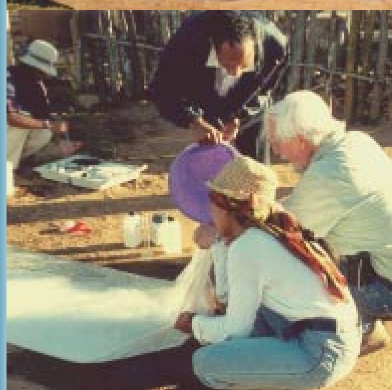
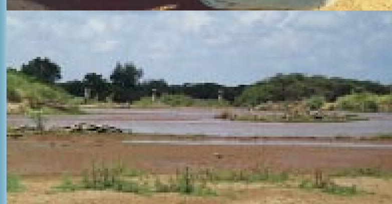
SUSTAINABLE DEVELOPMENT OF GROUNDWATER RESOURCES IN SOUTHERN AND EASTERN AFRICA

REGIONAL TECHNICAL CO-OPERATION PROJECT RAF/8/029





INTERNATIONAL ATOMIC ENERGY AGENCY

The International Atomic Energy Agency (IAEA) is an independent intergovernmental organization, in the United Nations family, that was created in 1957 “to accelerate and enlarge the contribution of atomic energy to peace, health, and prosperity throughout the world”. The IAEA assists its Member States, in the context of social and economic goals, in planning for and using nuclear science and technology for various peaceful purposes and facilitates the transfer of such technology and knowledge in a sustainable manner to developing Member States.

One of the major thrusts of the IAEA Technical Co-operation Programme in Africa pertains to water resources management. IAEA-supported activities aim at helping Member States to gain a better understanding and quantifiable estimates of the groundwater and surface water resources, to design and implement national strategies for national exploitation and management of these resources, and to enhance the safety of dams and artificial reservoirs.

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INTERNATIONAL ATOMIC ENERGY AGENCY

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TABLE OF CONTENTS

OVERVIEW

New wells constructed under a UNDP project in southwestern Madagascar are being protected from well-head pollution.

Water resources in the semi-arid areas of southern and eastern Africa are under increasing pressure as service is extended to rural populations and land-use shifts to more intensive production of crops and livestock.

As millions are invested in water systems to meet these demands and competition among users grows, information about groundwater resources is increasingly important.

Isotope data provide a unique tool for water managers to determine the availability and vulnerability of groundwater systems over the long-term, so that reliable supplies can be developed not just for next year, but for the next generation, which will be called on to pay for today's investments.

In March 1998, Government representatives and scientists from seven African countries met with International Atomic Energy Agency staff in Johannesburg, South Africa to explore how isotope hydrology could help them improve their groundwater resources managing practise. Over the next three years, a wide range of techniques were used to define the potential of regionally important aquifers, assess the vulnerability of their groundwater resources to pollution, and address other issues facing their national water authorities. This brochure shows how isotopic data have helped to develop a better understanding of groundwater resources in seven different project areas, and how these techniques can be used to address problems facing water resources managers throughout southern and eastern Africa.

THEMES FOR GROUNDWATER MANAGEMENT

The national projects under RAF/8/029 illustrate three broad areas – defining recharge processes, managing alluvial aquifers, and tracing nitrate pollution - where isotope data contributes to sustainable groundwater development.

Isotope data complement standard chemical and physical data on groundwater systems, tracing the origin and movement of water and solutes. Isotopes help build a deeper understanding of how groundwater has behaved in the past and help predict what may happen in years to come; a clear benefit to water resource managers and planners.

DEFINING RECHARGE PROCESSES

Groundwater recharge represents the amount of water that can be used on a sustainable basis.

Isotope data help define areas of active recharge, even as deforestation and erosion alter the hydrological cycle.

Isotopes can help locate major recharge areas and define long-term recharge rates.

In shallow fractured-rock systems, isotopes show residence time, while in regional confined aquifers flow rates also can be determined. This information benefits water planners, who need to develop groundwater supply systems that meet community needs over the long term.

TRACING NITRATE POLLUTION

High nitrate concentrations in groundwater is a significant human health problem in many countries. Nitrate can come from over-fertilized fields, feed-lots, latrines, and natural sources.

Nitrogen and oxygen isotopes can help distinguish which of these sources is responsible for groundwater pollution, so that appropriate corrective actions can be taken.

Isotopes distinguish between nitrate fertilizers & natural sources of nitrate that pollute groundwater.

MANAGING ALLUVIAL AQUIFERS

Aquifers located along river systems pose special challenges and opportunities for water managers. Conjunctive use of groundwater and surface water can help optimize water management for multiple objectives by storing water during floods and releasing water during low flows.

Major floods on the Ewaso Ngiro River recharge the Merti Aquifer.

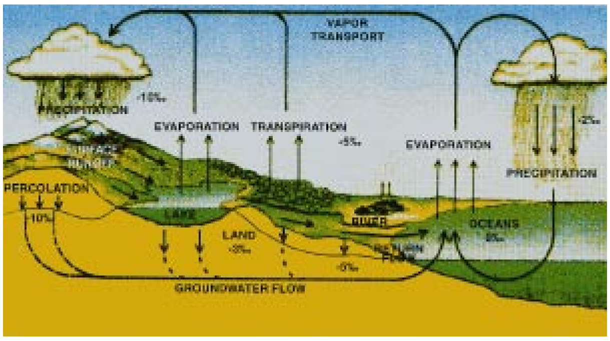
Isotopes are useful for distinguishing groundwater from river water and tracing connections between the two so that resource use can be kept in balance with supplies.

ISOTOPIC TOOLS FOR GROUNDWATER ASSESSMENT

The isotope hydrologist's tool kit keeps expanding as new techniques and instrumentation are developed. But a few standard methods can go a long way towards solving groundwater problems. Here's how some of the most common methods work.

STABLE ISOTOPES IN WATER (*^{2}H and ^{18}O*)

Deuterium (^{2}H) and ^{18}O are naturally occurring stable isotopes of hydrogen and oxygen present in water. Altitude and distance from the oceans change the stable isotope content of rainfall along the global meteoric water line. Evaporation from the soil produces additional fractionation.

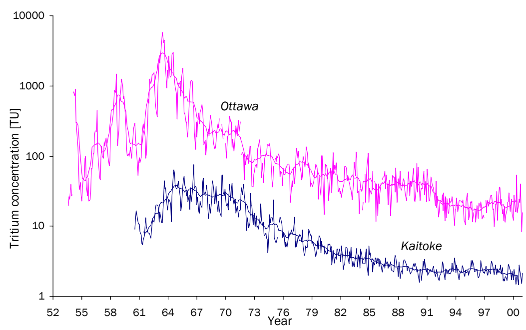


^{18}O Isotopes in the hydrological cycle.
IAEA Isotope Hydrology Section.

The isotopic signature of groundwater helps determine the origin of recharge - from local rainfall, river or lake water, or leakage from other aquifers – and the mixing or evaporation processes that take place.

RADIOCARBON (^{14}C) AND TRITIUM (^{3}H)

^{14}C and ^{3}H are radioactive isotopes. They are carried from the atmosphere into groundwater by rainfall and recharge. ^{14}C is produced naturally in the upper atmosphere. ^{3}H is largely a remnant of nuclear testing. Once rainfall enters the groundwater system and is isolated from the atmosphere, the initial ^{14}C and ^{3}H concentrations begin to decay with half-lives of 5730 and 12.32 years, respectively.

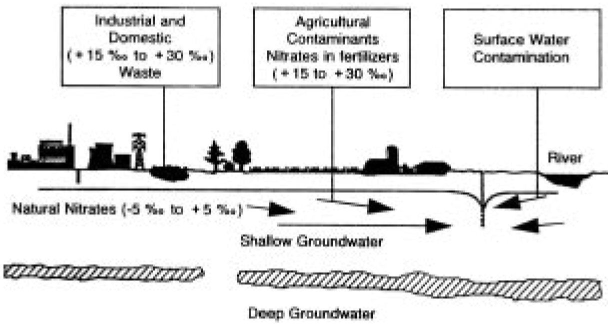


Tritium Input Function for N and S hemisphere.

The input functions describing the initial concentrations of ^{14}C and ^{3}H are well known, allowing isotope hydrologists to calculate the mean residence time of groundwater in unconfined aquifers, and hence its recharge rate.

NITROGEN ISOTOPES (^{15}N)

Where several potential sources may contribute to nitrate contamination, nitrogen isotopes can help determine the percentage per source. Nitrate isotopes are fractionated during biological uptake and metabolic processes, as well as in industrial processes producing nitrate fertilizers.



Nitrate Sources and Signatures.
IAEA Isotope Hydrology Section.

This results in distinct ^{15}N signatures for different sources, such as chemical fertilizers, sewage, and animal manure. More detailed analysis using ^{18}O in nitrate improves the separation of different nitrate sources.

STRONTIUM ISOTOPES ($^{87/86}Sr$)

Strontium isotopes track water-rock reactions after recharge takes place. Rocks and minerals of different types and different geological ages have varying contents of the radiogenic ^{87}Sr isotope. By relating the $^{87/86}Sr$ ratio in groundwater to the $^{87/86}Sr$ ratio in nearby rocks, isotope hydrologists can distinguish groundwater originating in different areas or traveling along different flow paths and trace reactions and mixing occurring in the aquifer.

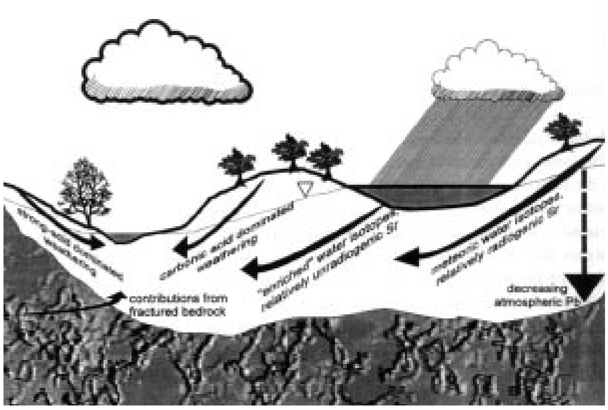


Figure from "Isotope Tracers in Catchment Hydrology" (1998), C. Kendall and J. J. McDonnell (Eds.).

DEFINING RECHARGE PROCESSES

GROUNDWATER REGULATION IN THE S.E. KALAHARI BASIN, NAMIBIA

Project Counterparts: G. Christelis, J. Kirchner, G. Tredoux, and A. Wierenga

Stock tank near Stampriet, Namibia.

PROBLEM

The Auob aquifer is a regional resource exploited by ranches and farms within the S.E. Kalahari Basin.

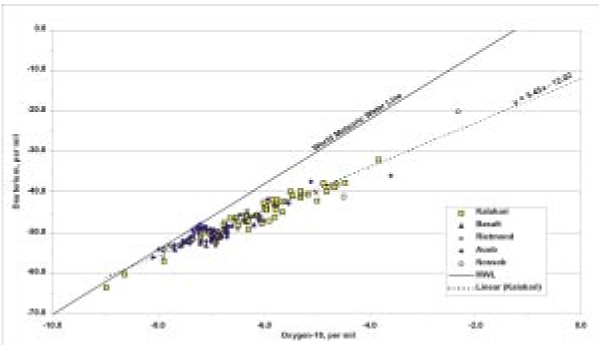
The overlying Kalahari and basalt aquifers also are locally important. Auob water levels have declined 10 meters or more in the last 30 years, prompting government action to prevent further declines.

OBJECTIVE

Determining recharge rates and mechanisms is critical to developing a groundwater management plan for the region.

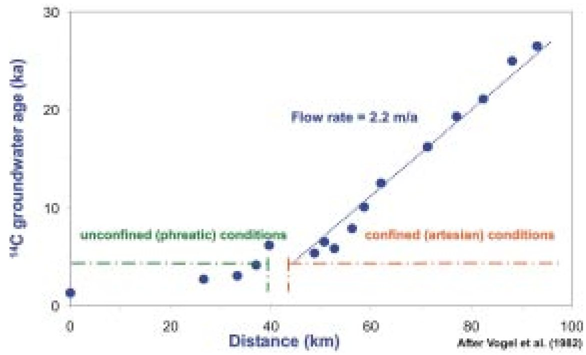
ISOTOPE APPLICATIONS

Isotopes help trace the fate of rainwater after it hits the groundwater. Infrequent heavy rains recharge all the aquifers. But the unconfined Kalahari and basalt aquifers are often highly evaporated, (see graph below) while the confined Auob and Nossub groundwater is less evaporated, plotting close to the meteoric water line. Satellite images (opposite page) show belts of small sinkholes that focus recharge through the Kalahari calcrete and into the Auob along the margins of the basin where the Auob is unconfined, allowing rapid recharge without evaporation.



S.E. Kalahari Stable Isotope Data

This new understanding of recharge processes raises questions about previous studies, which interpreted ^{18}O variations in terms of paleo-climate changes. Calcrete dissolution in sink-hole areas may also bias radiocarbon age estimates higher than is actually the case, suggesting that recharge and flow are somewhat faster than previously thought.

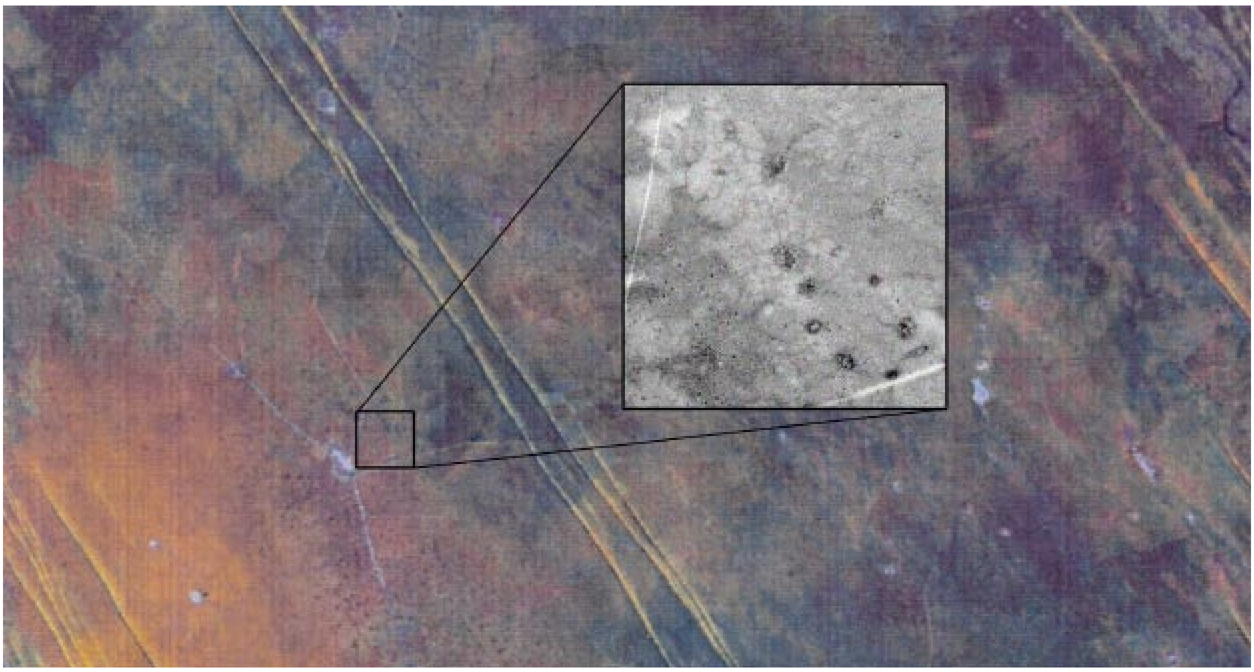


Auob Groundwater Age and Flow Rate.

Radiocarbon data for the Auob are still under review, but preliminary results (see graph above) suggest changes in flow rates consistent with geological data on the aquifer.

IMPACT

As all these pieces of project data are brought together, they will provide a firm technical basis for evaluating development scenarios and preparing groundwater management plans for the SE Kalahari Basin.



Sinkholes in Kalahari cover near Ulenhorst, Namibia.

DEFINING RECHARGE PROCESSES

GROUNDWATER DEVELOPMENT IN THE TAABOSCH AREA, SOUTH AFRICA

Project Counterparts: B. Th. Verhagen, M.J. Butler, E. van Wyk and M. Levin

Produce from irrigated farms is harvested for export markets.

PROBLEM

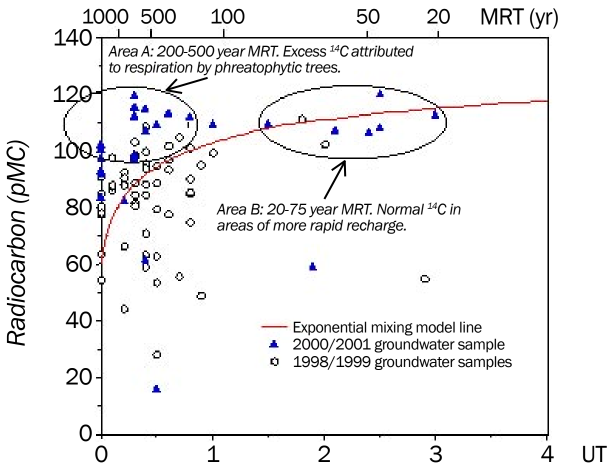
The key issue for a planned water supply for 26 villages in the Taaibosch area, Limpopo Province, was whether the well- fields along the Tshipize fault zone could sustain a potable groundwater supply system for use by households and small farms.

OBJECTIVE

The project sought to quantify recharge to the shallow basalt aquifer tapped along the fault zone, either from local rainfall or regional ground-water flow originating on the Blouberg mountains some 20 km south.

ISOTOPE APPLICATIONS

Tritium and radiocarbon results (see graph below) show that most areas receive very low recharge, this amount of recharge is less than previously estimated.



Radiocarbon data plotted against tritium.

In Area A, along the fault, the 200 year Mean Residence Time (MRT) for groundwater translates to a recharge rate of 4 mm per year, not enough to sustain the planned water system. But in Area

B, just north of the Blouberg, the recharge rate is higher, providing a better target for development. Isotope data also showed that the fault was not a regional groundwater collector, but that deeper sandstone aquifers do potentially form a larger regional resource.

View of the Blaoberg mountains from the north.

Farmers near the fault depend on groundwater.

IMPACT

The Tshipize fault well fields and water distribution system are on hold, whilst the sandstone aquifer is being evaluated.

Isotope data have been a catalyst for re-assessing comprehensively the groundwater resources in the Taaibosch area. Isotope and water quality studies - e.g. of high basalt nitrate values - and explorations are continuing.

These may prove that ground water in the deep sandstone aquifer could be the primary potable and sustainable water resource for the area, both in quality and quantity.

DEFINING RECHARGE PROCESSES

GROUNDWATER PROTECTION FOR THE WOBULENZI CATCHMENT, UGANDA

Project Counterparts: C. Tindimugaya, C. Mukwaya

Mrs. Afuwe of the Wobulenzi Water Users Assoc.

PROBLEM

The water supply for the town of Wobulenzi was recently upgraded, with motorized pumps and piped distribution, but the long-term yield of the aquifer and its vulnerability to pollution by the rapidly growing town were unknown.

OBJECTIVE

The project team used isotope and conventional techniques to locate important recharge areas and assess recharge rates throughout the catchment to provide a scientific basis for water resource planning and protection.

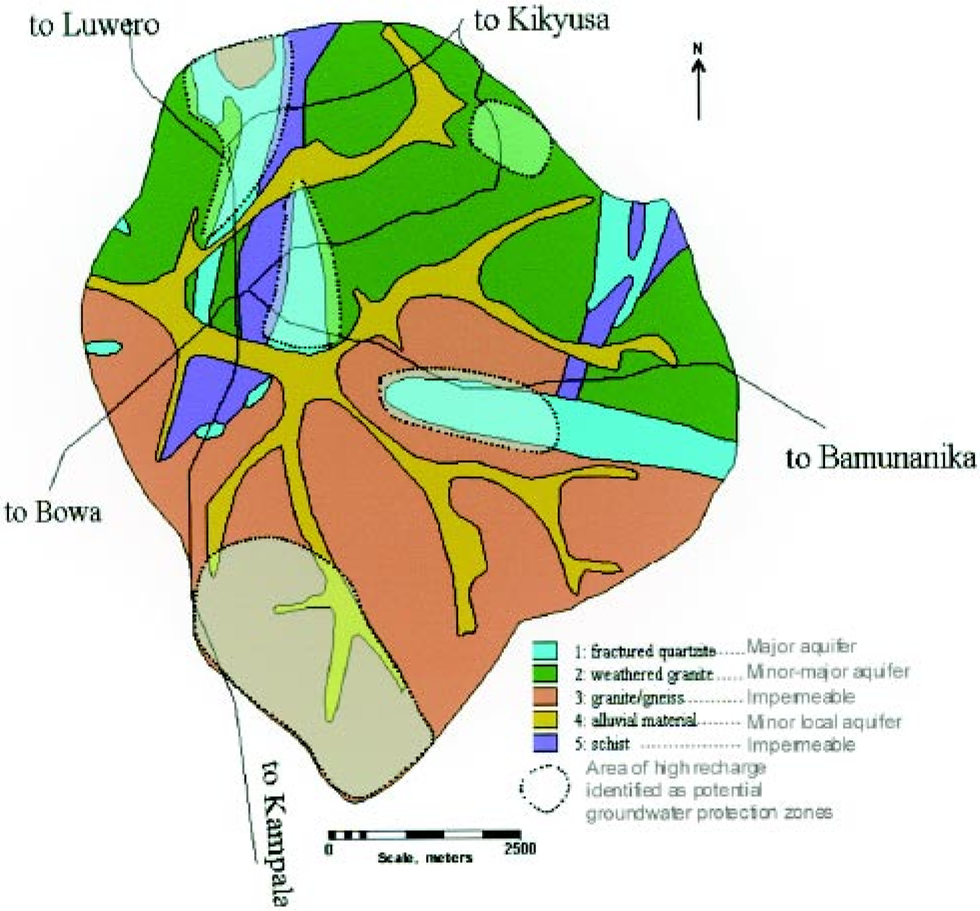
ISOTOPE APPLICATIONS

Tritium and Chlorofluorocarbons (CFCs) were used to assess recharge rates. Tritium data confirm results from soil moisture and modeling studies showing that recharge varies by as much as a factor of three in different areas

Tritium Results and Recharge Estimates

Location	Avg. Tritium (TU)	Mean Residence Time (yr)	Estimated Recharge (mm/yr)	Area-weighted Recharge (mm/yr)
Tweyanze	1.0	100	54	11.80
Sempa	2.0	80	77	15.40
Lumundi	3.3	30	130	39.00
Katikamu	1.4	90	62	17.36
Total				**83.64**

of the catchment. While all areas are actively recharged, some are significantly more vulnerable to groundwater pollution than others because of higher recharge and lower storage.



Hydrogeological map of the Wobulenzi Catchment.

IMPACT

The hydrogeological map of the Wobulenzi catchment, above, highlights areas where the tritium results indicate the most active recharge. The project team is working with the Wobulenzi water authority to develop guidelines for protecting these recharge areas, particularly where they intersect major aquifer units. Such cooperation between local and national stakeholders will be important in ensuring a safe and reliable water supply for Wobulenzi in the coming years. And the lessons learned in the Wobulenzi area will be applied throughout Uganda in the years to come.

DEFINING RECHARGE PROCESSES

RECHARGE AND GROUNDWATER SALINIZATION, SOUTHERN MADAGASCAR

Project Counterparts: J. Rajaobelison, V. Ramaroson, E. Mamifaranahary, A. Razafindrabetsiavalona, G. Bergeron, L. Guyot, R. Kourdian, A. Ranaivoarisoa , and L. Rakotondrajao

UNDP Water Monitor meets with villagers, S. Madagascar.

PROBLEM

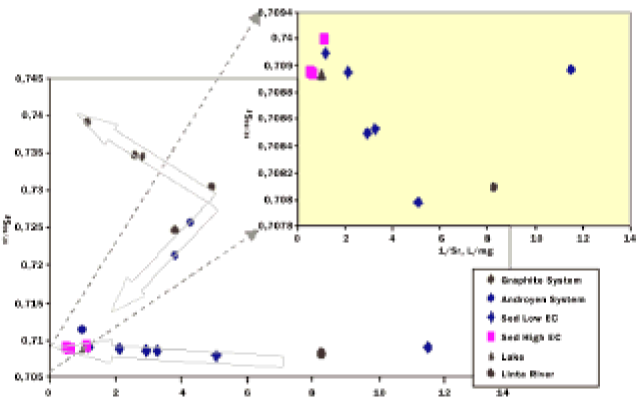
Over 30% of the village water supply boreholes in the southern interior and on the southwestern coastal platform of Madagascar encountered highly saline groundwater and were abandoned, increasing development costs.

OBJECTIVE

Determining the origin of the salinity and helping target fresh water zones where new drilling can focus were the objectives of the IAEA project.

ISOTOPE APPLICATIONS

Isotope data show that the groundwater is actively recharged with only slight evaporation.



Strontium Isotope Trends, Basement and Coastal Aquifers, S. Madagascar.

But older groundwater is more saline, indicating deeper circulation, reaction with the aquifer matrix, and/or mixing with older brines. Strontium (Sr) isotope results (see graph) confirm strong influences of water/rock interaction. The interior Graphite and Androyen formations have divergent Sr isotope ratios, reflecting mineralogical differences. The coastal groundwater with low electrical conductivity (EC) shows the influence of the Mahafaly limestone, while high EC coastal groundwater is near the Sr isotope ratio of modern seawater.

Absence of surface water has increased the importance of groundwater resources in southern Madagascar.

The isotope and geochemical data from this project suggest that salinity problems in the interior may be related to fluids trapped in the rock along ancient shear zones during regional metamorphism over 500 million years ago.

IMPACT

The hypothesis that salinity in the interior is tied to ancient shear zones will be tested as new boreholes are drilled under the World Bank project that is starting up just north of the current study area. In the meantime, the project has fostered a multidisciplinary working group to perform groundwater research and isotope hydrology in Madagascar. In itself, this is a major advance in technical capacity for the local water sector, which faces great challenges in developing and preserving water resources.

Hand held water pump.

EXPANDING IRRIGATION IN THE SAVE RIVER ALLUVIAL SYSTEM, ZIMBABWE

Project Counterpart: S. Sunguro

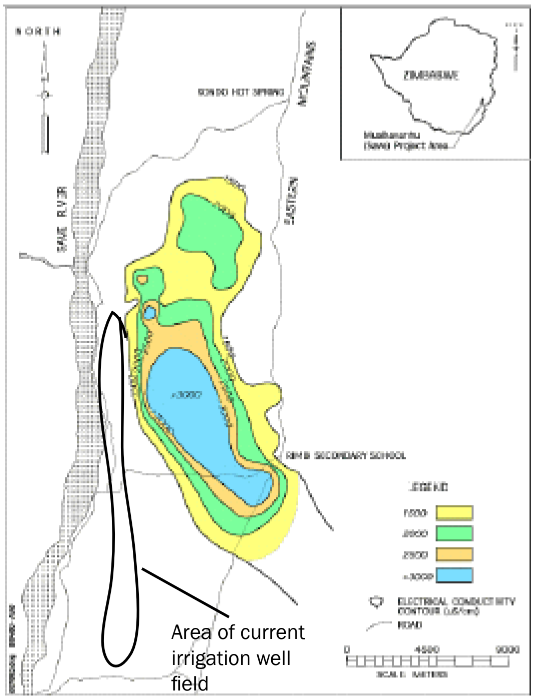
Irrigation well, Musikavanhu communal Area.

PROBLEM

Expanding irrigation to the 50,000 people in the Musikavanhu Communal Land requires more intensive use of groundwater, as the available surface water is already committed to commercial farms.

OBJECTIVE

The project seeks a better understanding of the recharge processes, surface water/groundwater interactions, and the sources of high salinity in the southern part of the aquifer so that the irrigation system along the river can be expanded.

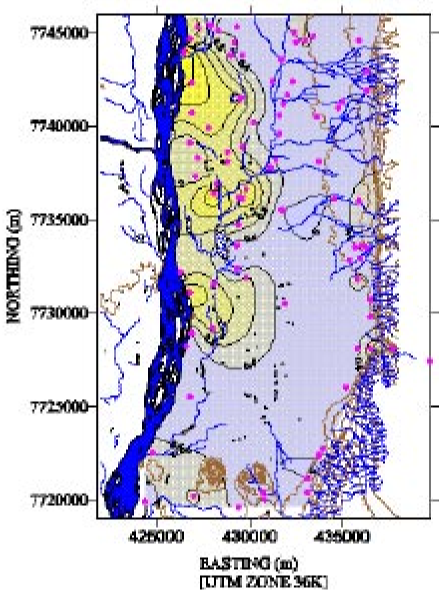


Groundwater Salinity in the Study Area.

ISOTOPE APPLICATIONS

Stable isotope, tritium, and ^{14}C data have mapped out areas of influence from mountain rainfall and river bank infiltration and indicate the relative rates of recharge from each source.

The distribution of tritium shows that the most active recharge is from the river. Along the river, the mean residence times of groundwater may be less than 50 years. In contrast, areas recharged by the mountains have mean residence times of 200 to 500 years or more.



Tritium Distribution in the Study Area.

IMPACT

These project results will help design and manage new irrigation wells in the Save valley. Data on recharge and flow will be used to balance production so that more families can benefit from irrigation without spreading the salts, leached from ancient pan deposits, to parts of the valley where the water quality is good. In these ways, isotope hydrology can help communal farmers improve utilization of their land and water resources.

MANAGING ALLUVIAL AQUIFERS

ASSESSING THE MERTI AQUIFER, NORTHEASTERN PROVINCE, KENYA

Project Counterparts: A. Gachanja, M. Tole

Groundwater sampling at Badhana, Kenya.

PROBLEM

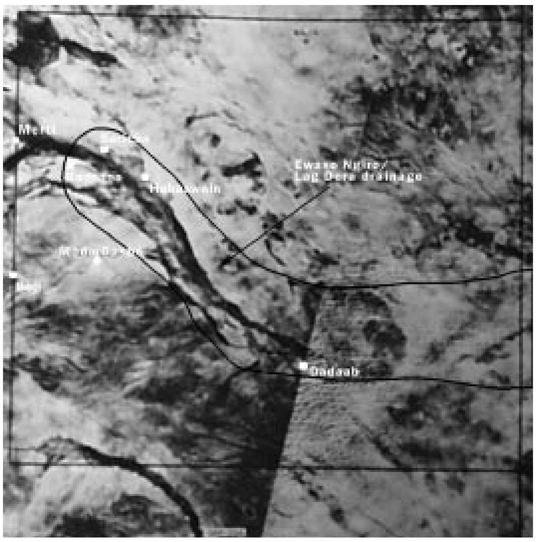
The availability of and access to water is critical to the scattered towns and nomads in the arid lowlands of the Northeastern Province of Kenya along the Ewaso Ngiro River.

OBJECTIVE

Isotope hydrology is being used to define sources and rates of recharge to the Merti Aquifer, which is the only reliable source of water for much of this region. Although the Ewaso Ngiro typically dries up before it reaches Sericho, there is evidence that the river fed a vast swamp stretching southeast from Badhana a century ago. And in years like 1997-98, when El Nino struck, large areas of the region are flooded even today.

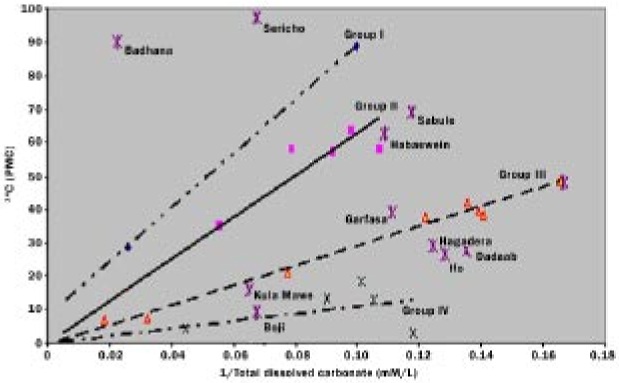
ISOTOPE APPLICATIONS

A 1974 US Geological Survey study of the Merti Aquifer proposed that recharge occurred during catastrophic floods, hundreds or thousands of years apart. The USGS defined four groups of water, based on ^{14}C and total carbonate content, which were ascribed to individual flood events. Most current results (see graph), fit with previous data, but new wells not included in the USGS study show evidence of recent recharge, perhaps from the El Nino floods.



Landsat photo of the study area of Merti Aquifer.

Tritium results also indicate recent recharge, even in places where ^{14}C groundwater 'ages' are a thousand years or more. Apparently, the ^{14}C data reflect local differences in carbonate chemistry during recharge as well as the timing of flood events.



^{14}C and Carbonate Data, Merti Aquifer.
Adapted from Pearson and Swarzenski, 1979.

Children in Badhana wait for the rain.

IMPACT

This new picture of the Merti Aquifer suggests higher recharge rates than indicated by previous studies. As continued studies refine recharge estimates for the Merti Aquifer, this information will be used by the Kenyan authorities to help maintain a balance between upstream use and downstream recharge and development.

TRACING NITRATE POLLUTION

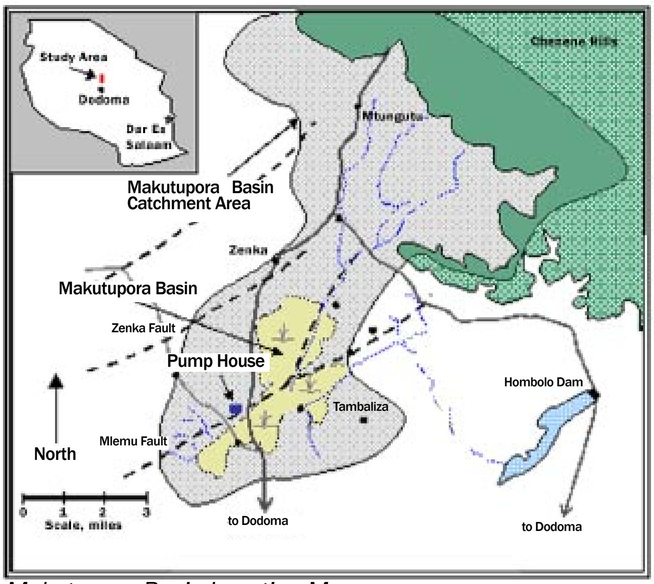
WATER QUALITY IN THE MAKUTUPORA BASIN, TANZANIA

Project Counterparts: L. Kongola, G, Nsanya, E. Mcharo

Harvest time at a farm near Zenka, Tanzania.

PROBLEM

Nitrate detected in the Makutupora Basin well field has raised concerns over safety of the water supply for the city of Dodoma.



Makutupora Basin Location Map.

OBJECTIVE

The project has assessed the potential sources of nitrate to the groundwater and their movement through the aquifer. The results will support groundwater protection and management and protect resources invested in wells, pumps, and pipelines.

ISOTOPE APPLICATIONS

^{3}H and ^{14}C data (see table) show a groundwater residence time of over a thousand years – far higher than previous estimates. This indicates large volumes of ground water are stored in the aquifer, helping to ensure future water supplies to Dodoma. But the increasing nitrate concentrations since the 1980s suggests that contaminants can short-circuit this flow system and degrade water quality. ^{15}N isotope data indicate mixed sources of nitrate, including human and animal wastes.

Source	Tritium (TU)	14C (pmc)	Residence Time (years)
Dincer, 1980	0.0 - 3.1 (+/- 1.0)	52.7 - 57.0	~ 30
Shindo et al, 1989-1994	0.5 - 0.8 (+/- 0.6)	N/A	25 - 120
Thorweihe, 1992-1994	MRT estimated from storage / recharge		< 10
This Study	0.0 - 0.2 (+/- 0.2)	53.3 - 63.2	> 1000

Mean residence time of Makutupora Basin Groundwater as estimated by various studies.

IMPACT

Evidence suggests that a growing human population, coupled with changing land use and agricultural patterns, may lead to increased releases of nitrate to shallow groundwater near the wellfield.

Rainfall flushes the shallow groundwater into small streams on the western side of the basin. These streams recharge the deep aquifer, which supplies Dodoma's water, as they cross a fault zone just upstream of the production wells.

More focused studies of these recharge features will help define the aquifer protection zones needed to safeguard the Dodoma water supply.

The project team surveys a stream-bed near the Mlemu Fault

THE NEXT STEPS IN SUSTAINABLE DEVELOPMENT

Through the Technical Co-operation mechanism, the International Atomic Energy Agency seeks to promote the sustainable utilisation of appropriate isotope techniques in a region of water scarcity. The RAF/8/029 participants have endeavoured to address specific problems in their respective countries, while working together at the regional level and exchanging information and experiences, so as to develop significant managerial and technical skills. They identified several steps to follow-up to make sure that isotope methods are integrated with water sector activities, including:

- *Demonstrating the benefits of isotope studies, including isotope's role in determining sustainability through-out the investment cycle;*
- *Defining best practices for isotopes, including Standard Operating Procedures (SOPs), for regional use;*
- *Developing university-based training through regional centers;*
- *Linking isotope projects to national monitoring networks and data management systems;*
- *Working within regional strategic planning and operations groups to define project needs and coordinate early in the planning process;*
- *Coordinating with policy and regulatory groups to ensure that sustainability is considered in all water development projects.*

Groundwater studies do not create more water, but good information can prevent costly mistakes, and can help increase the efficiency of resource use. Sometimes hard choices may need to be made, but the alternative could be the loss of useable water for all stakeholders.

SUSTAINABLE DEVELOPMENT OF GROUNDWATER RESOURCES IN SOUTHERN AND EASTERN AFRICA

Project RAF/8/029 represents an effort by the IAEA's Technical Co-operation programme to build the capacity of hydrogeologists in the participating countries in southern and eastern Africa and address local groundwater resource problems.

While the IAEA has contributed expertise and resources, much of the actual work on the project was conducted by the national project teams through support by their governments. This booklet is based in large part on the published and unpublished material provided by these teams; although their names are too numerous to list, the contributions of all participants are recognized. The contributions of the many isotope hydrologists who traveled to the seven RAF/8/029 countries on IAEA missions, including Prof. A. I. Aly, Dr. K. Froehlich, Dr. B. Marshall, Dr. R. Michel, Prof. K. Rozansky, Prof. B. Verhagen, Dr. P. Vrbka, and Prof. G. M. Zuppi must also be recognized. Their suggestions, interpretations, and questions have helped guide project activities.

The cooperation of the residents of the study areas, of the district water officials who provided guidance and data, of the local meteorological observers and of water-users group leaders was also vital and contributed to the project.

RAF/8/029 has benefited from extra-budgetary resources contributed by the U.S. Government, which supported the assignment of a regional project advisor to help coordinate the project.

INTERNATIONAL ATOMIC ENERGY AGENCY

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