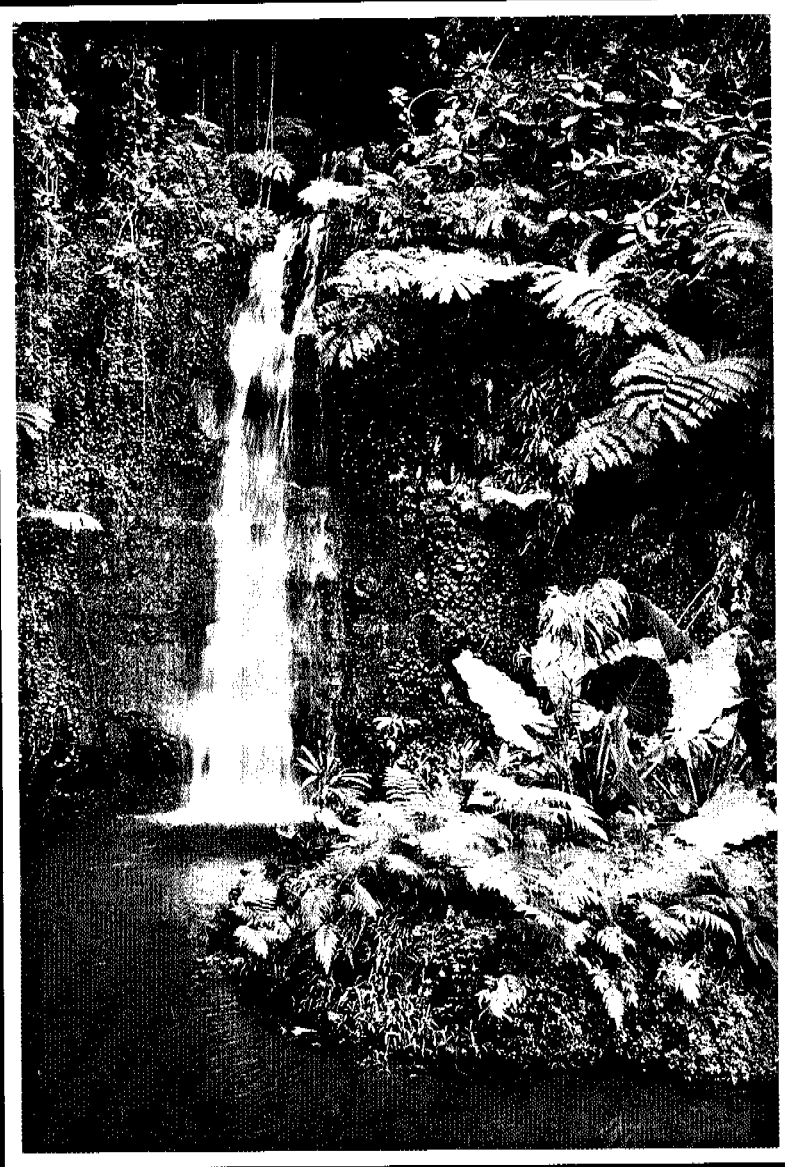


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**ISOTOPES IN WATER
AND
ENVIRONMENTAL
MANAGEMENT**



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Isotopes in Water and Environmental Management



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This booklet presents a brief profile of recent achievements in isotope hydrology and the involvement of the IAEA in this field. The principal responsibilities of the IAEA are transferring technologies, coordinating scientific research, managing specialized projects and maintaining analytical quality control. Agency scientists and facilities also serve as both focal points and promoters for worldwide activities in isotope hydrology.

Cover photo: H. Giller/IAEA

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Introduction:

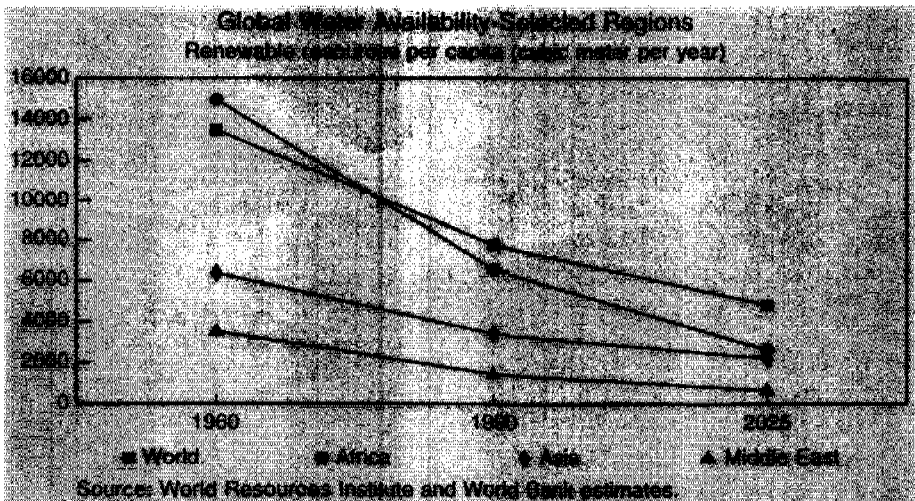
A Global Water Shortage

Water scarcity and degradation are growing concerns for countries around the world. Global demand for fresh water is doubling every 21 years according to the FAO. And as industrial, agricultural and domestic pollution threaten finite supplies, water is becoming an increasingly precious resource.

Across the world today, renewable water resources available per person are roughly half what they were in 1960. This figure is expected to drop by half again by the year 2025 according to estimates of the World Bank (see figure 1). Clearly, if water resources are not better managed, they could present a burden on economic growth as well as a potential danger to human health and the environment.

To help address this pressing need, nuclear science has developed a set of specific analytical tools - *isotope techniques* - that can improve, when used with non-nuclear techniques, the development and management of water resources wherever they are located.

Fig. 1:



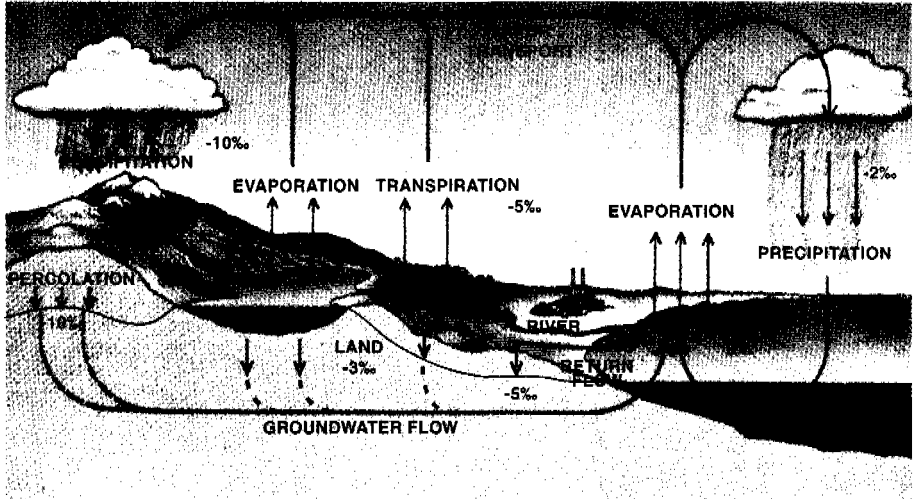
Isotope techniques provide invaluable information on the sources, movement and quantity of water in different environments, including rivers and lakes. They are particularly effective in investigating water reserves below the earth's surface, or groundwater. *Isotope hydrology* provides insights into water's behaviour and helps to build the foundations for rational utilization of this precious resource.

What Are Isotopes and What Can Be Learned From Them?

Elements consist of atoms of different mass called *isotopes*. During the evaporation and condensation of water, the concentration of oxygen and hydrogen isotopes that make up the water molecule undergoes small changes. Modern instruments can measure these with great precision.

The history and pathway of water in different parts of the hydrological cycle (see figure 2) can be followed by the abundance of the stable heavy isotopes of hydrogen (^2H) called deuterium, and oxygen (^{18}O). In this way, water in different environments develops isotopic "fingerprints" with which it can be identified and its origins traced.

Fig. 2: The hydrological cycle - a schematic representation of the movement of water both above and below the earth's surface. The figure indicates approximate oxygen-18 values [expressed in the delta (δ) notation in parts per thousand (‰) deviation from the standard mean ocean water]. The oxygen-18 values change through environmental processes and can be used to trace the pathway and history of water.



Some isotopes are radioactive, which means that they decay away with time. For example, those of tritium (^3H) and radiocarbon (^{14}C), are naturally produced in tiny amounts in the atmosphere. Large amounts of tritium and radiocarbon were also injected into the atmosphere by nuclear bomb tests in the 1960s.

These isotopes are carried into groundwater by infiltrating rain and they can also be measured with specialised, sensitive equipment. The known "half-life" (see figure 3) of these radioactive isotopes allows a measurement of their concentrations to be interpreted as an "age", or residence time, of groundwater. Residence time indicates the replenishment rate as well as the rate of movement of groundwater.

In summary, isotope techniques:

- can determine the origins and ages of different water bodies;
- can provide an estimate of the degree of mixing;
- can determine the location and proportion of water recharge; and
- can indicate the velocity of ground water flow.

Isotope techniques cannot "find" groundwater. The initial steps must be taken by geologists and geophysicists. With some springs, however, isotopes can provide preliminary indications of the flow paths and origins of the water.

Fig. 3: Environmental isotopes used in hydrology.

Isotope	Half-life (years)	Applications
^2H	Stable	Groundwater dating, recharge determination
^3H	12.32	Groundwater dating, recharge determination
^{14}C	5730	Groundwater dating, recharge determination
^{15}N	Stable	Groundwater dating, recharge determination
^{18}O	Stable	Groundwater dating, recharge determination
^{22}Rn	3.82	Groundwater dating, recharge determination
^{222}Rn	3.82	Groundwater dating, recharge determination
^{226}Ra	1600	Groundwater dating, recharge determination
^{230}Th	75,380	Groundwater dating, recharge determination
^{234}Th	24.10	Groundwater dating, recharge determination



Collecting water samples for isotope measurements from a well in Morocco.

This information is important to access the groundwater during drilling. Radioactive and non-radioactive or "stable" isotope information is thereafter, integrated with other available data to produce a comprehensive hydrological concept of the groundwater system. Hydrologists can then develop a water management model, and strategies for sustainable development can be formulated.

The movement of surface and groundwater can also be investigated by artificial tracing, where a substance is purposely injected into the water and then detected at some other point in the system. Numerous substances may be employed, such as ordinary table salt or dyes. However, in most applications the sensitivity of measurement required can only be achieved by injected radioisotopes, such as artificially produced ^3H or radioactive iodine, (^{131}I).

Isotopes measure water recharge

Recharge of groundwater is one critical aspect in resource management, and isotopes can help determine both the area and the rate of recharge. The area can be identified by measuring ^2H and ^{18}O concentrations and correlating them to the altitude at which precipitation could have infiltrated the ground. The rate can be measured by tracing levels of radioactive tritium in soil at various depths. In many instances, the tritium "peak" can be found at considerable depths, which indicates the distance travelled by the moisture since being deposited as tritium fallout in 1963.



Sampling soil from different depths in Senegal using a simple hand auger. From the soil sample, moisture can be extracted and measured for the stable isotope and tritium contents.

The tritium peak method has been applied all over the world, and in many different climates (see figures 4 and 5). In moister climates, where infiltration is high, artificial tritium can be injected as a tracer to determine the rate of recharge. Profiles of either environmental or artificial tritium can also give a measure of the movement of pollutant, such as nitrates and pesticides from agriculture.

Isotopes Help Manage Drinking Water Supplies

Groundwater is heavily utilized by densely populated communities in the Nile Valley in Egypt and Sudan. But its availability and sustainability in supplying the needs of growing populations is a problem. An IAEA Isotope Hydrology-assisted investigation, through the Technical Cooperation Programme, focussed on clarifying the role of Nile River in the replenishment of the local groundwater aquifers being exploited for domestic and agricultural purposes.

Using ^{18}O , ^2H , ^3H and ^{14}C , it was possible to distinguish between fresh water originating from Nile River infiltration and palaeowater representing a non-renewable resource. It has been demonstrated that the influence of the Nile water is seen up to 60 km from the river bank. The information about the relative contribution of fresh and old water in the exploitation of wells helped to design adequate management strategies for local water supply systems.

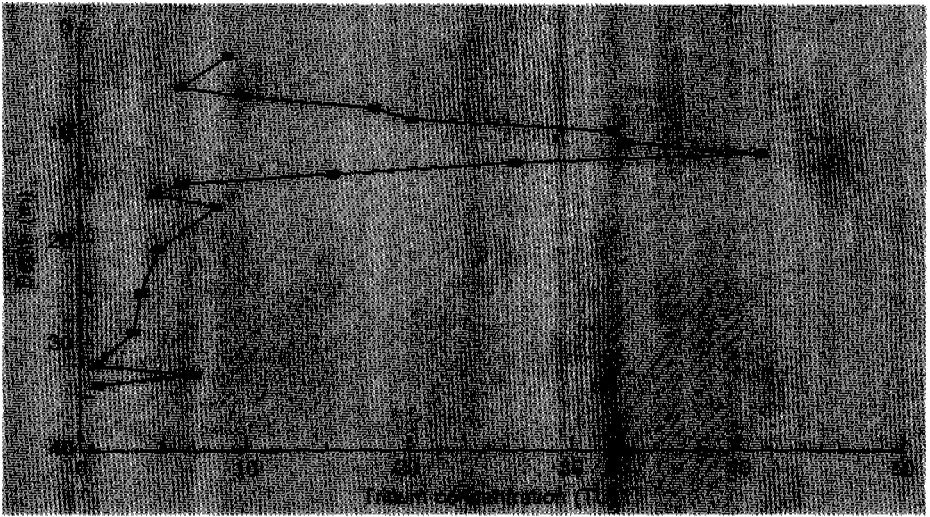


Fig. 4: In low-rainfall, arid conditions, infiltrating rainwater moves intermittently, and may remain in the unsaturated zone for decades. The "peak" in tritium concentrations of precipitation worldwide may still be found in soil profiles, such as this one from Senegal, which shows how far down moisture has moved from the surface since it was deposited by rain in the early 1960's.

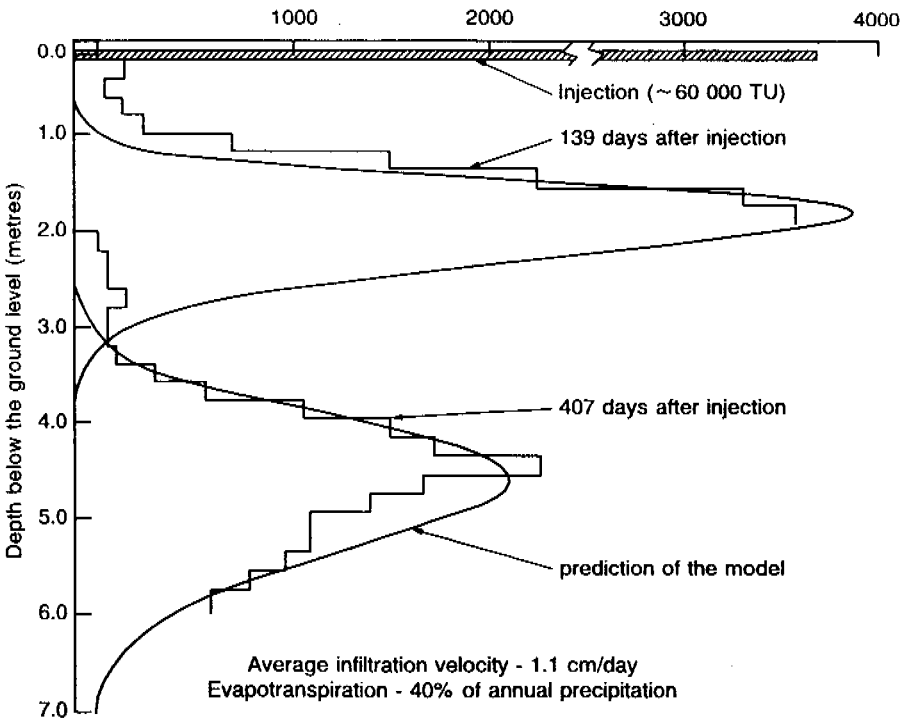


Fig. 5: In moist climates, water moves downwards through the soil fairly steadily. When tritium is injected, just below the surface, it moves with the water. The artificial "peak" can later be traced, and the infiltration rate measured.

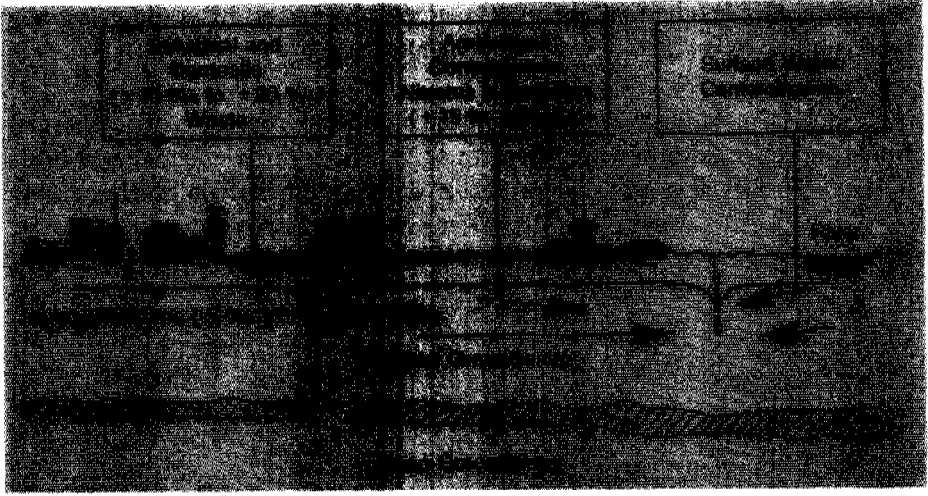


Fig. 6: Sources of nitrates - among the most common and serious pollutants of groundwater - and their nitrogen isotope values expressed as delta (δ) in parts per thousand (‰) deviation from the standard. Nitrogen isotope analysis of groundwater samples can assist in identifying the source of nitrate pollution which facilitates appropriate mitigation measures.

As in all other investigations stable isotopes, environmental tritium, chemistry and other tools will be applied to produce a comprehensive picture of the hydrological system.

Isotopes help track pollution

Pollution of surface water may be remedied by concerted prevention and controls, but it is more serious when pollution enters the groundwater. Polluted groundwater may remain in aquifers for centuries, even millennia, and is very difficult if not impossible to clean up.

Isotope techniques can assess the vulnerability of groundwater to pollution from the surface by determining how rapidly it moves and where it is being recharged. Surface sources of pollution can then be determined, e.g. natural, industrial, agricultural, or domestic. Isotope techniques can also identify incipient pollution, providing an early warning when the chemical or biological indicators do not give cause for concern. (See figure 6).

Isotopes help tap renewable energy sources

When rain water moves deep into the earth's crust, it is heated to high temperatures and stored in deep reservoirs as a geothermal energy resource. Sometimes it emerges at the surface as hot springs or geysers. In many

countries, this geothermal energy resource is harnessed by drilling into the reservoir and using the hot water to generate electric power.

Isotope techniques can determine the origin and flow paths of geothermal fluids and thus aid in the management of the energy resource. The isotopes ^{18}O and ^2H , as well as artificial tracers can determine the effects of exploitation

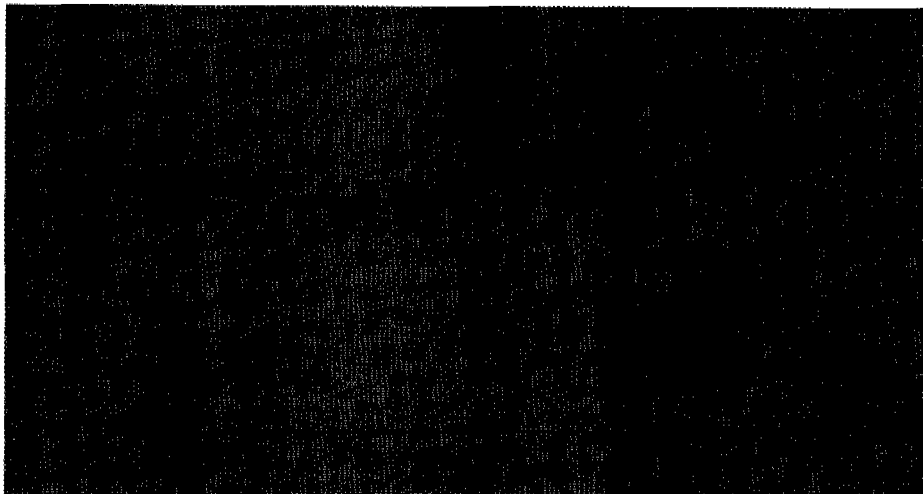


Fig. 7: Isotope and chemical methods complement each other in studying the Palinpinon geothermal field in the Philippines. Tritium and ^{18}O identify the incursion of cooler "meteoric" water during exploitation.

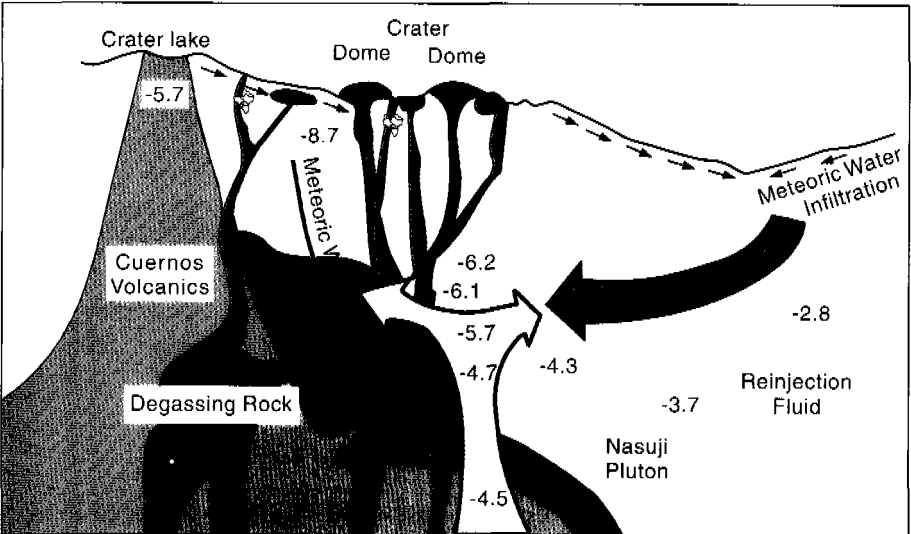


Fig. 8: IAEA technical assistance on isotope hydrology produced a hydrological model of the Palinpinon field during exploitation. The components of geothermal fluids and the processes affecting them were determined using isotope and chemical techniques.



In exploiting geothermal energy resources, isotope techniques help to define the regions of high heat flow and the origins of fluids. Deep wells drilled to depths up to 3 km tap the reservoir to extract the steam and transport it to the power plant.

and contribute to strategies for siting wells both for exploration and geothermal energy production; and for reinjection of cooled geothermal fluids which can extend the production period of the reservoir. (See figures 7 and 8).

Isotopes monitor global warming

The rapidly increasing concentration of carbon dioxide (CO_2) and methane (CH_4) in the atmosphere may be leading to global warming as a result of the so-called "greenhouse effect". Isotope techniques are also proving to be effective tools in unraveling this complex environmental phenomenon.

Analysis of carbon isotopes helps to explain what happens to the man-made "greenhouse" gases (CO_2) and (CH_4) in the atmosphere. Nitrogen and sulphur isotopes can reveal the connections between industrially produced oxides and acid rain. The oxygen and hydrogen isotopes in water are also very useful indicators of climate-related parameters such as surface air temperature, relative humidity and amount of precipitation.

Isotopes document climate changes

The isotopic composition of water can provide information about past climates. For example, radiocarbon measurements of groundwater in the Syrian desert indicate widely varying residence time or "age," ranging from very recent to nearly 40,000 years ago. Deuterium values of this very old water provide a striking record that the climate then was cooler than today (see figure 9).

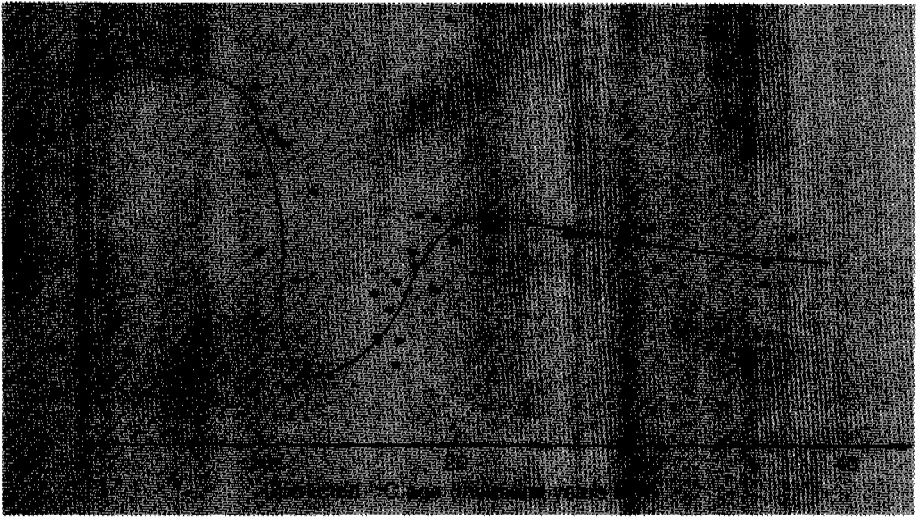
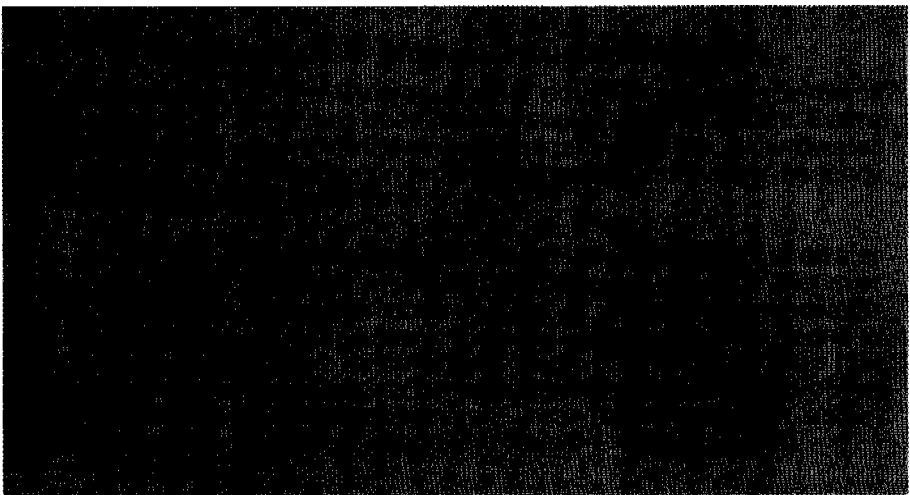


Fig. 9: Groundwater "ages" in the Syrian desert range up to 40,000 years. More negative values of ^2H indicate moister past climates with a very wet period about 10,000 to 20,000 years ago. More positive values, also found in the Sahara desert, indicate persistent aridity in the region. Isotope methods determined that the age of major groundwater reserves beneath the Sahara is greater than 10,000 years.

The presence of an enormous freshwater lake that filled the entire Dead Sea Valley about 20,000 years ago confirms that the coolest period revealed in the deuterium record was also the wettest one during the past 40,000 years. The isotopes showed that present day recharge in the region is negligible and that groundwater is not being replenished -- information that is invaluable to water resource management strategies.



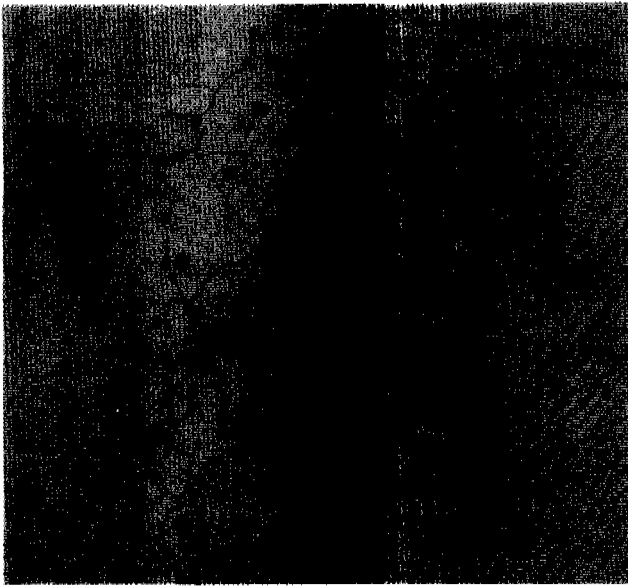


Fig. 10: Map of the Guayas aquifer showing lines of equal radiocarbon concentrations in percentage of modern carbon. Recent water (~100%) is found upstream in the delta, while older water (~10%) is found towards the river mouth and the sea.

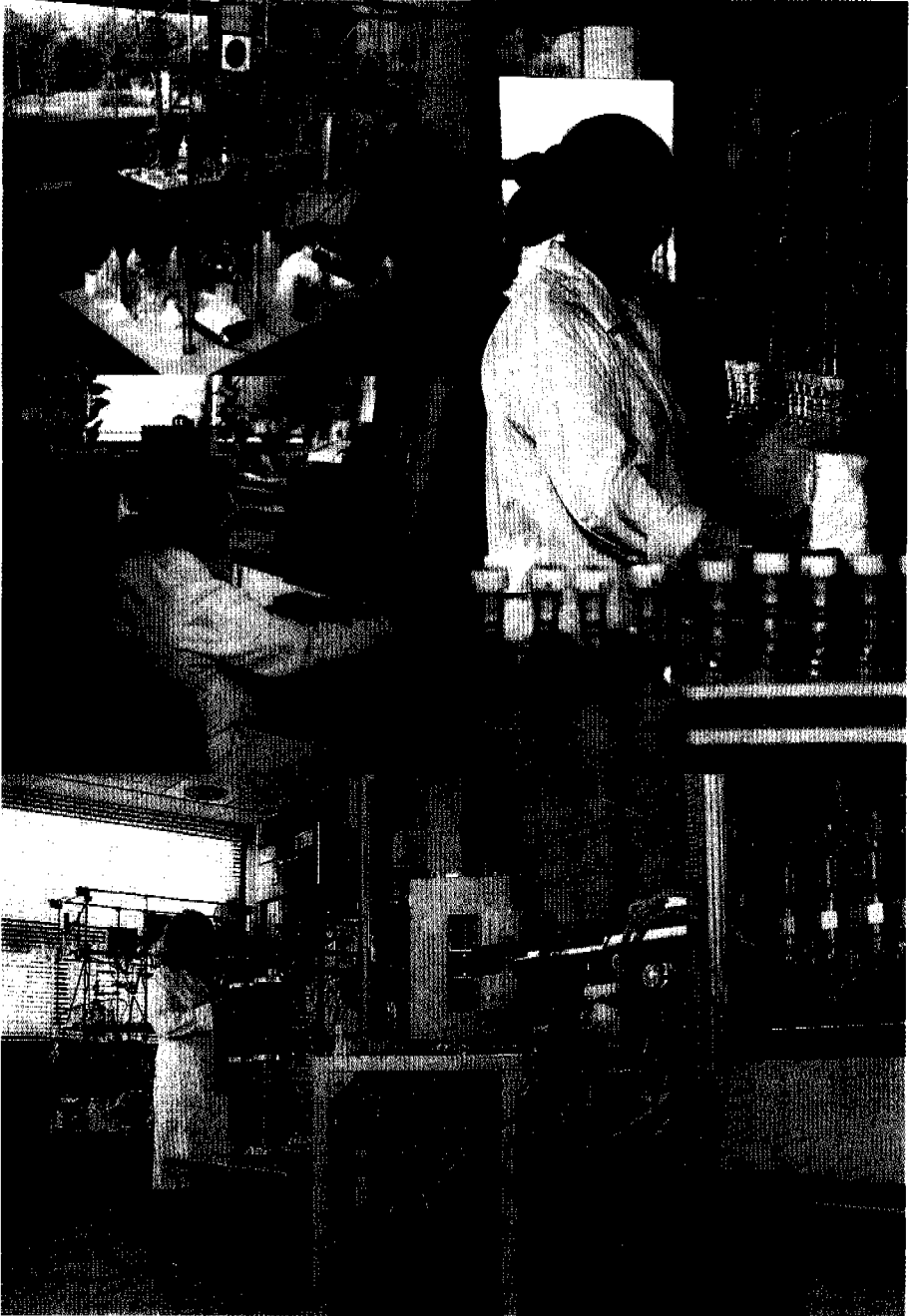
Isotope Analyses: Ensuring Quality Services through International Support

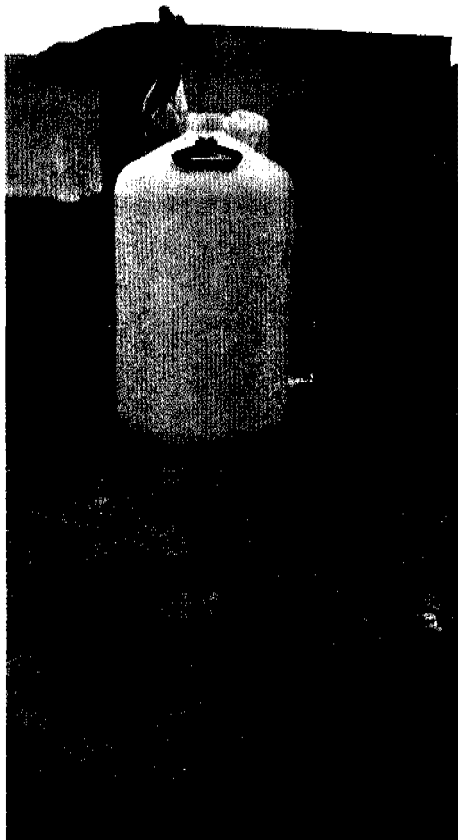
Worldwide research and application of isotope techniques is only possible with analytical facilities offering adequate precision. Since the late 1950s, IAEA's Isotope Hydrology Laboratory has played a pioneering role in refining and expanding such techniques.

The main activities of the laboratory include:

- measuring the isotopes ^2H , ^3H , ^{13}C , ^{14}C and ^{18}O in water and other environmental substances,
- developing new analytical techniques, and producing and supplying analytical standards,
- performing isotope and chemical analyses for Agency research, Technical Cooperation projects, and the Global Network for Isotopes in Precipitation.
- organising international analytical intercomparison programmes,
- assisting in the installation of analytical facilities in Member States, as well as providing training in isotope hydrology and chemical analytical techniques.

The IAEA isotope hydrology laboratory analyzes water samples from Member States. A water sample (50-500ml) is collected from a spring, well, faucet or from rainfall. In the laboratory, water samples are prepared for isotopic analysis, and stable isotope ratios are measured with a mass spectrometer.





Field precipitation of carbonate from water samples for ^{14}C analysis in the lab. The results indicate the age of water.

Isotope techniques offer proven methodologies relevant to water resources assessment and management. The costs involved in isotope investigations are modest compared to many other aspects of field investigations.

Human resources and analytical capabilities are being enhanced in both industrial and developing countries, often with support provided under the IAEA Technical Cooperation Programme. Coordinated Research Programmes are also enabling research through contracts and research agreements in Member States. Such programmes encourage investigations on a variety of themes, such as arid zone hydrology, pollution, geothermal energy, lake dynamics, geohydrological modelling as well as specific problems such as the rise in water level of the Caspian Sea.

Cooperation with International Organizations

The IAEA works with many other international organizations to implement its programme on water resources:

- The Global Network for Isotopes in Precipitation (see figure 13) is maintained in collaboration with the World Meteorological Organization (WMO), with which the Agency also collaborates on the Global Atmosphere Watch Programme.

Tracking the source of groundwater pollution

Venezuela's Lake Valencia is heavily polluted by industrial sources. Together with the nearby Taguaitay Reservoir it is becoming increasingly saline. The connection of the two water bodies to groundwater resources posed a possible threat to drinking water and irrigation supplies. A study undertaken by IAEA's Isotope Hydrology Section compared chloride and ^{35}S values. It concluded that the salinity in groundwater was derived from the reservoir, rather than from the lake thereby ensuring safe development of the groundwater in the vicinity of the Lake.

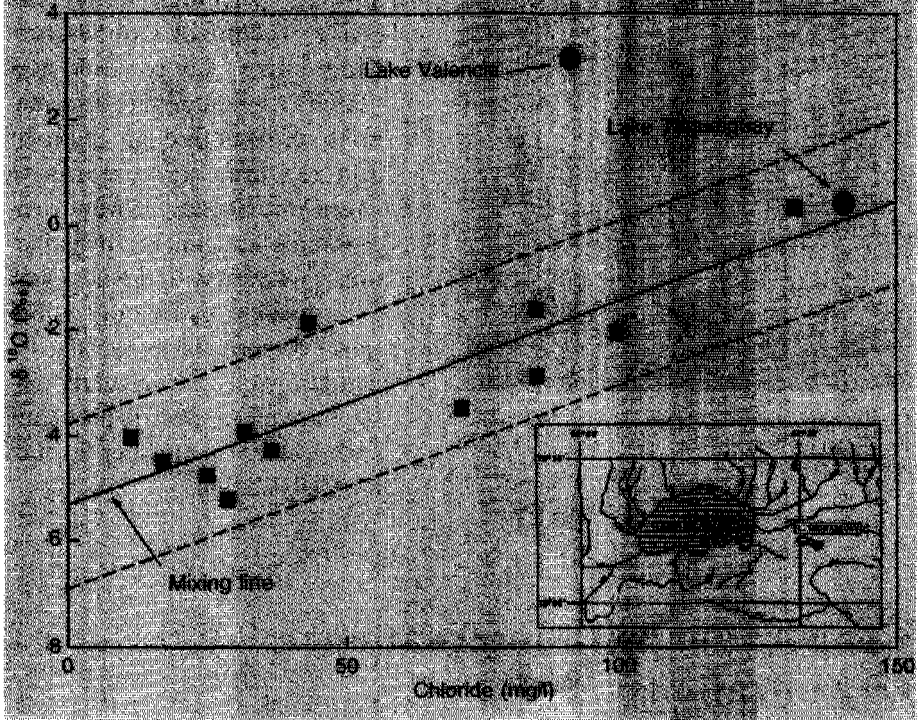


Fig. 11

- Regional and global problems associated with fresh water resources are carried out in cooperation with the UN Environment Program (UNEP), the World Health Organization (WHO) and the UN Economic Commission for Africa (UNECA).
- Close cooperation is maintained with in the International Geosphere Biosphere Programme (IGBP), the Global Environmental Monitoring System (GEMS), the Global Climate Observing System (GCOS) of WMO and Earthwatch of UNEP.

- Training programmes are conducted and results published together with UNESCO under its International Hydrological Programme (IHP).
- Cooperative efforts with UN Food and Agriculture Organization (FAO) and other UN bodies allow food security, soil erosion and sedimentation concerns to be addressed.
- Special interagency linkages have been created to address the pressing environmental problems of the rapidly rising Caspian Sea.

The IAEA-WMO Global Network for Isotopes in Precipitation

Interpretation of the isotopic composition in terrestrial water requires knowledge about the meteoric water that feeds them: rain and snow. Their isotopic composition is quite variable in time and space, and depends on climate, geography, nuclear fallout and other factors.

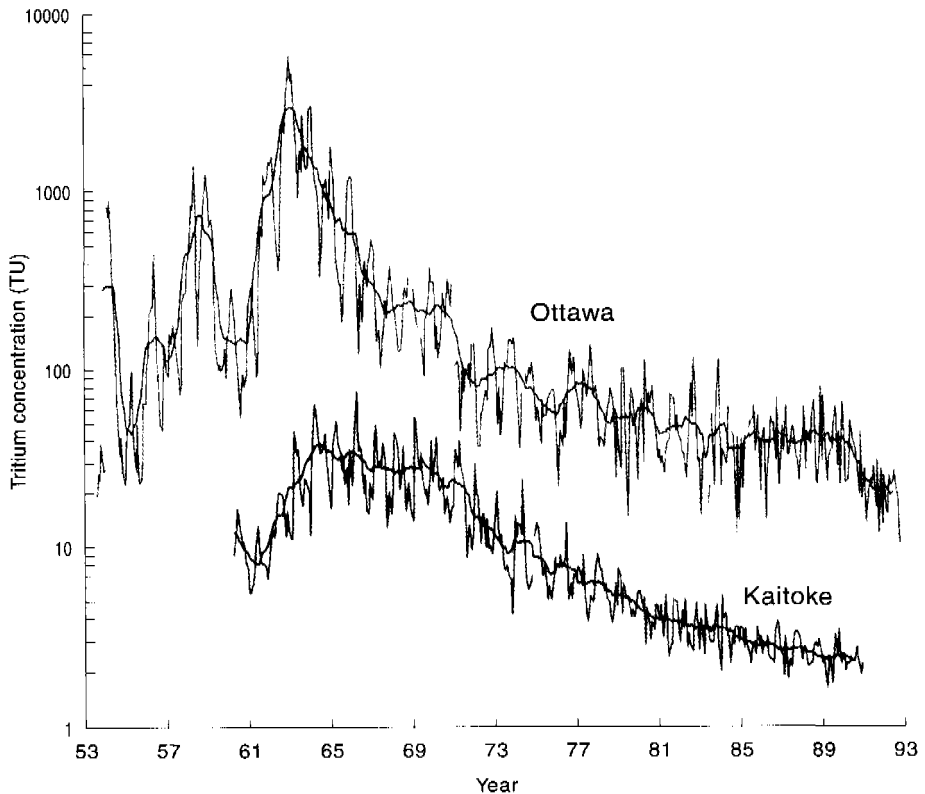
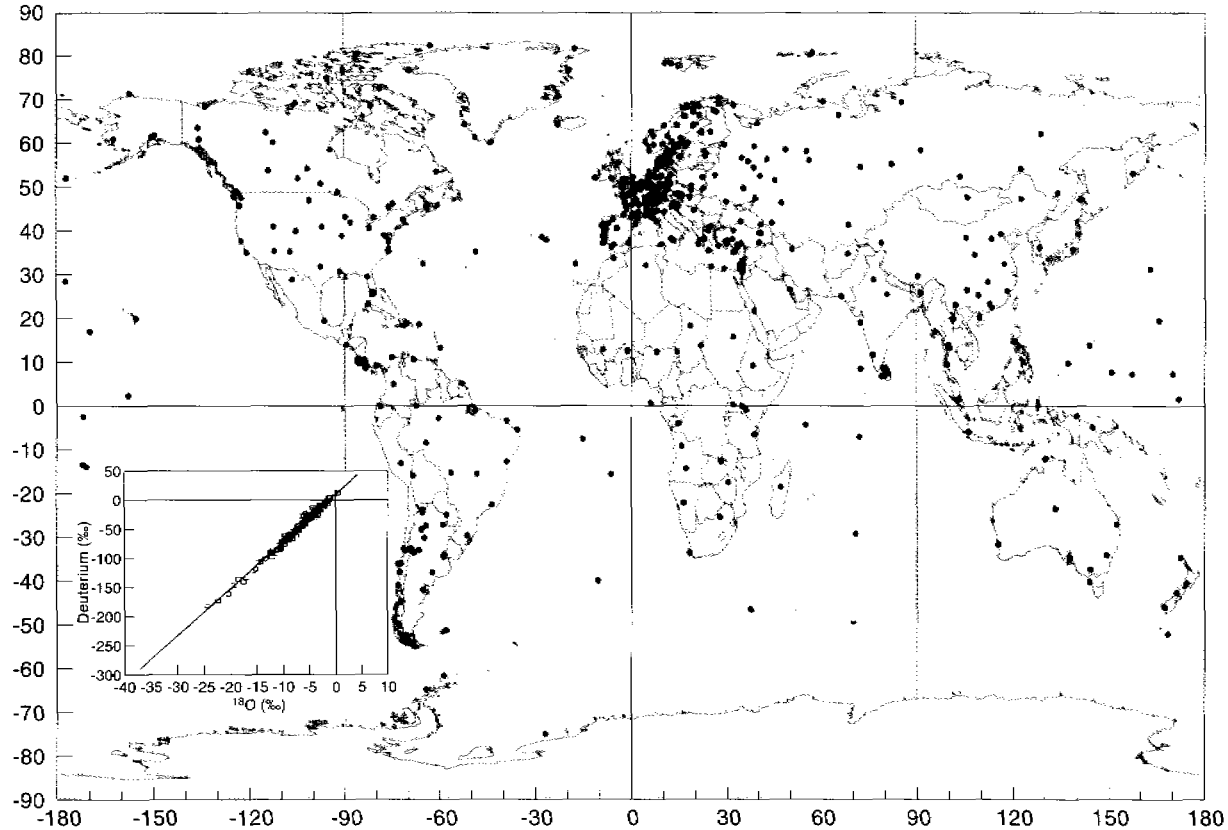
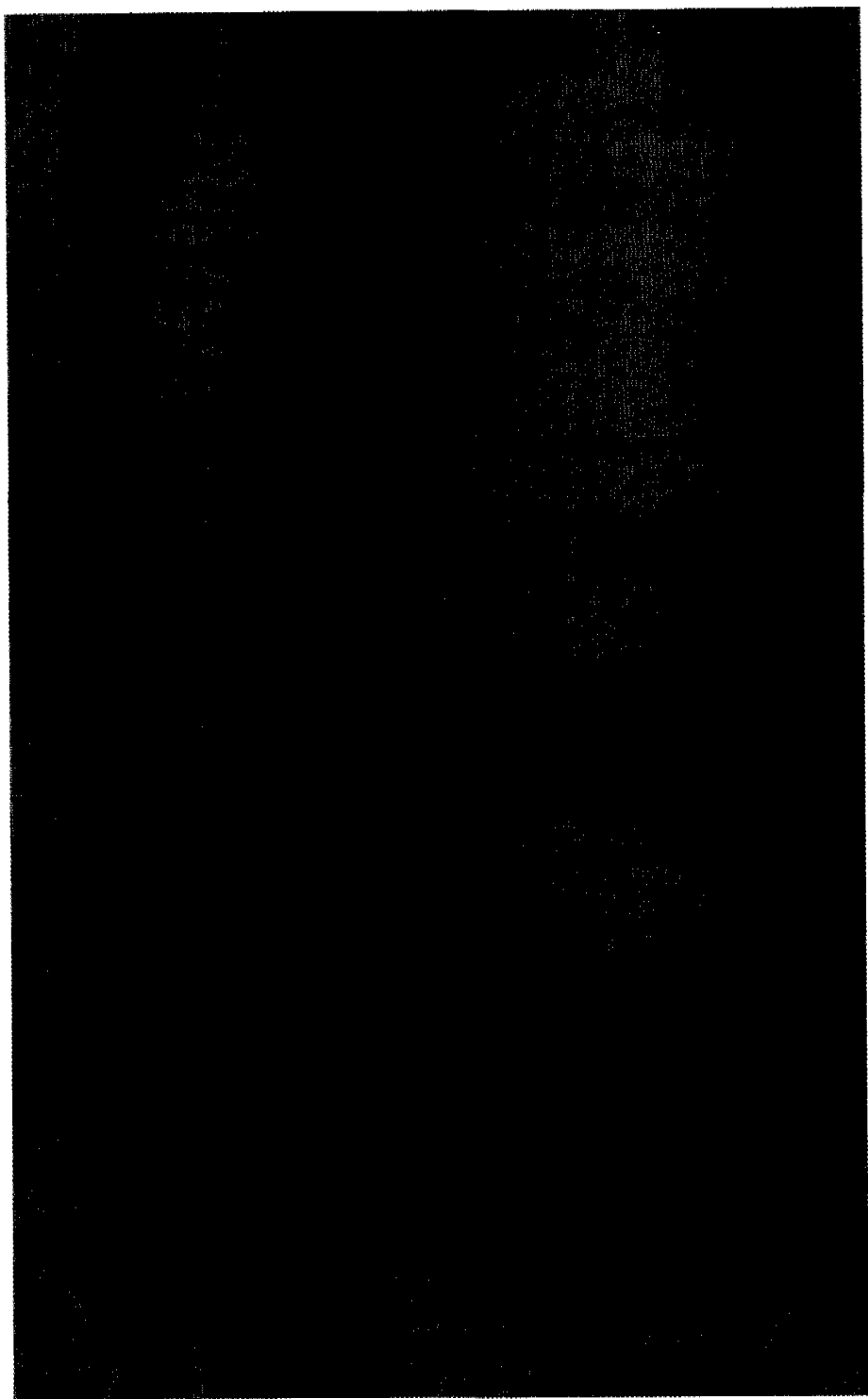


Fig. 12: Tritium levels in the atmosphere dramatically increased between 1953 to 1962 due to atmospheric nuclear weapon tests. Since the ban on thermonuclear tests, atmospheric levels have declined. Recharge in groundwater can be easily detected by measuring tritium levels and the vulnerability to pollution of an aquifer system can be assessed.

Fig. 13: Monthly composite samples of rain and snow are collected at stations around the world and analysed for ^{18}O , ^2H and ^3H . The Agency's laboratory in Vienna performs part of the analyses of the large numbers of samples while the remainder are analyzed in Member States. (Figure insert shows the relationship of ^{18}O and ^2H in precipitation worldwide, on which interpretation of hydrological processes are based).





The need for comprehensive global information was recognized many years ago, when the IAEA, in cooperation with the World Meteorological Organisation (WMO), launched the World Survey of Isotopes in Precipitation Network in 1961. The Survey, now called the Global Network for Isotopes in Precipitation (GNIP) has grown increasingly important in studies of the environment and climate change. (See figures 13 - 15).

The results of this survey, as well as statistical analyses, are published regularly in the Technical Report Series of the IAEA. The information is also available on diskettes and InterNet.

New Tools; New Applications; New Challenges

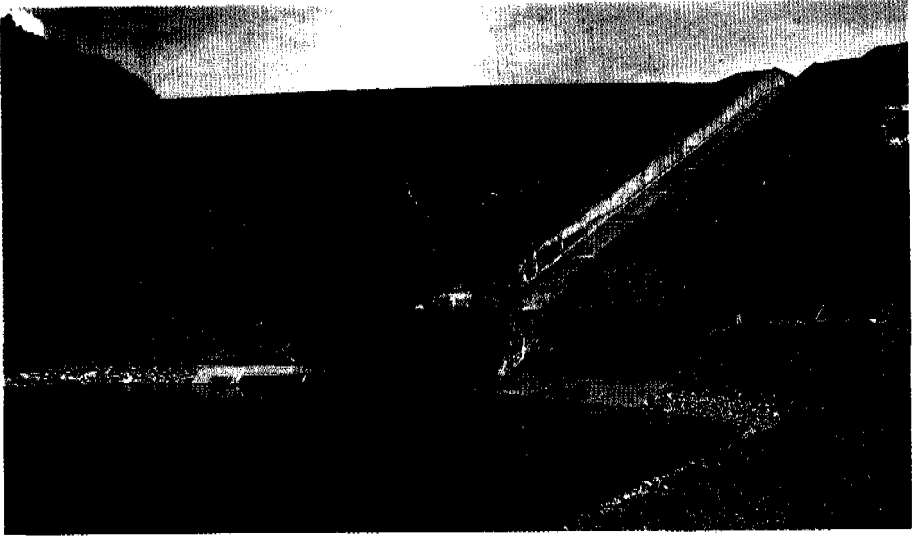
Isotope hydrology has evolved into a multidisciplinary field. As new approaches are developed, new applications and tools are being added to the isotope toolbox. For example:

- Boron isotopes can now be used to identify traces of sewage pollution in groundwater.
- Chlorine isotopes can supply information about the origin of the salinity and the complexities of flow in large, slow moving groundwater systems. They can estimate the age of water and may indicate the size of a reservoir.



A tandem particle accelerator in Switzerland. Accelerator Mass Spectrometry (AMS), a new and extremely sensitive technique for the measurement of radioactive and stable isotopes, has been developed at various centres around the world. It has revolutionized dating techniques and quickly found applications in hydrology.

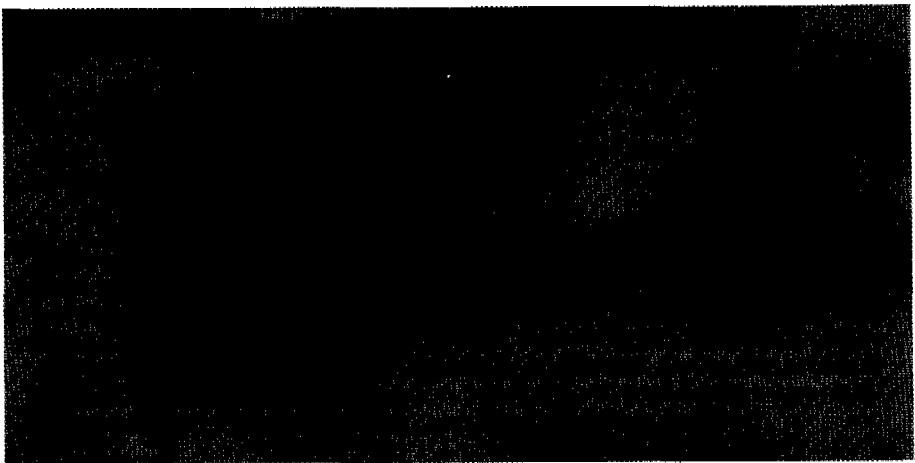
- Methods are now further refined for the measurement of isotopes like krypton-85 and helium-3 for determining the age of young water and the origins of fluids.
- Traces of now-banned chemical species such as freons can be employed as environmental tracers of surface pollutants in shallow ground water.



Isotope techniques can estimate the rate of sedimentation in dams.

Among the *key challenges* in future isotope applications are:

- Developing approaches to address the water problems of megacities
- Responding to the complex and deepening crisis of environmental pollution
- Contributing to understanding global climatic change
- Advancing professional sophistication in the practical application of isotope techniques
- Raising awareness of the role of isotope techniques in water resources management and geothermal energy resources.





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