Environmental isotope hydrology laboratories in developing countries

A report on their role, experience, and problems in areas of hydrological and geochemical investigations

by Roberto Gonfiantini and Willibald Stichler

Worldwide, water consumption has increased tenfold in this century, yet an estimated two billion people still live without an adequate supply of drinking water. In years ahead, the demand for fresh, clean water may rise even more rapidly, as the world's population grows and agricultural and industrial requirements expand. The picture helps to illustrate why efforts must intensify to protect existing water resources, develop new sources of sustainable water supplies, and improve water distribution and control systems.

The serious extent of needs and problems, particularly in developing countries, has heightened interest in water research and exploration, so that water resources can be more carefully evaluated and managed.

In a number of countries, steps have included setting up hydrology laboratories to analytically support field research by employing environmental isotopic techniques, among other tools. *(See box.)* More than 60 such laboratories for scientific investigations in hydrology and other fields of earth and environmental sciences have been established in 28 developing countries. *(See tables.)* In many cases, this has been done with substantial support in areas of planning, equipment, and operation from the IAEA through its scientific and technical programmes. The increasing demand for analytical services over the years from the IAEA's own Isotope Hydrology Laboratory in Vienna has made the establishment of national laboratories all the more necessary.

This article reports on the role, experience, and problems of environmental isotope hydrology laboratories in developing countries, based upon the IAEA's experience. It specifically offers guidance on important aspects of organization, staffing, and operation.

Mr Gonfiantini is Head of the IAEA's Isotope Hydrology Section, and Mr Stichler is a staff member of the Section.

Location of laboratories

The primary objective of environmental isotope hydrology laboratories in developing countries is to provide adequate analytical support for the application of isotope techniques to hydrological problems of practical importance. Additionally, support can be provided for research in allied fields, such as geothermal exploration, geochemistry, geology, and environmental studies. Such a broad work horizon should be encouraged.

At the present time, some laboratories belong to national institutions directly involved in water resources assessment and management, while others belong to research institutes which are part of national atomic energy commissions (AECs) or universities. There are advantages and disadvantages with either approach.

Water-related institutions. In principle, organizations directly involved with water resources assessment and management are the best suited to apply isotope techniques to practical hydrological problems and to host an environmental isotope hydrology laboratory. Traditionally their scientific and technical staffs have a hydrogeological, hydrological, or hydraulic engineering background. They also have considerable field experience in drilling and testing wells, measuring piezometric levels and discharges, sampling surface and groundwater for chemical analyses, mapping, and other areas. They are very much oriented to practical applications, and if an effective collaboration can be established between them and the laboratory's scientific staff, important results of practical and scientific interest can be achieved.

However, the conditions for such good co-operation between laboratory and field staff are

Environmental isotope hydrology laboratories in the Asian and Pacific region

		Analytical capability		
China:	Beijing Research Institute of Uranium Geology, Beijing	SI		
	Institute of Geology, Academia Sinica, Beijing	SI	T	C
	Institute of Mineral Deposits Chinese Academy of Geological Sciences, Beijing	SI		
	Geology Dept., Univ.of Beijing	SI		C
	Institute of Karst Geology, Ministry of Geology and Mineral Resources Guilin, Guangxi	SI	T	C
	Nanjing Research Institute of Hydrology and Water Resources	SI		
	Institute of Hydrogeology and Engineering Geology, Ministry of Geology and Mineral Resources Zhengding, Hebei	SI		
	Institute of Coal Geology and Exploration, Ministry of Coal Industry, Xi'an	SI		
	Institute of Salt Lakes, Academia Sinica, Xining	SI		
	Institute of Geochemistry, Academia Sinica, Guangshou	SI	T	C

Note: In China, there are about 30 laboratories equipped to carry out isotopic analyses of water. Only a partial listing is given here.

India:	Isotope Division, Bhabha Atomic Research Centre, Bombay	SI	T	C
	National Geophysical Research Institute, Hyderabad	SI	T	C
	Atomic Minerals Div., Hyderabad	SI		
	Nuclear Research Laboratory Indian Agricultural Research Institute, New Delhi	SI		
	Physical Research Laboratory Navrangpura, Ahmedabad	SI		C
Indonesia:	Centre for Application of Isotopes and Radiation, Jakarta*	SI	T	C
	Research Centre for Nuclear Materials and Instrumentation Yogyakarta	SI		C
Korea, Rep. of:	Advanced Energy Research Institute, Daeduk-Danji Choong-Nam*	SI		
Malaysia:	Nuclear Energy Unit, Ministry of Science, Technology and Environment, Kajang*	SI	T	
Pakistan:	Institute of Nuclear Science and Technology, Islamabad*	SI	T	C
Viet Nam:	Institute for Nuclear Research Centre of Nuclear Techniques Ho-Chi-Minh City*			C

SI = Stable isotopes; T = Tritium; C = Carbon-14
* Indicates laboratories for which IAEA support has been substantial.
Note: Listing based on information available to the IAEA

not always easy to achieve. One reason why is related to their scientific disciplines. It may be difficult for a physicist or a chemist to fully understand the geological background of groundwater systems (generally not known with sufficient detail) and the empirical approach often used in field investigations. On the other hand, hydrogeologists may find it difficult to gain sufficient insight into isotope techniques, including a basic understanding of the physico-chemical processes governing the isotopic fractionations among natural waters. Experts provided by the IAEA may help to build a bridge between the field and laboratory staff.

Another shortcoming of laboratories located in water-resource institutions is that the supporting infrastructure is frequently not adequate to assist a sophisticated laboratory during its routine operation. Often no electronic workshop is available, or glass-blowing facility, or library with books and scientific magazines in the isotopic field.

The situation is usually better for laboratories hosted by institutions dealing with geothermal waters. In fact, these institutions are more familiar with geochemical methods—and environmental isotope techniques belong to this category—that are commonly used during exploration of geothermal areas.

Research centres of national AECs. These research centres often consist of scientifically and technologically advanced laboratory complexes. Isotope hydrology laboratories located in these centres may enjoy in principle the best conditions for efficient routine work. However, because hydrological expertise is usually missing, they have to work closely with institutions dealing with water resources.

The success of such co-operation depends largely on the people involved at both institutions —on their ability, effort, and mutual interest in establishing and cultivating scientific contacts and collaboration. At the outset, IAEA experts can help to initiate contacts and discussions with hydrological institutions and to help select field problems for the application of isotope techniques. Once such a co-operation has been established, the laboratory's scientific staff should acquire a certain autonomy over the field work. Ideally, it should be ready and equipped to collect samples from selected sites, without always having to rely on the other institution. It also should take part in all investigations to gain insight into the problems, and be able to advise others on those aspects that are particularly suitable for the application of isotope techniques. For instance, some sampling techniques may present difficulties that only the isotope expert can help to overcome.

By all means, the idea of acting as a service laboratory that waits for customers and provides only the isotopic results should be rejected. This attitude diminishes the intellectual work involved, with a consequent loss of staff interest and scientific ability. Soon thereafter, the quality of analytical results would deteriorate.

Universities. In principle, universities are the ideal place for scientific research. Here, the interdisciplinary approach required for a hydrological, geochemical, and environmental investigation can be easily adopted. In addition, teaching and research activities contribute to the formation of young scientists, assuring development and continuity in any given scientific field. This would imply that new hydrologists (geochemists, environmental scientists) have a basic knowledge of these techniques, and would be ready to use them in their professional lives.

Universities, however, may present some disadvantages. First of all, especially in developing countries, their financial means are often insufficient, which affects the work continuity of a sophisticated laboratory. Secondly, they may be pursuing objectives which are scientifically interesting and important, but have minor practical impact. Some may not regard this point as a disadvantage, since the main objective of universities is the formation of new scientists, and scientific research is always an investment. But it is important to find the right balance between pure research and practical applications.

Staffing and infrastructure

Analytical instruments required at isotope hydrology laboratories, such as isotopic ratio mass spectrometers and low-level liquid scintillation counters, are readily available on the market. In principle, it is a relatively easy task to set up and equip a laboratory, if sufficient financial support can be obtained, a suitable infrastructure exists, and qualified staff are available.

The required infrastructure is rather simple: it includes having sufficient space (a minimum of about 300 square metres for a fully equipped laboratory with a mass spectrometer for stable isotopes, one or two liquid scintillation counters for tritium and carbon-14, and preparation systems); running water; reliable electrical power; air conditioning (indispensable in warm humid climates); dry ice and liquid nitrogen; an electronic workshop; and possibly a mechanical workshop.

The technical staff should include an adequate number of laboratory chemical technicians (ideally, at least one for each of the most important isotopes to be measured) and an electronic

Environmental isotope hydrology laboratories in the Latin American, Middle East and European regions

Latin America		Analytical capability		
Argentina:	Instituto de Geocronología y Geología Isótopica, Universidad de Buenos Aires	SI	T	C
Brasil:	Universidad Federal do Ceará Departamento de Física Fortaleza			C
	Centro de Energía Nuclear na Agricultura, Piracicaba*	SI		C
Chile:	Comisión Chilena de Energía Nuclear, Centro de Investigaciones Nucleares de la Reina, Santiago de Chile*	SI	T	C
Colombia:	Instituto de Asuntos Nucleares Bogotá*	SI	T	C
Cuba:	Instituto Nacional de Recursos Hidráulicos, La Habana		T	
Mexico:	Instituto de Investigaciones Eléctricas, Cuernavaca, Morelos	SI		
	Instituto Mexicano de Tecnología del Agua, Jiutepec Morelos*	SI		C
	Instituto de Física, Universidad Nacional Autónoma de México México DF	SI		
Uruguay:	Departamento de Radioquímica, Universidad de la República de Uruguay, Montevideo*			C
Middle East & Europe				
Albania:	Institute of Nuclear Physics Tirana*	SI	T	C
Greece:	National Research Centre for Physical Sciences, Athens*	SI	T	C
Iceland:	University of Iceland, Reykjavik*	SI	T	
Iran:	Water Resources Research Institute, Ministry of Energy Teheran*	SI	T	C
Jordan:	Water Authority of Jordan Amman*	SI	T	C
Poland:	Institute of Physics and Nuclear Techniques, Academy of Mining and Metallurgy, Krakow*	SI	T	C
Portugal:	Laboratorio Nacional de Engenharía e Tecnología Industrial Sacavém*	SI	T	C
Romania:	Institute of Atomic Physics Bucharest		T	C
Turkey:	General Directorate of State Hydraulic Works, Ankara*	SI		
Yugoslavia:	Center for Application of Radioisotopes in Science and Industry, Skopje*	SI	T	C

SI = Stable isotopes, T = Tritium, C = Carbon-14
* Indicates laboratories for which IAEA support has been substantial.
Note: Listing based on information available to the IAEA.

Environmental isotope hydrology laboratories in Africa

		Analytical capability		
Algeria	Centre de Dévéloppement des Téchniques Nucléares, Alger	SI	T	C
Egypt:	Middle Eastern Regional Radioisotope Center for the Arab Countries, Cairo		T	
	Atomic Energy Establishment	SI		
Sudan:	National Water Administration Groundwater Research Dept. Khartoum *		T	
Niger:	Département de Géologie Faculté des Sciences, Niamey *			C

SI = Stable isotopes; T = Tritium; C = Carbon-14
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engineer with experience in computer use and interfacing. A glass blower should also be available when required.

The scientific staff should include at the minimum a physicist, a geochemist, and/or a field hydrologist or hydrogeologist. The physicist should mainly be responsible for the performance of the laboratory and data quality, while the other two specialists identify research problems, and assist with sample collection and data interpretation.

In many cases, the IAEA usually can assist with training of scientific and technical staff, as well as provision of expert assistance during the laboratory's installation. Additionally, some equipment can be provided, including mass spectrometers needed to determine small variations in isotope ratios occurring in natural compounds, and liquid scintillation and proportional gas counters for detecting the extremely low concentrations of environmental radioactive isotopes.

Operation of the laboratory

In many developing countries, a number of problems arise during the routine operation of a laboratory, especially after equipment has been installed and IAEA's technical assistance has ended. The most serious concern:

Equipment maintenance and spare parts. Inevitably, the initial stock of spare parts provided with new instruments will be exhausted after 2 or 3 years, or some part of the instruments will break for which spare parts were not provided. To buy new parts from the manufacturer requires hard currency, which in many countries is difficult to obtain. Sometimes it may require more than a year to order a spare part, a delay that poses practical consequences. If a mass spectrometer, for example, remains out of operation for a year, it may be difficult to put it back into operation because of its high level of sophistication. Long periods of inactivity in an important part of the laboratory also affects staff morale and productivity.

Because of such potential problems, the decision to install an isotope hydrology laboratory, or for that matter any laboratory with sophisticated equipment, should take into account the availability of hard currency. Usually, the funds required are not large, and may range from US $1000 to $10 000 per year.

In some instances, the IAEA can help to solve equipment maintenance problems through technical co-operation projects at the national or regional level. Urgently needed spare parts could be provided, as well as experts who can help to detect sources of instrument malfunction and failures, and to make repairs. This channel of assistance, however, is preferred only in exceptional circumstances and for major repairs, and not for routine maintenance operations.

Staffing. The scientific and technical staff should be well selected and motivated, and if possible paid as well as staff at a similar professional level in other governmental and private institutions. This reduces the chance of losing skilled staff on whom considerable time and investment have been spent.

In actual fact, the mobility of skilled staff in developing countries is generally high because research institutions are not able to offer the same level of salaries and career opportunities as competitors. Unfortunately, the problem is not easily solved; yet it deserves adequate consideration by each country. Certainly, steps should be taken to avoid dismissal of staff, as has occurred.

Scientific exchanges. Another difficulty for scientists of developing countries is their isolation from the scientific community due to the scarcity of travel funds. Attendance at scientific meetings, visits to other institutes, and personal discussions with colleagues not only help scientists to keep abreast of scientific developments in their field, but also help to establish co-operation on specific problems. This ultimately contributes to sustaining a high quality of research and smooth operation of a scientific laboratory or institute.

To a limited degree, the IAEA can help through its programme of scientific visits and provision of financial support to its symposia and seminars. However, this cannot be sufficient to solve the problem.

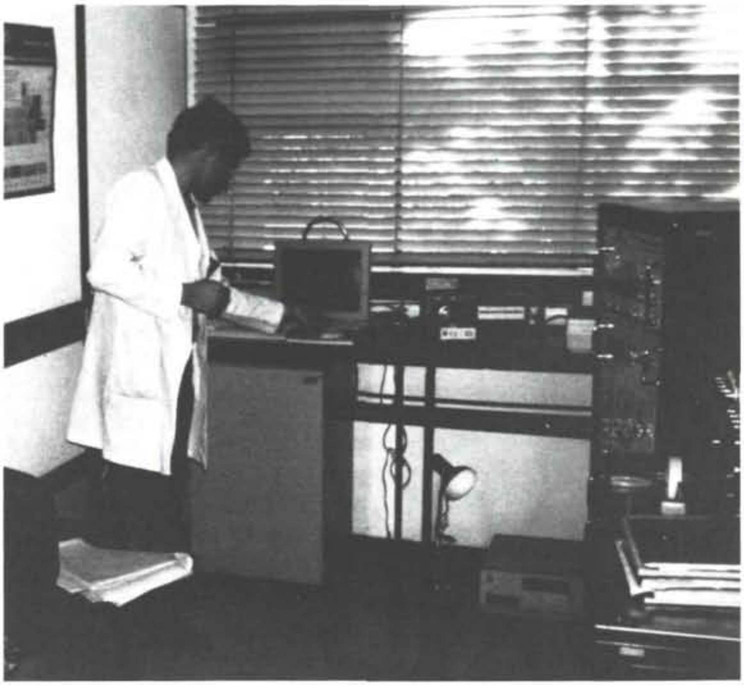
An excellent way to foster scientific contacts and co-operation is through co-ordinated research programmes, which bring together institutes from developing and advanced countries.

Isotopes in hydrological research

Environmental isotopes are abundant in nature and their analysis is an important part of scientific studies of the earth's natural resources. Isotopes are basically forms of an element that differ from each other in their nuclear, but not chemical, properties.

Since environmental isotopes are known to occur in different quantities in different waters, the amounts and ratios of several kinds of isotopes describe, or trace, the characteristics of the water supply. For instance, environmental isotopes indicate the source of sub–surface waters, the occurrence of recent recharge from rain and surface waters (a critical concern in arid lands), the age of groundwater, and the inter–connections between surface and groundwaters or between two water-bearing formations (aquifers). They thus help hydrologists to understand water systems that are usually quite complex and, in the case of groundwater systems, accessible to direct observation at only a few sites. Important isotopes in hydrological investigations are deuterium (hydrogen–2) and oxygen–18, both of which are stable, and tritium (hydrogen–3) and carbon–14, which are radioactive.

Nuclear techniques using isotopes have become precise tools that are often used in combination with other research methods in studying water resources. Sensitive modern instruments and equipment, such as liquid scintillation counters, allow accurate detection of extremely small quantities of environmental radioactive isotopes in water. Increasingly, these techniques are among the research tools being used by scientists in developing countries where environmental isotope hydrology laboratories have been established over the past 20 years.



Above, an isotope ratio mass spectometer at the laboratories of the Chilean Atomic Energy Commission. Below, a liquid scintillation counter at the Instituto de Asuntos Nucleares in Bogotá, Colombia.

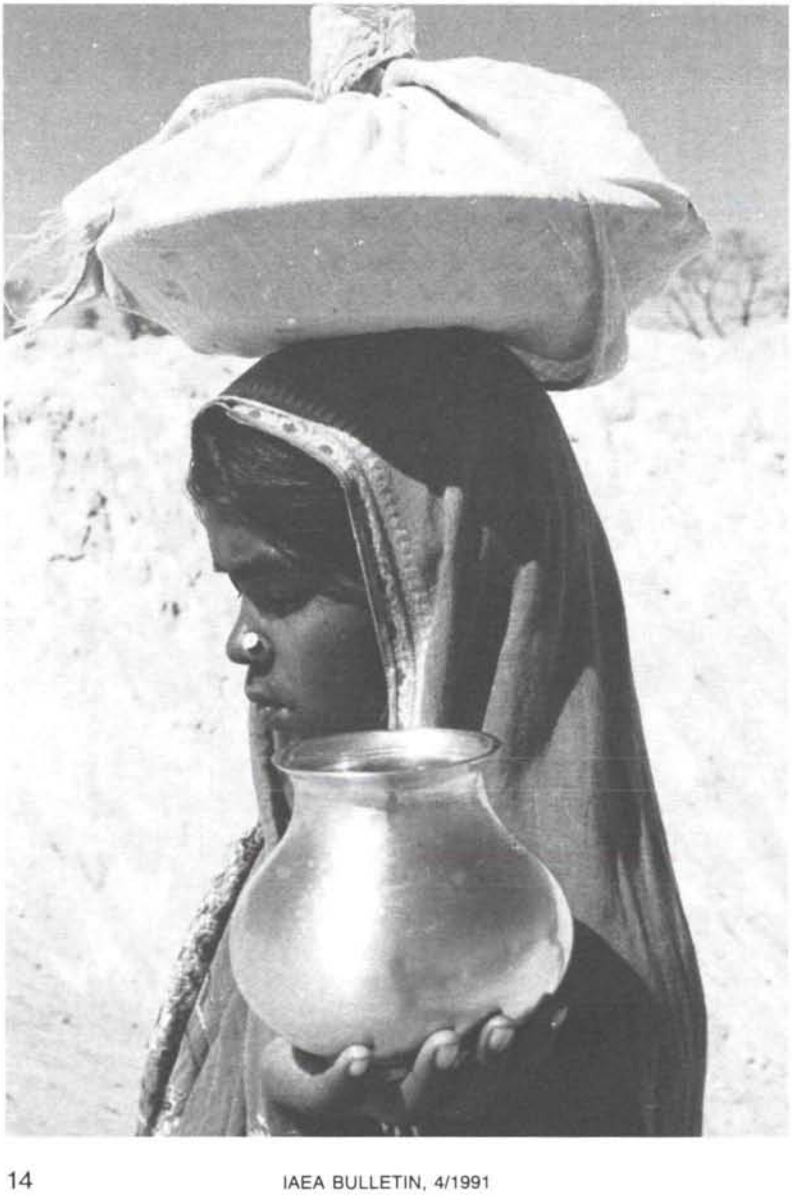
Relationships are especially reinforced at research co–ordination meetings taking place every 18–24 months which are attended by representatives from all the participating institutes.

In some respects, visits by IAEA experts to developing countries within the framework of technical co–operation projects can help to break the isolation of local scientists. One recent tendency has been to use experts from other developing countries of the same region. While this is in many respects a positive development because of the experts' familiarity with problems in the area, it can reduce opportunities for the local scientists to get in touch with advanced research trends. In the long run, the use of such regional experts may heighten rather than alleviate the isolation of local scientific communities, and it may contribute to widening the gap between developing countries and scientifically more advanced countries. Such a conclusion should not be taken generally, however. Qualifications and experience (including those of both the expert and the institution of origin) remain the most important factors in the selection of experts.

Other duties. In addition to the application of isotope techniques to hydrological, geochemical, and environmental problems, there are other important tasks which an environmental isotope laboratory should perform, and that host institutions might support and encourage. Some of these are:

- Establishment of a permanent national network of stations to collect precipitation samples for isotopic analyses (tritium, deuterium, oxygen–18). Over time, the observations will enable establishment of a database that will prove very useful for investigations.
- Periodic monitoring of the variations in isotopic composition of selected rivers, lakes, large springs, and other water bodies. This will contribute to the database and provide a set of information that may lead to other required investigations and applications.
- Planning and execution of laboratory experiments to determine isotopic fractionations that may occur under particular conditions encountered in field studies;
- Offering courses on the scientific background and applications of environmental isotopes;
- Hosting students to carry out experimental work toward their university degree.

In India and other countries, the demand for adequate supplies of drinking water is projected to rise rapidly in years ahead.



A balanced approach

While there are no general rules governing the establishment of an environmental isotope hydrology laboratory, each case can be assessed on its own merits. This task is often not easy, but considerations outlined here can promote sounder assessments of a proposed laboratory's location, staffing, and operation.

The prerequisites for the laboratory's location and efficient operation include an adequate infrastructure and financial resources to cover running costs, supplies of spare parts, and field investigations.

Overall, good infrastructures and support facilities usually are found at AEC research centres and, to a lesser extent, at universities, which also offer a stimulating intellectual environment. On the other hand, organizations dealing with water resources are better suited to identifying and evaluating field problems of practical importance.

Regarding financial requirements, national support to hydrology laboratories may be unpredictable in the long run, given general economic factors and shifting research priorities. To assist countries, the IAEA has set up mechanisms within the framework of regional co-operation programmes in Asia and the Pacific and in Latin America (known respectively as the RCA and ARCAL programmes) to provide some financial assistance.

Ultimately, however, the successful establishment and operation of an environmental isotope hydrology laboratory rests on the people involved. With a scientific staff that is motivated, skilled, and determined, the laboratory can serve as an important centre of national efforts to solve practical problems and protect precious natural resources.