INSIDE
TECHNICAL CO-OPERATION

International Atomic Energy Agency

June 1996 Vol. 2, No. 2

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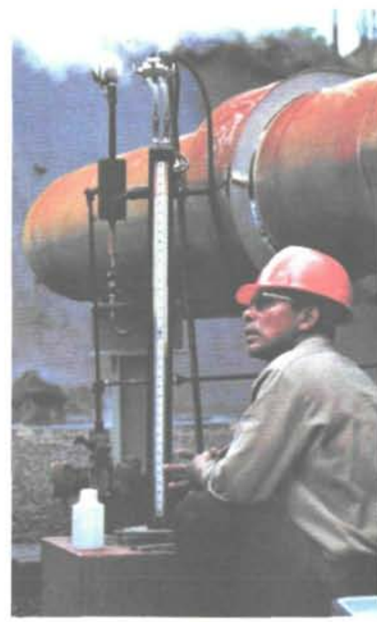
Harnessing the fire below

On opposite shores of the Pacific, in what is called the Circum-Pacific Belt of Fire, El Salvador and the Philippines are steadily developing their geothermal resources to produce electricity. Most countries within this vast girdle of ancient volcanic activity are endowed with geothermal reservoirs — bubbling cauldrons containing fluids several times hotter than boiling water. This dry steam and hot water are potential sources of high pressure to drive turbines and generate power.

Geothermal energy has many advantages, especially for countries that spend scarce hard currency to import fossil fuels for thermal power plants. It cuts the import bills for a start. Being an indigenous source, it also offers greater energy independence. Prefabricated modular systems now make it easier to install and start-up new plants. Another advantage is that geothermal plants can operate year round and are not vulnerable to drought, as hydro is, or fuel supply delays. Properly managed reservoirs can be sustained indefinitely.



A technician from El Salvador's Hydroelectrical Commission (CEL) sampling a geothermal well. (Credit: J. Gerardo/IAEA)

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Tapping the treasure beneath the Sahara

North Africa is a vast arid zone where shortages of water affect all economic activity and the health and well-being of millions of people. In most countries, water is drawn by hand or by versions of the Archimedes screw from shallow wells of groundwater resources. As populations rise and demand increases these sources have become insufficient.

A new source of groundwater is a complex system of water-holding rock expanses located deep underground. Water can be extracted by drilling boreholes several hundred metres down and pumping water to the surface. But experience worldwide shows that this is often a gamble and can even be counter-productive: expensive wells can run dry; the water can bring up unwelcome salts; and intensive extraction can cause surface subsidence. Controlled and sustainable management of the aquifer systems needs a great deal of sophisticated analysis.

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Capital replenishment in Venezuela

Caracas is confronted with a complex water crisis. On the one hand an acute shortage and on the other a glut of unwanted water that has to be carried away and discarded. Water supply is cut off in every district of the city for hours on some days and all day on others. Furthermore, *no* piped water reaches the crowded outskirts. Even the Water Ministry is not exempt. Each day the mass media announce the names of districts, even specific hospitals and schools, that are to receive piped water for that day. "Operation Help is delivering 40 tankerloads of water (about 1 million litres) to the district of Sucre where no water was received in a 20-day period," lamented a recent and typical news story.

Until the early 1960s Caracas, which lies in a shallow valley some 1000 metres above sea level, received domestic water supplies from shallow groundwater. In the 1950s and 1960s rainfed reservoirs were built on nearby higher ground to supply the city's under one million people with treated water. Since then, however, the population has increased rapidly to some five million today, and dwellings sprawl even up the slopes of the basin. The supply network was hard put to cope with increasing water demand even before reservoir levels began to fall after very low rainfall in northern Venezuela for a number of recent years.

Ironically, there is massive leakage from the concrete pipes laid below ground that bring water from the reservoirs down to the city. Furthermore, the natural drainage of the groundwater was blocked when the nearby Guaire River was "canalized" some years ago. With nowhere to go but upward, the groundwater, swollen by the leakage, has now risen so close to the surface that the underground railway as well as the foundations of other buildings are threatened. This water can no longer be used by the thirsty population because it has reached levels where it is contaminated with sewage and other pollutants. So in many parts of the thirsting city the sound of pumps attest to the ceaseless extraction of groundwater; only to be discarded far away.

Tankers supply water to thirsty districts in Caracas.
(Credit: H.F. Meyer/IAEA)

Since mid–1994 an IAEA Technical Co–operation project has been helping to resolve that part of the problem which involves the groundwater — using isotope techniques to precisely identify the quantity, flows and quality of water in deeper parts of the aquifer system below the city. The primary aim is to find new water sources to make up for at least part of the current shortfall of 260,000 cubic metres per day. A possible spin–off is that deep-water extraction methods being investigated may lower the water table sufficiently for the costly and wasteful pumping to be halted.

If the aquifer system is to be used, at least during dry spells or for limited local supply, a number of parameters must be established. How much water is held in the system? What is its rate of discharge and recharge? From where does the inflow come? How pure is the water in different parts of the system? What are the processes and pathways of pollution? Conventional hydrogeological techniques cannot provide definitive answers. Isotopes as tracers, coupled with geochemical techniques, can do so with remarkable accuracy and speed.

By the end of 1995 the water authority had 'mapped' the aquifer system — described as a vertical structure in two sub–systems with horizontally distinct areas — and also identified and characterized its sources of recharge. It seems that water from some specific depths could substantially reduce the drinking water shortfall. Other areas of the aquifer system could provide water good enough for irrigation, industrial, and other needs.

The project is transfering technology and knowhow to maintain constant quality control of extracted groundwater. It will

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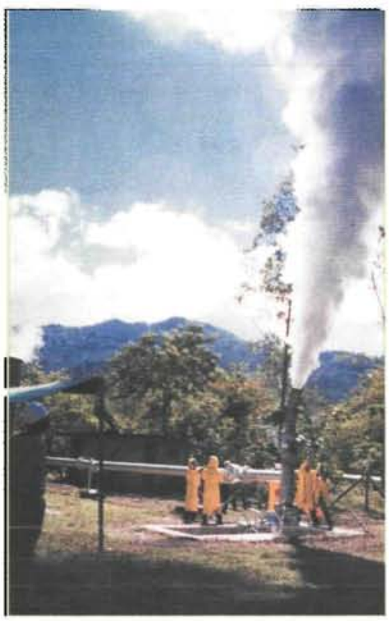
A key benefit in these times of concern about climate change and greenhouse gases is that energy could be exploited in an environmentally friendly regime. Station managers must make sure that the whole watershed in which a plant is sited is protected because that is the source of freshwater that keeps the reservoirs alive. All the extracted water can be re-injected into the reservoir, rather than discharged on the surface. The Philippines opted for geothermal, despite high capital costs, because it would cut projected carbon emissions to 5-10% compared to, for example, coal-fired electricity plants. The choice was endorsed by the Global Environment Facility when it recently provided US $30 million (the maximum possible under its rules) for a new geothermal plant in the Philippines.

The technology to exploit geothermal energy has been applied for nearly 100 years. The first geothermal plant, in Larderello, Italy, has produced electricity since 1904. But it is underused worldwide. Some 18 countries use the energy, but the power generated is only a small fraction of national production. USA, the world's largest electricity producer, generates over 2200 megawatts of electricity (MWe). Other major producers include Mexico (700+ MWe), Italy (500+) and Japan (200+). The real hindrance to developing geothermal has been that key data, for sustainable and environmentally safe management, have been virtually impossible to ascertain. How much steam and hot water is in the geothermal reservoir? At what rate is the reservoir replenished? Where does that water come from? At around US $2 million apiece, drilling wells is an expensive part of developing geothermal energy; so where is it best to drill?

Isotope hydrology techniques can help answer such questions very precisely and quickly. Radioisotopes used as tracers can be tracked deep underground. Stable isotopes can reveal directions, pathways and rates of waterflow in and out of reservoirs. These powerful tools can also show where to drill, and how best to feed extracted water back into the reservoir thus ensuring sustainable use of the resource and that the environment is not harmed by the waste water. Recent IAEA technical co-operation projects have helped Ethiopia, Greece, China, Guatemala, Indonesia, Mexico and Nicaragua to develop capability to exploit geothermal resources by transferring knowhow and equipment for applying isotopic techniques.

El Salvador and the Philippines are already harnessing geothermal heat. The IAEA is supporting activities because of the substantial commitment and high priority given to geothermal energy in the national economic development programmes.

The Philippines is already the world's second largest geothermal electricity producer. Most of its electricity is still generated by burning imported oil, but geothermal's share is now 24% (1,036-MWe) and climbing. A further 680-MWe is expected within three years from ongoing field development, and other potential fields being explored could provide 2500-plus MWe more by about the turn of the century, making it the top geothermal producer in the world.



Credit: J. Gerardo/IAEA

El Salvador also ranks among the world's top 10 geothermal energy producers, though its share is only 14% of national power production, which stands at 900-MWe. The field in Ahuachapan has operated since 1975 and now generates 58-MWe from 32 wells. A new field, in Berlin, began in 1992 and produces 5-MWe from 10 wells. With electricity demand soaring at an average of 9% a year since the economic reconstruction programme began in 1992, thermal power from imported oil and gas provides about 40% of the country's total power. Hydro power provides 46%; its further expansion is limited, however, because the only large river has been almost fully exploited.

The national plan is to double geothermal production in the next five years. At least $180 million of a new $215 million loan from the Inter-American Development Bank will be spent on developing geothermal sources — 15 new wells in Ahuachapan, 18 in Berlin, and exploration elsewhere. The government expects to cut fossil fuel imports by 20% within two years, a savings of some US $32.8 million annually, and progressively reduce them further. Some 225,000 additional households also will receive electricity. Overall, the Model Project is helping to improve national capabilities to interpret isotope and geochemical data critical for long-term geothermal exploration and generation. These stronger capabilities will enable El Salvador to provide analytical services to other countries of the region.

Tapping the treasure *(from page 1)*

Many hands at work. A common sight at shallow water wells in the Sahara region. (Credit: Carnemark/World Bank)

In 1995, IAEA Technical Co-operation started a four-year Model Project to assemble the basic data and to provide isotope technology to nine North African countries — Algeria, Egypt, Ethiopia, Libya, Mali, Morocco, Niger, Senegal and Sudan — so they could better manage their groundwater resources. Egypt, Ethiopia, Morocco and Senegal — with urgent problems to resolve — are in the first phase (1995/96) of the Model Project. The other five countries will join in the second phase beginning in 1997.

• Egypt now depends on the Nile for almost all its water. The Nile valley is overcrowded already, so the Model Project aims to "reclaim" fringes of the surrounding Sahara. There is already some settlement in Qena and Esna, in the northwest. Can the shallow Nile aquifer sustain some 50,000 hectares and two million people?

• The drought prone Moyale region (some 45,000 km^2) of Ethiopia is home to three million people and has one of the largest cattle concentrations in Africa. Can aquifers below assure a stable supply of water for them?

• South of the Atlas mountains in southwest Morocco, half a million people precariously farm 15,000 hectares in the plains of Tafilalt and Guelmim with supplies from a few ephemeral rivers. Could nearby aquifers provide them with ample and good quality water?

• In the far west of the Continent, 70% of the water supply to Senegal's capital, Dakar (population: 2 million), is drawn from coastal aquifers. Daily demand is 250,000 cubic metres. During dry periods, the estimated shortfall is as high as 100,000 cubic metres a day. How much more can aquifers provide, without causing salt-water intrusion?

These are the principal questions which the first phase of the Model Project is addressing by field studies and analyses of the isotopic composition of local water.

Three isotopes of special interest to hydrology are deuterium (H-2), tritium (H-3) and oxygen-18 (O-18). Because they are heavier than the two other isotopes (H-1 and O-16, respectively), water vapour rising from the ocean to form rainclouds has fewer H-2, H-3, and O-18 isotopes than seawater. When the clouds release their water, more of these isotopes are rained out first; and moisture remaining in the cloud, to be shed later, will have relatively fewer of them. Coastal rain is therefore isotopically different inland and different again in mountains.

Other changes in the ratios of H-2/H-1 and O-18/O-16 (depending mostly on temperature) occur as rainwater moves back to the oceans in various ways, depths and speeds. In the process water acquires telltale isotopic 'fingerprints' in different environments, and analysis of a sample can reveal its 'age', origin and how it got there. Isotope hydrology techniques measure the ratios of a number of other elemental isotopes, i.e., helium, carbon, nitrogen, sulphur and chlorine to aid a variety of investigations.

Preliminary results in Egypt appear to be promising. It has been ascertained that the shallow Nile aquifer is being replenished by the gigantic Nubian Sandstone aquifer which lies adjacent to it and at a deeper level. Ongoing studies expect to establish the rate and quantity of replenishment. The fact that the Nubian Sandstone aquifer contains 'palaeowater' which has not been

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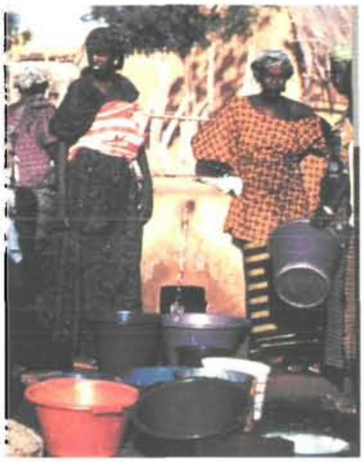
Isotopes and water management

We call the Earth the blue planet. Photographs from space show a characteristic seen nowhere else in the visible universe. Water is the foundation of all life on Earth. The Earth's surface is two-thirds water and experts calculate that the volume is nearly 1.5 billion cubic kilometers. But only about two per cent is freshwater, and nearly all of that is locked in glaciers, ice caps and deep groundwater reservoirs. Only an estimated 2000 cubic kilometres is readily available to meet human needs. This has been adequate to sustain life on Earth, but global demand for water is doubling every 21 years according to the Food and Agriculture Organization (FAO). As industrial, agricultural and domestic pollution threatens finite supplies, water is becoming an increasingly precious resource.

Recent history has witnessed conflict between nations over rights and access to fossil fuel resources. Such conflicts could also arise in the future over water shortages since many countries in the world lack readily available or abundant water resources to meet their needs. An increasing emphasis in IAEA technical co-operation activities focuses on helping countries (and supporting regional co-operation) to investigate and manage water resources using isotope hydrology. Isotopic techniques provide an important analytical tool for those responsible for managing natural resources. The Agency has established a dedicated isotope hydrology laboratory in Vienna that supports national development activities in natural resources management. Usually, TC projects develop experience and knowhow



Credit: Carnemark/World Bank

through training, expert advice and the provision of equipment to improve local infrastructure and build capacity to study water resources using tracer isotopes.

This issue of INSIDE TC is about using isotope techniques to efficiently and sustainably manage the exploitation and conservation of water. Isotopes are extremely powerful tools for investigating many areas of natural science. Most elements are made up of different isotopes which are virtually identical to one another chemically, but are of different atomic mass. Our indispensable water molecule is made up mostly of two isotopes — hydrogen (H-1) and oxygen (O-16). But along with these 'abundant' ones are 'rare' isotopes, occurring in relatively low and variable concentrations (H-2 and O-18). These rare isotopes permit a broad range of hydrological investigations.

Isotope hydrology has evolved into a multi-disciplinary field: 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 steam for transport to a power plant; In investigating sewage pollution in groundwater, boron isotopes can be used to track and measure pollution and contamination pathways. 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 'greenhouse effect'. Isotope techniques are also proving to be an effective tool in unravelling this complex environmental phenomenon through subatomic analysis of carbon isotopes to determine what happens to greenhouse gases in the atmosphere. The isotopic composition of water can provide information about past climates and enable experts to monitor and compare global warming phenomena and to assess climate change going back tens of thousands of years. Isotopic techniques are also being used to help explain environmental phenomena such as the rise in the sea level of the Caspian Sea. The next issue of INSIDE TC will look into these related applications of isotopic techniques that support environmental management of natural resources.

Over the last ten years the IAEA has supported some 160 technical co-operation projects amounting to $18.8 million in technology transfer and knowhow to help 63 countries develop national infrastructure in isotope hydrology applications. Over 550 students have been trained in isotope hydrology to develop indigenous skills to apply and analyze isotopic investigations for natural resource management. This INSIDE TC describes a few projects that are making a measurable contribution to improving the quality of life for people in communities at various corners of the globe.

actively recharged since the last rainy period some 6000 years ago, is not regarded as a problem. This aquifer covers an area of tens of hundreds of square kilometres, and is the largest known aquifer in the world. It is unlikely to be depleted by extraction for the reclaimed land area. The study is expected to determine how much and at what rate Nile aquifer water can be withdrawn without unwanted consequences.

Project trainees from Algeria, Morocco and Senegal conduct on-site chemical analysis of water beside a rural well in the Dakar peninsula. (Credit K. Froelich/IAEA)

> Rainwater that percolates into the ground usually makes its way back to the seas from where it came. Some of it is taken up by plants and eventually transpired into the atmosphere. Some reaches lakes and eventually evaporates. Some strikes a river and quickly returns to the sea. The rest inches along at various depths below the soil surface. Large pockets of this slow moving water saturate multiple layers of rock. These 'saturated zones', also called aquifers, often receive fresh rainfall fast enough to remain saturated. Water can be sustainably extracted from them in various ways from shallow wells to deep boreholes, depending on the rate of replenishment. Some very deep reservoirs received their water during perhaps prehistoric periods of heavy rainfall thousands of years ago. Unreplenished by new rains these 'palaeowaters' are seeping to the seas too, but so slowly that it may be millions of years before they are dry. Meanwhile they are 'ageing' and can be 'dated' by naturally occurring radioisotopes such as carbon–14 to establish whether or not the aquifer is a finite resource.

The news is mixed for Morocco. Isotope data have disproved earlier conventional hydrological indications that the aquifer in the north of the Tafilalt area is being replenished. It is shown to be palaeowater, and imprudent exploitation will mine it dry. But isotopic analyses show that two other systems, in the south of the Tafilalt Plain and in the Guelmim Plain have been replenished by recent rainfall. In May, isotope studies began in the unsaturated zone of the southern Tafilalt basin (through which rainwater percolates down to the aquifer) to quantify recharge and discharge, as well as possible contamination of the groundwater.

In Senegal, authorities hope that project related activities will enable greater withdrawal of groundwater, sufficient to make up 70% of the current shortfall. The focus of the project is to quantify how much could be extracted without threat of seawater intrusion into the aquifers, and to develop tools for prudent management of the resource. Senegal aleady has expertise in the use of isotopes in unsaturated zone investigations. The expertise will support the investigations in Morocco.

Ethiopia's Moyale regional investigations are identifying the replenishment characteristics of the aquifers and very probably the rate of recharge as well. This basic assessment is vital for good water resource management and cannot be derived by other means. Under the project, 14 borehole sites were geophysically surveyed and six new wells have been drilled so far.

Finding new water sources is only valuable if the resources are managed well. The establishment of good management practices is a central objective of the Model Project.

Toward this end, the development of computer models as management tools began early in 1996 with a seminar in Senegal and a workshop in Morocco. Further training and development of software based on project findings will be completed by the end of this year.

This computer software is patterned on that of the United States Geological Survey (USGS) and Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO), respectively. Specialists who were involved in developing the USGS and CSIRO models have been helpful in guiding the project work and providing necessary training.

Progress in seawater desalination

With over 1.4 billion cubic kilometres of seawater available on two-thirds of the world's surface, many water deficient populations could have access to a vast potential for freshwater if an economical means to desalinate seawater can be demonstrated. That is the working hypothesis of a feasibility study begun by the Agency in 1994. It has identified options for utilizing small- and medium-sized nuclear reactors as a possible power source to run desalination plants to produce low-cost potable water in North Africa.

One participant in the feasibility phase is Morocco which is about to undertake a joint pre-project study of a demonstration plant with assistance from the IAEA and China. The plan would utilize a 10 megawatt reactor supplied by China to produce 8,000 cubic meters a day of fresh water. Other participants in the study are Algeria, Egypt (which is also studying project design), Libya, Saudi Arabia and Tunisia. Over US $670,000 in financial support for the study was provided by Argentina, Canada, Jordan, Korea, Libya, USA and the Arab Atomic Energy Agency. The Agency will hold an international symposium on the subject in 1997, in collaboration with UNIDO, WHO, WMO and the EU.

Roundtable starts SIT campaign in Mali

Trypanosomiasis is a growing threat to Mali livestock. (Credit P. Fouchard/IAEA)

Livestock development in much of Africa is limited by the range of the tsetse fly, which transmits a type of sleeping sickness called nagana (see Cattle killer meets its match, *INSIDE TC*, March 1996). Livestock infection rates of up to 45% in the peri urban zone of Bamako have inspired the Government of Mali to convene a roundtable with its development partners to discuss co-ordinating activities for an integrated approach for tsetse and trypanosomiasis management. The French, German and US aid agencies have sponsored livestock related development projects in the area which were represented at the meeting.

The roundtable on 27-31 May 1996 discussed the possibility of initiating area-wide conventional fly suppression activities (traps, screens and chemical treatments) involving local communities to drastically reduce the tsetse population in an area of approximately 2000 km^2. This is a prerequisite for a potential sterile insect technique (SIT) intervention. The Government undertook to document through a socio-economic study the extent of the tsetse and trypanosomiasis problem. On the basis of these promising discussions, the Agency is moving ahead with technical feasibility planning for boundary mapping and fly range involving release/recapture studies with marked sterile males.

Capital replenishment *(from page 2)*

provide technical training; laboratory equipment especially for quality control of water; and help elaborate a mathematical model to predict changes in flow patterns and water table levels so that the aquifers can be sustainably and safely utilized.

The first substantial result of this work is a decision by the water authority, Hidrocapital, to construct new wells. Their sites and designs are based on data resulting from the IAEA project. Fifteen wells have already been drilled and 50 more will be completed this year. It is estimated that they will be able to provide more than 112,000 cubic metres a day, or some 46% of the current water deficit.

The city intends to continue the wells programme over the long term to ensure that strategic institutions such as hospitals and fire stations will have access to water in case of emergency. Ten hospitals are already being equipped with such wells.

Parched plains wait for mountain manna

The Atacama, lying along the Pacific Ocean coastline in South America, is the driest area in the world with barely a centimetre of rainfall a year. Just north of the Atacama, in Peru, a 7500 km^2 coastal plain gets no more rain, but it has sustained human settlements and agriculture for centuries on the banks of the only two perennial rivers running from the Andean mountains to the Pacific Ocean.

Two early settlements called Moquegua and Tacna have swollen into cities. They lie some 80 km apart, and 15 to 20 km inland. Some 200,000 people now live on this part of the coastal plain, sustained mainly by nearby copper mines and small industries. The port of Ilo, at the very north of the area, has grown into a town since a treaty made it the only access to the sea for neighbouring Bolivia. The busy road from La Paz runs through Moquegua province.

The increasing demand for water in these settlements is already beyond the capacity of the two rivers. The provincial water authorities are now urgently looking for ways to augment the supply, at least for drinking and domestic use. They are looking to the high plateau: the *altiplano* is a vast sub–region (many millions of hectares towering 3400–4000 metres above sea level between the eastern and western chains of Andean peaks in Peru and Bolivia) that gets 300–400 millimetres of rainfall a year. This is not a lot, but some geologists have suggested that there would be large enough aquifers there to supply the plains.

The hydrology of the plateau has never been studied. In 1995 IAEA Technical Co–operation began a two–year project aimed to provide the provinces a complete hydrological evaluation of the *altiplano*, as well as the means of transporting water to the coastal area. Findings from isotope analysis so far are mixed. Most of the aquifers are

Acute water shortages in the Atacama affect everyone. (Credit C. Fjeld/IAEA)

small, in compartments separated by impermeable barriers, and mostly replenished only by nearby rainfall. The hydrology is highly complex.

Evaporation and evapotranspiration (mainly from vegetation) have been found to be very high. The roots of bunchgrass and other native plants do not run deep, so if water close to the surface declines by much, because of extraction, it will seriously affect plant life and cause havoc to the wild vicunas, tamed llamas, alpacas and other animals. It will also jeopardize the lives and traditions of indigenous people who live in scattered settlements and grow crops that have acclimatized to the demanding conditions.

On the other hand some aquifer systems seem promising, and already wells are being drilled based on available study results. The study is using tritium and carbon–14 isotopes to unravel the complexities of the altiplano aquifers and to provide crucial data for development of flow models for accurate water resource management. Water from the high plateau could be transported to the thirsty coastal plain by using dry river beds and canals to feed the perennial rivers.

The Agency has, over many years, helped develop the infrastructure and capability of its counterpart, Peru's Institute for Nuclear Energy (IPEN), which has developed an analytical laboratory in Tacna. An atomic absorption spectrometer and well logging equipment were provided through this project, as well as expert services and training. The provincial water authorities and IPEN must now decide and implement plans to handle several specific problems. For example, the natural transportation route passes high altitude geothermal springs containing boiling water that is very saline and has high levels of boron and arsenic which are poison to plants and people.

Possible solutions include: building some 50 km of canals; constructing a power plant to use the hot water to make electricity and recycle the water into the geothermal reservoir; and building an expensive treatment plant to decontaminate the water. The project, which ends this year, expects to provide data which will help evaluate these options and bring water from the *altiplano*, like manna from the mountains, to the parched coastal plain.

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