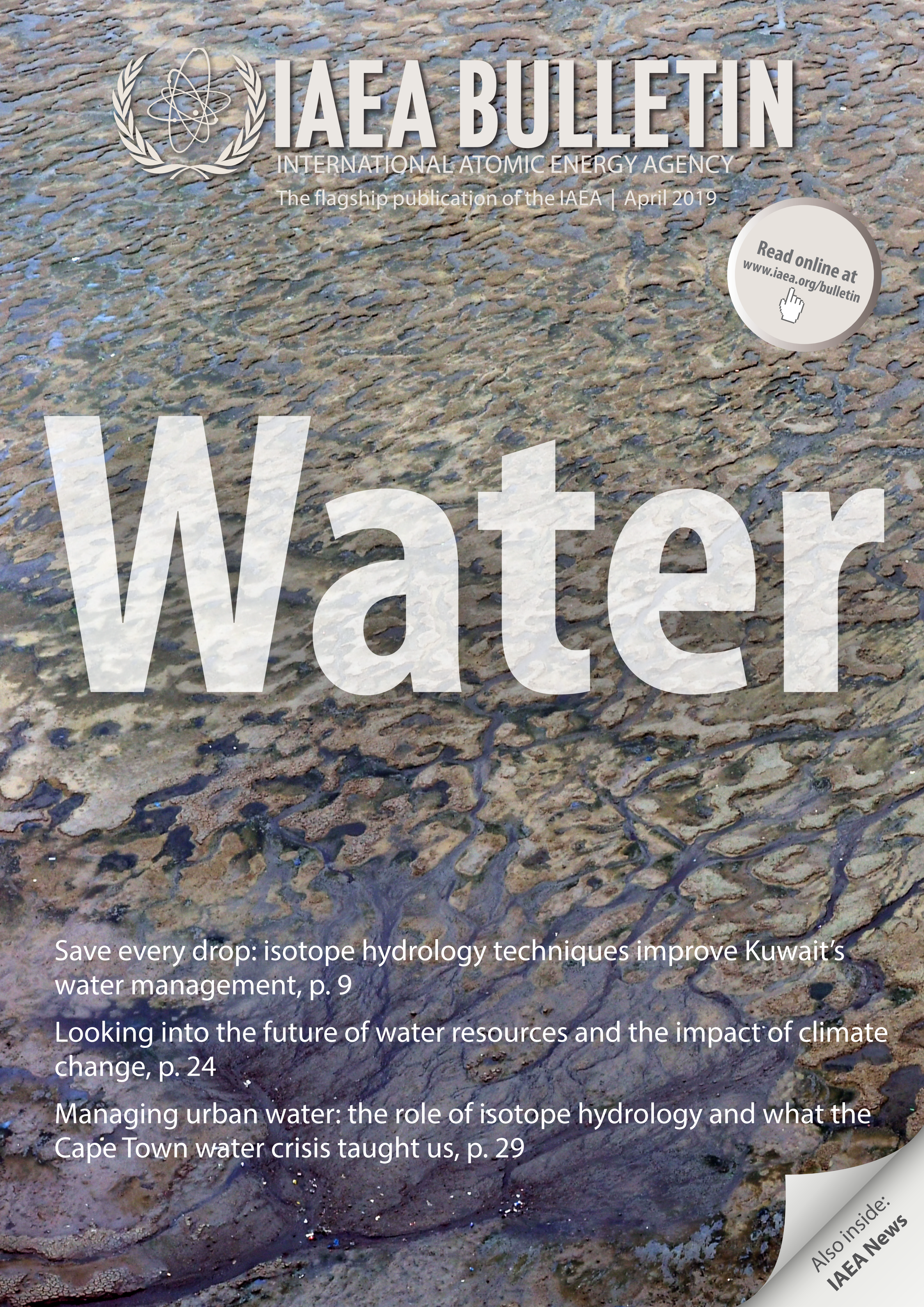


# IAEA BULLETIN

INTERNATIONAL ATOMIC ENERGY AGENCY

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# Water

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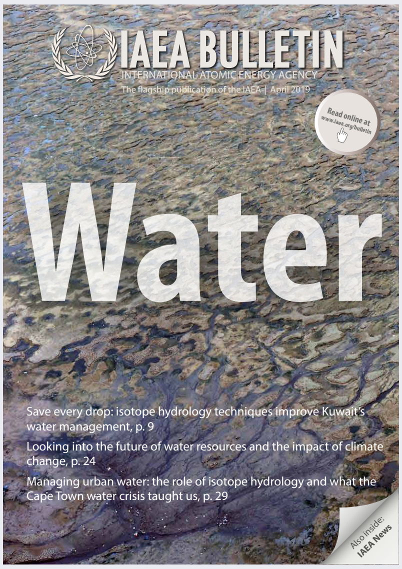


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Cover Photo:
Coastline during low tide, Persian Gulf, Kuwait
(Photo: D. Calma/IAEA)

IAEA

The International Atomic Energy Agency's mission is to prevent the spread of nuclear weapons and to help all countries — especially in the developing world — benefit from the peaceful, safe and secure use of nuclear science and technology.

Established as an autonomous organization under the United Nations in 1957, the IAEA is the only organization within the UN system with expertise in nuclear technologies. The IAEA's unique specialist laboratories help transfer knowledge and expertise to IAEA Member States in areas such as human health, food, water, industry and the environment.

The IAEA also serves as the global platform for strengthening nuclear security. The IAEA has established the Nuclear Security Series of international consensus guidance publications on nuclear security. The IAEA's work also focuses on helping to minimize the risk of nuclear and other radioactive material falling into the hands of terrorists and criminals, or of nuclear facilities being subjected to malicious acts.

The IAEA safety standards provide a system of fundamental safety principles and reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from the harmful effects of ionizing radiation. The IAEA safety standards have been developed for all types of nuclear facilities and activities that serve peaceful purposes, as well as for protective actions to reduce existing radiation risks.

The IAEA also verifies through its inspection system that Member States comply with their commitments under the Nuclear Non-Proliferation Treaty and other non-proliferation agreements to use nuclear material and facilities only for peaceful purposes.

The IAEA's work is multi-faceted and engages a wide variety of partners at the national, regional and international levels. IAEA programmes and budgets are set through decisions of its policymaking bodies — the 35-member Board of Governors and the General Conference of all Member States.

The IAEA is headquartered at the Vienna International Centre. Field and liaison offices are located in Geneva, New York, Tokyo and Toronto. The IAEA operates scientific laboratories in Monaco, Seibersdorf and Vienna. In addition, the IAEA supports and provides funding to the Abdus Salam International Centre for Theoretical Physics, in Trieste, Italy.

# Understanding the world's water resources

## By Yukiya Amano, Director General, IAEA

Water is a precious resource upon which life on earth depends. Yet we know remarkably little about how much of it we have, exactly where it is and how long supplies will last. Of all the earth's fresh water, 98% is hidden underground. To protect it from threats such as overextraction and pollution and manage it sustainably for future generations, we must study our groundwater in-depth.

The IAEA supports national experts in this quest by promoting the use of isotopic techniques and transferring scientific know-how. Data collected using these techniques help to improve water management policies.

Supporting Member States in managing and protecting their water supplies is part of our Atoms for Peace and Development mandate. We encourage countries to take full advantage of nuclear techniques to improve all aspects of the lives of their people and care for the environment. Preserving water resources is a vital element of this.

This edition of the *IAEA Bulletin* covers the use of nuclear techniques in the field of isotope hydrology and the work of the IAEA to make these techniques available to our Member States. It provides an overview of the science (page 4) and showcases countries where our combined efforts are making a difference. For instance, on page 6, we describe how Argentinian isotope hydrologists have been gathering data for policy-makers to design improved water management models across the country.

Authorities in Kuwait highlight their plans for more sustainable water use with the support of the IAEA (page 9), while researchers in the Philippines explain how they confirmed that groundwater in the north of their country was safe to drink (page 12). On page 14, we trace the origin of polluted water in Mauritius and, on page 16, uncover rich bodies of water hiding underground in the semi-arid region of the Sahel.

This edition of the *IAEA Bulletin* also includes a section on technology, showcasing methods in isotope hydrology that the IAEA has developed for Member States. These include the tritium/helium-3 dating technique (page 20) used to establish the precise age of young water, and the isotope-enabled water balance model (page 24), which can help scientists to predict the effects of climate change on water resources.

You can learn about the role of isotope hydrology in protecting the environment during fracking (page 22), and how the IAEA tests the ability of laboratories around the world to analyse water (page 26), while page 18 introduces the global isotope monitoring network that the IAEA has developed in cooperation with the World Meteorological Organization.

This year's International Symposium on Isotope Hydrology is the 15th of its kind. It brings together leading water and environmental professionals from around the world to advance understanding of the immense benefits of isotope hydrology in helping the world respond to our rapidly changing global environment.

I hope that this edition of the *IAEA Bulletin* will give you an insight into this wide-reaching and fascinating application of nuclear technology.

**"Supporting Member States in managing and protecting their water supplies is part of our Atoms for Peace and Development mandate."**

*—Yukiya Amano, Director General, IAEA*

(Photo: L. Potterton/IAEA)

(Photo: Escuela Superior Politécnica del Litoral/EPSOL, Ecuador)


(Photo: L. Gil/IAEA)

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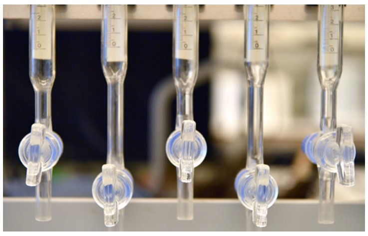
## Impact Stories





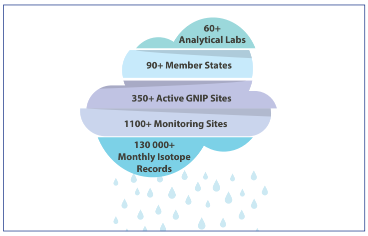




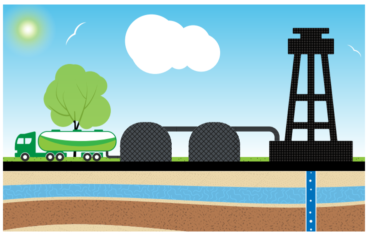




## Technology

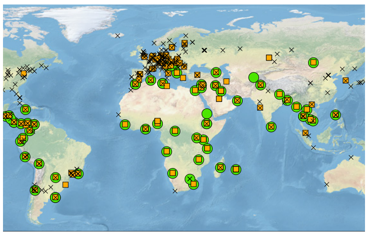














## World View



## IAEA Updates

# Isotope hydrology: an overview

By Lucía Ortega and Laura Gil


Isotopic techniques enable scientists to understand the components of the water cycle, helping them better assess the quantity, quality and sustainability of water.

In the water cycle, groundwater is the least understood component. Scientists use naturally occurring isotopes as tracers to find out whether groundwater is being replenished, where it comes from, how it moves underground and if it is vulnerable to pollution and changing climatic conditions.

Water from different places has different isotopic signatures or unique 'fingerprints'. Scientists use these 'fingerprints' to track the movement of water along its path through the entire water cycle: from evaporation, precipitation, infiltration, to runoff and evapotranspiration, then returning to the ocean or the atmosphere, and repeat.

## But what are isotopes?

A chemical element, like hydrogen, is made entirely from one type of atom. The type of atom comes in different varieties. These varieties are isotopes, and they all share the same chemical characteristics and number of protons and electrons, but a different number of neutrons. The difference in the number of neutrons makes each isotope weigh differently, and this weight difference is key for hydrological studies.

Isotope hydrology uses both stable and unstable isotopes. Stable isotopes are non-radioactive, meaning they don't emit radiation. Unstable isotopes (or radioisotopes) undergo radioactive decay and are therefore radioactive.

Here is a simple overview of how the science of isotope hydrology works.

## Origin and transport of water in the water cycle

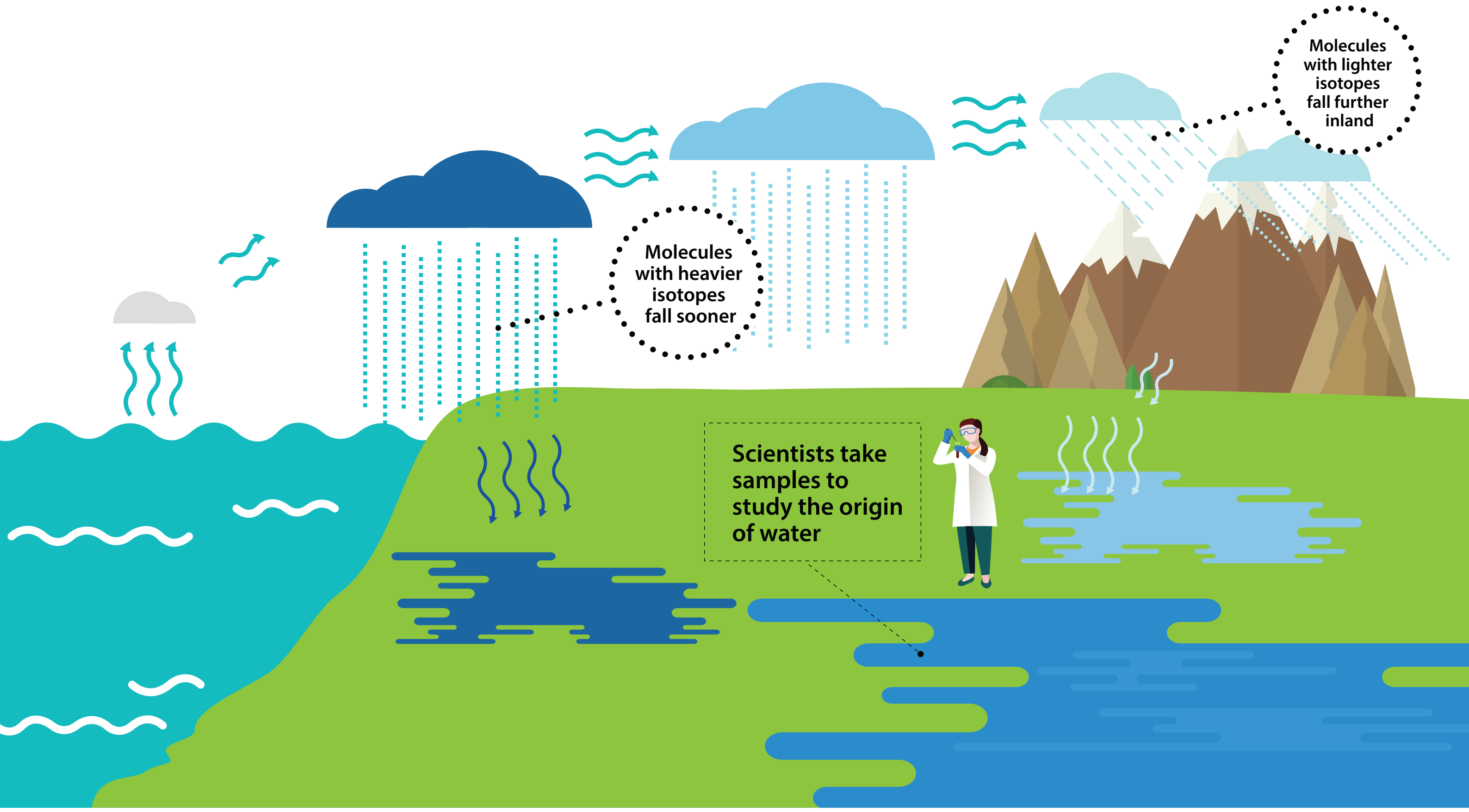
Every water molecule ($H_2O$) is made of two hydrogen (H) atoms and one oxygen (O) atom, but these are not all the same: some atoms' isotopes are lighter and some are heavier. Scientists use precise analytical equipment to measure these tiny weight differences in water samples. Why?

As water evaporates from the sea, the molecules with lighter isotopes tend to preferentially rise, forming clouds with specific isotopic signatures. These clouds have a mix of water molecules that fall in the form of rain. The water molecules with heavier isotopes fall first. Then, as the clouds lose these heavy isotopes and move further inland, lighter isotopes fall in a greater proportion.

As water falls to the earth, it fills lakes, rivers and aquifers. By measuring the ratio between heavy and light isotopes in these water bodies, scientists can decipher the origin and movement of water.

## Groundwater age

Isotopes are the most direct and powerful tools available to estimate the age, vulnerability and sustainability of water resources. When the groundwater in an aquifer is 'old', this means that the water flow is slow and that the aquifer can take a long time to replenish. On the contrary, young groundwater is easily and quickly renewed by rainwater, but can also be easily affected by pollution and changing climatic conditions. Understanding water's age gives scientists and governments a good idea of how quickly aquifers are being replenished.




In hydrology, some naturally occurring radioactive isotopes present in water, such as tritium ($^{3}H$), carbon-14 ($^{14}C$) and noble gas radioisotopes, are used to estimate groundwater age. This age can be from a few months up to a million years.

Because these isotopes decay over time, their abundance decreases as the years go by. Higher values mean 'younger' water, while lower values mean 'older' water. For example, groundwater with a detectable amount of tritium may be up to around 60 years old, whereas groundwater with no tritium must be older. While tritium is used for dating groundwater that has been recently recharged, i.e. that is younger than about 60 years, carbon-14 is used for water up to 40 000 years of age and krypton-81 for water that can be up to a million years old (see page 21).

## Water quality

Pollutants in surface water and groundwater come from various sources — such as agriculture, industry, or human waste — or may be present naturally due to geochemical processes taking place in aquifers.

Agriculture, industry and households each produce different kinds of pollutants. By studying the chemical and isotopic composition of a pollutant, scientists can determine its origins.

For example, nitrate ion ($NO_3^-$), which is made up of nitrogen and oxygen, is a common pollutant. Nitrogen has two stable isotopes of different weight. This difference in weight is not the same in human waste and in fertilizers. Fertilizers use nitrogen from the air, whereas humans and animals go through a biological process that changes nitrogen into different forms. As a result, pollutants derived from various sources can be identified based on these isotopic weight differences.

Knowing the origins of pollutants is the first step in addressing problems with water quality. The data isotope hydrologists gather are useful to policymakers in their strategic planning and management of water resources.

The IAEA supports scientists from around the world by promoting the use of isotope techniques, transferring scientific know-how to local water professionals. To learn more about how we do this, read on.

# Argentina applies isotopic techniques to water

## By Laura Gil

In Argentina, like in many parts of the world, water is at risk of overexploitation and contamination. To protect it, scientists are studying its invisible details with the help of nuclear technology and the support of the IAEA.

"Argentina is lucky to have a very good amount of water per inhabitant, but this water is distributed very unevenly across the country," said Daniel Cicerone, Environmental Manager at Argentina's National Atomic Energy Commission (CNEA). "In some regions, finding out if the water we are using on a daily basis is regularly recharged, running out or at risk of contamination can make the difference between poverty and prosperity."

The science behind this is called isotope hydrology — a discipline that, according to Douglas Kip Solomon, Professor of Geology and Geophysics at the University of Utah in the United States, "is one of the most powerful and trustworthy tools available to thoroughly assess groundwater."

**"Argentina is lucky to have a very good amount of water per inhabitant, but this water is distributed very unevenly across the country. In some regions, finding out if the water we are using on a daily basis is regularly recharged, running out or at risk of contamination can make the difference between poverty and prosperity."**

*— Daniel Cicerone, Environmental Manager, National Atomic Energy Commission, Argentina*

"Most of the fresh, usable water in the world is in the ground, but most of the water that's available to us is surface water," said Solomon, who is helping Argentinian experts map their water with the help of the IAEA. "It is extremely important that we understand the interactions between surface water and groundwater, so we know how to properly manage these resources and protect them."

## Hidden reserves

Since early 2016, Argentinian isotope hydrologists have been gathering and interpreting data from two strategic regions with the help of the IAEA. The idea is for policymakers to use this information and to design improved water management models — hydrological models — for these regions.

The two regions were selected for different reasons. The first is the arid valley of Mendoza, western Argentina, where people rely on the fresh underground water of the Uspallata and Yaguaráz aquifers, along with other, smaller ones. Authorities are keen to find out whether this water is being sustainably extracted, and if the aquifers have enough capacity to support increased water use.

"We need water for everything. Water is our daily bread," said Sergio Cirauqui, who works in a kayaking and rafting adventure shop at the top of a mountain in Uspallata. "But we are very conscious of the fact that water is a finite resource and that we have to take care of it. And as a finite resource, we should make almost sacred use of it."

**Mendoza, a region in Argentina where scientists use isotope hydrology to study the groundwater.**
(Photo: L. Gil/IAEA)

**Isotope hydrologists take water samples from Mendoza, western Argentina.**
(Photo: L. Gil/IAEA)

Argentinian isotope hydrologists have been hiking the mountains and plains of Mendoza for more than a year, collecting water from wells, lakes and rivers, accompanied by international and IAEA experts. Back in their labs, they are interpreting the results to paint a clearer picture of what is available.

“We look to find out exactly how water moves inside aquifers, how it interacts with rivers and how much of it is left,” said Sandra Ibáñez, Isotope Hydrologist at the University of Cuyo in Mendoza, who is participating in an IAEA technical cooperation project in the country.

Based on such data, policymakers are in a better position to establish rules for the use of water for drinking, agriculture and industry. Knowing that surface water is infiltrating groundwater, for example, can lead to stricter regulations on acceptable pollution levels.

“Once we have the results, we can decide what business activities to develop in Mendoza,” said Juan Andrés Pina, Deputy Director of the Groundwater Division at Mendoza’s General Department of Irrigation.

The second region under study is a streambed in Los Gigantes, Córdoba, an old uranium mining complex about 700 kilometres west of Buenos Aires. The site is under environmental remediation, and isotope hydrologists are working to find out more about the quality of the groundwater and its potential vulnerability to contamination.

Through the IAEA project, scientists have monitored the safety and quality of the water that was recharging the San Roque lake reservoir, a source for human consumption in the city of Córdoba.

“This interdisciplinary and interinstitutional study will help authorities improve the conceptual model and hydrological understanding of the area and strengthen the remediation of the site,” said Daniel Martínez, geologist and researcher at the National Council for Scientific and Technological Research (CONICET).

IAEA technical cooperation projects have been essential in transferring knowledge and technology to national and local institutions, said Raúl Ramírez García, Section Head at the IAEA’s Department of Technical Cooperation.

“The new information provided by isotopic techniques will help monitor the water resources and support the kind of decision making that will lead to social and economic benefits for the population of these regions,” Ramírez García said.

# Save every drop: isotope hydrology techniques improve Kuwait's water management

## By Aabha Dixit

Arid countries like Kuwait are increasingly focusing on techniques using stable isotopes to assess their groundwater resources and meet the challenge of managing these in a sustainable way for their growing populations.

"There are no permanent rivers or lakes in Kuwait, and groundwater is our only natural water resource. We have an average rainfall of just 115 millimetres per year and fresh water streams do not exist," said Muhammad Al-Rashed, Executive Director of the Water Research Center at the Kuwait Institute for Scientific Research (KISR). Therefore, effective water management policies are vital to ensure the quality and quantity of available water to meet the

**A scientist from KISR uses incubator to prepare water samples for bacteria analysis. Isotopic techniques are key in studying the quality of water.**
(Photo: D. Calma/IAEA)

**"We have to look at all available areas for potable water, and this is where isotope technology helps with investigations, as it looks at an optimum utilization of all water resources required for sustainable development."**

*— Khaled Hadi, Director of the Operations Division, Water Research Center, Kuwait Institute for Scientific Research*

(Photo: D.Clama/IAEA)

demand of the country's population of more than four million.

Kuwait's groundwater reserves are mainly in the north of the country and have limited recharge, as only a small percentage of rainwater reaches these aquifers.

Isotope hydrology techniques are one of the key scientific methods that experts in Kuwait use to trace fresh water movement and to assess the age of available groundwater. The various isotopes carried in the water act as 'tags', which can be used to determine the source, age, movement and interactions of water both above and below ground (see page 4 to learn more). The data obtained and visualized as hydrological maps enable experts to make evidence-based decisions on sustainable resource management. Al-Rashed and his colleagues have conducted several isotope hydrology studies for the management of groundwater in Kuwait.

Kuwait's water use is among the highest in the world, with a per capita consumption of over 400 litres per day. In Kuwait, the withdrawal rate of groundwater is 255 million cubic metres per year. In contrast, the natural underground inflow to the aquifers is estimated at 67 million cubic metres per year. With limited fresh water resources, Kuwait relies heavily on desalinating seawater, which is an expensive process.

"We have to look at all available areas for potable water, and this is where isotope technology helps with investigations, as it looks at an optimum utilization of all water resources required for sustainable development," said Khaled Hadi, the Director of the Operations Division at the Water Research Center in KISR.

National efforts focus on investigating groundwater resources using isotope hydrology in combination with physicochemical methods, evaluating precipitation recharge, establishing an optimum water production strategy and evaluating the feasibility of artificial recharge of aquifers, said Nader Al-Awadi, KISR's Executive Commissioner for International Cooperation.

## Water-related studies, lab support

The IAEA has been supporting Kuwait since 2000 through various technical cooperation projects, leading to the understanding of available groundwater resources and corrective actions to enhance water management policies.

For example, an IAEA-supported technical cooperation project on isotope investigations to evaluate groundwater hydrology in Kuwait focused on the collection of isotopic data of groundwater that were later integrated with data collected during previous studies for the isotopic mapping of groundwater covering the entire country. The application of isotope techniques helped in interpreting the origin, age and movement of groundwater, which are essential for the sustainable management of water resources.

Another project focused on the evaluation of potential contamination sources of nitrate and sulphate in the groundwater fields of Kuwait through isotopic characterization. It included studying the levels of naturally occurring radioactive materials in the groundwater. Researchers found that the major source of sulphate and nitrate in the groundwater is natural rather than a result of human activity.

Some of the water samples are sent to the IAEA Isotope Hydrology Laboratory in Vienna, Austria, for assessment.

The IAEA has also supported the establishment of Kuwait's Isotope Hydrology Laboratory with state-of-the-art instruments provided through IAEA technical cooperation projects. Other areas of capacity building assistance included training scientists and conducting research on a range of groundwater issues.

"The Government of Kuwait highly values the instrumental role the IAEA plays through its activities and support to Member States in promoting throughout the world capacity building, networking, knowledge sharing and partnership development in various aspects of the peaceful uses of nuclear science and technology," said Samira A. S. Omar, Director General of KISR.

# Water in Philippine city safe to drink, study finds

**By Miklos Gaspar**

**Isotopic techniques have confirmed that the city's water in the tanks behind these boys, and in new neighbourhoods in Tacloban, is safe to drink.**
(Photo: M. Gaspar/IAEA)

The drinking water of Tacloban, a city of 250 000 in the Philippines, is safe, getting regularly recharged and not under threat by the sea. Sounds simple? This conclusion took years of research and the analysis of thousands of water samples to establish, and required the use of isotopic techniques by researchers from the Philippine Nuclear Research Institute (PNRI), with support from the IAEA and the Food and Agriculture Organization of the United Nations (FAO).

When a storm surge caused by Typhoon Haiyan, one of the strongest tropical storms ever recorded, devastated much of this city and killed thousands in 2013, local authorities faced the daunting task of reconstruction, including moving people away from the most flood-prone areas. But could the waves that swept away buildings and people have reached the city's water reservoir?

There was a danger that the storm surge could have contaminated the aquifer — an underground layer of permeable rock containing groundwater — that is the city's main water source. Salt and other flood-borne contaminants, including organic matter from animal and human corpses, could have rendered the water unfit for consumption. The PNRI turned to the IAEA technical cooperation programme for assistance in the use of isotopic techniques to characterize the aquifer.

## Not all water molecules are created equal

While all water molecules consist of an oxygen and two hydrogen atoms, a small percentage of these atoms have extra neutrons in their nucleus. Exactly what percentage depends on the age and source of the water. Therefore, an analysis of the isotopic makeup of the groundwater enables researchers to find out whether the aquifer is getting recharged, i.e. receiving a regular dose of 'new' water from rain.

The scientists set up 32 monitoring stations for groundwater and used both conventional and nuclear techniques for the characterization of the water. They found very little sodium and chloride, thereby concluding that seawater did not enter the aquifer. They also found that the isotopic composition of the water in the aquifer is close to that of today's rainwater, which meant that the city's water supply was not in danger of disappearing, explained Raymond Sucgang, a senior researcher with the PNRI who led the project. "Tacloban is a growing city with a growing economy, so it is comforting to know that its groundwater is getting replenished from rain," he said.

The concentration of nitrogen and organic matter in the water was very low, which indicates that there was no biological contamination. "These potential contaminants probably decayed before they could get to the groundwater," Sucgang said.

The next step in the project is for the PNRI to determine the exact rate of water recharge and, based on that, make policy recommendations to the local government for the protection of the city's water supply. "It's good to know that there is no immediate danger, but a policy for sustainable water use is still required," Sucgang said.

## Looking for drinking water underground

Over the past few years, a new district has grown in the northern part of Tacloban, housing many of the people whose homes were devastated in the 2013 typhoon. Water availability in the area, which is home to 10 000 people, is a problem, and research by the PNRI has shown that the groundwater in this newly inhabited area is contaminated with lead and arsenic and therefore not fit for human consumption. The contamination probably comes from the unregulated landfill site at the edge of the subdivision, said Sucgang.

For local resident and community leader Eddie Rasonabe, this was devastating news. “We now know we cannot count on wells and will have to pay for water for now.” The handpumps initially built with the help of international aid agencies only tap into a shallow aquifer, and the water releases a foul smell, Rasonabe said. As a result, he is forced to buy mineral water for drinking and cooking — a considerable expense for this father of seven and many of his neighbours. But a solution is in sight: the local government has contracted private companies to bring drinking water from the city’s uncontaminated aquifer, and the PNRI is using isotopes to monitor whether the groundwater pumped from these deep production wells fulfils the quality requirements and to ensure that the extraction rate is sustainable.

**“It’s good to know that there is no immediate danger, but a policy for sustainable water use is still required.”**

*— Raymond Sucgang, Senior Researcher, Philippine Nuclear Research Institute*

Eddie Rasonabe cannot drink water from his well due to its high lead and arsenic content, according to a study by the PNRI. The neighbourhood was set up to house residents whose former homes were destroyed by Typhoon Haiyan in 2013.
(Photo: M. Gaspar/IAEA)

# Isotopes help trace the origin of urban water pollution in Mauritius

## By Luciana Viegas

Agricultural activities, illegal sewage disposal and animal breeding could be among the sources of nitrogen pollution in urban waterways around Port Louis, the capital of Mauritius, according to preliminary findings of an IAEA-supported study using isotopic techniques. In excessive levels, some compounds of nitrogen, such as nitrate, can find their way into urban waterways and pose a danger to people and the environment.

“Nitrate pollution is a major concern in the country,” said Yannick Fanny, Scientific Officer at the National Environmental Laboratory in Port Louis, the largest city and economic centre of the island, with a population of around 200 000. “The study was a breakthrough, and preliminary findings show that nitrate contamination most probably originates from manure and septic wastes, as well as from dissolved organic matter in the soil.”

**“Conventional chemistry will tell you how much nitrogen pollution there is in a river, but not where this pollution comes from. Analysing the isotopes of nitrate can give this kind of information.”**

*— Ioannis Matiatos, Isotope Hydrologist, IAEA*

Nitrogen is a key fertilizer and has been widely used since the mid-1900s. When overapplied, it can make its way into rivers and groundwater through agricultural run-off, but also through sewage systems, animal feedlots and industrial activities.

Nitrate is a nitrogen compound and an essential nutrient for plants. In excessive quantities, nitrate poses a concern for public health, since it can impair the blood’s ability to transport oxygen around the body. It can also cause algal blooms in lakes and rivers, reducing biodiversity and the ability of aquatic ecosystems to support valuable services, such as tourism and commercial fishing.

In 2016, scientists began working with the IAEA to use isotopic techniques to assess the origin of nitrate pollution after authorities had detected nitrate contamination around Port Louis. Contaminants were found in streams and rivers, threatening protected areas, such as the Rivulet Terre Rouge Estuary Bird Sanctuary. Toxic algal blooms in the ocean caused episodes of fish kill, raising complaints among local fishermen.

The sources for such pollution could have been manifold: inappropriate wastewater disposal systems from households, faulty septic tanks, industrial discharges, animal breeding and agricultural activities. Knowing who or what is responsible for nitrate pollution can help policymakers take informed action to protect rivers and groundwater.

Deciphering the origins of nitrates in waterways can be difficult. “Conventional chemistry will tell you how much nitrogen pollution there is in a river, but not where this pollution comes from,” said IAEA isotope hydrologist Ioannis Matiatos. “Analysing the isotopes of nitrate can give this kind of information.”

With technical assistance, scientists from the National Environmental Laboratory collected chemical and isotopic data in 14 river stations and 15 water boreholes around the city, and identified mechanisms influencing water quality around the area. They sampled and analysed nitrogen compounds in Port Louis’ waterways with support of the IAEA’s technical cooperation programme in the form of expert visits, training and equipment. The method they used involved analysing the unique ‘fingerprints’ of nitrate in water molecules by looking at the molecules’ isotopic composition (read more about this on page 5).

### Taking action

The results of the IAEA technical cooperation project will form the basis of a comprehensive report with findings and recommendations not only for government officials, but also local communities. “Targeted courses of action by all concerned stakeholders can help to swiftly remedy or improve the situation in these urban settings,” Fanny said.

The cooperation also set the ball rolling for increased water monitoring activities throughout Mauritius. The scientists at the National Environmental Laboratory have

**Isotope hydrologist takes water samples from a pollution site detected around Port Louis.**
(Photo: I. Matiatos/IAEA)

begun mapping areas that contribute the most to nitrogen pollution in waterways and are collecting source material samples to create an inventory of isotopic signatures for identifying pollutants.

"In the future, when there are incidents, authorities can quickly match water samples with pollution sources and immediately know what kind of activity is probably responsible," Matiatos said.

# Using isotopic techniques to map and analyse groundwater resources in the Sahel

## By Nathalie Mikhailova

**"In general, the aquifer systems located in the different shared basins represent a significant reserve of good quality water to cover most human needs."**

*— Kamel Zouari, Professor and Laboratory Head, National Engineering School of Sfax, Tunisia*

Despite a series of droughts and consistently low rainfall over the past few decades, the Sahel is home to rich bodies of water — hidden underground.

Increasing water demand resulting from population growth and the uncertainties caused by climate change and land use on water resources raise the question of how to ensure the safety and sufficiency of clean water for drinking, food production and sanitation. For a semi-arid region like the Sahel, having the right scientific tools to find out more about groundwater supplies could mean long-term access to clean water.

Through an IAEA technical cooperation project that began in 2012, scientists from Algeria, Benin, Burkina Faso, Cameroon, the Central African Republic, Chad, Ghana, Mali, Mauritania, Niger, Nigeria, Senegal and Togo were trained in water sampling for isotope analysis in order to carry out a detailed survey of groundwater supplies. The project covered parts of five major transboundary aquifer systems in the area: the Iullemeden Aquifer System, the Liptako-Gourma-Upper Volta System, the Senegalo-Mauritanian Basin, the Lake Chad Basin and the Taoudeni Basin.

Over 2000 water samples were collected from different aquifers over a four-year period during both the dry and humid seasons.

"By using isotopic and chemical tracers, scientists were able to collect important information on the origin, flow patterns, residence time and renewal rate of groundwater," said Kamel Zouari, Professor and Laboratory Head at the National Engineering School of Sfax, Tunisia, who worked on the project. "Scientists also determined the hydraulic interactions between shallow and deep aquifers and between aquifers and surface water. This information has been compiled in a dedicated database for each basin." To learn more about the techniques used, see page 4.

These research activities led to the creation of the first broad overview of groundwater in the Sahel, covering an area of five million square kilometres. "In general, the aquifer systems located in the different shared basins represent a significant reserve of good quality water to cover most human needs," said Zouari.

### Using data to develop water management practices

Scientists from each country produced national reports now available to their water authorities to use as a basis for decision making. In northern Ghana, for example, routine monitoring of the chemical and isotopic composition of groundwater revealed recharge mechanisms and sources of contamination that were previously overlooked.

"By using stable isotopes of water — oxygen-18 and hydrogen-2 — we revealed that the groundwater is meteoric, meaning its source is local precipitation," said Enoch Asare, Head of the Groundwater Division at the Ghana Water Resource Commission. Tritium analyses revealed that groundwater has recharged the aquifer in the last 50 years, he said. "Nitrogen-15 was used to determine sources of nitrate contamination in parts of the White Volta River Basin, showing that the contamination mostly emanated from human and animal waste." Identifying the source of contamination can help authorities protect the water, as it reveals how groundwater is being replenished, which is key to ensuring its sustainability.

The availability of groundwater to cover human needs depends on its quantity, quality and rate of replenishment. Information on the source and age of groundwater is required to properly assess the sustainability of the resource, particularly in view of existing or planned withdrawal activities.

"It is expected that the project's activities could further enhance the capacity of

stakeholders to better understand Ghana's hydrogeological system and thus establish policies that will safeguard the exploitation of groundwater resources, ensuring that water will be available at all times," Asare said.

A follow-up project to further integrate the management of groundwater resources in the Sahel countries began in 2018. It will follow the IAEA Water Availability Enhancement (IWAVE) methodology — led by Benin, Cameroon, Ghana, Niger and Nigeria — to identify gaps in national hydrological information and develop appropriate capacity building plans.

The IWAVE methodology consists of a gap analysis and stakeholder consultation, the development of an optimal strategy for groundwater management and the identification of essential technical capacities to invest in.

The established network of national institutions will contribute to better characterization, management and monitoring of groundwater resources using isotope hydrology and conventional techniques.

**Researchers from the University of Bangui take water samples from a well in the Central African Republic.**

(Photo: L. Gil/IAEA)

# The Global Network of Isotopes in Precipitation

Since 1961, the IAEA and the World Meteorological Organization (WMO) have been jointly conducting a worldwide survey of hydrogen ($^{2}H$, $^{3}H$) and oxygen ($^{18}O$) isotopes in precipitation.

This isotope monitoring network is called the Global Network of Isotopes in Precipitation, or GNIP. The initial objective was to systematically collect basic data on the isotope content of precipitation on a global scale to determine temporal and spatial variations of environmental isotopes in precipitation. With this information, scientists could find out the origin, movement and history of water. To support this work, the IAEA established its Isotope Hydrology Laboratory.

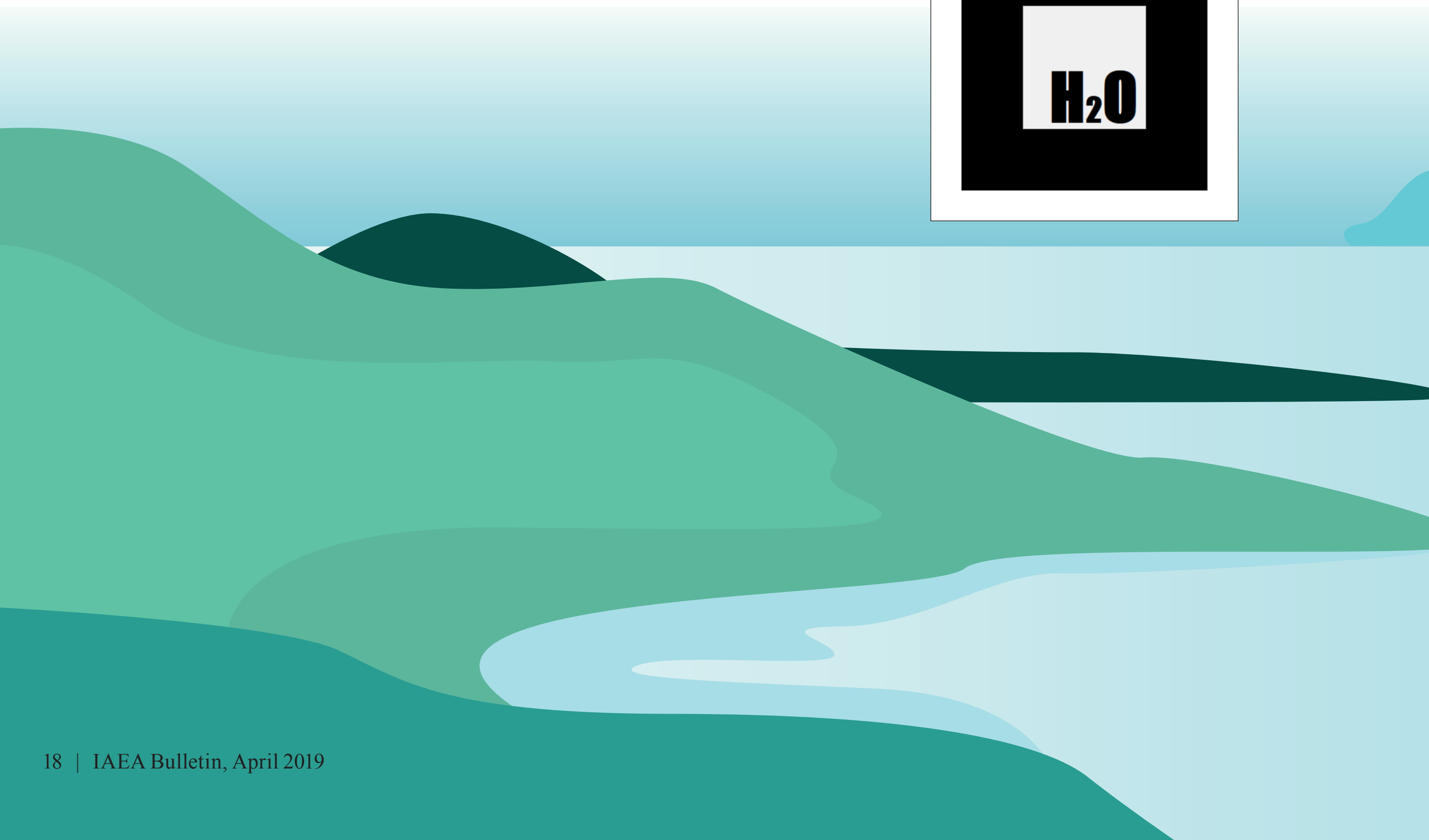
With this setup, basic isotope data started becoming available for hydrological investigations. These data were made accessible online to researchers and practitioners all over the world from the 1990s onwards. They are now used to study water resources, but also to interpret past climatic archives and animal migrations.

GNIP currently comprises more than 350 active sampling sites in over 90 countries and territories. While the IAEA Isotope Hydrology Laboratory is still a key player in analysing precipitation samples collected through GNIP, more than 60 laboratories — several of which have been established through IAEA technical cooperation projects — are contributing to this analytical challenge.

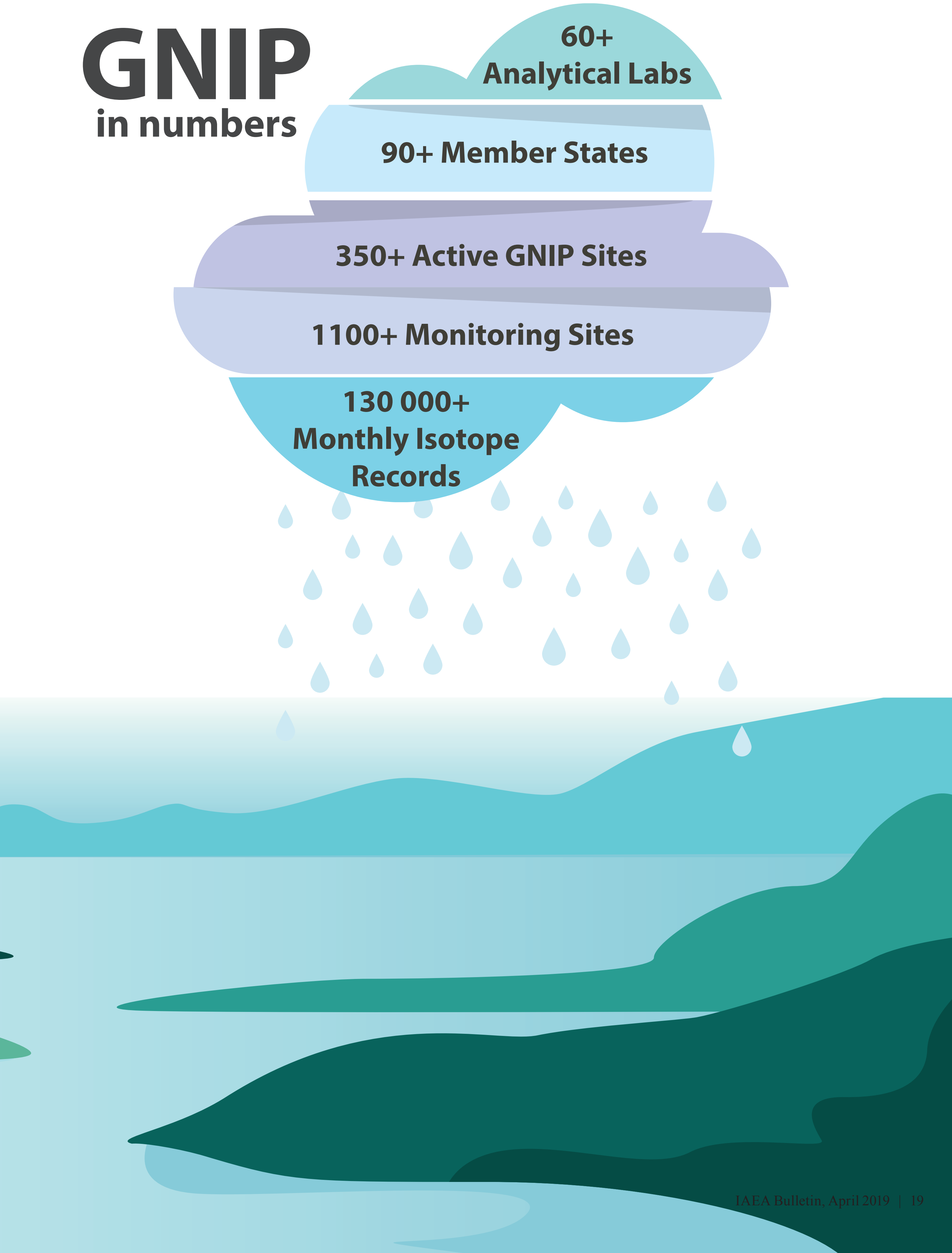
The IAEA maintains the central database for GNIP, which has more than 130 000 precipitation isotope records from more than a thousand sites. The Agency is also actively involved in research and development to help scientists collect precipitation samples. For example, it developed an evaporation-safe precipitation sampler that is reliable, easy to use and requires less pre-processing in the laboratory.

Historical and current data from the GNIP database are used to validate and further improve climatic prediction models (see page 24), as well as for other applications.

To learn more, try this: h2o.iaea.org



# GNIP
## in numbers



# Manage your water budget with the help of the tritium/helium-3 technique

## By Nicole Jawerth

Managing water is like managing money in your bank account: you need to know exactly how much will be coming in, how much you can take out, and what could cause that to change. A miscalculation could have serious, potentially long-lasting consequences. In the world of water, this could mean water shortages or contaminated, unusable water resources.

To set up a reliable water budget, one of the key factors is knowing the exact age of water. For young water, which is more likely to be affected by current climate conditions and contamination, scientists use the tritium/helium-3 technique. With this and other techniques, scientists from 23 countries are working with the IAEA to collect data about water resources.

"The age of water tells you where it most likely came from, how quickly it is replenished, and how likely it is to be contaminated," said Hamid Marah, Scientific Director at Morocco's National Centre for Nuclear Energy, Sciences and Technology (CNESTEN). "With the tritium/helium-3 technique, we can say if water is 1, 5 or 25 years old instead of just saying it's young, old or both."

**Scientists use isotopic techniques to study the age and origin of water from springs in northern Morocco.**
(Photo: CNESTEN)

The age of water can range from a few months to millions of years. If water is one year old, for example, this means it will take one year for it to be replenished and is much more likely to be affected by current climate conditions and contaminants. If water is 50 000 years old, it will take 50 000 years to be replenished and is less likely to be contaminated or affected by changes in the current climate.

Nearly all of the world's available fresh water supplies are found in aquifers, which are the porous layers of permeable rock under the earth's surface. The water they contain is called groundwater. As groundwater is recharged, or replenished, it eventually flows into the sea or out onto the earth's surface naturally as rivers, springs and lakes.

"The growing demand for groundwater, combined with the impact of agriculture, climate change and human activity makes sustainability even more important," Marah said. "By extracting too much water from an aquifer, the level of water goes down and this can be catastrophic. We are not talking about 10 to 20 years from now: its impact lasts for generations."

The tritium/helium-3 technique is one of the most commonly used techniques for studying young water, which is water under 60 years old (see The Science box). The data collected from these studies can help decision makers develop more targeted and sustainable water resource management strategies and policies.

"Using nuclear techniques for water resource studies is breaking paradigms and changing our classical understanding of the key drivers controlling hydrological processes," said Ricardo Sánchez-Murillo, Isotope Hydrologist and Associate Professor at the National University of Costa Rica. "In Costa Rica, for example, results from using isotopic techniques are making their way into water management plans and decision making, helping the country achieve United Nations Sustainable Development Goal 6 on water by 2030."

## A more exact budget

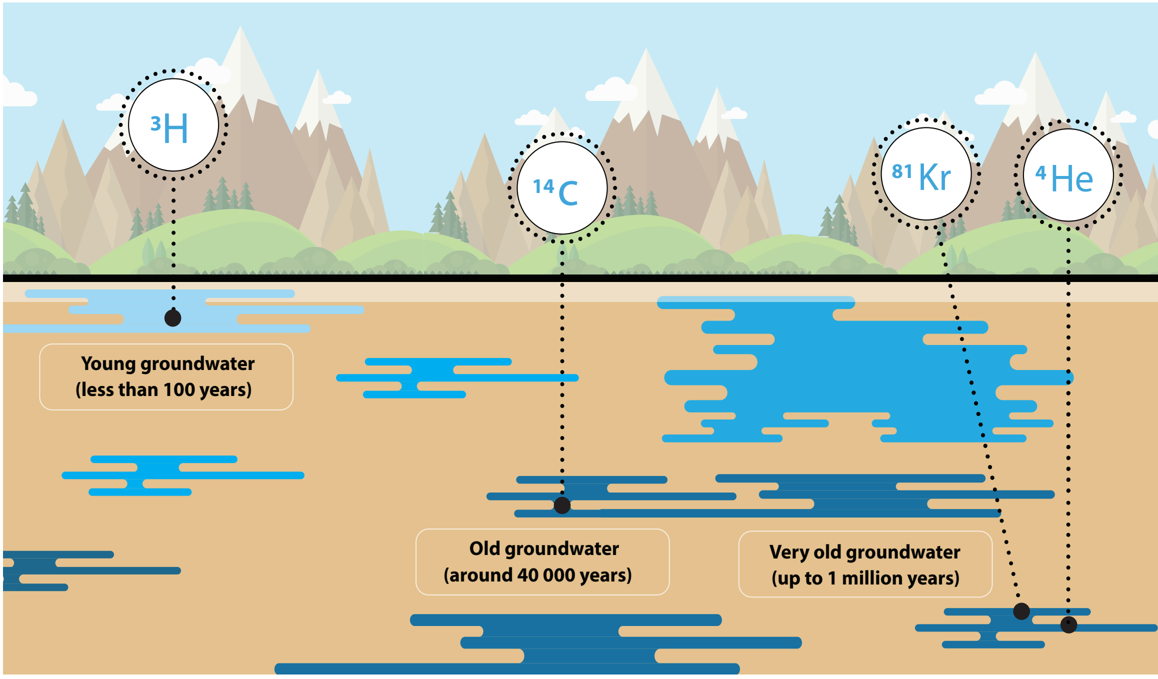
The tritium/helium-3 technique has become an increasingly important technique over the last decade because previous methods using just tritium are becoming less useful.

"Tritium can tell us the age of groundwater and whether it's being recharged, which is very important information, but tritium alone cannot give us the level of detail we need. Decision makers need to know more: what does it mean that the water is young? How young is young?" Marah said. Due to atmospheric tests of thermonuclear devices in the 1950s, levels of tritium in the atmosphere sharply increased in the 1960s and have since gradually declined. "From the 1960s to 1990s, tritium was a good tracer, but today there is less tritium in the atmosphere because it has been decaying into helium-3, so we now focus more on the ratio of tritium to helium-3, which is much more precise."

Helium is a noble gas, which means it is stable and does not have chemical reactions with other elements found in rocks or water. This makes it a consistent and reliable reference point. By knowing the concentration of helium that comes from tritium — helium-3 — compared to the total helium in the water, as well as the concentration of other noble gases, scientists can determine the exact age of young water.

"The use of noble gases for water studies is growing because now analytical devices have improved enough to detect the very small amounts these gases come in," said Takuya Matsumoto, an isotope analyst at the IAEA. "For many countries, though, it is not economical or feasible to set up their own labs to do these analyses. The IAEA Isotope Hydrology Laboratory makes this service available to countries so they can benefit from this sophisticated technique."

The IAEA Isotope Hydrology Laboratory is one of just a handful of laboratories in the world capable of performing these analyses. Beginning in 2010, a team of IAEA and external experts from ten countries spent six years setting up, calibrating and testing the IAEA's mass spectrometer machine, as well as the mathematical model for analysing results. They also developed guidelines for using the tritium/helium-3 technique. The lab has since been working around the clock processing between 300 to 400 samples each year from countries worldwide.




**Naturally occurring radioactive isotopes present in water, such as tritium ($^{3}H$) and carbon-14 ($^{14}C$), and noble gas isotopes dissolved in the water, such as krypton-81 ($^{81}Kr$), can be used to estimate groundwater age.**

(Image: IAEA)

## THE SCIENCE

Tritium is one of the three isotopes of hydrogen. As a radioactive isotope, tritium decays over a certain period of time and turns into helium-3, a stable isotope, which does not decay. Scientists know that it takes about 12 years for half of tritium atoms in water to decay into helium-3.

Scientists use a specialized machine called a mass spectrometer to sort the isotopes by weight and identify their concentrations. By knowing these concentrations and how long it takes for tritium to become helium-3, scientists can track and determine how old the water is and how often it is replenished.

# Fracking: how isotope hydrology can support environmental assessments to help protect groundwater

## By Miklos Gaspar

Any industrial activity near water reserves could, in principle, cause contamination. Isotope hydrology offers a unique combination of methods to monitor water quality and trace the source of pollution if any is identified. Increasingly, countries are making use of this technology to protect surface and ground water near sites used for oil extraction with a technique known as fracking.

Hydraulic fracturing, or fracking, has opened up previously inaccessible oil and natural gas resources for production. It accounts for about half of the total oil output of the United States, and many developing countries are considering using it for the first time.

Fracking is a well-stimulation technique in which rock is fractured by injecting fluid at high pressure. This fluid consists of water, sand and other chemical additives. Injected through a well, fracking creates cracks in deep-rock formations, through which natural gas and oil can flow more freely. This method allows access to oil and gas that are trapped in tight formations and are not accessible using conventional drill and pump methods.

Surface water may be contaminated through spillage during fracking, or accidental release from the waste pit in which the fracking fluid is recovered after extraction; groundwater can be contaminated if the fluid escapes through, for example, abandoned or leaking wells; and drinking water may also be contaminated if natural gas leaks into shallow aquifers.

In many cases where contamination is suspected, identifying the source and extent of the contamination is difficult due to a lack of baseline data, said Jennifer McIntosh, Professor of Hydrology and Atmospheric Sciences at the University of Arizona in the US. “There is an opportunity for the scientific community to provide guidance on the best analytical methods for evaluating fugitive gas leakage and fracking fluid or water contamination of groundwater,” she said.

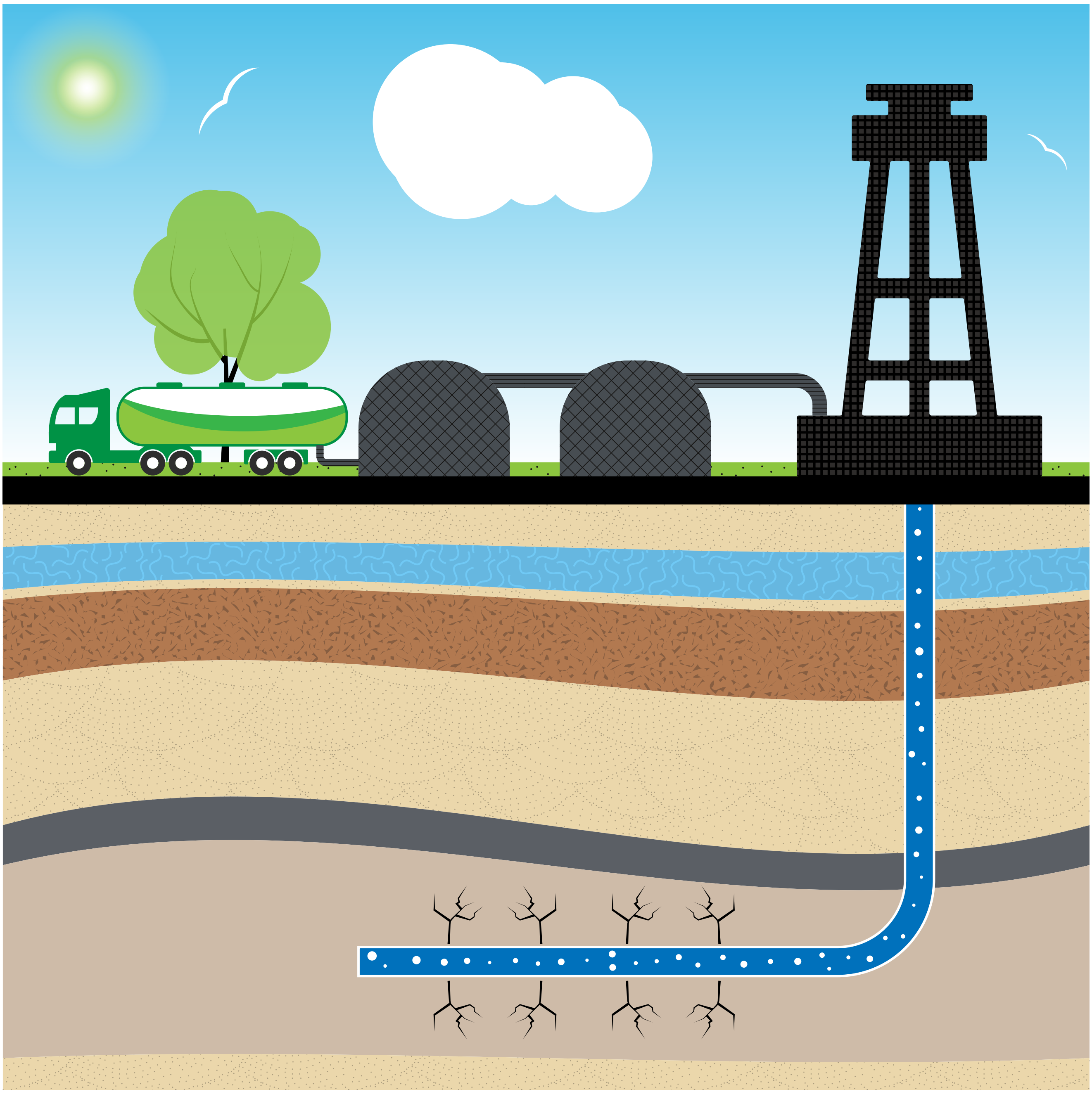
### How isotope hydrology can help

A recent paper by McIntosh and 14 other authors from leading universities around the world explained how various isotope hydrology techniques can be used to monitor the impact of fracking on ground and surface water. It also provided recommendations on which method to use under a diverse set of circumstances and environmental conditions. The initial ideas for the paper entitled A Critical Review of State-of-the-Art and Emerging Approaches to Identify Fracking-Derived Gases and Associated Contaminants in Aquifers, which appeared in the journal *Environmental Science and Technology* in December 2018, were developed at an IAEA technical meeting two years earlier.

Recent analytical developments using naturally occurring isotope tracers in hydrocarbons, high-resolution data sets of natural gases and associated fluids from surface to target reservoirs, and the incorporation of noble gas geochemistry and microbiology into more traditional hydrogeological and geochemical approaches offer powerful analytical tools for identifying the sources of contaminated fluid.

Substances such as naturally occurring radioactive materials or salt can occur naturally in groundwater, but their presence can also be the result of pollution. Isotope hydrology can be used to distinguish these sources. A source’s isotopic make-up depends on its origin: measuring minor element concentrations, stable isotopes of water and dissolved components, and radiogenic isotopes of iodine, radon and strontium can provide data on the origins of the water and its dissolved components. This, in addition to traditional chemical analysis of ions, can reveal the water’s origin and whether the substances it contains are the result of fracking, other human activity or are naturally present in the environment.

Ideally before fracking begins, a background isotopic survey of the area’s ground and surface waters should be made to



establish a pre-drilling characterization of the area's waters. Suspicions of pollution due to fracking activities can then be isotopically tested against this baseline, McIntosh explained.

An emerging complex isotopic approach, using 'clumped isotopes' of methane gas, allows scientists to probe the molecular position of hydrogen isotopes in the methane gas relative to its single carbon atom, giving new diagnostic insights into which gas reservoirs the suspected stray gases may have come from, or to distinguish whether the methane is from deep thermogenic sources or was produced naturally in aquifers by soil bacteria, or a mixture of the above. "New groundwater age radiotracers like krypton-81 and argon isotopes can help to determine how long pollutants related to fracking and oil and gas production may reside in drinking water aquifers," McIntosh said.

The final section of the paper provides guidelines for a phased programme to identify contamination. It offers a strategic roadmap that would enable regulatory officials to select the best isotope hydrological method in site-specific cases.

Some of the approaches developed to detect contamination in fracking have broader applications, including for the subsurface storage of carbon dioxide and nuclear waste disposal, McIntosh added.

**Hydraulic fracturing, or fracking, is a well-stimulation technique in which rock is fractured by injecting fluid at high pressure to access oil and gas. Isotope hydrologists can monitor water quality and trace the source of pollution, if any.**

# Looking into the future of water resources and the impact of climate change

## By Nicole Jawerth

How will climate change influence water supplies a hundred years from now? To answer questions like this, water scientists use scientific models. Among these is the IAEA's isotope-enabled water balance model, which can help experts accurately and reliably predict the impact of climate change on water resources far into the future. The information they collect can support decision makers in developing sustainable water use policies for generations to come.

Models draw on existing data and are used to study and understand ideas, objects and processes that are difficult to observe directly. This includes making predictions, such as forecasting next week's weather conditions or estimating unemployment rates over the next five years. While models present a more general and simplified version of the real world, each aspect of a model is calibrated to provide an accurate reflection of how the real world works.

Water balance models describe the water cycle in terms of precipitation, evapotranspiration, stream flow and changes in water storage. Unlike many traditional water balance models, the IAEA's model uses isotopes to calibrate the model and verify its accuracy because isotopes are distinct and consistent in their behaviour (see page 4). With a well-calibrated and verified water balance model, scientists can get an accurate estimate of what to expect in the future, such as the impact of climate change on water resources a hundred years or more from now.

### Precise long-term predictions

For any country and climate, precision in these long-term water studies is important because an over or underestimation of future water supplies can have detrimental effects, said Dessie Nedaw Habtemariam, Associate Professor at Addis Ababa University in Ethiopia.

"If we misestimate how fast water is replenished, for example, and our estimate is too high, and then communicate these results to the decision makers, they could implement policies that result in groundwater being extracted faster than it can be recharged," Habtemariam said. Groundwater — water in the layer of permeable rock under the earth's surface — is a primary source of fresh water for the majority of Ethiopia's population. "This would lead to a sharp decline in available groundwater supplies, which could mean an abandonment of boreholes and may even lead to drinking water shortages."

Underestimation, on the other hand, could lead to unnecessarily stringent water policies or influence development decisions, such as hampering urban expansion due to a lack of water resources.

For these long-term studies of over 100 years or more, getting accurate results using other water balance models has been a major challenge, said Tricia Stadnyk, Associate Professor of water resources engineering at the University of Manitoba in Canada. "Many water balance models do a very good job at simulating the flow of water in streams, rivers and other water bodies, but are very bad at getting the amount of evapotranspiration right," she said, referring to the process of evaporation of water from land and the movement of water from plants to the atmosphere. "For climate change predictions, this is a huge problem because one of the big things we look at is evapotranspiration."

As temperatures become more extreme due to climate change, the rate of evapotranspiration does too. The more evapotranspiration, the less water on the earth's surface, and vice versa. This, in turn, influences the entire annual water cycle and can lead to unpredictable extremes that swing from too little water, causing drought, to too much water, causing floods.

No climate is immune to these changes. They can affect a climate like Canada's, where more than 60% of the land mass is some form of permafrost — frozen ground

— and there are four distinct seasons, or one like Ethiopia's, where much of the country is tropical and the temperature remains more or less constant throughout the year.

These diverse conditions can be captured by adjusting the model, which makes it globally applicable. Scientists from several countries are working with the IAEA to receive training and support in using the IAEA's isotope-enabled water balance model and other models for improving water resource management. In Ethiopia, for example, a three-year technical cooperation project is being launched to study the upper Awash Basin — a large groundwater reservoir supplying fresh water to more than 2.6 million people. Other countries, like Canada, are setting up or have set up isotope sampling networks to improve accuracy when using models such as the IAEA's.

**The IAEA's isotope-enabled water balance model can help experts accurately and reliably predict the impact of climate change on water resources far into the future.**

(Photo: L. Toro/IAEA)

## The IAEA's isotope-enabled water balance model

Scientists use the IAEA's isotope-enabled water balance model to simulate and estimate the long-term influence of climate change on the movement and availability of water throughout the water cycle — from the air, to the earth's surface, into the ground, and repeat. The model integrates isotope mass balance for each water balance component on a monthly step to improve its calibration and validation process.

First introduced in 2015, the model's user-friendly, open-source software includes pre-processing, modelling and analysis tools to make it easier to plug in data and visualize and analyze results. It is designed to work with a variety of local and global datasets related to, among others, climate, vegetation, precipitation, water flow, topography and soil. The isotopic data used for calibrating the model and validating its results generally draws on locally collected data, as well as data from global repositories, such as the IAEA's Global Network of Isotopes in Precipitations (GNIP, see page 18) and the Global Network of Isotopes in Rivers (GNIR).

# Making the grade

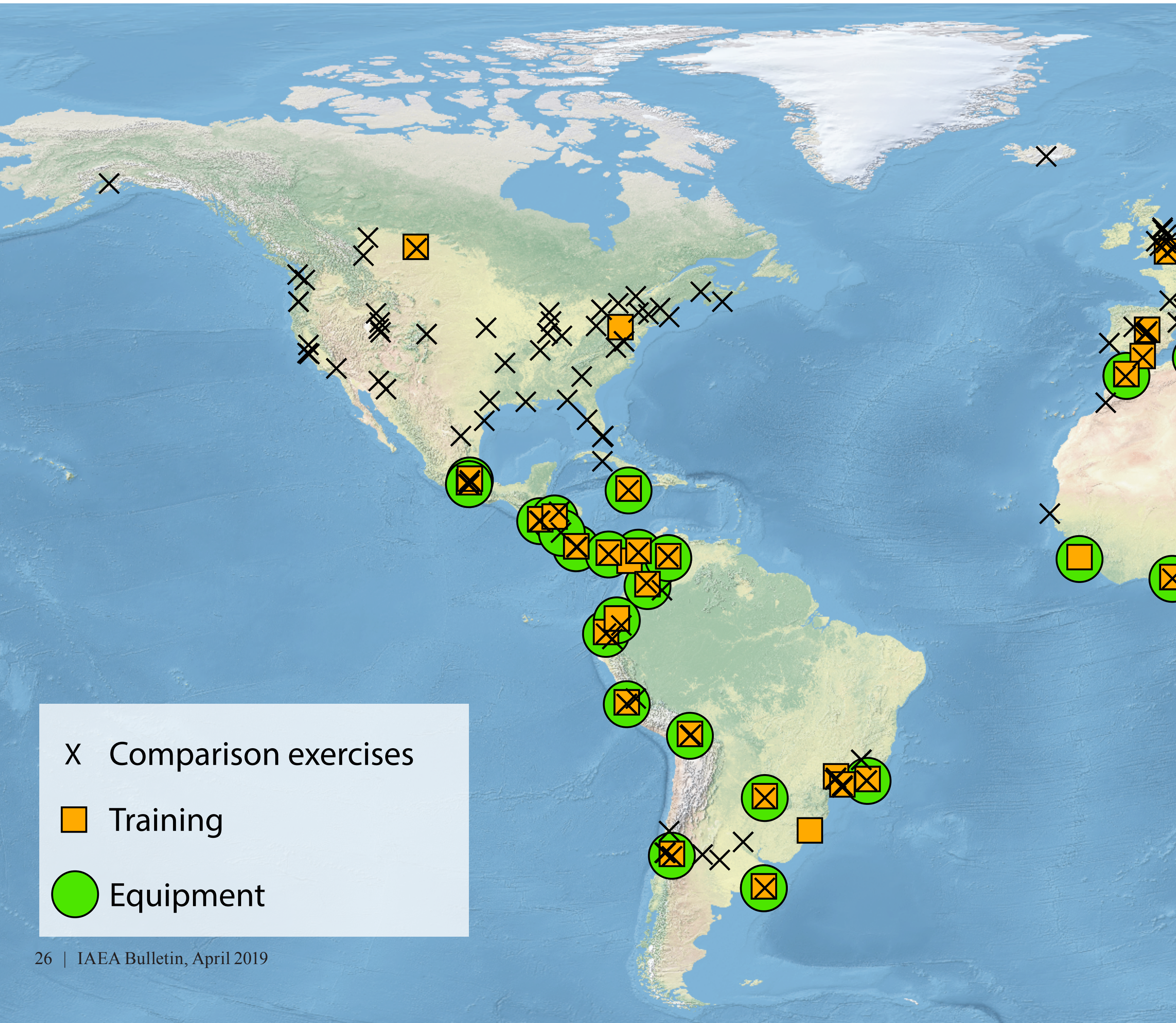
## IAEA tests how well laboratories analyse water

**By Laura Gil**

Excellent, good, questionable or unacceptable: how good is your water chemistry analysis? Scientists can find out through comparison. For the past 30 years, the IAEA has been conducting isotope hydrology interlaboratory comparisons among hundreds of laboratories and has become a global source of isotope hydrology proficiency tests.

"A key aspect in any science is the quality of your measurements," said Luis González Hita, Hydrology Technologist at the Mexican Institute of Water Technology. "This is true for isotope hydrology, too. Guaranteeing that our data are correct and reliable gives us a solid base for convincing policymakers."

Isotope hydrologists are scientists who study water resources using isotopic data. Their studies provide critical information for developing strategies and policies to protect water. Approximately every four years, over



300 isotope hydrology laboratories take part in global interlaboratory comparison proficiency tests organized by the IAEA.

Comparing data with IAEA test samples, which include a wide range of waters from around the world, helps staff in each laboratory detect and improve analytical weaknesses. It helps them ensure they are consistently producing accurate and precise data.

Regular cross-comparisons are ever more relevant today: technology is advancing rapidly, making isotope hydrology methods and instruments cheaper and more accessible. Although these technology changes have their benefits, they lead to a higher risk of error because newcomers to the field often have less advanced training.

"Nowadays, especially with laser-based methods, technology does a lot of the work," González Hita said. "This means that scientists are relying more on methods to do the assessments, but it also means they're relying less on skill sets."

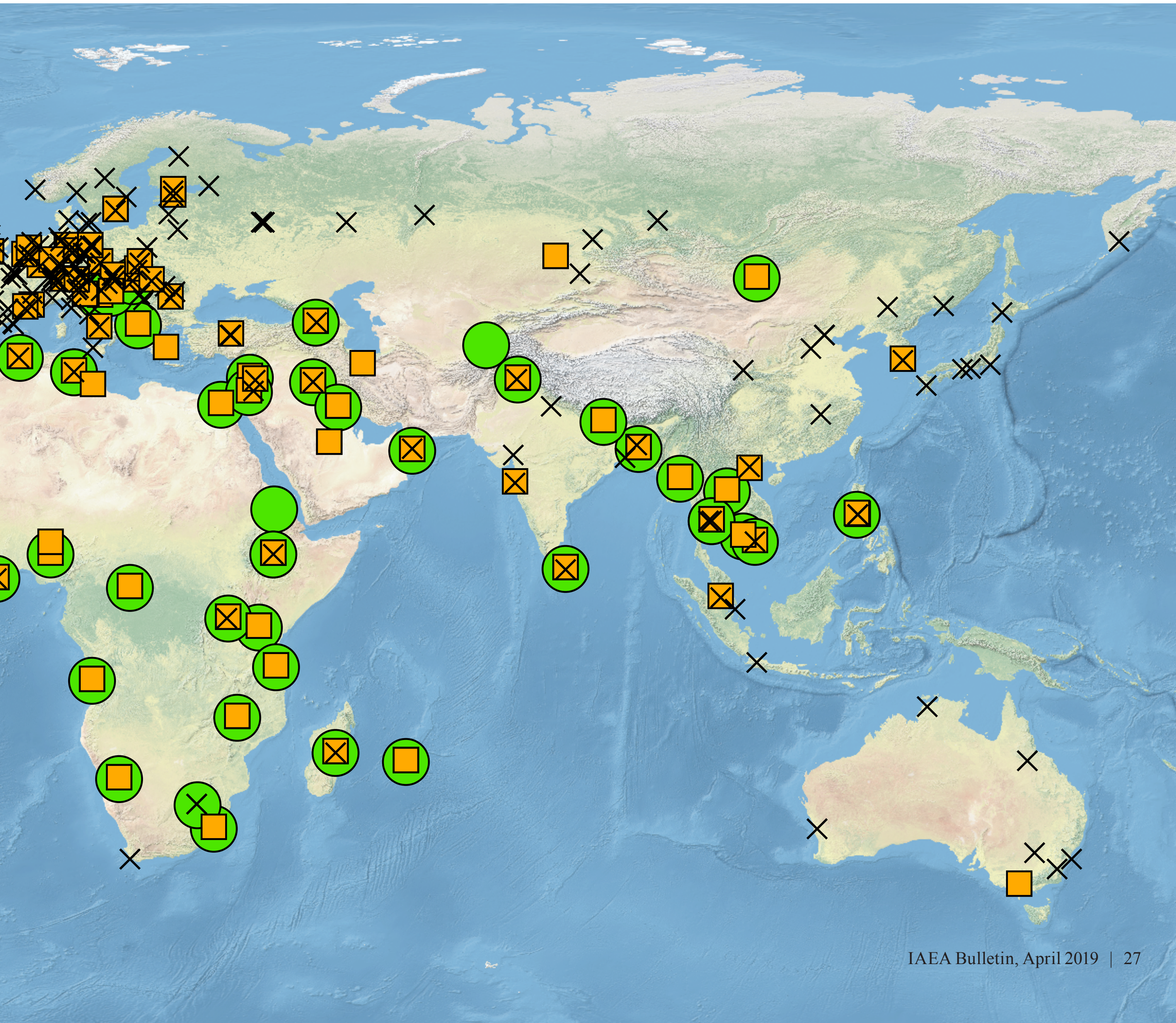
## Seeking excellence

There are two types of interlaboratory comparison projects. One is the Water Isotope Interlaboratory Comparison (WICO), which tests laboratories' ability to conduct measurements of deuterium ($^{2}H$) and oxygen-18 ($^{18}O$) in water samples. Measuring these isotopes accurately allows scientists to determine the age and origin of water (read more on page 4).

The other is the International Tritium Intercomparison (TRIC), which checks

**The map shows cities that have participated in interlaboratory comparison exercises (WICO & TRIC) since 2016, places where the IAEA has trained experts in isotope hydrology since 2007 and locations where the IAEA has donated isotope laser instruments since 2007 through the IAEA technical cooperation programme.**

(Source: IAEA)



> **"A key aspect in any science is the quality of your measurements. This is true for isotope hydrology, too. Guaranteeing that our data are correct and reliable gives us a solid base for convincing policymakers."**
>
> *— Luis González Hita, Hydrology Technologist, Mexican Institute of Water Technology*

laboratories' ability to measure the natural radioisotope tritium ($^3H$) in water. Tritium measurements are used to analyse water replenishment rates and to study water younger than 60 years old (see page 4). TRIC checks how precise and correct these measurements are. The most recent TRIC exercise took place in 2018 with a record participation of 90 laboratories.

"The way these interlab comparison projects work is simple," said Leonard Wassenaar, Head of the IAEA Isotope Hydrology Laboratory based in Vienna, Austria. "We prepare and carefully verify water samples here and ship them to each laboratory. They analyse them and send us their results, which we then compare to our IAEA reference values. At the end, we compile the results in a general anonymous report for the scientific community, and in parallel send a detailed report to each lab individually with suggestions and recommendations for improvement."

The reports the IAEA produces after each exercise contain evidence-based recommendations to help laboratories refine their methods and improve their performance. They also help IAEA experts to identify gaps and target further assistance, including training laboratory staff, through the IAEA technical cooperation programme.

## Testing vigilance

The largest ever global interlaboratory comparison for stable isotopes was the most recent WICO exercise in 2016 involving 235 laboratories. Its results were published in the *Rapid Communications in Mass Spectrometry* scientific journal in November 2017.

During the WICO 2016 exercise, Wassenaar and his team tried something new.

"We added methanol to one of the water samples to test the laboratories' vigilance in detecting interfering pollutants — without warning them, of course," said Wassenaar. "After finding out that many overlooked this, we came up with a few strategies for them to identify the presence of interfering contaminants in water that could lead to incorrect results."

Most of the laboratories involved in WICO 2016 produced acceptable to excellent results when analysing oxygen isotopes, and about half did when analysing deuterium. But around 5 to 6% had unacceptably poor results, which Wassenaar said could be due to the rapid increase in the number of instruments in labs, such as low-cost lasers, especially among less experienced laboratories.

"We concluded that poor laboratory performance probably resulted from unquantifiable 'known unknowns'," Wassenaar said. "When laboratories appear to be doing everything right but still perform poorly, it could be from mistakes like errors in their Excel processing spreadsheets, or an instrument that is not properly maintained. These are mistakes and human errors that are common but may not be apparent to the laboratory."

These, he added, include knowledge-based or skill-based factors, such as operator experience, basic data processing mistakes, measurement protocol violations, compromised samples or poorly functioning analytical instruments.

Recent studies published in the *Accreditation and Quality Assurance* journal have suggested that human errors can significantly contribute to underperforming geochemical analysis outcomes. The post-WICO 2016 survey of participating laboratories supports the premise that human, technical and instrumental errors are the main drivers for poor water isotope performance.

"Finding errors leads to adjustment. It is important to know where we are producing reliable results, and where not," González Hita said. His laboratory in Mexico scored highly in the latest WICO test. "WICO 2016 allowed us to confirm that we are making good quality analyses. This is also good to know for neighbouring countries, because they can rely on our services and we can share best practices."

# Managing urban water: the role of isotope hydrology and what the Cape Town water crisis taught us

## By Jodie Miller

The 2017 to 2018 water crisis in Cape Town, South Africa, provided an opportunity to evaluate the role of isotope hydrology in maintaining the integrity of urban water supply networks. The integrity of water supplies is critical to the long-term sustainability of southern Africa's economy, and requires an understanding of the relationship between climate, water resource utilization and the implications of this relationship on socio-economic factors. A region's water budget — the relationship between water input and output — has significant socio-economic implications, including the ability to support urban centres, reduce poverty, protect food and energy supplies and develop scientific skills to inform local water management strategies.

In recent years, these issues have come to a head as severe drought has affected Cape Town, a city at the southern tip of Africa with a population of approximately 3.8 million. Below average rainfall between 2014 and 2017 resulted in Cape Town experiencing extreme water stress over the summer of 2017 to 2018. The city derives most of its water supplies from six surface water storage facilities with a combined total capacity of 828 991 million litres. By March 2018, the total storage in these facilities reached its lowest recorded level at less than 20%, with the largest of the reservoirs, the Theewaterskloof reservoir, at only 13.5% of its 480 188 million litre capacity. Various pronouncements of an imminent 'Day Zero' were made — the day the city would turn off the municipal water supply to maintain the most critical infrastructure, such as hospitals. In response, all residents were required to reduce water consumption to just 50 litres per person per day.

In the end, 'Day Zero' never arrived. The city's collective efforts to save water allowed the stored water to last until the arrival of the winter rains. However, the possibility of shutting down the municipal water network transformed the way people use and value water and led to a real change in water use patterns. At the same time, the question of how a large urban centre could protect and supplement its short-term water security raised important scientific questions, including how we track and measure the relative contributions of many diverse water inputs to supply networks. Desalination, grey water recycling, direct rainwater harvesting and groundwater abstraction are all used to supplement surface water storage reservoirs across many municipal networks at a variety of scales. But these can compromise water quality. Managing both water quantity and quality in the light of increasingly diversified input streams requires new approaches and scientific tools to develop best practice strategies.

### Urban isotope hydrology

Among the scientific tools available to help track the sources of the municipal network's different inputs is the study of the stable isotopes of water. The study and application of naturally occurring hydrogen and oxygen isotopes in the water cycle is at the core of isotope hydrology.

Because of widespread urbanization and population growth, urban isotope hydrology has gained traction in recent years as a tool to understand processes involved in urban water supply. The most important component of urban isotope hydrology is 'fingerprinting' the isotope characteristics of each input to the urban water network to track each component through the system. This information can be used by water managers to plan long and short-term water management policies, including monitoring relative contributions, residence times in the network, leakage and resultant losses from the system and pollution or contamination management.

Tap water samples collected from private homes throughout the town of Stellenbosch, home of Stellenbosch University and the epicentre of the country's premier wine-growing districts, were analysed to determine the oxygen-18 ($^{18}O$) and deuterium ($^{2}H$) isotope ratios. The results paint a fascinating

Jodie Miller is an Associate Professor at the Department of Earth Sciences at Stellenbosch University in South Africa. She works mostly on isotope hydrology projects throughout Mozambique, Namibia and South Africa. She is involved in an IAEA coordinated research project on Urban Isotope Hydrology, is Vice-President of the International Association of GeoChemistry (IAGC) and the Champion of the Biogeochemistry Research Infrastructure Platform for the South African Department of Science and Technology.

Average rainfall since 2014 has made the water level at the Theewaterskloof dam in South Africa's Western Cape drop to critical levels.
(Photo: A. Silva Garduno/IAEA)

picture of how sensitive urban isotope hydrology is in 'seeing' fluctuations in the urban water network. Instead of the uniform water we physically see coming out of the taps, the isotope ratios record highs and lows, matching and diverging patterns.

In essence, isotopes provide the fingerprint of each segment of the local water supply network: the source, different treatment plant, and information on how long water remains in the distribution network. As water managers seek to secure long-term sustainable water supplies for growing urban centres the world over, urban isotope hydrology will become an essential component of the water manager's toolkit.

Jodie Miller collects a water sample in Western Cape.
(Photo: A. Silva Garduno/IAEA)

# Isotope mapping of groundwater pollution and renewal

## By Joel Podgorski, Michael Berg and Rolf Kipfer

Obtaining good quality groundwater for drinking, industry and agriculture is becoming increasingly difficult due to population growth, water overexploitation, land use and climatic changes. Groundwater resources provide 50% of the world's drinking water and 43% of the water used for irrigation. But near-surface groundwater aquifers are easily contaminated by fertilizer and pesticides, chemical spills and wastewater. Furthermore, overexploitation and uncontrolled withdrawal of water from aquifers can lead to a loss of water supply due to rapidly declining water levels.

To assist water managers in protecting and conserving groundwater resources, aquifer vulnerability maps are useful. They help identify areas of the landscape that are particularly sensitive to contamination or overexploitation and therefore help inform water management and remediation efforts. Mapping groundwater vulnerability is also key to supporting United Nations Sustainable Development Goal 6, or SDG 6, which calls for securing sustainable water for all, in particular safe water (Target 6.1). It also advocates for integrated water resources management (Target 6.5).

### Aquifer vulnerability

From a technical perspective, there are many ways of assessing an aquifer's vulnerability to water pollution or overexploitation. In the past, general geological features, borehole data and regional hydrological data were used. However, these are often imprecise or inaccurate, or missing altogether. Complex computer models have also been used, but these require accurate data and often suffer from high computational costs and limited data availability, and as a result are usually restricted to small study areas.

Chemical indicators and statistical analyses can be used to link available environmental data to groundwater vulnerability. One example is nitrate, which is a water pollutant introduced mainly by agriculture that is easy and inexpensive to measure. To generate groundwater vulnerability or protection maps, the pollutant (such as nitrate) or vulnerability indicator data must be available over an appropriate area of concern to produce reliable and accurate predictive maps.

### Online mapping

To show that statistical mapping of aquifer vulnerability is effective, data from an existing vulnerability map in Canada were re-analysed using the free online Groundwater Assessment Platform (GAP) (www.gapmaps.org). The aquifer vulnerability maps by GAP produced an accurate probability prediction map of high aquifer vulnerability, without the need to collect a lot of data from the entire study area.

### Using tritium to map water recharge rates

Trace amounts of the radioisotope tritium occur naturally in rainfall by an interaction of cosmic radiation in the upper atmosphere. During the above-ground nuclear weapons testing that took place between 1952 and 1962, vast amounts of tritium were injected into the water cycle, which, as a result, became a measurable indicator of modern groundwater recharge. Although global tritium levels in rainfall have since declined to low pre-bomb natural levels, sensitive analytical detection capabilities still allow us to accurately detect the isotope.

One principle advantage of using tritium, or $^3H$, for mapping is that the isotope is a fundamental building block of the water molecule ($^1H^3HO$) and is therefore present in rainfall. This means that any detectable tritium in other parts of the water cycle — rivers, lakes, groundwater — reveals the presence of contemporary water from recent rainfall. This can tell us that the water we are dealing with is from the past few decades — data that we can use to directly identify and map aquifers' susceptibility to contamination via rainfall, even if the groundwater has never been contaminated.

So far, statistical mapping methods for estimating aquifer vulnerability have generally not been widely used with tritium

Joel Podgorski, Michael Berg and Rolf Kipfer work in the Department of Water Resources and Drinking Water (W+T) of the Swiss Federal Institute of Aquatic Science and Technology (Eawag).

Eawag is a Swiss water research institute concerned with concepts and technologies for dealing sustainably with water bodies and water as a resource.
In collaboration with universities, other research institutions, public bodies, industry and non-governmental organizations, Eawag works with its global network to harmonize ecological, economic and social interests in respect of water usage.

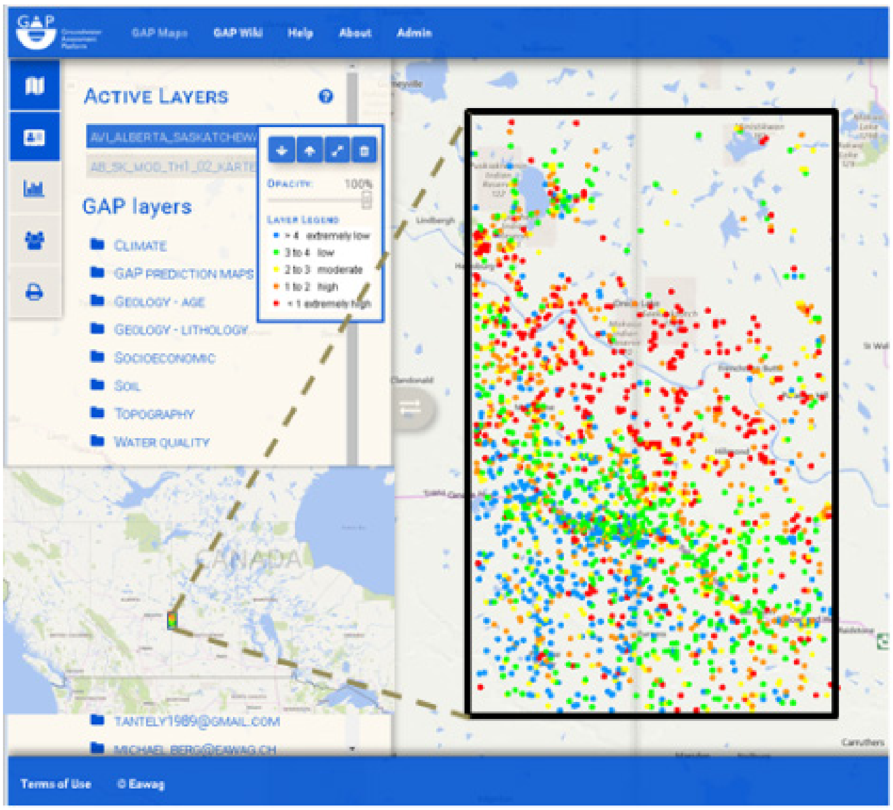
measurements. This is because tritium is not commonly included in groundwater studies, and the analysis is still costly. In the meantime, other easily collected water quality or isotopic parameters can be used in vulnerability mapping. For example, carbon-14, the stable isotopic composition of water ($^{2}H$, $^{18}O$), nitrate and chloride can also help to evaluate the age of groundwater or check if it has been exposed to contamination.

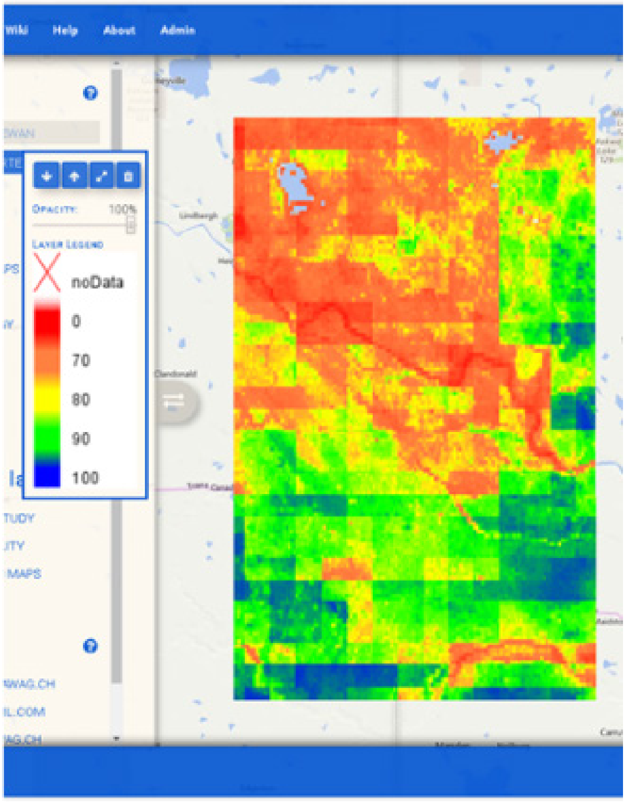
The statistical and online mapping of aquifer vulnerability and groundwater replenishment using isotopes and chemistry represents a significant advancement and a practical application of tritium and related natural isotopic tracers. Currently, there is great potential in applying the IAEA's extensive global datasets on $^{3}H$, $^{2}H$ and $^{18}O$, along with the geostatistical mapping described above, to global ground and surface water quality and quantity issues. New efforts are being made in this area by the IAEA in cooperation with the Swiss Federal Institute of Aquatic Science and Technology (Eawag) toward evidence-based assessments and mapping of safe drinking water on a global scale. We also expect the use of isotope mapping to assist experts from around the world in managing groundwater in a balanced and sustainable manner.

*This piece was written in collaboration with IAEA isotope hydrologists.*

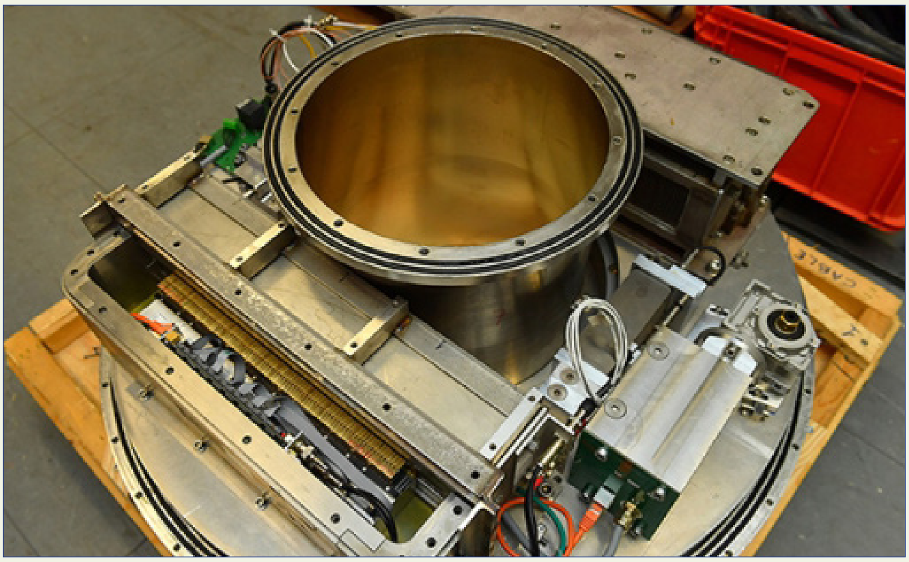
**An index aquifer vulnerability study from western Canada (left) compared with a new logistic regression map of these vulnerability index values on the online GAP platform (right). The red colour shows areas with the highest vulnerability. The green areas are less vulnerable or adequately protected from surface contamination.**

(Image: Eawag)



# New safeguards tool bolsters IAEA's verification of spent nuclear fuel



**The components inside the PGET tool, which is used to verify spent nuclear fuel.** (Photo: D. Calma/IAEA)

For all States with a comprehensive safeguards agreement in force, the IAEA seeks to verify that all nuclear material remains in peaceful activities. It achieves this through the application of technical measures known as safeguards. The new passive gamma emission tomography (PGET) tool will enable the IAEA to verify the number of fuel rods — or pins — in spent nuclear fuel assemblies.

Unlike other tools used for verifying the content of spent nuclear fuel, such as the digital Cerenkov viewing device and the spent fuel attribute tester, the PGET tool can also confirm the absence of missing pins from a spent fuel assembly in a closed container. This is very useful for applying safeguards at nuclear power plants, underwater storage facilities and encapsulation plants at geological repositories. According to Tim White, an IAEA technology expert, the use of passive gamma emission tomography to verify nuclear material will be a "very valuable addition to the IAEA safeguards toolkit".

At the end of their useful lives in a reactor, fuel rods are stored and eventually disposed of or, in some cases, reprocessed. Verifying that the nuclear material in the rods is not diverted from peaceful use is a crucial part of assuring the international community that States are honouring their non-proliferation obligations.

To detect the presence of uranium or plutonium, the PGET tool takes three simultaneous measurements — of gross neutron and gamma ray counts, gamma ray spectrometry and tomographic imaging of spent fuel pin positions. It takes the tool only five minutes to take these measurements and an additional minute to process and analyse the data. In this way PGET "offers inspectors an additional data point," said White. "It allows for a more complete picture of activities and increases the robustness of the verification process."

The IAEA is still in the early stages of integrating PGET into its safeguards activities. It has been tested in spent fuel ponds at three nuclear power plants and is now ready for deployment in safeguards verification practices and for use in the field by safeguards inspectors. The European Atomic Energy Community (Euratom) has also expressed an interest in utilizing this technology for verification activities and a number of countries may follow suit.

*— By Matt Fisher*

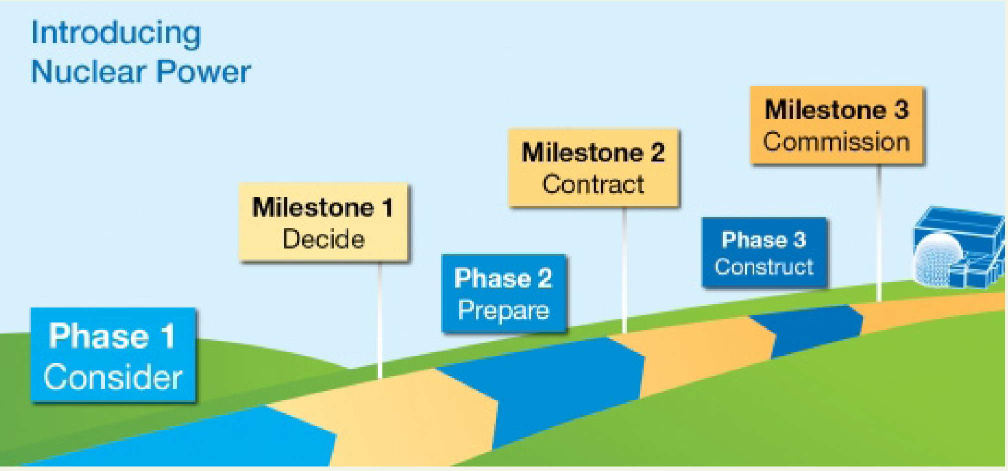
# Siting and site evaluation for nuclear power plants in focus at IAEA workshop in Uzbekistan

Uzbekistan, the latest country to launch a nuclear power programme, has initiated the process to select a site for a nuclear power plant and aims to grant a site licence in September 2020, local officials have confirmed. Uzbekistan is among about 30 countries that are considering, planning or actively working to include nuclear power into their energy mix.

At the request of Uzbekistan's Government, the IAEA and the newly established nuclear energy development agency Uzatom held a workshop in February 2019 in Tashkent on safety and non-safety aspects to be considered in siting and site evaluation for nuclear power plants.

The workshop with participation of Uzatom, the nuclear regulatory body, and other relevant national organizations, focused on IAEA safety review services, safety standards and other resources supporting the siting and site evaluation for nuclear power plants.

"Embarking on a nuclear power programme requires a long-term commitment to nuclear safety that starts as soon as the decision to proceed is taken," said Greg Rzentkowski, Director of the Division of Nuclear Installation Safety of the IAEA. "Two important steps early in the process are the establishment of an effective legal and regulatory framework and ensuring that




**The Milestones approach for nuclear power is a phased, comprehensive method to assist countries that are considering or planning their first nuclear power plant.**
(Image: IAEA)

potential sites are properly evaluated before being selected for a nuclear installation. The IAEA safety standards provide clear guidance in both areas, and we encourage all countries to apply them."

The workshop introduced the IAEA Milestones approach for the development of a new nuclear power programme. It lists 'site and supporting facilities' as one of 19 nuclear infrastructure topics that would require action during the development of a nuclear power programme.

In line with the Milestones approach, the IAEA provides integrated services, including on safety, security, legal and regulatory frameworks, human resource development, emergency planning and safeguards. These include peer reviews and advisory missions such as the Integrated Nuclear Infrastructure Review and the Site and External Events Design review service.

*— By Ayhan Altinyollar*

# How nuclear techniques help feed China

**The use of nuclear technologies is fully integrated into agricultural research at the China Academy of Agricultural Sciences. Here a technician is preparing samples for a food safety test.** (Photo: M. Gaspar/IAEA)

With 19% of the world's population but only 7% of its arable land, China is in a bind: how to feed its growing and increasingly affluent population while protecting its natural resources. The country's agricultural scientists have made growing use of nuclear and isotopic techniques in crop production over the past decades. In cooperation with the IAEA and the Food and Agriculture Organization of the United Nations (FAO), they are now helping experts from Asia and beyond in the development of new crop varieties, using irradiation.

While in many countries, nuclear research in agriculture is carried out by nuclear agencies that work independently from the country's agricultural research establishment, in China the use of nuclear techniques in agriculture is integrated into the work of the Chinese Academy of Agricultural Sciences (CAAS) and provincial academies of agricultural sciences. This ensures that the findings are put to use immediately.

And indeed, the second most widely used wheat mutant variety in China, Luyuan 502, was developed by CAAS's Institute of Crop Sciences and the Shandong Academy of Agricultural Sciences, using space induced mutation breeding (see The Science box). It has a yield that is 11% higher than the traditional variety and is also more tolerant to drought and main diseases, said Luxiang Liu, Deputy Director General of the Institute. It has been planted on over 3.6 million hectares — almost as large an area as Switzerland. It is one of 11 wheat varieties developed for improved salt and drought tolerance, grain quality and yield, Liu said.

Through close cooperation with the IAEA and FAO, China has released over 1000 mutant crop varieties in the past 60 years, and varieties developed in China account for a quarter of mutants listed currently in the IAEA/FAO's database of mutant varieties produced worldwide, said Sobhana Sivasankar, Head of the Plant Breeding and Genetics Section at the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture.

The new mutation induction and high-throughput mutant selection approaches established at the Institute serve as a model to researchers from around the world, she added.

The Institute uses heavy ion beam accelerators, cosmic rays and gamma rays along with chemicals to induce mutations in a wide variety of crops, including wheat, rice, maize, soybean and vegetables. "Nuclear techniques are at the heart of our work, fully integrated into the development of plant varieties for the improvement of food security," Liu said.

The Institute has also become a key contributor to the IAEA technical cooperation programme over the years: more than 150 plant breeders from over 30 countries have participated in training courses and benefited from fellowships at CAAS.

Indonesia's nuclear agency, BATAN, and CAAS are looking for ways to collaborate on plant mutation breeding and Indonesian researchers are looking for ways to learn from China's experience, said Totti Tjiptosumirat, Head of BATAN's Center for Isotopes and Radiation Application. "Active dissemination and promotion of China's activities in plant mutation breeding would benefit agricultural research across Asia," he said.

## From food safety to authenticity

Several of CAAS' other institutes use nuclear-related and isotopic techniques in their research and development work and participate in several IAEA technical cooperation and coordinated research projects. The Institute of Quality Standards and Testing Technology for Agro-Products has developed a protocol to detect fake honey, using isotopic analysis. A large amount of what is sold in China as honey is estimated to be produced synthetically in labs rather than by bees in hives, so this has been an important tool in cracking down on fraudsters, said Chen Gang, who leads the research work using isotopic techniques at the Institute. A programme is also in place to trace the geographical origin of beef using stable isotopes, he added.

The Institute uses isotopic techniques to test the safety and to verify the authenticity of milk and dairy products — work that was the outcome of IAEA coordinated research and technical cooperation projects that lasted from 2013 to 2018. "After a few years of support, we are now fully self-sufficient," Gang said.

**Chinese scientists are looking to use nuclear-related techniques to better trace the metabolism of cattle like these on a farm near Beijing and increase the amount of nitrogen cows use from fodder.**

(Photo: M. Gaspar/IAEA)

## Improving nutrition efficiency

Various CAAS institutes use stable isotopes to study the absorption, transfer and metabolism of nutrients in animals. The results are used to optimize feed composition and feeding schedules. Isotope tracing offers higher sensitivity than conventional analytical methods, and this is particularly advantageous when studying the absorption of micronutrients, vitamins, hormones and drugs, said Dengpan Bu, Professor at the Institute of Animal Science.

While China has perfected the use of many nuclear techniques, in several areas it is looking to the IAEA and the FAO for support: the country's dairy industry is dogged by the low protein absorption rate of dairy cows. Less than half of the protein in animal feed is used by the ruminants, the rest ends up in their manure and urine. "This is wasteful for the farmer and the high nitrogen content in the manure hurts the environment," Bu said. The use of isotopes to trace nitrogen as it travels from feed through the animal's body would help improve nitrogen efficiency by making the necessary adjustments to the composition of the feed. This will be particularly important as dairy consumption in China, currently at a third of the global average per person, continues to rise. "We are looking for international expertise, through the IAEA and the FAO, to help us tackle this problem."

*— By Miklos Gaspar*

## THE SCIENCE

### Space induced mutation breeding

Irradiation causes mutation, which generates random genetic variations, resulting in mutant plants with new and useful traits. Mutation breeding does not involve gene transformation, but rather uses a plant's own genetic components and mimics the natural process of spontaneous mutation, the motor of evolution. By using radiation, scientists can significantly shorten the time it takes to breed new and improved plant varieties.

Space-induced mutation breeding, also called space mutagenesis, involves taking the seeds to space, where cosmic rays are stronger, and these rays are used to induce mutation.  Satellites, space shuttles and high-altitude balloons are used to carry out the experiments. One advantage of this method is that the risk of damaging the plants are lower than when using gamma irradiation on earth.

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