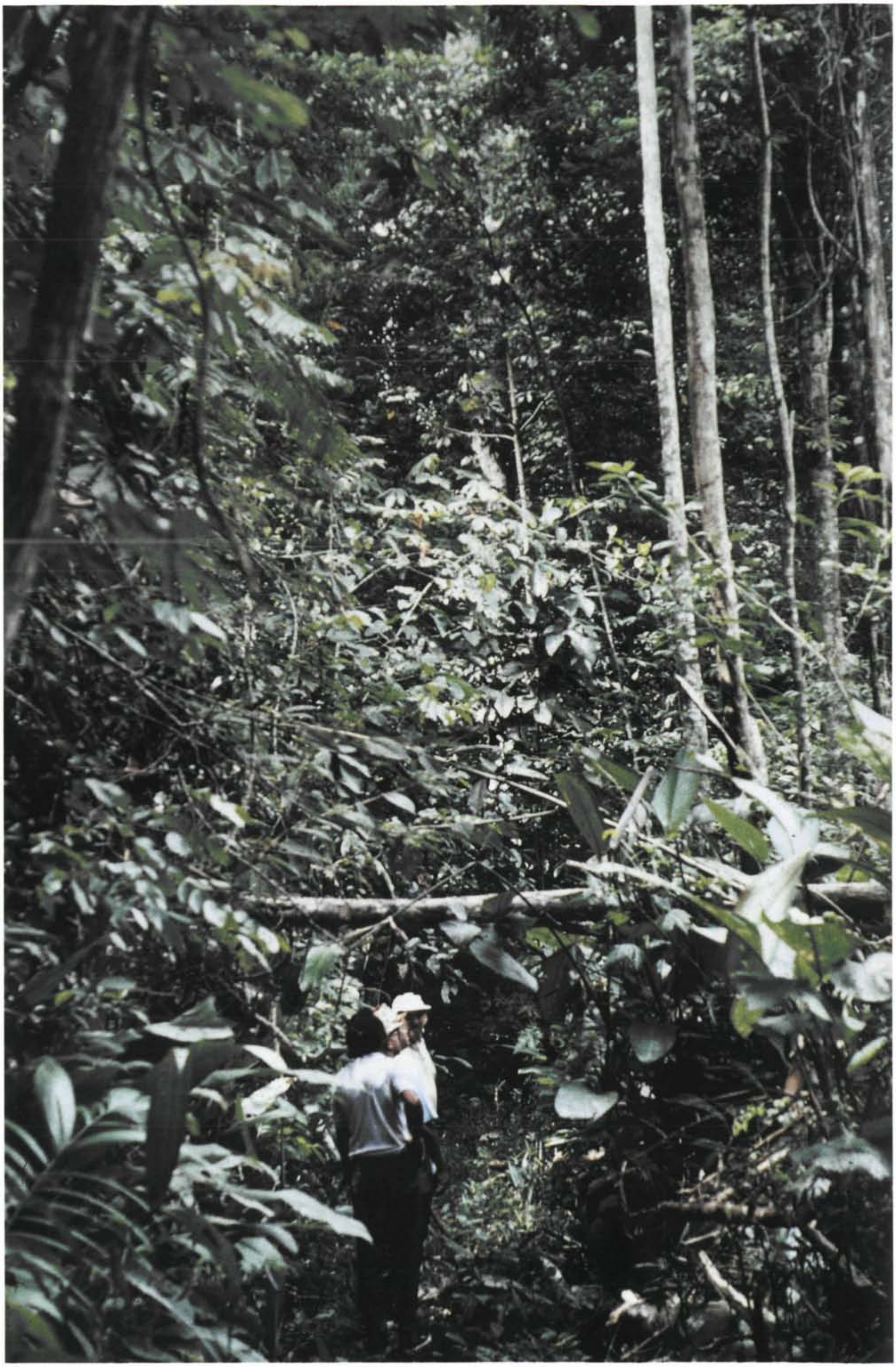

Isotopes are being used to study ecological effects in the Brazilian Amazon.

Isotopes in environmental research

Studies of Brazil's Amazon Basin are helping to evaluate effects of changing land use on the ecology and climate

by Glynn Bowen, Kazimierz Rozanski, and Peter Vose

The threat of substantial modification of our environment is becoming more and more real.

Rapidly increasing concentrations of greenhouse gases in the atmosphere, deterioration of water resources, deforestation, and industrial pollutants are only a few examples of the increasing pressure on the global ecosystem. There is an urgent need for a proper assessment of possible socio-economic consequences of these far-reaching changes and for a formulation of adequate response strategies. These strategies require a much better understanding of these extremely complex systems, which have heterogenous internal structures, and numerous feedback mechanisms.

Environmental problems can be defined on different scales, all of which are interconnected. Some are more or less restricted to site, such as erosion of fragile soils that are over-exploited. Poor resource management, especially over large areas, will lead to off-site effects, such as eutrophication of water by nitrate and phosphate. Logging of forests could affect sedimentation of streams, water quality, and food chains for aquatic animals. Off-site effects which can affect whole landscapes can be distant from the source — for example, possible changes to precipitation from large-scale clearance of rain forests, or acid rain that originated far away. Finally, there are very worrying global effects, notably climate change with global warming.

Radioactive and stable isotopes have long been considered a very efficient tool for studying physical and biological aspects of how the global ecosystem functions. Their applications in environmental research are numerous, embracing research at all levels.

This article looks at only a few of the approaches to environmental problems that involve the use of isotopes. Special attention is given to studies of the Amazon Basin.

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The Amazon Basin

The Amazon Basin has an area of 6 million square kilometres and is the world's largest continental evaporative basin. It contains about half of the Earth's tropical forest. It is a home to approximately 80 000 plant species and possibly 30 million animal species, most of them insects. The Amazon River contributes 20% of the world's river discharge to the oceans. This unique ecosystem of global significance is currently under serious threat, due to widespread deforestation. Over the last decade, approximately 180 000 square kilometres of primary forest has been lost in the Brazilian part of Amazonia.

The IAEA has a long association with environmental isotope research in Brazil via different projects supported through technical co-operation programmes. The most ambitious undertaking to date was initiated in 1985. This is a large multi-disciplinary effort concerned with isotope-aided studies of the effects of changing land use on the ecology and climate of the Brazilian Amazon. The project brings together about 80 scientists from a number of Brazilian institutes. It receives technical back-up from the Joint FAO/IAEA Division and the Isotope Hydrology Section of the Agency's Division of Physical and Chemical Sciences.

Within Brazil, the project is co-ordinated by the National Atomic Energy Commission (CNEN) and includes a number of Brazilian institutes. The project has highly effective interfaces with a number of entities outside Brazil. For example, the Government of Sweden has contributed considerably to the hydrology programme through the Swedish Agency for Research Co-operation with Developing Countries (SAREC). There are effective interfaces with the Office Français de Recherche Scientifique pour le Développement en Coopération (ORSTOM) in France, National Science Foundation in the United States, Max Planck Institute of Limnology in Germany, Department of Earth Sciences, Waterloo University in Canada, World Wildlife Fund, and other institutes.

Regional water balances — evapotranspiration

Environmental isotopes are very efficient tools in water cycle studies, partly due to the fact that three different isotopes incorporated in water molecules can effectively be used as tracers. Tritium, a radioactive tracer, is especially useful in studying dynamics of water movement in different compartments of the hydrosphere, both on the local and global scales. Heavy stable isotopes of hydrogen and oxygen (deuterium and oxygen-18) provide information about steady-state characteristics of the water cycle.

The distribution of tritium, deuterium, and oxygen-18 content in precipitation has been monitored monthly since the early 1960s by the global network of stations jointly operated by the IAEA and World Meteorological Organization (WMO). This unique isotope database makes possible numerous applications of environmental isotopes to hydrology, climatology, and atmospheric sciences. *(See the related article in this edition of the IAEA Bulletin.)*

In recent years, more and more investigations of various aspects of water transport in the atmosphere have been done with the aid of isotope methods. The methodological approach to these problems has evolved from semi-empirical "isolated air mass" models to global-scale general circulation models (GCMs). These take into account the considerable complexity of the atmospheric processes leading to the formation of precipitation at different time and space scales. Recent studies have been aimed at incorporating isotopic cycles in GCMs, and they have confirmed the usefulness of the IAEA/WMO database for verification and further improvement of these types of models.

Large-scale deforestation will tend to change the regional water balance through reduction of the evapotranspiration flux to the atmosphere. This problem is especially critical for the Amazon Basin. Dense plant cover and relatively high surface air temperatures make the "biological water pump" very effective, returning a major part of precipitation back to the atmosphere. The regional isotope model of the transport of water vapour in the Basin's atmosphere (based on early studies of isotope data in precipitation) revealed that close to 50% of the Basin's precipitation consists of recycled moisture. *(See Figure 1.)* More recent data tend to confirm this. Such a high contribution of recycled moisture makes the water cycle sensitive to deforestation: weakening of the biological water pump will cause more water to run off to the rivers and the local temperatures will rise.

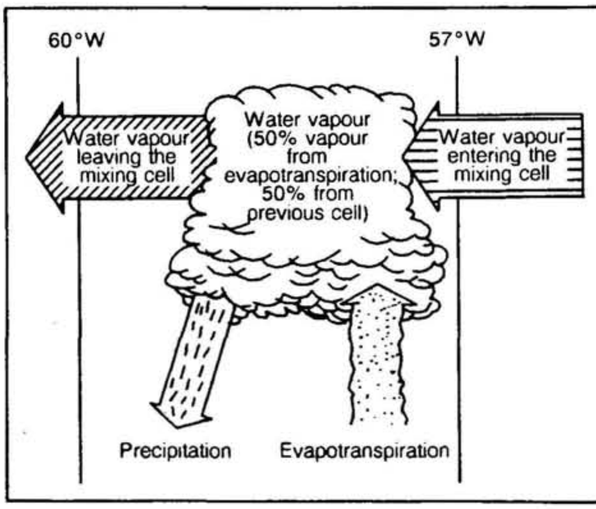
In an attempt to gain a more detailed understanding of the transport patterns of water vapour over the Basin, a special network of stations collecting precipitation samples for isotope analyses has recently been established within the framework of the Brazilian project. Data obtained in this way, supplemented by isotope analyses of water vapour, should allow development of a more advanced model of atmospheric moisture routing in this region. Access to realistic models of atmospheric circulation and the transport of water vapour in this region is particularly important, in view of the possible regional and global effects of the removal of the Amazonian forest.

If deforestation leads to a reduction in the amount of water returned to the atmosphere, it is likely that the effects will vary according to the size of the cleared area. There is little detailed knowledge of the comparative water budgets of isolated and unisolated forest areas or of adjacent forest clearings of different size. However, investigations being done through the Brazilian project, which encompass neutron moisture gauging, micro-meteorology, and plant physiological studies, have indicated that the influence of the forest edge extends at least 100 metres into the forest at ground level. This implies that from the meteorological point of view the effects of deforestation may be somewhat greater in scope than the actual size of the deforested area. This effect will be accentuated as deforestation continues and an increasingly higher ratio of forest edge to undisturbed forest develops.

Surface water routing

The second important step in gaining a deeper insight into the dynamics of the water cycle over the Amazon Basin lies in a better understanding of the routing of mesoscale surface water of the Amazon's main channel and its tributaries. Isotope data gathered by the regional precipitation network, supplemented by systematic, Basin-wide isotope monitoring of river water in the main channel and in the floodplain, is expected to be very helpful in this respect. In particular, it should be possible to derive proportions of water stored in the main channel

Figure 1. Simplified scheme of rain formation over the Amazon Basin.



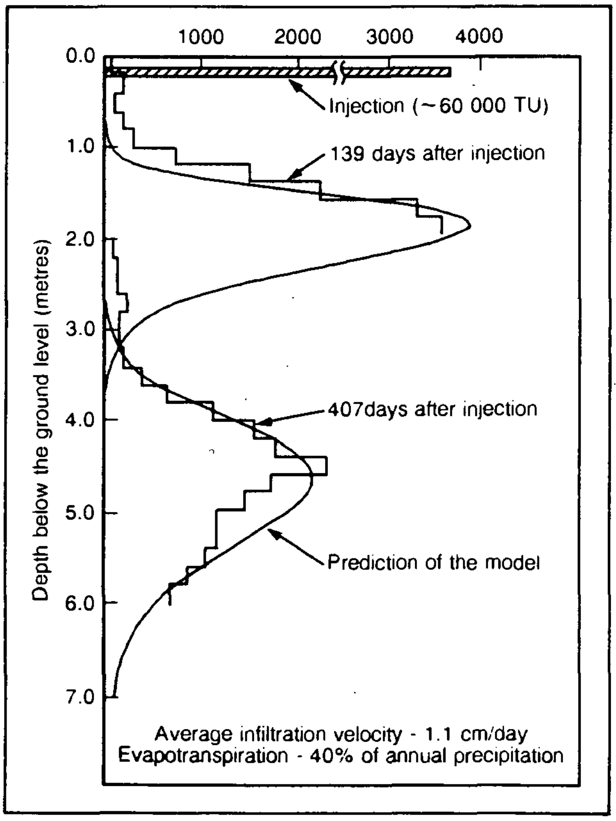
The illustration shows a general scheme to explain rain formation in the Amazon from two sources of vapour: the Atlantic Ocean and the forest. (Illustration based on oxygen-18 and deuterium studies of natural waters and vapour by Salati et al. and Dall'Olio et al.)

and in the floodplain. It should also be possible to derive the rates of water transfer between these two major storage elements at various seasons and in each segment of the river valley. Preliminary isotope analyses suggest that up to 30% of the water in the main channel is derived from water which has passed through the floodplain.

Water transport in soil. The environmental isotope data also yield site-specific information about water transport and storage in the unsaturated zone. Numerous studies have shown that tritium is a very powerful tracer of water movement in the unsaturated zone.

In a study carried out under the Brazilian project, it was possible to evaluate the average infiltration velocity and the evapotranspiration flux for both the undisturbed forest and cleared area in the region. *(See Figure 2.)* While isotope tracing provides information about dynamics of water movement in the unsaturated zone, the storage of water in the soil is commonly determined using neutron gauges.

Figure 2. Results of infiltration experiment in Central Amazon.



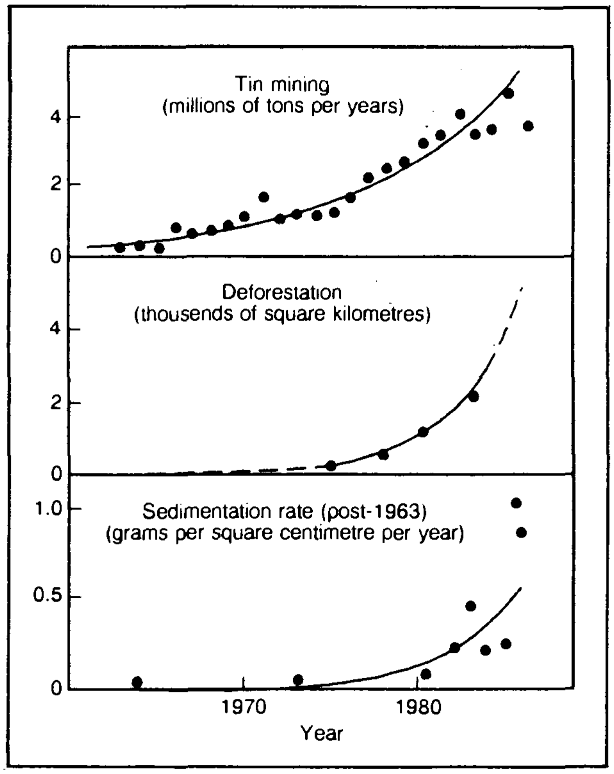
The graph shows results of an infiltration experiment carried out near Manaus (Central Amazon) in the framework of the IAEA Brazilian project. Artificially injected tritium was used as a tracer of water movement in the unsaturated zone. Soil samples were collected 139 and 407 days after the injection and the tritium content in the extracted soil water was measured. From the position of the tracer peak and the water content in the soil, it was possible to determine average infiltration velocity and average evapotranspiration flux for this region. A numerical model was developed which allows simulation of water movement in the soil in 1-day intervals.

Sedimentation. Increased sedimentation in rivers has long been recognized as a major consequence of deforestation. However, it is difficult to obtain a baseline study or determination of change in sedimentation rate in Amazon whitewater rivers. The histories of sedimentation in floodplain lakes of the Jamari and Jiparana rivers, which drain Rondonia, are being determined geochronologically through the analysis of lead-210 and caesium-137 stratigraphies in sediment cores. Results from Lago Paca, a small lake on the Jamari floodplain, indicate a tenfold increase in sedimentation during the last decade, which is directly correlated with deforestation and tin mining. *(See Figure 3.)*

Site nutrient effects

Site-specific effects, by their nature, feed into larger scale effects. The larger the area, the larger the off-site effect. The tropical forest, nutritionally, is a finely balanced system. A major perturbation, such as deforestation, raises questions of the dynamics of soil resources of nitrogen, sulphur, and other nutrients. How much will be lost? Will enough remain to regenerate the original forest? Will these be enough for farming activities on the cleared land? Or will this tropical soil system, like so many others, go into a downward, irreversible

Figure 3. Effects of mining and deforestation on the rate of sedimentation.



Lead-210 studies have shown that sedimentation in Lago Paca in Rondonia is directly related to deforestation and hydraulic tin mining. (Data of Forsberg, Godov, and Victoria)

fertility spiral? How can sustainable systems be developed?

Isotope methods, some relatively new, have a major role in site-specific studies. Some indicative examples include:

● *Studying turnover of organic matter.* Changes in the carbon-13/carbon-12 isotopic ratio of organic matter were used to determine the respective contributions of organic carbon derived from forest and pasture. In Amazon studies, after 1 year the proportion of carbon derived from pasture was 5% in the zero to 20 centimetre layer, while after 2 years it was 20%. About 40% of the carbon derived from the forest had disappeared. However, pasture had replaced lost organic matter by a significant degree.

● *Studying biological nitrogen fixation.* One of the ways nitrogen levels in soil can be maintained for productivity is by biological nitrogen fixation. The occurrence and extent of this can be assessed using nitrogen-15 technology, including the abundance of naturally occurring nitrogen-15 in plants.

● *Studying nitrogen availability and losses.* The experimental use of nitrogen-15 is invaluable for defining losses of soil nitrogen to the atmosphere and to groundwater, as well as the availability of nitrogen from decomposing organic matter. Studies can similarly be done with stable and radioactive sulphur isotopes.

Aquatic food chains

Natural variations in stable isotopes of carbon, nitrogen, and sulphur are being used to trace the flow of energy through aquatic food webs. In the Amazon, the work has focussed primarily on carbon-13, which has been used to identify the plant energy source for fish, alligators, and aquatic insects. The most surprising discovery to date is that C_4 grasses, which account for more than half of the primary production of the Amazon floodplain, appear to contribute very little to aquatic food webs. Data showed overwhelming dominance of C_3 carbon sources as fish food for 90% of the commercial fish yield in the Amazon.

Pollutants

There are many types of pollutants and isotope methods are instrumental to research on these; for example, to eliminate the pollutant or to understand and minimize its effects. Isotopically labelled agrochemicals have long been used to study movement and degradation of pesticides. Powerful isotope-based DNA probes now are being developed to monitor the development of decomposer organisms for recalcitrant pollutants in soil.

A major concern in industralized countries is water pollution from nitrate that arises from the high use of fertilizer. One partial solution is to select genotypes of crop plants that produce well, with much lower use of fertilizer (that is, lessening the soil loading). Some varieties of cereals, for example, are more efficient in their use of applied nitrogen fertilizer than other varieties. Isotopes such as nitrogen-15 can play a key role in studying reasons for this and to act as a guide to plant breeders for defining properties to include in their breeding programmes.

Similarly, the stable isotopes nitrogen-15 and sulphur-34 are invaluable in plant studies concerned with the effects of atmospheric pollution. So are carbon-14 and phosphorus-32 isotopes used extensively in plant physiologial studies.

Erosion and desertification

Erosion and desertification are two major environmental problems throughout the world. Some six million hectares are desertified each year. Isotopes often have a role in measuring erosion; for example, changes in caesium-137 levels in surface soils have been used to measure erosion (the caesium having arisen from fallout).

In the rehabilitation of eroded/desertified soils, nitrogen-fixing trees play a key role. Nitrogen-15 is essential for examining nitrogen fixation by different trees and varieties, including the effects of tree management and other factors. Additionally, in leguminous trees, determining carbon-13/carbon-12 ratios offers great possibilities for selection of plant genotypes that use water efficiently for growth. These and other aspects are being studied in the soils programme of the Joint FAO/IAEA Division.

Assessing the changes

This article has indicated some potential uses of isotopes in environmental research; they are very powerful tools which have not been fully exploited. While the major problem of global climate change has not been specifically addressed here, the clearing of the Amazon forest, one focus of the IAEA's environmental programme, may have serious consequences for the global climate. These include substantial reduction of the amount of latent heat transported to the regions outside the tropics and acceleration of the greenhouse effect via release of vast amounts of carbon dioxide and other greenhouse gases.

Results from today's climate models suggest that a complete and rapid destruction of the Amazon forest could be irreversible. Changes in the regional hydrological cycle and the disruption of complex plant–animal interactions could be so severe that, once the forest is destroyed, it might not be able to re-establish itself. Therefore, certain "outputs" from various aspects of the Amazon model will be important "inputs" to global change models being developed. That is one end of the scale. Another aspect is that isotope methods will be valuable in defining and accommodating anticipated change. Two examples are the use of carbon and nitrogen isotopes in studying changes in soil organic matter, and the use of carbon-13/carbon-12 ratios for indicating plant genotypes that use water efficiently, particularly in the drier climate predicted for many parts of the world.