
Surface water quality maps and models — water chemistry, common and emerging pollutants, trends

Groundwater

Hydrogeological setting maps — surface and subsurface geology, aquifer thickness and extent, resistive layer thickness and extent
Aquifer characteristics maps — porosity, hydraulic conductivity, transmissivity, anisotropy, storativity
Groundwater storage and flow maps and models — saturated thickness, water levels, vertical/horizontal gradients
Groundwater quality maps and models — water chemistry, common and emerging pollutants, trends

Water budget

Precipitation maps and models — point precipitation, areal/regional precipitation, extreme events
Runoff and recharge to groundwater maps — runoff coefficients, infiltration and recharge rates
Evapotranspiration maps and models — temperature, point evaporation, meteorological data
Surface and groundwater interaction maps and models — hydraulic gradient, groundwater discharge to surface water, surface water seepage to groundwater

Engineered water system

Withdrawal rate and location maps and models — withdrawal by category, rates, trends
Conveyance rate and losses maps and models — conveyance by category, rates, trends
Consumptive use maps and models — consumptive use by category, rates, trends
Reclaimed wastewater maps and models — rates, volumes, trends

practices on: a) data collection, management and interpretation; b) advanced techniques to assess groundwater resources; c) sampling programs such as Reconnaissance Sampling for chemistry and isotopes in water, and; d) techniques to more accurately estimate surface water flow in gauged and ungauged basins. The project also strengthened the collaboration of technical experts in the field with the institutions providing isotopic analysis and nuclear applications in hydrology. This is important because of the way isotopes can calibrate models and information systems for water management, and confirm otherwise unobservable groundwater data. These results occurred because of the recognition that groundwater must be comprehensively understood and that effective management required the authority of a groundwater champion.

- NWRB's expertise in groundwater management has led to its designation as lead agency for national groundwater management, responsible for national SDG 6.4-.6 plans and targets
- New investments in groundwater modelling and GIS software improved methods and capabilities to interpret data/information, producing new analysis of water balance and base flow computation as standard water management practice;
- Groundwater resource assessments/vulnerability assessments are being implemented in 9 water stressed regions with NWRB mandated for mitigation, planning/regulation;
- MGB has begun training on Resources Vulnerability Assessment and planning as standard water management practice and produced initial studies.
- Groundwater monitoring has expanded with 16 operational stations established since 2013 and 18 more planned for completion 2016–2017.

OMAN

While not as sweeping the results in OMAN are encouraging as the counterpart Ministry of Regional Municipalities and Water Resources continues to make progress following the analytical phase to define requirements. This is expected to strengthen its mandate for groundwater management. Further, MRMWR has produced some key outputs for establishing the National Water Resource Assessment System, including improved national assessment of monitoring networks, improving datasets and data management and numerical modelling, sampling, enhanced capacity in isotope analysis and noble gases sampling collection.

- Groundwater Monitoring Network established and generating data on 127 catchments for National Ground Water Database (NGWD)
- Rainfall and wadi gauging stations established and National Water Balance Project in preparation
- Characterization and vulnerability of aquifers initiated.

These results are important cornerstones on which national water resource management programs will make further progress towards enhanced water availability.

COSTA RICA

The IWAVE experience has been highly significant contributing to new water legislation and empowering the IWAVE counterpart, the National Water Directorate – DINA to manage and protect vulnerable aquifers. DINA has acquired the tools, experience and now the mandate to take charge of groundwater management, understand and predict changes and help ensure water availability in the future. Other important outcomes:

- Costa Rica's National Water Law LEY PARA LA GESTIÓN INTEGRADA DEL RECURSO HÍDRICO, of 27 March 2014, requiring the National Water Directorate of MINAE to develop and categorize aquifers and recharge areas (10), conduct aquifer vulnerability studies (11), develop and maintain monitoring networks for aquifer status as well as an inventory of relevant information and data.
- Highlights from the National Integrated Water Management Plan:
- Creation of a centralized Information System for Integrated Management of Water Resources;
- Completion of nation-wide water balance assessment at catchment scale;
- Management and Protection Plans in development for recharge zones.
- Comprehensive surface and groundwater sampling programme for isotope analysis and development of thematic nation-wide baseline isotope maps

Mainstreaming IWAVE - RLA7018

Beginning in 2013 and becoming operational in 2014, the Regional Division for Latin America and Caribbean (TCLA) made effort to mainstream the IWAVE methodology and coordinate national outputs from water resource assessments in 13 member states. While realizing modest success, it has changed thinking and gained acceptance that structure, methodological discipline and collaborative action is more valuable than standalone/site specific management of water resource. The project has produced some significant outputs: promoted collaboration on data acquisition, introduced vulnerability studies in 4 participating member states and developed predictive models of possible water futures based on climate variables. Most importantly, it has left a will and commitment to continue to collaborate based on the common IWAVE methodology.

RLA7018 “Improving Knowledge of Groundwater Resources to Contribute to their Protection, Integrated Management and Governance” is ‘mainstreaming’ the IWAVE methodology in the Latin America region. The project promotes cooperation between Argentina, Bolivia, Brazil, Chile, Columbia, Costa Rica, Cuba, Ecuador, Honduras, Mexico, Paraguay, Uruguay and Venezuela, and will be operational until 2017. Following the established IWAVE methodology the common identified gaps include:

- Hydro-meteorological knowledge: deficiencies in capturing existing data (including isotopes) in different water bodies, insufficient training, few certified laboratories, deficiencies in hydrological and hydrogeological conceptual models, limited use of numerical models and lack of unified hydrogeological maps.
- Knowledge of uses of water resources: deficiencies in the capture and validation of data.
- Planning and management of water resources: institutional weaknesses, insufficient development of conceptual frameworks linked to integrated management of water resources and lack of predictive models involving global change.

The outputs produced or in production are:

- Inter-intra agency surveys on water use produced
- Generation of hydrological database
- Establishment of isotope monitoring networks
- Production of Hydrogeological/Land use maps
- Development of hydrogeological conceptual models
- Development of numerical models of flow and transport
- Quantification of the water footprints
- Predictive model of global change initiated
- Development / Implementation of National Water Agendas

Lessons learned

An evaluation of the IWAVE experience has been undertaken and resulted in several modifications, additions and recommendations that will guide its further development as a technical/management framework for water resource assessment. At the policy level, the essential learnings are clear:

- The successful application of isotope studies in hydrology requires the availability of geochemical and geophysical information and data, without which very little effectiveness can be achieved through isotope studies;
- The analytical, consultative and acquisition steps underlying the IWAVE methodology foster a culture of learning, sharing and collective action, as well as ensure the enabling environment for effective isotope studies;
- The confidence building, sharing and learning culture that emerged at the national level is equally applicable at regional, trans-boundary level;
- The structure, discipline and harmonization of the IWAVE approach produce standards, practices and exchange mechanisms that will promote greater collaboration between member states. and;
- The IWAVE methodology should become a prerequisite for all IAEA isotope hydrology projects.

Looking forward

The post-2015 Sustainable Development Goals recently approved by the international community will guide multi- and bi-lateral development cooperation for the next 15 years. SDG 6 is the centrepiece of development cooperation in water resource management. It seeks by 2030 to: Ensure availability and sustainable management of water and sanitation for all. ‘Water for all’ is an ambitious goal, but the SDGs also recognize that successful achievement within this timeframe will not happen without national capabilities in science, technology and innovation – ‘STI’ is incorporated in SDG 17. Water resource management tools such as isotope hydrology and frameworks such as national integrated water resource plans should assume new and important standing in national plans and programmes to achieve SDG 6.

Since groundwater represents about 97% of the Earth’s easily recoverable fresh water, water for all will be achieved in large measure through sustainable exploitation of groundwater, with contributions from conservation and recycling.

Under SDG 6, the key management framework is integrated water resource management, as reflected in SDG 6.5 -"By 2030, implement integrated water resources management at all levels, including through trans-boundary cooperation as appropriate". Groundwater assessment is an essential element of IWRM and thus a cornerstone for achievement of 'water for all' SDG 6. IWAVE methodology can be considered a precondition for sustainable management of groundwater because isotope studies are the only practical means of accurately confirming age, recharge and residence time of aquifers. Therefore, Member States seeking to achieve SDG 6.5 will benefit from incorporation of the IWAVE methodology and outputs within their integrated water resource management plans. Programmatically, linkage to SDG 6.5, provides necessary context and sustainability to water assessments as a key component of national IWRM plans and programmes and it gives focus and recognition to the role of science and technical institutions contributing to sustainable development goals.

Regional Cooperation

Since water is a resource system the most appropriate scope for strengthening national water assessment capabilities is transboundary or regional cooperation and the most important focus for programming is at the basin level. By focusing on basin management and building a common methodology for water resource assessment, several mutually reinforcing outcomes are likely to result:

- confidence and trust in data and information
- common understandings of constraints and opportunities.
- exchange of information and collaboration

These outcomes promote cooperation and thus enable informed political/policy discussions and resolution of common problems. Thus, a possible concept for future trans-boundary regional projects incorporating IWAVE methodology could be: To strengthen national capacity to contribute to Integrated Management of River Basins through the establishment of comprehensive and systematic water resource assessments.

Possible technical outputs at the basin level:

- Hydrological gap sketch for riparian countries
- Detailed gap profiles and hydrological gap plans
- Development of IWAVE based joint work plans producing:
  - Integrated surveys of water use
  - Hydrological data bases
  - Monitoring networks
  - Hydrological and land maps
  - Hydrogeological conceptual models
  - Numerical models of flow and transport
  - Quantification of the water footprints
  - Predictive model of global change
  - Basin Water Agendas for decision making and political declaration.

The WRP is working with TC Regional Divisions to introduce IWAVE as a common framework for comprehensive water resource assessment that strengthens capacities and promotes collaboration between member states, and contributing leadership and strategic direction to better enable isotope hydrology and national counterparts to help achieve the SDG 6 targets and thereby ensure that water for all does not become an empty promise.

R. Kastens, P. Aggarwal, L. Araguas-Araguas, M. Choudhry, B. Kumar

Groundwater Modelling at TEPCO's Fukushima Daiichi Nuclear Power Station

An Experts' Meeting on groundwater modelling at the Tokyo Electric Power Company's (TEPCO's) Fukushima Daiichi Nuclear Power Station (NPS) was convened by the IAEA in cooperation with the Ministry of Economy, Trade and Industry (METI) of the Government of Japan in Tokyo, from 15–19 February 2016. The IAEA group of experts reviewed the status of groundwater inflow, countermeasures and modelling with METI and TEPCO participants, conducted a site visit to Fukushima Daiichi NPS, and held a technical seminar with METI, TEPCO, and other Japanese hydrology experts covering overall groundwater issues. In particular, the continuing inflow of groundwater into the reactor and turbine buildings at TEPCO's Fukushima Daiichi NPS results in accumulation of significant quantities of contaminated water every day, increasing the need for treatment and on-site storage tanks. Managing this substantial water storage on site poses additional challenges for eventual decommissioning operations. Therefore, problems associated with groundwater are among the most serious challenges that require immediate and comprehensive countermeasures.

The 2016 meeting follows the 3rd Mission of the International Peer Review of Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4 that took place in February 2015, that recommended TEPCO should consider producing a better calibrated, robust groundwater model, which would allow TEPCO to continuously evaluate and optimize the performance of various countermeasures taken at the Fukushima Daiichi NPS. IAEA Member States subsequently adopted Resolution (GC(59)/RES/12) in September 2015 wherein the importance of characterization of detailed hydrogeological settings of nuclear power plant sites was highlighted, along with a request to the IAEA to continue taking follow-up actions from the September 2014 Technical Meeting.

The 2016 meeting reflected the common view that a new groundwater model that allows the simulation of transient (non-steady state) groundwater flow be developed with the following objectives:

- To provide local water balances (inside the recently implemented ice wall system and at the model scale),
- To provide accurate flow conditions for a transport model;
- To define guidelines for optimal survey of water levels (frequency, and locations);
- To provide an estimate of the duration of the countermeasures.

In addition, a hydrogeological study of groundwater underneath the plant site was recommended to provide a better understanding of the rate and source of recharge and interconnections between different aquifer layers. This study was initiated in April 2016 with sampling for stable isotopes, tritium, and helium-3 and the analytical results will be integrated with other hydrogeological data to reach a comprehensive understanding of groundwater flow.

P. Aggarwal

Avoiding stress on the Guarani — Brazil expands efforts to assess the largest aquifer in South America

Following the results of the Guarani Aquifer Project and the resulting Strategic Action Plan (2009), Brazilian agencies at the federal and state levels have taken action to promote further studies in the Guarani Aquifer System (GAS). Major concerns driving the investigation are aquifer vulnerability and protection.

Because of the excessive time needed to replace groundwater extracted from the deep confined portions of the aquifer there is a need to factor a more sustainable exploration of the water. Groundwater alone will not be able to supply water indefinitely, although with the present rate of extraction GAS will be capable of delivering water for approximately 200 years.

The low rate of redistribution of the recharge waters, even in the shallower portions of the aquifer, makes it is imperative to manage groundwater as integrated with surface waters in order to achieve a more sustainable and prolonged use of the groundwater. A simple example is to use preferentially surface water during periods of high reservoir levels and high river runoff in opposition to increased use of groundwater during low base flow and drought seasons.

Surface waters are much more susceptible to climate change. Reservoir levels and river runoff in the populous NE region of São Paulo have recently suffered from a prolonged drought, affecting millions of inhabitants. As result of global warming, this extreme climate change is becoming more frequent and, consequently, there is a need to improve the rational and conservative use of water in all segments of consumption (residential, industrial and agricultural). Therefore we need to better assess the groundwater reserves by accurately delineating geometry and hydraulic properties of the aquifer, as well as its water chemical quality.

Brazil is facing two main challenges concerning the GAS; to increase the knowledge level about GAS regional and local dynamics, and to be able to translate this knowledge into management guidelines at state or city level. The GAS aquifer is considered to be ideal for this hands-off task, but still, a strong articulation and cooperation among academics and stake holder actors need to take place.

With increasing demand and high production cost of surface water, groundwater becomes more attractive. However as we have seen in other regions around the world, where groundwater has been explored extensively and for longer periods of time, depletion of the aquifer is of real concern. This scenario has been already detected in some more populated cities using GAS waters.

Recent estimates indicate that there are over 20 000 active water-producing wells in the state of São Paulo. The majority consists of shallow wells exploring shallower and younger aquifers overlying GAS. Because of excellent hydraulic properties of Guarani Aquifer (transmissivity of 500 to 1200 m^2/day), even in areas with wells over 500 m deep, drilling has increased production (2000 wells) over shallower less productive aquifers, nonetheless water quality becomes a concern, for high salinity and elevated concentrations of fluorine.

In 2011 São Paulo state Water Resource Council launched a two-year project to evaluate the vulnerability of the narrow recharge (outcrop) area of the GAS, which covers approximately 14.000 km^2, and vital for replenishing the confined portions of the aquifer. Following the experience of São Paulo, the Brazilian National Water Agency (ANA) executed a similar project for the remaining of the Guarani recharge area in Brazilian territory (52.500 km^2). Both projects produced more detailed mapping (1:250.000) to better delineate the outcropping areas of the Guarani Aquifer. and also to better understand its contact relationships with the adjacent geological units. Emphasis was also given to the pollution and water quality.

These results allow state water management agencies to launch GAS recharge areas protection programs close connected to land use and environmental policies. Less generic water permits concession guidelines for GAS extraction are also foreseen. In some aspects these strategies are already accepted at recently developed water state master plans and also river basin water plans at the overall GAS region. This means a paradigm shift into a more comprehensive and integrated water resources assessment and policies. It must be emphasized that groundwater issues have definitely arrived at stake holders and public policy agendas and that debates are more evolved and mature.

The Quaraí river basin lying at the southern region of Brazil, a wide unconfined GAS region in the border with Uruguay, represents a concrete example regarding these new approaches. Based on hydrological and hydrogeological assessments (financed by the La Plata River Basin Project CIC/OEA) an integrated model has been developed in

Outcrop in Botucatu, São Paulo

Quarry in Taquara, Rio Grande do Sul

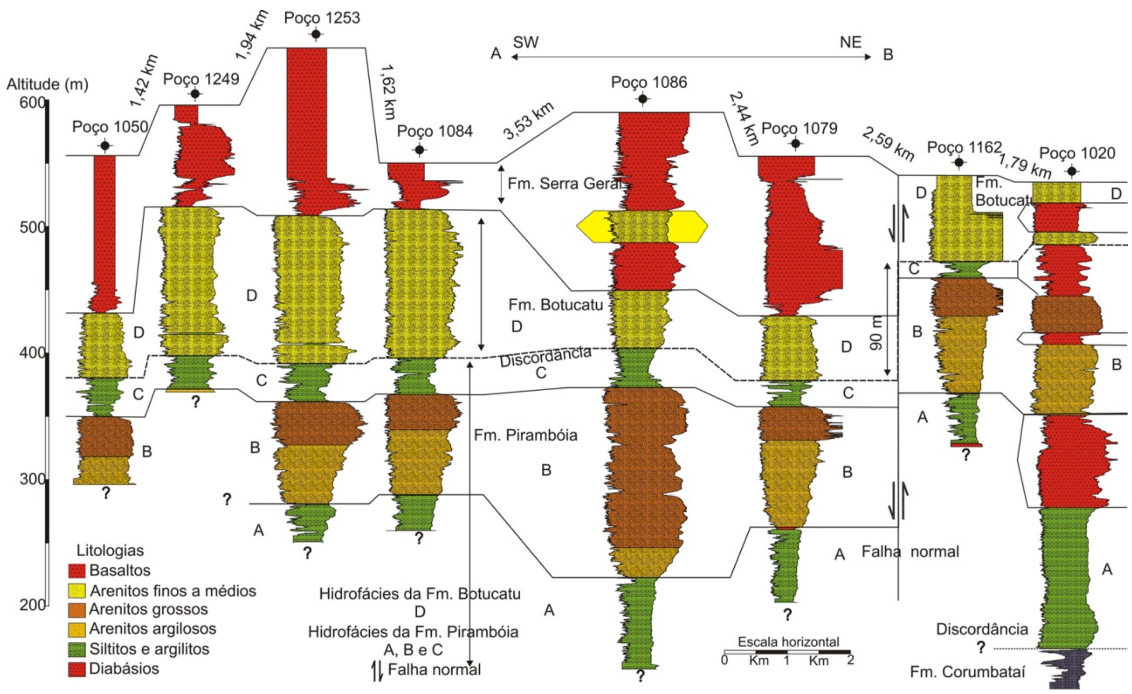

Fig. 1. Geological cross-section of GAS in Ribeirão Preto, São Paulo.

order to establish overall water permit guidelines. Local community and water state agencies are participating actively and there is a great potential for replication in other similar regions.

Similar steps are been taken by the Water Resource Council of the state of São Paulo. Pilot river basins are being chosen for enhanced and detailed assessments of reserves and recharge estimates. These results are going to be adopted by management agencies and formally are going to be included into the state water management framework. Regarding GAS recharge estimates, important results are being produced by academic groups and the CPRM - Brazilian Geological Survey.

The unconfined GAS behavior and its recharge and discharge relationships are being understood based on the new available data on groundwater level taken from full equipped monitoring wells from the RIMAS Project and other monitoring networks (CETESB-SP and DAEE-SP). The RIMAS Project run by the CPRM comprises about 40 wells built on the unconfined GAS within the southern states (RS, SC, PR, MS and SP) and offers already 6 years of daily level measurements. All this information is available at the CPRM website. Another remarkable initiative from the CPRM concerning groundwater is the SIAGAS (Groundwater Information System) where water well information (public and private drillings) is being registered at country level. For certain regions, mainly the GAS regions, this data bank is suitable for research and management initiatives, such as river basin groundwater budget.

Besides the many new outcomes and public initiatives, mainly concerning GAS unconfined regions, there is still a bumpy road ahead to understanding the overall regional aquifer dynamics at the transboundary Paraná sedimentary basin.

Recent and ongoing studies conducted at UNESP have shown that Guarani Aquifer has quite a variable thickness and heterogeneous distributions (e.g., Fig. 1), most notably in the southern and western portions of the aquifer (Rio Grande do Sul, Santa Catarina, Paraná and Mato Grosso do Sul states). Facies and thickness changes can be depositional or tectonically controlled. The later is essentially produced by mafic igneous intrusion and associated fault responsible for the emplacement of the upper confining unit Serra Geral Formation. Many questions concerning hydraulics and hydrogeochemistry in the deeper confined aquifer still remain. Some of them are being solved actually by ongoing subsurface geology studies and hydrogeochemistry and isotope assessments. Recent groundwater ages determined using Kr and noble gas methods furnished residence time over half a million years. These results reinforce the need to protect the groundwater, as replenishment of extracted water remains in deficit, implying that water is being "mined".

Outcrop in Botucatu, São Paulo.

University research projects have played important role on the GAS assessment. Over 50 thesis and dissertations have been produced in recent years. Many of these works have benefited from the federal and state databases, but substantial and valuable data have been made available, ranging from surface and subsurface mapping to water chemistry and isotope analyses.

The most valuable outcome of the many initiatives described is the exchange of experiences among the diverse sectors. This has led to a greater public awareness through the discussion of the important contribution of the Guarani Aquifer to provide the much needed water for the social and economic development of the Brazilian territories covered by the aquifer. One major drive for investing in the above-mentioned projects is the threat to water quality caused by those needed it most.

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What causes the variability in isotope ratios of precipitation?

Tropical and mid-latitude precipitation is fundamentally of two types, spatially-limited and high-intensity convective or widespread and lower-intensity stratiform, owing to differences in cloud vertical air motions and microphysical processes governing rain formation. These processes are difficult to observe or model, but precipitation partitioning (into convective and stratiform fractions) is an excellent means to understand these processes. Therefore, precipitation partitioning is also critical for understanding how the water cycle responds to climate changes. Isotopic measurements since the early 1950s have shown that stable isotope ratios are different in precipitation from different clouds, such as convective showers and frontal rains, they have been interpreted using a Rayleigh Distillation model, regardless of the nature of clouds or precipitation. While this has successfully explained some isotopic trends, variations during individual storms or across different regions cannot be accounted for and a comprehensive understanding of precipitation isotope variability is yet to be found.

A new approach has recently been proposed by the IAEA Water Resources Programme, using two independent data sets - convective and stratiform precipitation fractions, derived from the Tropical Rainfall Measuring Mission satellite or synoptic cloud observations along with stable isotope and tritium compositions of surface precipitation, derived from GNIP. With data from 28 tropical and two midlatitude locations, it is shown that isotope ratios reflect rain type proportions and are negatively correlated with stratiform fractions. Convective rain forms as particles are lifted in strong updrafts. Condensation and riming associated with boundary layer moisture produces higher isotope ratios, along with higher tritium when riming in deep convection occurs with entrained air at higher altitudes. Stratiform rain, on the other hand, forms with ice particles growing as they fall slowly in very weak upward air motions and grow by vapor diffusion, These particles melt in an approximately 500 m thick layer before falling as relatively small rain drops (compared to convective rain) while undergoing isotopic exchange with low altitude moisture. As a result, stratiform rain has lower isotope ratios and tritium.

Based on these results, stable isotope ratios can be used to monitor changes in the character of precipitation in response to periodic variability or changes in climate. These results, reported recently in Nature Geoscience (2016, vol.9, pp624–629), also help to provide observational constraints for an improved simulation of convection in climate models and a better understanding of isotope variations in proxy archives, such as speleothems and tropical ice. This will be particularly important in forecasting the

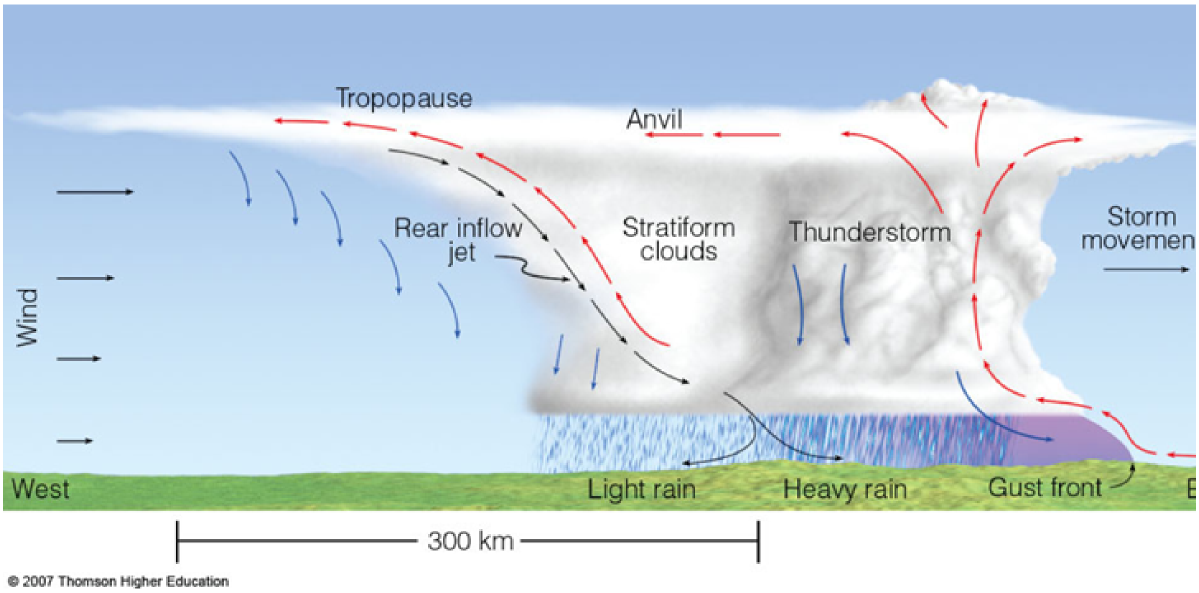


Diagram showing the genesis on convective and stratiform precipitation

occurrence of violent weather events, which occur with increasing frequency. The new understandings and methodology provides a potential new tool to help member states achieve Sustainable Development Goal 13 'Take urgent action to combat climate change and its impacts' and the SDG6 target (13.3): "Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning".

P.Aggarwal

New isotopic tools for monitoring water quality in rivers and lakes

The exponential growth of the human population and the rapid co-development of agricultural and industrial sectors in recent decades have caused a sharp increase of nitrogen concentrations to rivers and lakes worldwide. The increasing concentrations of the nitrogen species, like nitrate and ammonia, have altered the global N cycle - the cycle of chemical reactions in which atmospheric nitrogen is compounded, dissolved in rain, and deposited in the soil, where it is assimilated and metabolized by bacteria and plants, eventually returning to the atmosphere by bacterial decomposition of organic matter. This often results in the eutrophication of rivers and lakes, and reducing the biodiversity and ability of aquatic ecosystems to provide valuable services for the world's population. Two of the most commonly recognized symptoms of eutrophication are harmful algal blooms and hypoxia (acute oxygen deficiency in a biotic environment).

Given that consumption of water with high concentrations of nitrate can pose risks to human health, organizations such as the World Health Organization (WHO) and governmental agencies, such as the US Environmental Protection Agency (EPA), have established quality standards for water resources and developed regulations and action guidelines for the use of water in the consumption sector.

Nitrogen species are widely distributed compounds primarily as a result of diverse agricultural activities utilizing N-containing fertilizers. Other significant anthropogenic sources of nitrogen pollution and eutrophication are the disposal of sewage by centralized and individual systems, animal feeding operations, and elevated atmospheric N deposition.

The isotopic ratios of nitrogen ($\delta^{15}N$ and $\delta^{18}O$) in conjunction with other indicators constitute a promising and powerful tool for determining the sources of nitrogen in water resources, as well as the multiple nitrogen source contributions, and aid in assessing the biogeochemical processes nitrogen undergoes in rivers and lakes. Integrating isotope techniques with conventional aquatic assessment

Sampling of river water in Bangladesh

approaches results in more effective management practices that preserve water quality and efficacious remediation efforts (e.g., better nutrient management vs. in stream remediation) of lakes and rivers undergoing eutrophication issues. The IAEA Coordinated Research Project (CRP) "Isotopes to study nitrogen pollution and eutrophication of rivers and lakes" aims at improving capability and expertise among Member States in the use environmental isotopes to better assess nitrogen pollution on water resources variability, availability and sustainability. Participating countries include: Argentina, Belgium, Canada, Chile, China, Cuba, Finland, Ghana, Greece, India, Italy, Kenya, Malaysia, Morocco, Sri Lanka, United Kingdom, United States of America, Viet Nam. Conclusions and findings will be presented early 2019.

***Eutrophication** is a form of water pollution. It occurs most often when excessive fertilizers run into lakes and rivers. This encourages the growth of algae (algal bloom) and other aquatic plants. Following this, overcrowding occurs and plants compete for sunlight, space and oxygen.*

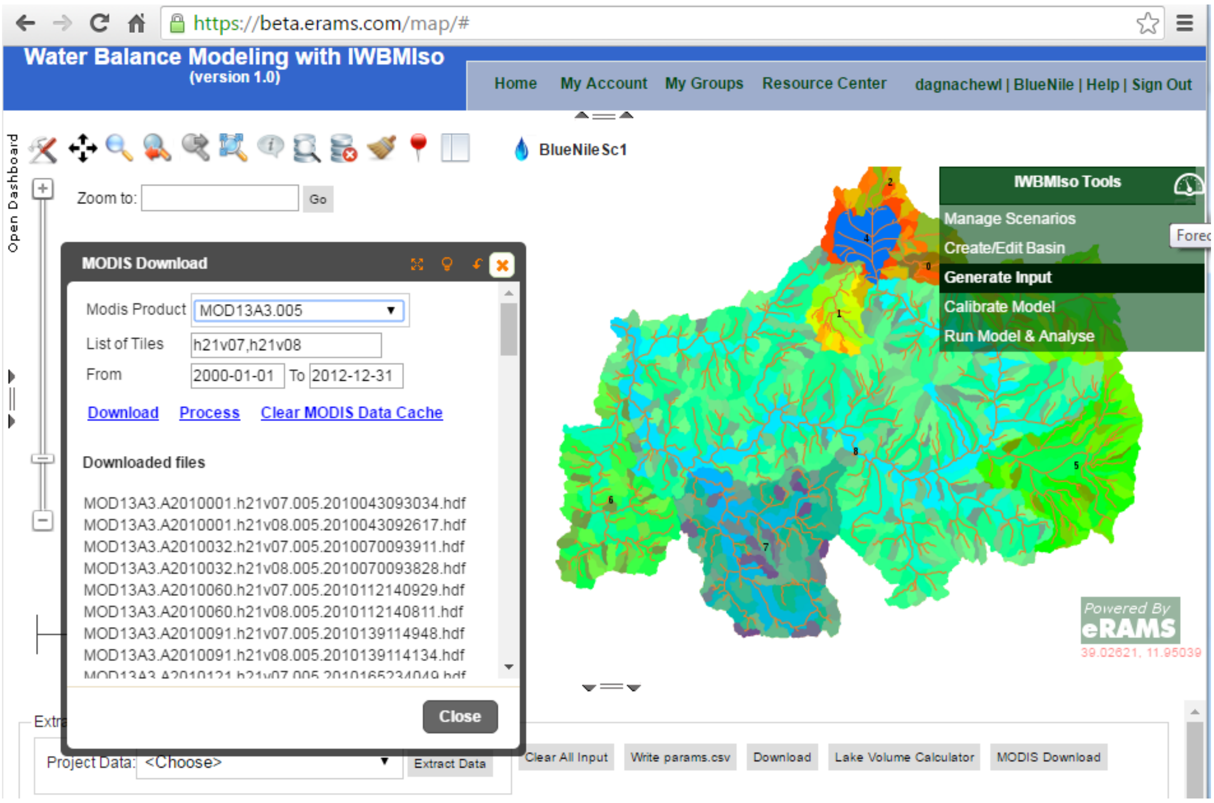
The IAEA Isotope Hydrology Laboratory is currently testing lower cost laser spectrography to simultaneously analyze nitrate converted N_2O directly. This laser-based nitrate capacity is expected to help facilitate access to nitrate isotope data for Member States seeking to achieve the SDG6 target (6.6): "By 2020, protect and restore water-related ecosystems, including mountain forests, wetlands, rivers, aquifers and lakes". The promotion of routine use of new analysis technologies on N isotopes will lead to a greater confidence in assessments of pollution issues of water resources and the adoption of sound remediation strategies.

I. Matiatos

Deployment of the IAEA Water Balance Model with Isotopes (IWBMIso)

The Isotope Hydrology Section of the International Atomic Energy Agency (IAEA) supports the use of isotope hydrology to improve knowledge of water resources and to improve water management. The Global Network of Isotopes in Precipitation (GNIP) and the Global Network of Isotopes in Rivers (GNIR) are two large databases initiated and maintained by IAEA to provide global data on isotope contents of precipitation and rivers.

The IAEA has been exploring the use of GNIP and GNIR data in hydrological models for application to hydrological studies and water resources management issues in basins around the globe. The principal premise of this effort is to contribute to the improvement of water balance by providing an additional means of constraining model calibration and validation processes. Although this is not the first of its kind, this approach is unique in that it provides a tightly coupled catchment-lake water balance model with integrated isotope mass balance for each component of the water cycle at a monthly time step. A monthly water balance model was selected as the initial approach based on the typical monthly or longer frequency of isotope data availability and on an assessment of the limited spatial and temporal distribution of supporting physical and meteorological data in many of the basins. The resulting model is the IAEA Water Balance Model with Isotopes (IWBMIso).



A screen image showing options for data used in IWBMIso

While data limitations were a major consideration in IWBMIso development, other factors considered included user knowledge and skills, web accessibility, and limited resources for usersto purchase commercial software. To address these concerns and to facilitate the use of IWBMIso by a broad range of users, IWBMIso is integrated with a set of associated Geographic Information Systems (GIS) pre-processing, model application, and analysis tools. These tools have been integrated into a more accessible package using the Colorado State University Environmental Risk Assessment and Management System (eRAMS) framework. In addition to the use of global datasets, the model is designed to run with local data, which can be processed to the model input format using tools available in the eRAMS framework.

The catchment water balance model in IWBMIso is tightly coupled with a lake water balance model. It also simulates the oxygen-18 (δ^{18}O) and deuterium (δ^{2}H) stable isotope ratios of the storage and flux components. IWBMIso is a combination of concepts developed from a simple monthly water balance model, a monthly isotope-enabled water balance model, a daily hydrologic model Precipitation Runoff Modelling System (PRMS), and an isotope-enabled lake model. The Craig-Gordon isotope fractionation model, and its further development for various reservoirs and systems are the basis for the isotope mass balance component of the model.

IWBMIso is designed to work with globally available datasets. Some of the global climate data sources that can readily be used in the model include the Climate Research Unit (CRU) Timeseries climate data, the Global Precipitation Climatology Centre (GPCC), the Tropical Rainfall Measuring Mission (TRMM), and other satellite derived rainfall estimates. MODIS is an important source of vegetation related data, including the vegetation index (NDVI), vegetation continuous field (VCF]) and Leaf Area Index (LAI). The 90-meter resolution shuttle radar topographic mission (SRTM) data is an excellent source for global digital elevation model, which is needed for watershed delineation and related parameters. GNIP and GNIR are the global repository of environmental isotopes data from various sources, including precipitation, rivers, lakes, groundwater and snow. The portal Waterisotopes.org is another important source of global gridded precipitation isotope data. The eRAMS geospatial platform facilitates the download, pre- and post-processing of all the needed and available global datasets for any part of the world. The IWBMIso model provides an important new technical capability for IAEA member States seeking to achieve the new Sustainable Development Goal 6 'Water and Sanitation for All' and the new SDG target for integrated water resource management 6.5 "By 2030, implement integrated water resources management at all levels, including through trans-boundary cooperation as appropriate".

The IWBMIso-eRAMS application is packaged as a virtual machine (VM) installation for desktop and notebook computers. A copy of the VM can already be requested from D.Belachew@iaea.org. It is also available online at https://beta.erams.com. Trainings and workshops on the use and application of the model will be organized by IAEA regularly.

D. Belachew

Increased recognition and demand for age dating of groundwater in major aquifers

About one third of Earth's largest groundwater basins are being rapidly depleted by human consumption, despite having little accurate data about how much water remains in them, according to new studies based on data from NASA's Gravity Recovery and Climate Experiment (GRACE) satellites. GRACE measures dips and bumps in Earth's gravity, which are affected by the mass of water.

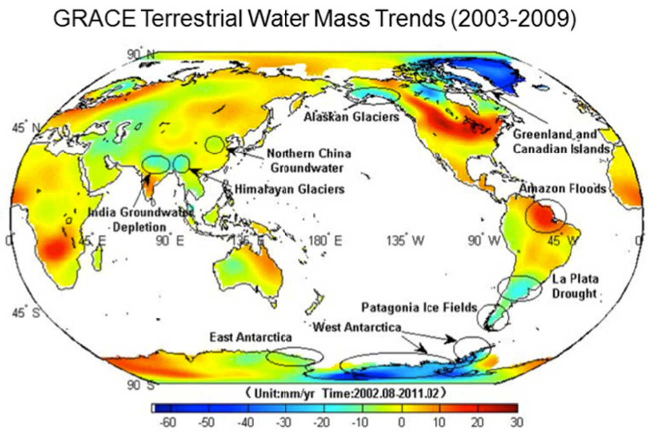
Researchers found that 13 of the planet's 37 largest aquifers studied between 2003 and 2013 were being depleted while receiving little to no recharge.

Eight were classified as "overstressed," with nearly no natural replenishment to offset usage. Another five were found to be "extremely" or "highly" stressed, depending upon the level of replenishment in each. Those aquifers were still being depleted but had some water flowing back into them. The most overburdened aquifers are in the world's driest areas, where populations draw heavily on underground water. Climate change and population growth are expected to intensify the problem.

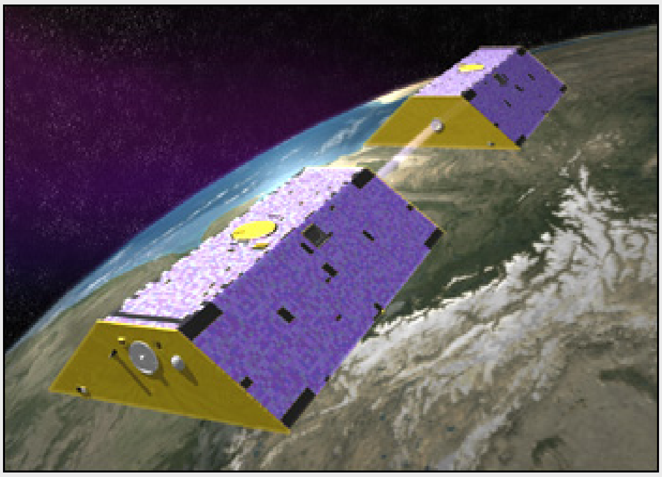
The Arabian Aquifer System, an important water source for more than 60 million people, is the most overstressed in the world. The Indus Basin aquifer of north western India and Pakistan is the second-most overstressed, and the Murzuk-Djado Basin in northern Africa is third. California's Central Valley, used heavily for agriculture and suffering rapid depletion, was slightly better off, but was still labelled highly stressed.

In a companion study, scientists conclude that the total remaining volume of the world's usable groundwater is poorly known, with estimates that often vary widely. The total groundwater volume is likely far less than rudimentary estimates made decades ago. By comparing their satellite-derived groundwater loss rates to what little data exist on groundwater availability, the researchers found major discrepancies in projected "time to depletion." In the overstressed Northwest Sahara Aquifer System, for example, time to depletion estimates varied between 10 years and 21,000 years. The study notes that the dearth of groundwater is already leading to significant ecological damage, including depleted rivers, declining water quality and subsiding land.

This means that significant segments of Earth's population are consuming groundwater quickly without knowing when it might run out. The depth and thickness of many large aquifers make it tough and costly to study aquifers and the use of groundwater age and other isotope fingerprints provide means to help quantify renewable and non-renewable groundwater. Available physical and chemical measurements are simply insufficient, and given how



Source: Jin (2013)

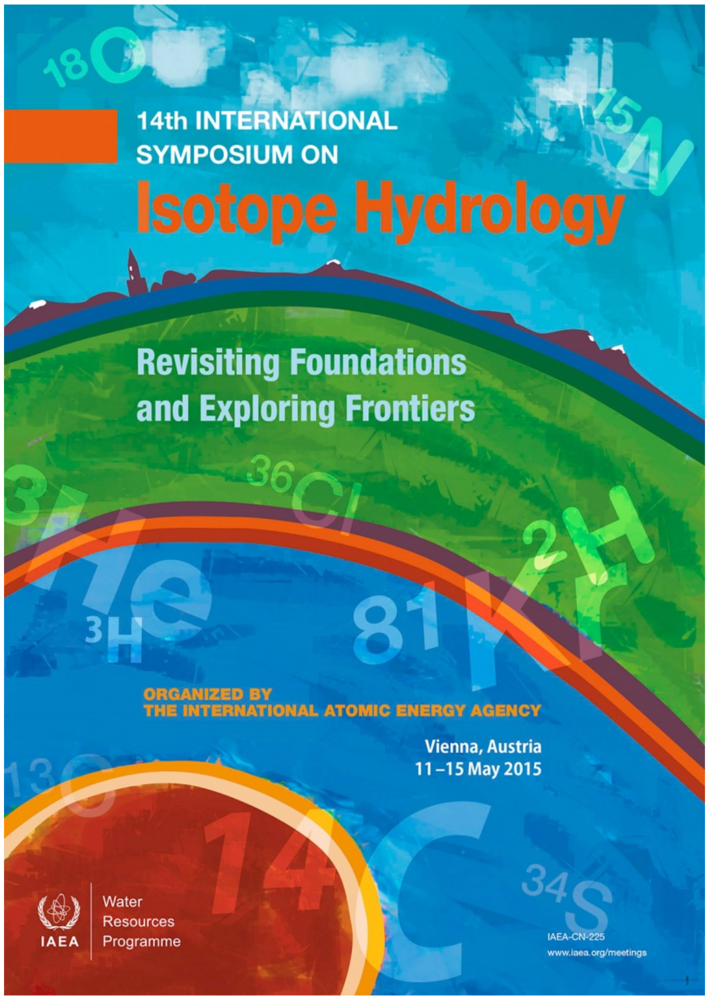


The two identical satellites orbit one behind the other in the same orbital plane at approximate distance of 220 kilometers (137 miles). As the pair circles the Earth, areas of slightly stronger gravity (greater mass concentration) affect the lead satellite first, pulling it away from the trailing satellite. As the satellites continue along their orbital path, the trailing satellite is pulled toward the lead satellite as it passes over the gravity anomaly. The change in distance would certainly be imperceptible to our eyes, but an extremely precise microwave ranging system on GRACE detects these minuscule changes in the distance between the satellites. A highly accurate measuring device known as an accelerometer, located at each satellite's center of mass, measures the non-gravitational accelerations (such as those due to atmospheric drag) so that only accelerations caused by gravity are considered. Satellite Global Positioning System (GPS) receivers determine the exact position of the satellite over the Earth to within a centimeter or less. Members of the GRACE science team can download all this information from the satellites, and use it to construct monthly maps of the Earth's average gravity field, and variations reflecting changes in groundwater, during the planned five-year mission.

quickly humans are consuming the world's groundwater reserves, we need a coordinated global effort to determine how much is left. This will make important contributions to achieving the sustainable development goals (SDGs), and in particular, Goal 6 'Water for All'

R. Kastens

International Symposium on Isotope Hydrology: Revisiting Foundations and Exploring Frontiers, 11–15 May 2015



The 15th edition of the International Symposium on Isotope Hydrology was held at IAEA Headquarters in Vienna, Austria, from 11 to 15 May 2015. Since 1963 these IAEA symposia have provided a unique opportunity to review and advance the science and application of isotope hydrology worldwide. Building upon the contributions and the exchange of information at the symposia, the International Atomic Energy Agency (IAEA) has played a crucial role in promoting and expanding the use of isotopes in hydrology to gain unique insights into the functioning of terrestrial and atmospheric water cycles. After more than 50 years of development as a scientific discipline, isotope hydrology has widespread applications in water resources assessment and management, in the study of past and future changes in the Earth's climate as well as of climate impacts on the water cycle, and in 'forensics' related to ecological, wildlife and food source traceability.

The 2015 IAEA symposium featured the theme of 'Revisiting Foundations and Exploring Frontiers' of isotope hydrology, with a review of the foundational efforts of pioneering scientists along with new developments and advances. The Symposium attracted a record number of 347 participants from 77 countries and international organizations. The programme included 88 oral presentations and 239 posters, covering a diverse spectrum of hydrological, climatological and environmental disciplines relevant to the IAEA's work, such as: a) isotopes in precipitation, atmosphere-hydrosphere interactions, paleoclimate and paleo-hydrology, b) studies on assessment of groundwater resources, age dating and noble gas isotope studies, e) surface water isotopic and pollution studies, d) advances in laser spectroscopy and other recently developed analytical methods, and f) nutrient cycles and contamination. A special session was devoted to commemorate 50 years of IAEA Technical Cooperation projects in isotope hydrology, water resources assessment and hydrological modelling. The final session was devoted to review some the environmental fields where further isotope tools and applications can contribute to the global water and climate agendas, including talks on news analytical methods and approaches to address various emerging issues on catchment hydrology, groundwater flow and transport, ecohydrology, surface and groundwater pollution, use of isotopes in climate studies, etc.

Participants gained understanding of the many new analytical developments that will make groundwater analysis cheaper, faster and less laborious in future, as well as new services available and to be available in the near future. The 21 papers presented at the Symposium have been published as a compendium

Sustainable Development of Water Resources

As availability of freshwater becomes more critical to the economic and social development of all nations, it has become evident that water often lies at the heart of global efforts to reduce poverty and achieve sustainable development. The recently adopted Sustainable Development Goals (SDGs) of the United Nations recognize this role, and accordingly include a separate and independent goal on water. This entails that society as a whole must change the way it develops, uses and manages water resources, to prevent unsustainable overexploitation and widespread pollution of resources, and to mitigate the impact of climate change on rainfall patterns. A simple accounting of the volume and flow rates of surface water courses and underground bodies is insufficient for good water resources management. A comprehensive understanding of the origin, history and dynamics of each component of the water cycle water is a critical pre-requisite for the proper assessment of the reliability and potential of the hydrological systems as the source of water supply in medium and long-terms. These efforts will require the use of all available scientific tools, such as remote sensing, geophysics, hydrological monitoring and modelling. Recent advances in the understating of parameters controlling the distribution of isotopes in the water cycle, as well as in measurement technologies for stable and radioactive isotopes, as demonstrated in some of the research papers in this special issue, will allow a greater use of isotopes for efficient and reliable water resources assessment and management.

and available on the Water Resource Programme website.

The next quadrennial IAEA Symposium on Isotope Hydrology will take place in Vienna in 2019, the theme for which will be decided at a special experts meeting in mid-2017.

L. Araguás Araguás

News in Brief

Record Participation in the IHL International Water Isotope Inter Comparison Test (WICO2016)

The quadrennial water isotope inter-comparison logged the highest number of participating laboratories in WICO's history. The participation rate increased 48 % increase over the previous 2011 WICO test, to a record 251 international laboratories. Almost all of the increase was due to the proliferation of low cost laser spectrometers for conducting water isotope analyses. The scope of WICO2016 was expanded over previous efforts to include an significantly expanded isotopic range of test waters to assist those member states working on paleoclimate (isotopically depleted sample for ice cores), scientists working in low latitudes, the tropics and highly evaporative environments (isotopically enriched sample), plus a seawater saline sample. The outcome of WICO is to evaluate and inform laboratories where they may improve water isotope analyses to provide the highest possible accurate and precise isotope data for use in the hydrological sciences.

New CRPs (started in 2016)

Use of Long-lived Radionuclides for Dating Very Old Groundwaters

The increasing global water demand for agriculture, domestic and industrial uses, combined with the impact of pollution and climate change on surface waters, is forcing local water authorities to rely more and more on groundwater. Deep aquifer systems, containing older groundwater, probably recharged thousands of years ago or at distant areas, are becoming the most important fresh water resource in many areas. A proper understanding of the origin, age and dynamics of old groundwaters is a key prerequisite for the assessment of the reliability and potential of these resources as a major source of water supply in medium and long-terms. The overall aim of the CRP is to assess the usefulness of the newly available radioisotopes and noble gases (carbon-14, krypton-81, chlorine-36, helium-4, etc…) to better estimate groundwater ages and dynamics that will help towards the optimal management of deep groundwater resources

Use of Isotope Hydrology to Characterize Groundwater Systems in the Vicinity of Nuclear Power Plants

Nuclear energy remains the largest source of low-carbon electricity in the world. Although the NPPs site selection and operation follows strict safety guidelines, there is always the case of unforeseen accidents, e.g., the Great East Japan Earthquake of March 11, 2011 which triggered an extremely severe nuclear accident at the Fukushima Daiichi, which resulted in the release of radioactive materials into the environment and the contamination of groundwater. The main focus of the CRP is to develop guidelines for comprehensive characterization of local and regional groundwater systems in the vicinity of Nuclear Power Plants (NPPs) by using isotope techniques. The CRP aims to use newly developed isotope tools, like noble gases isotopes, to provide better information on the dynamics of very fast and/or very slow moving groundwater near the NPPs that will assist in controlling contamination of water resources in case of unforeseen incidents.

Isotopes to Study Nitrogen Pollution and Eutrophication of Rivers and Lakes

As part of water resources management, the aspects related to water quality have become a common area of interest in many Member States due to the severe impact of pollution in most water systems. Water quality in lakes and rivers around the globe is deteriorating due to rising nutrient levels and other chemical pollutants, mainly from agriculture and urban wastes, resulting in change of water systems to eutrophic state. The loading of nitrogen is expected to increase significantly over the next century due to increasing agricultural use of N-based fertilizers in the developing world. The overall aim of the CRP is to explore the use of environmental isotopes to better understand nitrogen pollution and eutrophication in rivers and lakes for optimal water resources management and remediation strategies. The CRP also aims to promote new methodologies that will facilitate access to a low-cost use of N-isotope data.

Potential topics for CRPs in 2018–2019

Variability in the isotopic composition of precipitation and its implications for assessing climate change impacts

Evaluation and sustainable use of water sources for domestic supply in urban areas

Sustainability of water sources used for irrigation

Use of isotope-enabled catchment hydrology models for improved estimates of water balance

Global monitoring of nitrogen isotopes in atmospheric waters

Impressum

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